DOCUMENT RESUME

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| TITLE | Marine Science Technician Second Class, 15-2. Military Curriculum Materials for Vocational and Technical Education. |
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| SPONS AGENCY | Office of Education (DHEW), Washington, D.C. |
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| AVAILABLE FROM | Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210. |
| PUB TYPE | Guides - Classroom Use - Materials (For Learner) (051) |
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| IDENTIFIERS | Military Curriculum Project |

ABSTRACT

This course, adapted from military curriculum materials for use in vocational and technical education, was designed to provide the theory portion of the Marine Science Technician Program. It includes a review of basic subjects, marine biology, oceanography, as well as meteorologic observations and recording. The course consists of a lesson book and six texts. Eleven lessons are presented covering the following topics: review of mathematics; applied physics; geological and physical oceanography; marine biology and water motions; basic meteorology and meteorological elements; atmospheric circulation, air masses, fronts, and special phenomena; surface weather and physical oceanographic observational equipment and instruments; geological oceanographic, upper air, and communications equipment and instruments; surface weather observation and meteorological codes and plotting; ice and bathythermograph observations, Nansen and STD casts, and safety procedures for oceanographic observations; and data processing and analysis. Each lesson contains numerous charts and detailed procedures. The course contains reading assignments, review exercises, and answers for student self-study and evaluation. The course is intended to be used in an on-the-job or laboratory learning situation. (KC)

## MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

# The National Center Mission Statement

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- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL

Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)





THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION

# Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

# Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

# What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

| | |
|---|---|
| Agriculture | Food Service |
| Aviation | Health |
| Building & Construction Trades | Heating & Air Conditioning |
| Clerical Occupations | Machine Shop |
| Communications | Management & Supervision |
| Drafting | Meteorology & Navigation |
| Electronics | Photography |
| Engine Mechanics | Public Service |

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

# How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

**EAST CENTRAL**
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

**NORTHWEST**
William Daniels
Director
Building 17
Airdustrial Park
Olympia, WA 98504
206/753-0879

**MIDWEST**
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

**SOUTHEAST**
James F. Shill, Ph.D.
Director
Mississippi State University
Drawer DX
Mississippi State, MS 39762
601/325-2510

**NORTHEAST**
Joseph F. Kelly, Ph.D.
Director
225 West State Street
Trenton, NJ 08625
609/292-6562

**WESTERN**
Lawrence F. H. Zane, Ph.D.
Director
1776 University Ave.
Honolulu, HI 96822
808/948-7834

# MARINE SCIENCE TECHNICIAN SECOND CLASS

Table of Contents

**Developed by:**

United States Coast Guard

**Development and Review Dates**

March 1972

**Occupational Area:**

Meteorology and Navigation

**Cost:** **Print Pages:**

741

**Availability:**
Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

**Suggested Background:**

None

**Target Audiences:**

Grades 11-adult

**Organization of Materials:**

Student course book with lesson assignments, review exercises and answers; texts

**Type of Instruction:**

Individualized, self-paced

| Type of Materials: | No. of Pages: | Average Completion Time: |
|---|---|---|
| *Course Book for Marine Science Technician Second Class* | 71 | Flexible |
| *Review of Mathematics and Basic Physics* | 131 | Flexible |
| *The Hydrosphere* | 78 | Flexible |
| *The Atmosphere* | 92 | Flexible |
| *Instruments and Equipment* | 158 | Flexible |
| *Observations and Codes* | 124 | Flexible |
| *Data Processing and Analysis* | 95 | Flexible |

**Supplementary Materials Required:**

None

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Course Description

This course is designed to provide the theory portion of the Marines Science Technician program. It includes a review of basic subjects, marine biology, oceanography, and meteorologic observations and recording. This course consists of a lesson book and six texts. Eleven lessons are presented. Two additional lessons were deleted because they deal with specific military administration and requirements.

Lesson 1 — *Review of Mathematics* contains five assignments covering number systems, arithmetic, exponents, radicals, logarithms, the slide rule, working with numbers, and numerical trigonometry.

Lesson 2 — *Applied Physics* contains six assignments covering matter and energy, mass, force, and motion, laws of motion, gas laws, and optical phenomena.

Lesson 3 — *Geological and Physical Oceanography* contains four lessons covering an introduction to oceanography, marine geology, and physical oceanography.

Lesson 4 — *Marine Biology and Water Motions* contains five assignments covering fouling and deterioration, bioluminescence, deep scattering layers, coral reefs, harmful and useful aspects of marine life, waves and surf, currents, and tides.

Lesson 5 — *Basic Meteorology and Meteorological Elements* contains three lessons discussing the history of meteorology, the earth-sun relationship, the effects of the earth, pressure, temperatures, humidity, winds, luminous meteors, lithometeors, and hydro meteors (all types of precipitation).

Lesson 6 — *Atmospheric Circulation, Air Masses, Fronts, and Special Phenomena* contains five assignments covering general circulation, secondary circulations, tertiary circulations, air masses, fronts, easterly waves and the ITCZ, thunderstorms, tornadoes, water spouts, dust devils, and tropical cyclones.

Lesson 7 — *Surface Weather and Physical Oceanographic Observational Equipment and Instruments* contains four assignments covering thermometers, pressure instruments, wind measuring instruments, winches, wire rope, platform rigging, platform area safety, water samples, and temperature measuring equipment.

Lesson 8 — *Geological Oceanographic Equipment, Upper Air Equipment and Instruments, Communications Equipment; and Special Instrumentation* contains five assignments covering bottom samples, processing laboratory areas and associated equipment, sampling nets, sonar pingers, underwater cameras, transparency measurement devices, balloons, upper air accessory equipment, theodolites, electrical upper air equipment, electronic upper air equipment, the teletypewriter, the facsimile, meteorological satellites, and automatic weather stations.

Lesson 9 — *Surface Weather Observation and Meteorological Codes and Plotting* contains four assignments explaining general terms, definitions, and procedures for observations, observations of atmospheric phenomena, code systems information, primary meteoroligical codes; map plotting; and Navy RADFO messages.

Lesson 10 — *Ice and Bathythermograph Observations, Nansen and STD Casts, and Safety Procedures for Oceanographic Observations* contains five assignments on the characteristics of ice, shipboard observations and codes, aircraft ice recpn plot and message, the mechanical bathythermograph, the expendable bathythermograph, installation of the XBT launcher and recorder, encoding bathythermograph observations, the Nansen cast routine, the winch card, deep casts, the STD cast routine, data retrieval, determining water transparency with the Secchi disc, safety procedures and hand signals for casts.

Lesson 11 — *Data Processing and Analysis* contains seven assignments covering surface analysis, upper air chart analysis, communications systems, teletype weather messages, quality control, processing salinity data, the modified Winkler method for dissolved oxygen analysis, and processing station data.

Each lesson contains numerous charts and detailed procedures. Some military equipment and procedures are included, but the model might be useful for civilian applications. This course contains reading assignments, review exercises and answers for student self-study and evaluation. The course would best be used with an on-the-job or laboratory learning situation.

3

15-2

COURSE BOOK FOR

# MARINE SCIENCE TECHNICIAN SECOND CLASS

EDITION 1

U.S. COAST GUA[illegible] UTE
OKLAHOMA CIT[illegible] OMA

MARCH [illegible]

**CODE 234 1**

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# MARINE SCIENCE TECHNICIAN SECOND

First Edition

MST2 (1 ed)

A correspondence course developed by
the U. S. Coast Guard Institute

Oklahoma City, Oklahoma
March 1972

## INSTRUCTIONS FOR USING CORRESPONDENCE COURSE ANSWER SHEETS (CGI-2800)

The correspondence course answer sheets are graded by automatic data processing equipment and should not be stapled or wrinkled in any manner. To avoid delays, fill in all blocks and spaces carefully and completely. Use a No. 1 or No. 2 black lead pencil. Print your name, rank/rate, service number, and short course title. The guidelines below will help you mark the other blocks or spaces correctly.

1. PRESENT UNIT ADDRESS: Print the address of the unit to which you are attached. If you are going to be transferred soon and would like to receive the grade results at your new unit, indicate your new address. Also indicate the date of the address change and darken the space designated by the arrow.

2. DATE LESSON OR TEST SUBMITTED: Mark the month and day. Do not show the year. To indicate the month, darken the space next to the appropriate month. To indicate the day, always use two numbers. You will need to add a zero before dates consisting of one number.

   EXAMPLE: 2 December becomes 02 December; 28 March remains 28 March

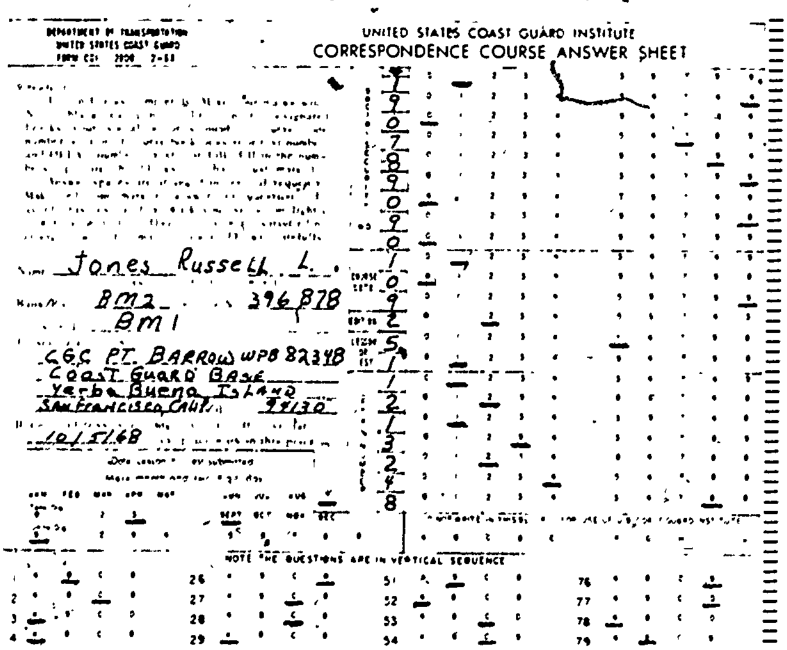
3. SOCIAL SECURITY NUMBER: Enter your social security number in the vertical blocks. Next, carefully fill in the spaces opposite the blocks you have just marked.

4. COURSE CODE AND EDITION: Enter the course code number and the edition number of your course in the vertical blocks. You can find this information on the cover of your course book, or you can obtain it from your Educational Services Officer. Next, carefully fill in the spaces opposite the blocks you have just marked.

5. LESSON OR TEST: Enter the lesson number or the test series number in the vertical blocks. Every lesson number and every test series number must have two digits. For lessons 1 through 9, add a zero before the number (01, 02, etc.). For tests, use the test series number (51, 52, 53, etc.) that appears in the center of the test cover. After you have filled in the blocks, darken the spaces opposite the blocks you have just marked.

6. OPFAC NUMBER: Enter the operating facility number of the unit to which you are attached. You can obtain this number from your Educational Services Officer. Darken the spaces opposite the blocks you have just marked.

The answer spaces on the lower portion of the answer sheet are arranged in vertical sequence. Make only ONE mark to answer one question. When an item is to be omitted, leave the answer spaces blank. Do NOT write in the answer spaces or make any marks other than the mark required to answer the question or item.



LIST OF LESSONS



WARNING

THE MATERIAL IN THIS COURSE IS FOR TRAINING ONLY. IT SHOULD NEVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, OR OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. ALWAYS CHECK THE LATEST DIRECTIVES AND PUBLICATIONS ON THE JOB.

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# REVIEW OF MATHEMATICS

## FIRST ASSIGNMENT

In Pamphlet No. 460 read from page 1 through page 15 and answer questions 1 through 21.

1. What does a number represent?

   A. A symbol
   B. A sum
   C. A product
   D. An idea

2. What determines the place value which corresponds to a given position in a number?

   A. The base of the number system
   B. The type of the number system
   C. The size of the number
   D. The placement of the decimal

3. What number do the mathematical symbols, $2 \times 10 \times 100 + 7 \times 10 \times 10 + 0 \times 10 \times 1 + 7 \times 1$, represent?

   A. 277
   B. 2,707
   C. 20,717
   D. 27,107

4. If a number system is said to be a base-six system, what does the symbol "10" represent?

   A. 6
   B. 7
   C. 10
   D. 12

5. What is the decimal equivalent of the binary number 0101?

   A. 3
   B. 5
   C. 7
   D. 11

6. How is the precision of a number indicated?

   A. By the number of digits to the left of the decimal point
   B. By the positional value of the number
   C. By the number system used
   D. By the number of digits to the right of the decimal point

7. In an arithmetical computation, what factor determines the accuracy of a problem?

   A. The length of the problem
   B. The number of digits involved
   C. The least precise value used
   D. The number of significant digits involved

8. Round off the expression 0.0345065 to the nearest millionth.

   A. 0.03450
   B. 0.034506
   C. 0.034507
   D. 0.03451

9. What is the reciprocal of the number 8?

   A. 0.125
   B. 0.163
   C. 0.2
   D. 0.8

10. You disregard the signs of numbers when you are adding ______________.

    A. numbers algebraically
    B. positive numbers
    C. numbers arithmetically
    D. negative numbers

11. What type(s) of fraction is/are indicated by a numerator that is numerically smaller than the denominator?

    1. Mixed
    2. Proper
    3. Improper

    A. 1
    B. 2
    C. 1 and 3
    D. 1, 2, and 3

12. How may you change the fraction 3/8 to twenty-fourths?

    A. Multiply the numerator by 3
    B. Multiply the denominator by 3
    C. Divide 8 into 24 to get 3 and multiply the numerator by 3
    D. Multiply both terms of the fraction by 3

13. What lowest common denominator (LCD) would be used to add 1/9, 4/7, 3/35, and 3/25?

A. 1,575
B. 2,205
C. $3^2 \times 7 \times 9 \times 5$
D. $9 \times 7 \times 35 \times 25$

14. What is the least common multiple (LCM) of 60, 36, and 18?

A. 180
B. 540
C. 1,080
D. 2,160

15. Find the greatest common divisor (GCD) of 6, 15, and 21.

A. 3
B. 6
C. 210
D. $3^3 \times 2 \times 5 \times 7$

16. If a baseball player's batting average is quoted as 265, how often has he gotten a hit?

A. 0.265% of the time
B. 2.65 times out of 100
C. 26.5% of the time
D. 265% of the time

17. The decimal fraction 0.00014 can be written as what percent?

A. 0.0000014%
B. 0.0014%
C. 0.014%
D. 0.14%

18. What is the rate, base, and percentage of the equation 3/4 = 75%?

A. Rate 3, base 4, percentage 75%
B. Rate 4, base 3, percentage 75%
C. Rate 75%, base 3, percentage 4
D. Rate 75%, base 4, percentage 3

19. Which of the following ratios is equivalent to the inverse of the ratio 42:48?

A. 3/4
B. 4/3
C. 7/8
D. 8/7

20. Which of the following methods may be used to express the same proportion?

A. 3/6 = 1/2; 3:6 = 1:2; 3:6::1:2
B. 3/6 = 1/2; 3:2 = 1:6; 3/1 = 6/2
C. 3 x 6:1 x 2; 3/6 = 1/2; 3:6 = 1:2
D. 3-6 = 1-2; 3/6 = 1/2; 3:6 = 1:2

21. Which letters of the proportion a/b = c/d represent the extremes?

A. a and c
B. a and d
C. c and b
D. d and c

## SECOND ASSIGNMENT

In Pamphlet No. 460 read from page 19 through page 34 and answer questions 22 through 31.

22. What does the term $5^3$ mean?

A. The cube root of 5 is 3
B. 5 is multiplied by 3
C. 5 is multiplied as a factor 3 times
D. 3 is taken as a factor 5 times

23. Identify the base, exponent, and power associated with the expression $3^2 = 9$.

A. Base is 2; exponent is 3; power is 9
B. Base is 3; exponent is 2; power is 9
C. Base is 3; exponent is 9; power is 2
D. Base is 9; exponent is 2; power is 3

24. What is another name for the square root sign ($\sqrt{\ }$)?

A. Extraction sign
B. Radian sign
C. Factor sign
D. Radical sign

25. If a negative number is raised to the 54th power the sign of the power ____________.

A. is positive
B. fluctuates
C. is negative
D. depends on the base

9

26. What number is the third power of 1.5?

A. 0.015
B. 0.5
C. 2.25
D. 3.375

27. What is the product of $2^2 \times 2^3$?

A. $2^5$
B. $2^6$
C. $4^5$
D. $4^6$

28. What is the sum of $9^0$ plus $9^1$?

A. 0
B. 1
C. 9
D. 10

29. What is the decimal equivalent of $10^{-5}$?

A. 0.01
B. 0.001
C. 0.0001
D. 0.00001

30. What is the sum of $2\sqrt{10}$ plus $1/2\sqrt{10}$?

A. $\sqrt{10}$
B. $2\sqrt{10} + 5$
C. $2\ 1/2\sqrt{10}$
D. $2\ 1/2\sqrt{20}$

31. What is the solution of the expression $\sqrt[3]{27}/\sqrt{9}$?

A. 1
B. $\sqrt[2]{3}$
C. $\sqrt[3]{3}$
D. $\sqrt[3]{27}/\sqrt{9}$

THIRD ASSIGNMENT

In Pamphlet No. 460 read from page 35 through page 52 and answer questions 32 through 41.

32. In the expression $3^4 = 81$, which number may be interpreted as a logarithm?

A. 3
B. 4
C. 64
D. 81

33. What is the logarithmic form of the expression $2^5=32$?

A. $\log_2 5 = 32$
B. $\log_2 32 = 5$
C. $\log_5 32 = 2$
D. $\log_{32} 5 = 2$

34. What number is used as the base of the system of logarithms for most ordinary computations?

A. 2
B. 2.3026
C. 2.71828
D. 10

35. What is the common logarithm of 100,000?

A. 3
B. 5
C. 7
D. 10

36. What is the log of 70?

A. 0.1213
B. 1.1213
C. 1.84510
D. 2.84510

see appendix I

37. What is the log of 0.0024?

A. 0.38021
B. 7.38021-10
C. 8.38021-10
D. 9.38021-10

38. Which of the following relationships between scales on a slide rule is CORRECT?

A. The numbers on the D scale are the square roots of those on the A scale
B. The numbers on the A scale are the square roots of those on the D scale
C. The numbers on the A scale are the squares of those on the B scale
D. The numbers on the D scale are the square roots of those on the C scale

39. How many digits will be to the left of the decimal point in the square root of 400,000?

A. Two
B. Three
C. Four
D. Five

40. Which of the following slide rule scales are used to extract a cube root?

A. A and D
B. A and K
C. B and K
D. D and K

41. When you take a cube root, what system is used to mark off the number of places when you insert the decimal point?

A. Groups of two
B. Groups of three
C. Groups of four
D. Groups of five

FOURTH ASSIGNMENT

In Pamphlet No. 460 read from page 53 through page 66 and answer questions 42 through 46.

42. Which of the following numbers is real and is greater than zero?

A. $i$
B. $i^2$
C. $i^3$
D. $i^4$

43. If r = 1, s = 3, t = 12, and x = 15, what is the value of the expression $t - 2rx/s$?

A. -3
B. -2
C. 2
D. 3

44. In the expression xy, what is the coefficient of xy?

A. 1
B. x
C. y
D. xy

45. Convert binary 110110.001 to its decimal equivalent.

A. 48.250
B. 54.125
C. 54.875
D. 62.025

46. Convert octal 67.5 to its binary equivalent.

A. 101 110 . 110
B. 110 101 . 111
C. 110 111 . 101
D. 111 110 . 011

FIFTH ASSIGNMENT

In Pamphlet No. 460 read from page 67 through page 77 and answer questions 47 through 50.

47. What is the hypotenuse of a right triangle whose sides are 5 and 12 units?

A. 13
B. 14
C. 15
D. 16

48. If the hypotenuse of a right triangle is 8 units and one leg is 4 units, what is the length of the second leg?

A. 4.00
B. 6.73
C. 6.93
D. 8.94

49. What is the sine of an angle 49 degrees 48 minutes?

A. 0.6455
B. 0.7536
C. 0.7638
D. 1.1833

see appendix II

50. What is the interpolated value for the sin 16.58?

A. 0.2845
B. 0.2849
C. 0.2854
D. 0.2856

LESSON 2

APPLIED PHYSICS

FIRST ASSIGNMENT

In Pamphlet No. 460 read from page 79 to Mass, Force, and Motion on page 83 and answer questions 1 through 12.

1. What is the smallest unit into which water can be divided and still retain the characteristic properties of water?

A. Atom
B. Proton
C. Electron
D. Molecule

2. A positive electrical charge is characteristic of which component of an atom?

A. Proton
B. Neutron
C. Nucleus
D. Electron

3. Which of the following describes a small quantity of sea water?

A. Mixture
B. Substance
C. Compound
D. Molecule

4. Which of the following statements BEST describe the Principle of Conservation of Matter?

A. Matter can change appearance
B. Matter will combine with matter
C. Matter cannot be destroyed
D. Matter can form different substances

5. Which of the following examples indicates a chemical change?

A. Iron oxide forming on a structural beam
B. Radium atoms changing into lead atoms
C. Water vapor condensing to form rain drops
D. Sugar dissolving in water

6. Which of the following properties of matter states that two objects cannot occupy the same space at the same time?

A. Permanance
B. Porosity
C. Impenetrability
D. Density

7. Which of the following properties of matter remains the same regardless of altitude or latitude?

A. Mass
B. Weight
C. Density
D. Gravitation

8. If an object is 10 cm long, 6 cm wide, and 4 cm thick and weighs 180 g, what is the density of the object?

A. 0.11 g/cm$^3$
B. 0.75 g/cm$^3$
C. 1.33 g/cm$^3$
D. 9.00 g/cm$^3$

9. Which of the following is used as a standard to determine the specific gravity of a substance?

A. Lead
B. Water
C. Oxygen
D. Carbon

10. The metric (cgs) system has been adopted by the scientific community to measure which of the following units?

A. Length, mass, and time
B. Gravity, density, and force
C. Centimeters, grams, and seconds
D. Circular motion, gravity, and speed

11. What is the approximate equivalent of 24 pounds as expressed in kilograms?

A. 0.996
B. 10.896
C. 18.786
D. 24.000

12

12. In the metric system, what is the unit of distance when the unit of force is the dyne?

A. Erg
B. Joule
C. Angstrom
D. Centimeter

## SECOND ASSIGNMENT

In Pamphlet No. 460 read from Mass, Force, and Motion on page 83 to Change of State on page 92 and answer questions 13 through 26.

13. When no external forces act on a moving object, how will the object move?

A. In a curved line at a decreasing speed
B. In a straight line at a constant speed
C. In a curved line at a constant speed
D. In a straight line at a decreasing speed

14. The wind would blow at right angles across isobars if which of the following forces were the only force affecting wind flow?

A. Coriolis
B. Centripetal
C. Centrifugal
D. Pressure gradient

15. If speed were constant, which of the following objects would experience the greatest deflection due to Coriolis effect?

A. An object moving northeast at 30° N lat.
B. An object moving south at 40° S lat.
C. An object moving north at 60° N lat.
D. An object crossing the Equator moving due North

16. Which of the following influence winds to flow in a circular path?

A. Coriolis effect, speed, and centripetal effect
B. Centrifugal effect, speed, and centripetal effect
C. Centripetal effect, Coriolis effect, and pressure gradient
D. Coriolis effect, pressure gradient force, and centrifugal effect

17. Air pressure on an aircraft increases when the aircraft ________.

A. ascends
B. descends
C. accelerates
D. turns sharply

18. How may one atmosphere of pressure be expressed?

A. 1,013.25 mb, 760 mm, or 29.92 in.
B. 1,013.25 mb, 760 mb, or 29.92 in.
C. 1,013.25 mm, 29.92 in., or 14.7 psi
D. 1,013.25 mm, 29.92 mb, or 14.7 in.

19. What are the standard conditions under which gases must be compared, densities determined, and the gas constants derived?

A. 0° C temperature and 760 mb pressure
B. 15° C temperature and 1,013.25 mb pressure
C. 0° C temperature and 760 mm pressure
D. 15° C temperature and 1,013.25 mm pressure

20. On what does the pressure of an enclosed gas depend?

A. The number of molecules in the container of gas
B. The average space between the gas molecules within the container
C. The force with which the gas molecules strike the walls of the container
D. The number of times the gas molecules strike the walls of the container per unit of time

21. Which of the following actions results in a decrease in atmospheric density?

A. A decrease in temperature or increase in pressure
B. An increase in pressure or increase in moisture
C. An increase in temperature or decrease in pressure
D. A decrease in moisture or increase in pressure

22. If the partial pressures of an enclosed gas are 3 cm, 14 cm, 26 cm, and 51 cm of mercury respectively, what is the total pressure of the enclosed gases?

A. 23.5 cm
B. 47 cm
C. 51 cm
D. 94 cm

23. If the pressure of an enclosed gas is held constant at $10^6$ dynes per square centimeter, what will be the volume of the gas at 200° absolute if the original volume was 240 cubic centimeters at a temperature of 300° absolute?

A. 100 cc
B. 120 cc
C. 140 cc
D. 160 cc

24. If a closed box is submerged in a tub of water so that the bottom of the box does not touch the bottom of the tub, where will the force of the water pressure be exerted on the box?

A. Sides of the box ONLY
B. Top of the box ONLY
C. Top, bottom, and sides of the box
D. Top and bottom of the box ONLY

25. Which of the following statements describes Bernoulli's theorem?

A. The pressure of a flowing liquid is directly proportional to the velocity of the liquid
B. The pressure of a flowing liquid is inversely proportional to the velocity of the liquid
C. The pressure of a flowing liquid is equal to the velocity of the liquid
D. The pressure of a flowing liquid is not affected by the velocity of the liquid

26. Which of the following gas laws states that equal volumes of all gases under equal pressures and temperatures contain equal numbers of molecules?

A. Dalton's Law
B. Avogradro's Number
C. The Equation of State
D. The Hydrostatic Equation

## THIRD ASSIGNMENT

In Pamphlet No. 460 read from Change of State on page 92 to Energy Considerations on page 95 and answer questions 27 through 32.

27. How many calories of heat are required to raise the temperature of 1,500 grams of water from 25° C to 85° C?

A. 60
B. 1,500
C. 90,000
D. 127,500

28. Which of the following changes of state will produce the same result?

A. Melting and fusion
B. Melting and evaporation
C. Freezing and condensation
D. Condensation and evaporation

29. Which of the following requires the greatest amount of time for either heating or cooling if the temperature remains constant?

A. A forest area
B. An ice surface
C. An area of dry sand
D. An ocean surface

30. Which of the following has the greatest effect on atmospheric pressure?

A. Density
B. Humidity
C. Altitude
D. Temperature

31. How is an object heated when the object is in direct contact with the source of heat?

A. By advection
B. By radiation
C. By conduction
D. By convection

32. What method of heat transfer is responsible for the transportation of the greatest amount of heat from one latitude to another?

A. Radiation
B. Convection
C. Conduction
D. Advection

## FOURTH ASSIGNMENT

In Pamphlet No. 460 read from Energy Considerations on page 95 to Stability and Instability on page 101 and answer questions 33 through 41.

33. A ball resting on top of a hill possesses which of the following types of energy?

A. Heat
B. Kinetic
C. Electrical
D. Potential

34. As a parcel of air descends adiabatically in the atmosphere, what happens to the temperature of the parcel?

A. The temperature decreases
B. The temperature increases
C. The temperature remains constant
D. The temperature varies irregularly

35. What would you call the rate at which the temperature of a descending air parcel changes?

A. The mean slope
B. The adiabatic lapse rate
C. The vertical temperature gradient
D. The horizontal temperature gradient

36. At what lapse rate is a parcel of air being cooled if the temperature lowers at the rate of 2° to 3° F per 1,000 feet?

A. Autoconvective
B. Superadiabatic
C. Dry adiabatic
D. Saturation adiabatic

37. Why is the saturation adiabatic lapse rate different from the dry adiabatic lapse rate?

A. Because of the release of the latent heat of condensation
B. Due to the conservation of internal energy
C. Due to the conservation of angular momentum
D. Because of the increase of the environmental lapse rate

38. If adiabatic cooling is offset by the heat of fusion, a parcel of air rising isothermally is in what stage?

A. Dry
B. Hail
C. Rain
D. Snow

39. Which of the following stages of the reversible adiabatic process is eliminated in the irreversible process?

A. Dry
B. Hail
C. Rain
D. Snow

40. What accounts for the formation of large rain drops from cloud droplets in tropical regions?

A. Fusion
B. Condensation
C. Coalescence
D. Sublimation

41. At what temperature is silver iodide most effective as a source of ice crystal nuclei?

A. -10° F
B. -10° C
C. -20° F
D. -20° C

## FIFTH ASSIGNMENT

In Pamphlet No. 460 read from Stability and Instability on page 101 to Optical Phenomena on page 106 and answer questions 42 through 45.

42. When the lifting force is removed, what is the stability of an air parcel that tends to move still farther away from its original position?

A. Unstable
B. Absolutely unstable
C. Conditionally stable
D. Stable

43. What is the stability of a column of air if the lapse rate is less than the saturation adiabatic lapse rate?

A. Absolutely stable
B. Conditionally stable
C. Relatively unstable
D. Conditionally unstable

44. When you are determining energy areas on an AROWAGRAM, what is the average thickness of the layer of air that you should use in the computation of the average mixing ratio?

A. 100 millibars
B. 100 feet
C. 100 meters
D. 100 kilometers

45. As a parcel of air is lifted, at what rate of temperature change do the dewpoint and the dry-bulb temperature approach each other?

A. 0.55°C per 1,000 feet
B. 1°C per 1,000 feet
C. 3.2°F per 1,000 feet
D. 4.5°F per 1,000 feet

## SIXTH ASSIGNMENT

In Pamphlet No. 460 read from Optical Phenomena on page 106 through page 115 and answer questions 46 through 50.

46. What does the color of visible light depend upon?

A. Frequency ONLY
B. Wavelength ONLY
C. Frequency and wavelength
D. Density of the medium through which light travels

47. What property of an object permits virtually 100 percent of the light striking the object to pass through the object?

A. Opacity
B. Transparency
C. Translucency
D. Absorptivity

48. Which of the following terms describes sunlight glancing from the ripples on a lake?

A. Incident transmission
B. Specular reflection
C. Diffused reflection
D. Regular reflection

49. If the speed of light travels through the air twice as fast as light travels through a particular substance, what is the refraction index of that substance?

A. 0.25
B. 0.5
C. 2
D. 4

50. What two primary colors in overlapping beams will produce a light of the secondary color cyan?

A. Yellow and magenta
B. Green and red
C. Blue and red
D. Blue and green

LESSON 3

# GEOLOGICAL AND PHYSICAL OCEANOGRAPHY

## FIRST ASSIGNMENT

In Pamphlet No. 461 read from page 1 through page 7 and answer questions 1 through 11.

1. Which of the following oceanic areas has an approximate one-to-one ratio with the earth's total land cover?

A. Antarctic
B. Atlantic
C. Indian
D. Pacific

2. What continental nation has the LONGEST border with the ocean?

A. Australia
B. Canada
C. Soviet Union
D. United States

3. The Federal government's broad national objective in oceanography is to ____________.

A. protect life and property
B. comprehend and exploit the ocean
C. strengthen basic science
D. manage ocean resources

4. What federal organization has the FINAL review and approval of annual reports submitted by the Interagency Committee on Oceanography?

A. Environmental Protection Agency
B. Commission on Marine Science
C. Federal Council for Science and Technology
D. National Oceanic and Atmospheric Administration

5. Early international cooperation in the fields of oceanography were stimulated by the efforts and reports of ____________.

A. Captain Cook
B. Lieutenant Maury
C. Sir John Murray
D. Commander Wilkes

6. Many of the world's marine biological stations are modelled after the station in ________.

A. La Jolla, California
B. Nanaimo, British Columbia
C. Naples, Italy
D. Vladivostok, U.S.S.R.

7. Early exploration of Alaskan coastal waters included environmental data and samples collected by scientists aboard the cutter ___________.

A. BEAR
B. BALTIMORE
C. HAMILTON
D. LINCOLN

8. In what year did the Coast Guard begin operations in support of the International Ice Patrol?

A. 1912
B. 1914
C. 1917
D. 1919

9. What type of oceanographic plan did the Coast Guard develop in response to Section 94 (Oceanographic Research), Title 14, USC?

A. A ten-year operational plan
B. A nine-year provisional plan
C. A five-year long-range plan
D. A two-year temporary plan

10. Any request for assistance in cooperative oceanography projects that duplicate established programs requires the approval of the ________.

A. Commandant
B. area commander
C. district commander
D. Coast Guard Oceanographic Unit

11. Which of the following cutters is designated a WAGO?

A. CASCO
B. LAUREL
C. GLACIER
D. ACUSHNET

SECOND ASSIGNMENT

In Pamphlet No. 461 read from page 9 through page 17 and answer questions 12 through 21.

12. The water of the ocean accounts for what percent of the water on earth?

A. 55%
B. 70%
C. 85%
D. 95%

13. The earth's mantle is also called the ______.

A. asthenosphere
B. centrosphere
C. exosphere
D. lithosphere

14. Which of the following areas of the earth contains the GREATEST mass?

A. Crust
B. Mantle
C. Inner core
D. Outer core

15. On a global scale, the overall average for the width of the continental shelf is ______ miles.

A. 300
B. 100
C. 30
D. 10

16. What two features bound the area referred to as the Continental Rise?

1. Continental Slope
2. Continental Break
3. Continental Borderland
4. Ocean Basin

A. 3 and 4
B. 2 and 3
C. 1 and 4
D. 1 and 2

17. Of the major underwater ridges, the widest ridge is located in the ________ Ocean.

A. Indian
B. Pacific
C. Atlantic
D. Arctic

18. The major cause of bottom topography modification in the ocean is a result of ________.

A. water currents
B. wave action
C. severe storms
D. sedimentation

19. From the following list of pelagic sediments, the only siliceous category is ________ ooze.

A. radiolarian
B. globigerina
C. coccolith
D. pteropod

20. Which of the following classifications are used MOST often to classify terrigenous deposits on a sea floor?

1. Color
2. Texture
3. Composition of material

A. 2 and 3 only
B. 1 and 3 only
C. 1 and 2 only
D. 1, 2, and 3

21. The reflection mode of sound transmission is affected most seriously by bottom ________.

A. absorption
B. reverberation
C. scattering
D. topography

THIRD ASSIGNMENT

In Pamphlet No. 461 read from page 19 to Transparency on page 28 and answer questions 22 through 36.

22. Which of the following recent developments has had the GREATEST impact on the field of oceanography?

A. Improved instrumentation
B. High speed computer systems
C. Refinement of observational techniques
D. Cooperation among science specialists in many fields

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23. In middle latitudes, the mixed layer of the ocean extends to an average depth of ____ feet.

A. 300
B. 900
C. 1,200
D. 1,500

24. An increase in scattering within a layer of water will also increase ________ within the same layer.

A. radiation
B. absorption
C. conduction
D. reverberation

25. In open ocean areas, sea surface temperatures show the GREATEST diurnal variation in ___________ regions.

A. semi-polar
B. temperate
C. tropical
D. polar

26. The GREATEST decrease in temperature through the thermocline layer is found at _______ latitudes.

A. low
B. high
C. lower-middle
D. upper-middle

27. Which of the following constituents of sea water represents the GREATEST portion of dissolved solids in a water sample?

A. Sodium
B. Potassium
C. Magnesium
D. Chlorine

28. Throughout the world, which of the following factors controls the average surface salinity distribution?

A. River discharge and land runoff combined with precipitation
B. The effect of ocean currents and evaporation
C. The difference between evaporation and precipitation
D. The amount of ice deterioration and precipitation

29. The pressure at a depth of 100 fathoms is approximately ___________.

A. 200 bars
B. 20 bars
C. 100 decibars
D. 10 decibars

30. Which of the following parameters are numerically identical?

1. Density
2. Specific volume
3. Specific gravity
4. Specific volume anomaly

A. 1 and 2
B. 1 and 3
C. 2 and 3
D. 3 and 4

31 Which of the following actions decrease sea water density?

1. Precipitation
2. Melting of ice
3. Heating

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

32. In the ocean, convective circulation is set in motion by which of the following conditions?

A. An abundance of precipitation
B. Heating of surface water
C. Formation of sea ice
D. Run-off from land

33. The viscosity of sea water increases with an increase in which of the following parameters?

1. Temperature
2. Salinity
3. Pressure

A. 1 2, and 3
B. 1 and 3 only
C. 2 and 3 only
D. 2 only

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34. Of the following actions, which tends to increase the specific heat of sea water?

A. Sea ice formation
B. River discharge
C. Surface cooling
D. Evaporation

35. Which of the following results in an increase in the electrical conductivity of a sea water sample?

A. Increase in temperature and/or salinity
B. Decrease in temperature and/or salinity
C. Increase in temperature but decrease in salinity
D. Decrease in temperature but increase in salinity

36. Surface tension increases as a result of an increase in ______________.

A. salinity
B. pressure
C. temperature
D. compressibility

FOURTH ASSIGNMENT

In Pamphlet No. 461 read from Transparency on page 28 through page 40 and answer questions 37 through 50.

37. Nearly one-half the total radiant energy received at the sea surface is absorbed in the first few __________.

A. fathoms
B. meters
C. feet
D. inches

38. What percent of the earth's ice-covered water surface is covered with glacier ice?

A. 0.15%
B. 2.85%
C. 5.00%
D. 95.00%

39. An ice MINIMUM in the Northern Hemisphere is generally present during the month of ________.

A. September
B. August
C. July
D. June

40. The average thickness of arctic polar pack ice is _____ meters.

A. 9.0
B. 7.0
C. 4.5
D. 3.5

41. Exposed openings in sea ice that quickly freeze over are referred to as ____________.

A. leads
B. cracks
C. polynyas
D. skylights

42. Which of the following locations produces The GREATEST percentage of the world's glaciers?

A. Antarctica
B. West coast of Greenland
C. East coast of Greenland
D. North coast of Ellesmere Island

43. In the Greenland area, what is the average height of locally calved icebergs?

A. 20 meters
B. 50 meters
C. 70 meters
D. 120 meters

44. In polar waters, what percentage of the mass of an iceberg remains submerged?

A. 67%
B. 75%
C. 82%
D. 90%

45. The velocity of sound in the sea increases with an increase in which of the following parameters?

1. Temperature
2. Pressure
3. Salinity

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

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46. In the mixed layer, which of the following parameters tends to refract sound beams upward?

A. Chlorinity
B. Conductivity
C. Pressure
D. Temperature

47. The reflective characteristics of sound are dependent upon which of the following?

1. Frequency of sound source
2. Angle of incidence
3. Pulse interval

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

48. Sound waves travel in straight lines if the medium through which they travel maintains a constant ___________.

A. salinity
B. speed
C. pressure
D. temperature

49. Which of the following parameters may cause reverberation of an emitted sound pulse?

1. Sea surface
2. Bottom topography
3. Schooling fish

A. 2 and 3 only
B. 1 and 3 only
C. 1 and 2 only
D. 1, 2, and 3

50. A sound channel in the sea is characterized by a ___________.

A. density minimum
B. density maximum
C. velocity minimum
D. velocity maximum

LESSON 4

# MARINE BIOLOGY AND WATER MOTIONS

## FIRST ASSIGNMENT

In Pamphlet No. 461 read from page 41 through page 53 and answer questions 1 through 12.

1. All marine life is divided into what three categories?

   A. Pelagic, benthos, and plankton
   B. Pelagic, benthos, and nekton
   C. Plankton, nekton, and pelagic
   D. Plankton, benthos, and nekton

2. Which of the following chemical nutrients become a primary food source in the sea as a result of photosynthesis?

   A. Carbonates, nitrates, and silicates
   B. Carbonates, nitrates, and phosphates
   C. Phosphates, nitrates, and silicates
   D. Phosphates, carbonates, and silicates

3. Phytoplankton are produced in which of the following oceanic zones?

   A. Mesopelagic
   B. Euphotic
   C. Bathypelagic
   D. Abyssopelagic

4. Which of the following effects of marine fouling and deterioration is considered the MOST serious to the naval services?

   A. Large dollar loss
   B. Reduction in readiness
   C. Impairment of vessel handling
   D. Deterioration of support facilities

5. Which of the fouling organisms listed below is a crustacean?

   A. Annelids
   B. Ascidian
   C. Shipworms
   D. Gribbles

6. In MOST cases, the rhythm of bioluminescent flashing depends upon the ___________.

   A. amount of organisms
   B. type of organisms
   C. kind of stimulation
   D. time of stimulation

7. During daylight hours, a well-defined deep scattering layer (D.S.L.) is frequently observed at a depth between _________ meters.

   A. 10 and 150
   B. 150 and 300
   C. 300 and 350
   D. 400 and 600

8. Studies of the deep scattering layer indicate the PRIMARY food source for biological make-up of the layer is ____________.

   A. zooplankton
   B. phytoplankton
   C. lantern fish
   D. chemical nutrients

9. A sound similar to that of radio static is made by which of the following oceanic dwellers?

   A. Silver perch
   B. Snapping shrimp
   C. Barnacles
   D. Croakers

10. The MOST common noises produced by nekton are a product of their _______.

   A. swim-bladder
   B. claws
   C. fins
   D. teeth

11. The formation of a coral reef is PRIMARILY what type of process?

   A. Biological
   B. Geological
   C. Chemical
   D. Physical

12. Which of the following obnoxious animals is classified as venomous?

   A. Shark
   B. Moray eel
   C. Barracuda
   D. Stonefish

## SECOND ASSIGNMENT

In Pamphlet No. 461 read from page 55 to Currents on page 59 and answer questions 13 through 18.

13. If the period of a particular wave train is 8 seconds, what is the length of waves in that train?

A. 41 feet
B. 82 feet
C. 164 feet
D. 328 feet

14. The highest one-third of all waves observed for a given sea is referred to as the __________ height.

A. wave
B. swell
C. average
D. significant

15. Which of the following are characteristics of swell waves?

1. Dispersion
2. Confused sea state
3. Angular spreading

A. 2 and 3 only
B. 1 and 3 only
C. 1 and 2 only
D. 1, 2, and 3

16. In relation to a storm center at sea, the distance between wave crests is GREATEST in the area that is ______________.

A. inside the fetch but near the windward end of the fetch
B. inside the fetch but near the leeward end of the fetch
C. outside the fetch but downwind from the leeward end of the fetch
D. outside the fetch but upwind from the leeward end of the fetch

17. What wave factor determines when any given wave will be influenced by bottom topography?

A. Height
B. Length
C. Period
D. Amplitude

18. Which of the following statements concerning waves is true in ALL cases?

A. Wave velocity decreases when water depth decreases
B. Wave direction changes as water depth decreases
C. Wavelength increases as the water depth decreases
D. Waves passing over submarine ridges move faster than waves passing over depressions

## THIRD ASSIGNMENT

In Pamphlet No. 461 read from Currents on page 59 to Tidal Phenomenon on page 66 and answer questions 19 through 30.

19. Knowledge of subsurface ocean currents is based PRIMARILY upon ____________.

A. temperature distribution
B. salinity differences
C. density computations
D. direct observation

20. A current in the Bering Straits is an example of which of the following current classifications?

A. Tidal
B. Hydraulic
C. Geopotential
D. Wind driven

21. What percentage of a local wind's velocity is used to determine the local current's drift?

A. 33%
B. 20%
C. 10%
D. 2%

22. The direction toward which a tidal current tends to move floating objects is known as _______.

A. drift
B. plane
C. range
D. set

23. The MAXIMUM speed of ocean currents in the middle latitudes rarely EXCEEDS ______ knots.

A. 5.0
B. 3.0
C. 2.0
D. 0.5

24. The deflection of a wind-driven current is the GREATEST at which of the following latitudes?

A. 65° S
B. 32° S
C. 10° N
D. 45° N

25. A deep-water subsurface ocean current maintains nearly the same velocity characteristics of the related surface current in which of the following relative locations?

A. Throughout the mixed layer and thermocline
B. The upper part of the mixed layer only
C. The lower part of the mixed layer only
D. Throughout the mixed layer

26. With present knowledge of current eddies near the Gulf Stream, large scale eddies are known to exist for what period of time?

A. In excess of a month
B. In excess of three months
C. Not longer than four weeks
D. Not longer than a week

27. Vertical ocean currents rarely EXCEED a depth of ________ meters.

A. 100
B. 300
C. 500
D. 1,000

28. A line of debris in the open ocean indicates the presence of a __________ current.

A. cross
B. rotary
C. downward
D. diverging

29. What wind direction causes upwelling along the coast of Peru?

A. Westerly
B. Northerly
C. Northwesterly
D. Southwesterly

30. The theory of ocean currents must be modified for water movement shoreward of the ________ contour.

A. 200-fathom
B. 150-fathom
C. 100-fathom
D. 50-fathom

FOURTH ASSIGNMENT

In Pamphlet No. 461 read from Tidal Phenomenon on page 66 to Tidal Currents on page 73 and answer questions 31 through 39.

31. What is the term applied to that brief period at high and low tide when no change of water level is apparent?

A. Stand
B. Slack
C. Crest
D. Still water

32. Which of the following conditions results in unequal tidal heights between succeeding low and high tides at a given place during a similar time period?

A. Declination of the moon
B. Declination of the sun
C. Phase of the moon
D. Phase of the sun

33. A semidiurnal tide is characterized by which of the following tidal actions?

A. Two high tides and one low tide daily
B. Two high and two low tides daily
C. One high tide and two low tides daily
D. One high and one low tide daily

34. When the opposing effects of the moon and the sun are such that they produce low high tides and high low tides, the tides are referred to as ______ tides.

A. gravitational
B. spring
C. lunar
D. neap

35. A perigean tide occurs when the moon is ________________.

A. aligned with the sun
B. opposed to the sun
C. closest to the earth
D. farthest from the earth

36. How long is the nodal period of the moon?

A. 12.4 hours
B. 18.6 years
C. 24.8 hours
D. 29.5 days

37. The level that is used at a tidal station from which to measure water height and bottom depth is referred to as ____________.

A. mean sea level
B. mean low water
C. nodal level
D. tidal datum

38. A desirable observational program to obtain tidal data should be conducted over a MINIMUM time period of one ________ cycle.

A. lunar
B. nodal
C. solar
D. tidal

39. Which of the following Tide Tables provides information for finding the approximate height of the tide at any time between low and high water?

A. Table 1
B. Table 3
C. Table 5
D. Table 7

## FIFTH ASSIGNMENT

In Pamphlet No. 461 read from Tidal Currents on page 73 through page 78 and answer questions 40 through 50.

40. At which of the following locations is a tidal current MOST pronounced?

A. At harbor inlets
B. At broad river mouths
C. Near coastal bays
D. Near offshore islands

41. A hydraulic tidal current is a result of changing __________.

A. water height
B. water velocity
C. current set
D. current drift

42. An offshore, unrestricted tidal current is referred to as a/an __________ current.

A. elliptical
B. hydraulic
C. perigean
D. rotary

43. An offshore, semidiurnal tidal current requires what MINIMUM time period to complete an elliptical pattern?

A. 3.1 hours
B. 6.2 hours
C. 12.4 hours
D. 24.8 hours

44. What time period is used to obtain the mean value of a tidal current?

A. 19 years
B. 1 year
C. 6 months
D. 28 days

45. Which of the following conditions can cause a nontidal current to occur?

A. Moon phase
B. Local wind
C. Water stand
D. Slack water

46. Which of the following statements BEST describes tidal current action in an inland stream or estuary?

A. The velocity maximum of the current is reached near shore
B. The velocity maximum of the current is reached at half-tide
C. The tidal current reverses first near shore
D. The tidal current reverses first at midstream

47. The velocity of an outgoing tidal current is generally STRONGEST near the __________.

A. surface
B. bottom
C. left bank, as you look downstream
D. right bank, as you look downstream

48. How often are Tidal Current Tables published by NOAA?

A. Monthly
B. Annually
C. Quarterly
D. Semiannually

49. From the list below, what data are contained in Tidal Current Tables?

1. Times and strengths of flood currents
2. Times and strengths of ebb currents
3. Times of slack water

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

50. Which of the following portions of Tidal Current Tables contains information about velocity MAXIMUMS of a current?

A. Table 5
B. Table 3
C. Table 2
D. Table 1

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LESSON 5

BASIC METEOROLOGY AND METEOROLOGICAL ELEMENTS

FIRST ASSIGNMENT

In Pamphlet No. 462 read from page 1 through page 13 and answer questions 1 through 23.

1. An early collection of meteorological material widely recognized as an authoritative treatise on weather was written by ________.

A. Virgil
B. Aristotle
C. Hippocrates
D. Theophrastus

2. Which of the following men invented the air thermometer?

A. Bacon
B. Hooke
C. Galileo
D. Torricelli

3. The polar front and wave theory of cyclone development was the work of ________.

A. Haley
B. Boyle
C. Byers
D. Bjerknes

4. Since WWII, the MAJOR advancement in theoretical and practical meteorology has been in the field of ____________.

A. physics
B. chemistry
C. electronics
D. mathematics

5. MOST of the energy radiated by the sun is in the form of ________ waves.

A. heat
B. light
C. electric
D. ultraviolet

6. Which of the following earth's motion have an effect on world-wide weather patterns?

1. Precessional motion
2. Revolution
3. Rotation
4. Solar motion

A. 1, 2, 3, and 4
B. 2, 3, and 4 only
C. 2 and 3 only
D. 3 and 4 only

7. The sun's rays shine perpendicular to the Tropic of Capricorn during the __________.

A. winter solstice
B. vernal equinox
C. summer solstice
D. autumnal equinox

8. That area of the earth between the Tropic of Capricorn and the Tropic of Cancer is referred to as which of the following?

1. Equatorial Zone
2. Torrid Zone
3. Tropical Zone
4. Tropics

A. 1, 2, 3, and 4
B. 1, 2, and 3 only
C. 1, 2, and 4 only
D. 2, 3, and 4 only

9. Which of the following characteristics of a substance has the GREATEST effect on type and intensity of the electromagnetic energy radiated by the substance?

A. Size
B. Color
C. Composition
D. Temperature

10. Which of the following methods of heat transfer has the LEAST effect in meteorology?

A. Advection
B. Conduction
C. Convection
D. Radiation

11. The temperature of the earth's surface being heated by oblique rays is lower than the surface area heated by perpendicular rays because of the ____________.

A. absorption of light rays
B. dispersion of energy
C. scattering of energy
D. reflection of light rays

12. On an average, the earth absorbs what percentage of incoming solar radiation?

A. 25%
B. 36%
C. 51%
D. 75%

13. What is the average albedo of the earth?

A. Between 13 and 28 percent
B. Between 36 and 43 percent
C. Between 45 and 52 percent
D. Between 55 and 65 percent

14. When the sun is directly overhead, which of the following surfaces will have the LOWEST albedo?

A. Water
B. Forest
C. Dirty snow
D. Cloud tops

15. On an average, what percentage of insolation is absorbed by the earth's atmosphere?

A. 3%
B. 8%
C. 13%
D. 36%

16. Practically all the radiation received in northern polar regions during winter is a result of ______________.

A. counterradiation
B. atmospheric radiation
C. terrestrial radiation
D. diffuse sky radiation

17. Of the following atmospheric zones, which zone is NOT a meteorological classification?

A. Thermosphere
B. Stratosphere
C. Ozonesphere
D. Exosphere

18. Above what area(s) of the earth does the troposphere extend to the GREATEST height?

A. The Equator
B. The poles
C. The mid-latitudes
D. The poles in summer and the Equator in winter

19. The MAXIMUM amount of water vapor an air parcel can hold is ________ percent by volume.

A. one
B. four
C. six
D. ten

20. The composition of the air above the tropopause is about the same as the air below the tropopause EXCEPT for the amount of ________.

A. oxygen
B. nitrogen
C. carbon dioxide
D. water vapor

21. Absorption of ultraviolet radiation by ozone results in a temperature increase in the ________.

A. exosphere
B. mesosphere
C. troposphere
D. stratosphere

22. The COLDEST temperature in the atmosphere is reached at the base of the ____________.

A. mesopause
B. mesosphere
C. stratopause
D. stratosphere

28

23. The forecast of temperature inversions is MOST frequently made for which of the following electrical layers of the atmosphere?

A. D-layer
B. Ionosphere
C. Ozonesphere
D. Troposphere

## SECOND ASSIGNMENT

In Pamphlet No. 462 read from page 15 to Clouds on page 23 and answer questions 24 through 38.

24. The MOST dominant meteorological element controlling the type and intensity of weather is ____________.

A. wind
B. pressure
C. temperature
D. water vapor

25. What physical characteristics of air cause the air to exert pressure?

A. Weight and density
B. Elasticity and density
C. Compressibility and volume
D. Elasticity and compressibility

26. Temperature is a measure of which of the following parameters of a substance?

1. Heat intensity
2. Molecular motion
3. Hotness or coldness

A. 1, 2, and 3
B. 1 and 3 only
C. 2 and 3 only
D. 3 only

27. How many scale divisions are there between the boiling and the freezing point of water on the Kelvin temperature scale?

A. 459
B. 273
C. 180
D. 100

28. In an area of unobstructed air flow, the temperature of the air near the earth's surface is referred to as the __________ temperature.

A. mean
B. free air
C. virtual
D. potential

29. Which of the following will cause water vapor to condense in a closed container of saturated air?

A. Increase in pressure
B. Increase in temperature
C. Decrease in temperature
D. Decrease in pressure

30. Which of the following humidity terms is/are expressed in percentage form?

1. Relative humidity
2. Mixing ratio
3. Saturation mixing ratio

A. 1 only
B. 1 and 2 only
C. 1 and 3 only
D. 1, 2, and 3

31. The DIRECT cause of windflow is variation in ______________.

A. temperature
B. pressure
C. humidity
D. density

32. Which of the following luminous meteors is NOT related to clouds which result in adverse weather conditions?

A. Halos
B. Coronas
C. Auroras
D. Rainbows

33. Light rays which enter a substance, are bent within the substance, and leave the substance at a different angle have been ___________.

A. diffracted
B. refracted
C. diffused
D. reflected

29

34. Which of the following atmospheric phenomena are electrical in nature?

1. Fogbows
2. Auroras
3. Airglow

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

35. A very red appearance of the sun's disk at sunset is a result of __________.

A. smoke
B. sand
C. haze
D. dust

36. All frozen forms of precipitation are referred to as __________.

A. lithometeors
B. hydrometeors
C. igneous meteors
D. luminous meteors

KEY

37. Of the following solid forms of precipitation, the equivalent of drizzle is __________.

A. hail
B. sleet
C. snow grains
D. snow pellets

38. Accretion is the process by which water droplets __________.

A. grow in size by continued condensation
B. sublimate into ice crystals because of air turbulence
C. evaporate and then sublimate directly into ice crystals
D. accumulate more layers by colliding with and holding smaller droplets

## THIRD ASSIGNMENT

In Pamphlet No. 462 read from Clouds on page 23 through page 38 and answer questions 39 through 50.

39. Which of the following conditions are required for cloud formation?

1. Sufficient wind
2. Presence of moisture
3. A cooling process
4. Presence of hygroscopic nuclei

A. 1, 2, and 3
B. 1, 3, and 4
C. 2, 3, and 4
D. 2 and 4 only

40. Radiational cooling is a process that cools the air by __________.

A. contact with a cooler surface
B. reradiation of long-wave energy
C. reradiation of short-wave energy
D. contact with an overlying cooler air parcel

41. In polar regions, what is the EXTREME lower limit of the high etage?

A. 20,000 feet
B. 16,500 feet
C. 13,000 feet
D. 10,000 feet

42. Which of the following cloud species is NOT associated with cumulus clouds?

A. Congestus
B. Humilis
C. Mediocris
D. Spissatus

43. The ice crystal composition of cirrus clouds determines which of the following characteristics of cirrus clouds?

1. Shape
2. Height
3. Transparency

A. 3 only
B. 2 and 3 only
C. 1 and 3 only
D. 1, 2, and 3

44. A cloud type that is NOT divided into any species but exists in several varieties is ________.

A. altostratus
B. cirrostratus
C. nimbostratus
D. stratocumulus

45. Heavy, intermittent showers, sometimes mixed with hail, are a characteristic form of precipitation associated with ________ clouds.

A. stratus
B. altostratus
C. cumulonimbus
D. nimbostratus

46. By which of the following processes may saturation of an air mass be reached?

A. An increase in temperature
B. An increase in dewpoint
C. A decrease in humidity
D. A decrease in dewpoint

47. Fog produced by the transport of moist air over a cooler surface is referred to as ______ fog.

A. frontal
B. upslope
C. advection
D. radiation

48. Sea fog is formed when the wind transports ________________.

A. moist, cool air over a warmer ocean surface
B. moist, warm air over a colder ocean surface
C. dry, cool air over a warmer ocean surface
D. dry, warm air over a colder ocean surface

49. What type fog is formed as a result of an increase in dewpoint?

A. Sea fog
B. Steam fog
C. Radiation fog
D. Land advection fog

50. Dew which is frozen after forming is referred to as ________.

A. frost
B. hoarfrost
C. deposit ice
D. white dew

# LESSON 6

## ATMOSPHERIC CIRCULATION, AIR MASSES, FRONTS, AND SPECIAL PHENOMENA

### FIRST ASSIGNMENT

In Pamphlet No. 462 read from page 39 to Secondary Circulations on page 48 and answer questions 1 through 9.

1. Circulation within the atmosphere that is modified by minor, local meteorological conditions is referred to as _________ circulation.

   A. general
   B. tertiary
   C. secondary
   D. primary

2. General global circulation is set in motion by which of the following parameters?

   A. Density
   B. Moisture
   C. Pressure
   D. Temperature

3. If we consider basic temperature gradients over the earth, in what month do the steepest gradients occur in the Southern Hemisphere?

   A. June
   B. March
   C. September
   D. December

4. The polar regions of the earth are areas of _______________.

   A. migratory low pressure
   B. permanent low pressure
   C. permanent high pressure
   D. seasonal high pressure

5. The 3-cell theory of atmospheric circulation divides the earth into how many circulation belts?

   A. Three
   B. Four
   C. Six
   D. Eight

6. Vertical circulation in the atmosphere is found at which of the following latitudes?

   A. 0°, 30°, 60°, and 90°
   B. 0° and 60° only
   C. 30° and 60° only
   D. 30° and 90° only

7. A wind that blows parallel to curved isobars is referred to as a/an _________ wind.

   A. geostrophic
   B. gradient
   C. isallobaric
   D. cyclostrophic

8. Friction affects the direction of wind flow to an average altitude of ________ feet.

   A. 10,000
   B. 8,000
   C. 5,000
   D. 3,000

9. An area of divergence is generally associated with an area of ___________.

   A. precipitation
   B. upward air flow
   C. inward air flow
   D. high barometric pressure

### SECOND ASSIGNMENT

In Pamphlet No. 462 read from Secondary Circulations on page 48 through page 58 and answer questions 10 through 21.

10. In the Northern Hemisphere, the sub-tropical high over the Pacific Ocean is WEAKEST during the ______________.

   A. autumn
   B. winter
   C. spring
   D. summer

11. Which of the following atmospheric conditions are conducive to anticyclonic formation during winter over continental areas?

A. Low temperature and high density
B. Low temperature and low density
C. High temperature and high density
D. High temperature and low density

12. What frontal system has the GREATEST effect on the weather of the United States?

A. Arctic front
B. Polar front
C. Temperate front
D. Extratropical front

13. A counterclockwise circulation of air in the Southern Hemisphere is known as a/an _______.

A. cyclone
B. tornado
C. hurricane
D. anticyclone

14. Which of the following conditions describes cycloysis?

A. Decrease and extinction of a cyclone
B. Formation of a new cyclone
C. Intensification of an existing cyclone
D. Second stage of cyclone development

15. What type of weather is generally associated with a monsoon circulation in winter?

A. Clear skies
B. Violent showers
C. Moderate intermittent showers
D. Considerable convective cloudiness

16. Which of the following characteristics is associated with the jetstream?

A. The velocity of a particular jetstream is constant everywhere
B. The depth of the jetstream exceeds the width of the stream
C. A relationship exists between a break in the tropopause and the jetstream
D. A jetstream nearly always flows westward

17. In what direction do tertiary winds tend to blow in areas of adjacent land and water bodies?

A. From land toward water during daylight and darkness
B. From water toward land during daylight and darkness
C. From land toward water at night and from water toward land during the day
D. From water toward land at night and from land toward water during the day

18. Which of the following winds are classified as anabatic?

A. Foehn
B. Valley
C. Glacier
D. Mountain

19. A chinook wind is warmed as a result of the _______________.

A. expansion of ascending air
B. expansion of descending air
C. compression of descending air
D. contraction of ascending air

20. A glacier wind is generally characterized as _____________.

A. warm and dry
B. warm and moist
C. cold and moist
D. cold and dry

21. For which of the following reasons is the hazard to aircraft GREATER on the leeward side of steep mountains than the windward side?

A. Updrafts are more pronounced on the leeward side
B. Severe downdrafts often accompany the pronounced eddies on the leeward side
C. Friction is more pronounced on the leeward side
D. Eddies tend to be stationary on the leeward side

## THIRD ASSIGNMENT

In Pamphlet No. 462 read from page 59 through page 66 and answer questions 22 through 31.

22. What are the two basic classifications of air masses?

A. Continental and maritime
B. Moisture content and geographical
C. Geographical and thermodynamical
D. Moisture content and thermodynamical

23. Which of the following reasons points to the difference between cPk and cPw air masses?

A. cPk originates over continents
B. cPk originates in polar regions
C. cPk air is colder than the underlying surface
D. cPk is warmer than the underlying surface

24. Which of the following air masses has the HIGHEST moisture content?

A. Superior
B. Equatorial
C. Maritime arctic
D. Maritime polar

25. Which of the following will effect a change in the type of weather associated with a particular air mass?

1. Speed of air mass
2. Underlying terrain
3. Direction of air mass travel

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

26. During winter, the occasional heavy downpours along the California coast are associated with which of the following air masses?

A. Continental tropical
B. Continental polar
C. Maritime polar
D. Maritime tropical

27. From the list below, which areas are source regions for continental tropical air masses?

1. Interior of Russia
2. Northern Africa
3. Asia Minor
4. Interior of Australia

A. 1, 2, 3, and 4
B. 1, 2, and 3 only
C. 1, 3, and 4 only
D. 2, 3, and 4 only

28. The MOST predominant air mass of the Southern Hemisphere is ___________.

A. maritime tropical
B. maritime polar
C. continental polar
D. continental tropical

29. During the summer, which of the following air masses are associated with the sea fogs of the Grand Banks?

A. Maritime tropical
B. Maritime polar
C. Continental polar
D. Continental tropical

30. A conservative property of an air mass with respect to dry adiabatic temperature changes is ___________.

A. wet-bulb temperature
B. equivalent temperature
C. potential temperature
D. relative humidity

31. When we define air-mass properties, which of the following temperatures use the 1,000-mb level as a point of reference?

1. Equivalent temperature
2. Equivalent potential temperature
3. Potential wet-bulb temperature

A. 1, 2, and 3
B. 1 and 2 only
C. 1 and 3 only
D. 2 and 3 only

## FOURTH ASSIGNMENT

In Pamphlet No. 462 read from page 67 through page 77 and answer questions 32 through 38.

32. The distribution of cloudiness and precipitation along a frontal surface is PRIMARILY dependent upon which of the following factors?

A. Vertical velocities within the cooler air mass
B. Vertical velocities within the warmer air mass
C. Horizontal velocities of the coldest air mass
D. Horizontal velocities of the warmest air mass

33. In the Northern Hemisphere, the general wind flow with the passage of a warm front is ________________.

A. a wind shift from southeasterly to southwesterly
B. a wind shift from northeasterly to southeasterly
C. a backing wind from southwesterly to southeasterly
D. a backing wind from southeasterly to northeasterly

34. Where is the warmest air associated with a warm type occlusion?

A. Ahead of the surface front
B. Ahead of the front aloft
C. Behind the front aloft
D. Behind the surface front

35. A cold front that encounters colder, stagnant air on the leeward side of a mountain range becomes what type of front?

A. Warm
B. Stationary
C. Upper cold
D. Upper occluded

36. Which of the following situations tends to develop the GREATEST number of storm centers?

A. A cold air mass passing over a warm ocean current
B. A cold air mass passing over a cold ocean current
C. A warm air mass passing over a cold ocean current
D. A warm air mass passing over a warm ocean current

37. An easterly wave that slopes to the west with altitude is referred to as a/an ______ wave.

A. stable
B. neutral
C. stationary
D. unstable

38. The intertropical convergence zone is the result of converging ______________.

A. easterlies
B. westerlies
C. trade winds
D. antitrade winds

## FIFTH ASSIGNMENT

In Pamphlet No. 462 read from page 79 through page 92 and answer questions 39 through 50.

39. Which of the following atmospheric conditions are necessary for thunderstorm formation?

1. Sufficient wind
2. Presence of moisture
3. A cooling process
4. Presence of hygroscopic nuclei

A. 1 and 3 only
B. 1, 2, and 3
C. 1, 2, and 4
D. 2, 3, and 4

40. Downdrafts are associated with which of the following stages of thunderstorm development?

1. Cumulus
2. Mature
3. Anvil

A. 1 and 2
B. 1 and 3
C. 2 only
D. 2 and 3

41. Within a thunderstorm, which of the following relationships is true concerning turbulence?

A. Turbulence varies directly with the intensity of precipitation
B. Turbulence varies inversely with the intensity of the freezing level
C. Turbulence varies directly with the intensity of the cloud formation
D. Turbulence varies inversely with the intensity of snow and ice crystals

42. When flight is required in areas of thunderstorm activity, the safest procedure for pilots to follow is to fly __________ the storms.

A. through
B. around
C. under
D. over

43. In which of the following locations is tornadic activity MOST likely to develop?

A. In the trough of an occluded front
B. In advance of a cold front
C. Behind a squall line
D. Along a warm front

44. Which of the following comparative statements concerning hurricane and tornado activity is/are TRUE?

1. A hurricane has a longer life cycle
2. A hurricane causes greater damage
3. A hurricane has greater wind velocities

A. 1 only
B. 1 and 2 only
C. 1, 2, and 3
D. 2 and 3 only

45. Tropical lows are classified by ______.

A. wind speed
B. source region
C. central pressure
D. temperature gradient

46. The cloud system associated with an approaching tropical storm is characteristic of which of the following frontal system's cloud distribution?

A. Upper warm front
B. Cold-type occlusion
C. Cold front
D. Warm front

47. One of the FIRST signs of an approaching hurricane in the open sea is a ______.

A. line of heavy cumulonimbus clouds
B. gradual decrease in wind speed
C. well-defined pressure drop
D. long, heavy swell

48. If a tropical cyclone is moving due north in the Northern Hemisphere, in what direction is the LEAST dangerous quadrant?

A. Southwesterly
B. Southeasterly
C. Northeasterly
D. Northwesterly

49. Which of the following conditions of readiness apply(ies) to tornadic activity?

1. Condition I
2. Condition II
3. Condition III
4. Condition IV

A. 1, 2, 3, and 4
B. 1, 2, and 3 only
C. 1 and 2 only
D. 1 only

50. Which of the following nighttime coastal warning displays indicates winds in excess of 48 knots?

A. Two red lights
B. A red light over a white light
C. A white light over a red light
D. A red light between two white lights

LESSON 7

## SURFACE WEATHER AND PHYSICAL OCEANOGRAPHIC OBSERVATIONAL EQUIPMENT AND INSTRUMENTS

### FIRST ASSIGNMENT

In Pamphlet No. 463 read from page 1 to Wind Measuring Instruments on page 15 and answer questions 1 through 14.

1. The metal back on which a standard air thermometer is mounted should be cleaned with ______________.

A. an ivory black and oil mixture
B. an alcohol cleaning agent
C. any abrasive cleaning agent
D. a bicarbonate of soda solution

2. A mercury air thermometer becomes ineffective as temperatures approach ______________.

A. -29°F
B. -35°F
C. -39°F
D. -45°F

3. The thermometers of a hand electric psychrometer (ML-450A/UM) have a temperature range of ________.

A. 140°F
B. 120°F
C. 100°F
D. 80°F

4. You are using a hand electric psychrometer and notice that the mercury column of the wet-bulb thermometer has separated. Which of the following actions should you perform FIRST to correct this situation?

A. Replace both thermometers
B. Replace the wet-bulb thermometer only
C. Heat the thermometer bulb with a lighted electric light bulb
D. Mount the wet-bulb thermometer on a sling and spin the thermometer

5. From the list below, what might cause failure of the variable illumination characteristic of a hand electric psychrometer if the fan motor is operating properly?

1. Defective illuminating lamp
2. Defective battery cells
3. Defective rheostat-switch

A. 1 only
B. 1 or 2
C. 1 or 3
D. 1, 2, or 3

6. What does the term "aneroid" mean?

A. Without liquid
B. Without air
C. Pressure
D. Airborne

7. A pressure reading obtained from an aneroid barometer must be corrected for ____________.

A. instrument error
B. temperature change
C. gravity change
D. latitude error

8. On an open-scale barograph, sudden movement of the pen arm due to any jar or shock is minimized or prevented by the ____________.

A. current pressure adjustment
B. pen shock lever
C. rocker arms
D. dashpots

9. The clock of an open-scale barograph should normally be wound every ____________.

A. eight days
B. four days
C. other day
D. day

10. To remove dried ink from the pen section of an open-scale barograph, you should soak the pen in ________.

A. double-distilled water
B. a bicarbonate of soda solution
C. an alcohol and clock oil solution
D. the ink normally used in the pen

11. On a marine barograph, a temperature compensation device is located in the ________ assembly.

A. element
B. pen shaft
C. chart drive
D. antibacklash gear

12. The cistern and the vertical glass tube of a Fortin barometer are joined by a ________.

A. molded glass flare
B. piece of brass tubing
C. piece of soft kid leather
D. specially configured glass bowl

13. Without interpolation, the stationary scale of a Fortin barometer indicates pressure readings to the nearest ________ inch.

A. 0.100
B. 0.050
C. 0.005
D. 0.002

14. What is the basic difference between a Fortin and a Tonnelot barometer?

A. The attached thermometer
B. The adjustable vernier
C. The cistern assembly
D. The mercury tube

## SECOND ASSIGNMENT

In Pamphlet No. 463 read from Wind Measuring Instruments on page 15 through page 38 and answer questions 15 through 27.

15. The wind speed indicator of a wind measuring set (AN/UMQ-5) is a/an ________ graduated in knots.

A. wattmeter
B. voltmeter
C. ohmmeter
D. ammeter

16. Ink pens of the recorder (RD-108/UMQ-5) are fed by ________.

A. capillary action
B. a pressurized cylinder
C. ambient pressure
D. vacuum control

17. Under normal operating conditions, how often should the chart paper on the AN/UMQ-5 wind recorder be changed?

A. Weekly
B. Every ten days
C. Twice monthly
D. Monthly

18. Which of the following components of a wind measuring set (AN/PMQ-3) require(s) periodic lubrication?

1. Wind speed transmitter
2. Trigger assembly
3. Mounting hub

A. 3 only
B. 2 and 3
C. 1 and 2
D. 1 only

19. If the measuring tube of a rain gage (ML-217) were filled to the half-full mark, what would be the amount of precipitation present in the tube?

A. 2.00 inches
B. 0.50 inch
C. 0.20 inch
D. 0.05 inch

20. How often should winch controls be tested?

A. Before each watch
B. Before each operation
C. On a daily basis
D. On a weekly basis

21. What are the three basic parts of a wire rope?

1. Core
2. Fiber
3. Strand
4. Wire

A. 1, 2, and 3
B. 1, 2, and 4
C. 1, 3, and 4
D. 2, 3, and 4

22. The process of galvanizing wire rope will __________ the rope's strength.

A. halve
B. double
C. increase
D. decrease

23. If the wires in the strands, as well as the strands in the rope itself are both laid to the right, the wire rope lay is termed "__________."

A. right lang lay
B. right regular lay
C. left reverse lay
D. right reverse lay

24. Most new installations of oceanographic wire are of the __________ type construction.

A. 3 x 16
B. 3 x 19
C. 7 x 16
D. 7 x 19

25. Which of the following methods should be used to overwind right lay wire rope on a drum and to underwind right lay wire rope on a drum, respectively?

1. Left to right
2. Right to left

A. 1 and 1
B. 1 and 2
C. 2 and 1
D. 2 and 2

26. Experience has shown that the relationship of the diameter of a sheave to the diameter of the wire rope used should be a MINIMUM of __________.

A. 32 to 1
B. 20 to 1
C. 10 to 1
D. 2 to 1

27. What are the three basic parts of a wire rope clip?

1. Crossbar
2. U-bolt
3. Roddle
4. Nut

A. 1, 2, and 3
B. 1, 2, and 4
C. 1, 3, and 4
D. 2, 3, and 4

THIRD ASSIGNMENT

In Pamphlet No. 463 read from page 39 to Mechanical Bathythermograph (BT) on page 50 and answer questions 28 through 36.

28. Under normal operating conditions, how often should a meter wheel be disassembled and inspected for internal wear?

A. After each cruise
B. Monthly
C. Quarterly
D. Annually

29. During oceanographic observations, which of the following operational characteristics should a good safety program provide?

1. Safe operation
2. Rapid operation
3. Proficient operation

A. 1 only
B. 1 and 2
C. 1 and 3
D. 2 and 3

30. Safety instructions covering oceanographic programs may be issued at which of the following levels of command?

1. Commandant
2. Area commander
3. District commander
4. Unit commander

A. 1 and 2 only
B. 1 and 4 only
C. 1, 2, and 4 only
D. 1, 2, 3, and 4

31. What is the PRIMARY purpose for the reversing action of a Nansen bottle?

A. To allow gathering of samples at great depths
B. To obtain an uncontaminated sample
C. To isolate samples for oxygen analysis
D. To gather samples in arctic regions

32. When the RMS-12 sampler is used, the power to the STD Measuring System is interrupted for about ______ seconds.

A. 5
B. 20
C. 45
D. 60

33. Which of the following sea water temperature readings is MOST commonly observed?

A. Thermistor chain
B. Bathythermograph
C. Nansen
D. Bucket

34. Of the following temperature measuring instruments, which gives the LEAST representative data of a water column's in situ temperature?

A. Expendable bathythermograph
B. Mechanical bathythermograph
C. Deep-sea reversing thermometer
D. Salinity-temperature-depth system

35. At what point on a deep-sea reversing thermometer does the mercury in the main stem separate?

A. Pig-tail
B. Reservoir
C. Auxiliary bulb
D. Appendix dead arm

36. What component of a deep-sea reversing thermometer is subject to damage if the thermometer is stored improperly at very low ambient temperatures?

A. Auxiliary thermometer
B. Break-off point
C. Reservoir
D. Pig-tail

## FOURTH ASSIGNMENT

In Pamphlet No. 463 read from Mechanical Bathythermograph (BT) on page 50 to Bottom Samplers on page 72 and answer questions 37 through 50.

37. On a mechanical BT, the recording stylus is part of the ______________.

A. helical spring
B. Bourdon tube
C. piston head
D. bellows

38. An indication of a mechanical BT's depth range is stamped on the _________ of the instrument.

A. nosepiece
B. moveable sleeve
C. body tube
D. tail fin

39. The temperature sensing element of an XBT is a _____________.

A. capacitor
B. thermistor
C. copper coil
D. Bourdon tube

40. A 1,500-foot XBT probe's deployment cycle time is _______ seconds.

A. 120
B. 90
C. 60
D. 30

41. What is the power source for a BTS (AN/SSQ-36)?

A. A temperature differential activated battery
B. A time delayed dry-cell battery
C. A pressure activated battery
D. A water activated battery

42. The signal converter electronics of an STD system requires a _______ power supply.

A. 28 VDC
B. 115 VAC
C. 150 ma
D. 230 ma

43. Which of the following components of a 9040 STD contain(s) a Paraloc oscillator?

1. Temperature
2. Salinity
3. Mixer
4. Depth

A. 3 only
B. 1 and 2 only
C. 1, 2, and 4 only
D. 1, 2, 3, and 4

44. What component of the 9040 STD system's deck equipment amplifies the FM signal received from the underwater unit?

A. Discriminator
B. Bandpass filter
C. Distribution amplifier
D. Preamplifier circuit

45. The temperature range of the 9040 STD system is accurate from ______________.

A. -2°C to +36°C
B. -2°C to +39°C
C. -10°C to +36°C
D. -10°C to +40°C

46. Which of the following electronic components of the 9040 STD system is considered as part of the underwater unit's lower electronics?

A. Mixer
B. Balance amplifier
C. Operational amplifier
D. Second order temperature compensation

47. The constant current required to activate the mixer of a 9040 STD system is __________.

A. 115 VDC
B. 28 VDC
C. 150 ma
D. 28 ma

48. If the temperature probes of a 9040 STD system require cleaning, you should use ______________.

A. a diluted hydrochloric acid solution
B. any commercial household detergent
C. a bicarbonate of soda solution
D. trichlorethylene

49. Which of the following components of an STD system's plotter should be kept free of any oil or oil spills?

A. Slidewire
B. Pen slide bars
C. Chart mechanism
D. Manual chart drive

50. An STD system's underwater unit that has flooded should be rinsed immediately in distilled water followed by another rinse in __________.

A. alcohol
B. trichlorethylene
C. nondetergent oil
D. a weak hydrochloric acid soulution

LESSON 8

# GEOLOGICAL AND BIOLOGICAL OCEANOGRAPHIC EQUIPMENT; UPPER AIR EQUIPMENT AND INSTRUMENTS; COMMUNICATIONS EQUIPMENT; AND SPECIAL INSTRUMENTATION

## FIRST ASSIGNMENT

In Pamphlet No. 463 read from Bottom Samplers on page 72 to Salinometer on page 85 and answer questions 1 through 6.

1. Which of the following factors should you consider when selecting a bottom sampler?

   1. Nature of investigation
   2. Bottom character
   3. Water depth

A. 1, 2, and 3
B. 1 and 2 only
C. 2 and 3 only
D. 2 only

2. The normal free-fall distance of a Phleger corer is ________ feet.

A. 12
B. 20
C. 28
D. 36

3. Which of the following corers presently in use is designed to obtain the LONGEST bottom sample?

A. Ewing
B. Boomerang
C. Kullenberg
D. Hydro-plastic

4. Which of the following corers may be used as piston-type corers?

   1. Boomerang
   2. Kullenberg
   3. Phleger
   4. PVC

A. 1 and 3
B. 2 and 3
C. 2 and 4
D. 3 and 4

5. Which of the following components of a Boomerang corer can be reused after the float component is retrieved?

A. Nose piece
B. Pilot weight
C. Core catcher
D. Ballast weight

6. Which of the following bottom samplers have the capacity to collect equal amounts of sample?

A. Scoopfish and Van Veen
B. Orange Peel and Van Veen
C. Clamshell and Orange Peel
D. Clamshell and Van Veen

## SECOND ASSIGNMENT

In Pamphlet No. 463 read from Salinometer on page 85 to Sampling Nets on page 99 and answer questions 7 through 16.

7. What power supply is required for the operation of a Model 6220 salinometer?

A. 115 VAC only
B. 230 VAC only
C. 115 or 230 VAC
D. 115 and 230 VAC

8. Copenhagen Standard Sea Water represents a known ____________ value.

A. salinity
B. chlorinity
C. conductivity
D. standardization

9. The zero-adjust screw on the face of a Model 6220 salinometer is used to adjust the __________.

A. NULL/TEMPERATURE INDICATOR needle
B. CONDUCTIVITY RATIO dials
C. STANDARDIZE dials
D. FILL CONTROL needle

10. What information about a water sample is derived directly from a salinometer?

A. Salinity value
B. Chlorinity value
C. Conductivity ratio
D. Standardization ratio

11. Upon securing after a day's run of water samples on a salinometer, rinse the sample cell with ____________.

A. Tergitol solution
B. distilled water
C. Copenhagen Standard Sea Water
D. any commercial cleaning agent

12. In a lab that is properly equipped for oxygen analysis, the GREATEST number of bottles on hand have a ______ ml capacity.

A. 50
B. 100
C. 125
D. 250

13. For an oxygen analysis program, which of the following chemicals should be carried in the GREATEST quantity?

A. Alkaline iodide
B. Sodium thiosulfate
C. Manganous sulfate
D. Potassium biiodate

14. The MOST serious accidents in a laboratory area are a result of ____________.

A. confined spaces
B. handling glassware
C. rough weather conditions
D. contact with strong chemicals

15. If you handle acid-dichromate, it is recommended that you wear ______________.

A. safety goggles and rubber gloves
B. safety goggles and a nose plug
C. rubber gloves and a rubber coat
D. safety goggles, a nose plug, and a rubber coat

16. Acid-dichromate is considered to be good if it maintains a __________ color.

A. greenish
B. milky white
C. light yellow
D. dark brown

## THIRD ASSIGNMENT

In Pamphlet No. 463 read from Sampling Nets on page 99 through page 118 and answer questions 17 through 23.

17. What criterion is used for selecting the mesh size for a biological sampling net?

A. The depth of sampling
B. The time period of sampling
C. The type of sample desired
D. The place where the sample is sought

18. Normally, what portion of a midwater trawl is the first to enter the water?

A. Depressor
B. Cod end
C. Net bridle
D. Net mouth

19. Of PRIME importance to a ship towing a midwater trawl is the __________.

A. mesh of net
B. speed of tow
C. depth of tow
D. depth of water

20. In an area where counter currents exist, the path of a drogue current measuring array will generally represent the flow of the ________.

A. general water mass
B. strongest subsurface current
C. strongest surface current
D. internal waves

21. The GEK current measuring device measures ____________ current.

A. net
B. tidal
C. bottom
D. surface

22. Which of the following components are subassemblies of a sonar pinger?

1. Driver
2. Receiver
3. Transducer
4. Pulse transformer

A. 1, 2, and 3
B. 1, 2, and 4
C. 1, 3, and 4
D. 2, 3, and 4

23. How often, if ever, does the sonar pinger skip a pulse for direct and indirect ping matching?

A. Every other minute
B. Every 10th second
C. Every 30th second
D. The pinger never skips a pulse

## FOURTH ASSIGNMENT

In Pamphlet No. 463 read from page 119 through page 137 and answer questions 24 through 40.

24. Which of the following gases is harmful to balloons made of neoprene?

A. Argon
B. Ozone
C. Nitrogen
D. Carbon dioxide

25. Which of the following balloons can be black?

1. 10-gram ceiling
2. 100-gram pilot
3. 300-gram radiosonde

A. 1, 2, and 3
B. 1 and 2 only
C. 2 only
D. 1 only

26. Which of the following balloons should be conditioned prior to use?

1. 10-gram neoprene
2. 100-gram neoprene
3. 600-gram latex

A. 1, 2, and 3
B. 1 and 2 only
C. 2 only
D. 3 only

27. Grade D helium bottles are normally identified by which of the following characteristics?

A. Orange body with gray stripe
B. Orange colored cap and buff body
C. Buff colored cap and gray body
D. Left-hand threads on the valve outlet

28. Which of the following precautions should you observe when you are transporting helium bottles?

A. Remove the regulator
B. Remove the discharge valve
C. Move the cylinders in cradles only
D. Transport the bottles on carts only

29. The recommended inflation pressure for upper-air balloons is ______ psi.

A. 200
B. 110
C. 43
D. 20

30. The protractor of a meteorological plotting board is secured in such a way as to allow rotation in ____________.

A. range
B. azimuth
C. elevation
D. direction

31. Which of the following illumination lamps of a shore-type theodolite is/are controlled by a rheostat?

1. Elevation scale
2. Azimuth scale
3. Crosshairs

A. 1, 2, and 3
B. 1 and 2 only
C. 2 and 3 only
D. 3 only

32. Before the evaporation tray of a humidity chamber is filled with a solution of sodium chloride and water, the interior of the tray should be coated with ____________.

A. alcohol
B. face soap
C. petroleum jelly
D. light machine oil

33. Which of the following batteries used with upper-air equipment is/are water-activiated?

1. BA-292/AM
2. BA-353/AM
3. BA-380/AM

A. 1, 2, and 3
B. 1 and 2 only
C. 1 only
D. 2 and 3 only

34. Which of the following components is/are included as part of an entire radiosonde instrument?

1. Battery
2. Radio transmitter
3. Barometric-pressure switch

A. 2 only
B. 2 and 3 only
C. 1 and 2 only
D. 1, 2, and 3

35. To adjust the pressure setting on a radiosonde, use the ______________.

A. audio tuning slug
B. filament switch
C. detent wheel
D. baroswitch

36. Which of the following signals is/are received from a radiosonde?

1. Temperature
2. Pressure
3. Dew point

A. 1 only
B. 1 and 2 only
C. 1 and 3 only
D. 1, 2, and 3

37. Which of the following switches is located on the power supply component of an AN/SMQ-1?

A. Chart illumination
B. Signal selector
C. Chart drive
D. Heater

38. Which of the following power supplies is required to operate a Radiosonde Receptor, AN/SMQ-1?

A. 115 VAC
B. 230 VAC
C. 115 or 230 VAC
D. 115 and 230 VAC

39. Which of the following sections is NOT an integral part of the receiver section of an AN/SMQ-1?

A. Detector
B. Discriminator
C. Frequency meter
D. Half-wave dipole antenna

40. A Radiosonde Receptor, AN/SMQ-1, may be calibrated by using a ____________.

A. voltmeter
B. signal generator
C. circular computer
D. frequency counter

FIFTH ASSIGNMENT

In Pamphlet No. 463 read from page 139 through page 154 and answer questions 41 through 50.

41. Why is the model 28 teletypewriter preferred over older models for use aboard ship?

A. It is shockproof
B. It is vibration free
C. It requires less maintenance
D. Space requirements are no longer critical

42. A model 28 teletypewriter is adjusted to handle _______ characters per line.

A. 59
B. 64
C. 69
D. 74

43. A weather keyboard on a teletypewriter has a "+" symbol in the uppercase position of the letter ______.

A. K
B. N
C. S
D. Z

44. On the model 28 teletypewriter, which of the following keys can lock a local machine's keyboard?

1. BLANK
2. BREAK
3. KBD LOCK

A. 3 only
B. 2 and 3 only
C. 1 and 3 only
D. 1, 2, and 3

45. In what relative position of a type box are the lowercase characters located?

A. Left side
B. Right side
C. Bottom half
D. Top half

46. What type of solution, if any, is recommended for proper cleaning of a type box?

A. Any commercial type cleaner
B. Trichlorethylene
C. Alcohol
D. None

47. What is the shelf storage life of the chemically treated paper used with the Alden facsimile recorder?

A. An indefinite period
B. Three years
C. Six months
D. Three months

48. On an Alden facsimile recorder, what compensates for all normal line level variations?

A. White level control
B. Signal level switch
C. Signal monitor switch
D. Automatic gain control

49. On early NOMAD buoys, which of the following observed parameters determined the frequency of observation transmission?

A. Wind velocity
B. Temperature variation
C. Moisture concentration
D. Wave height distribution

50. Station magnetic orientation is an observed parameter transmitted by which of the following automated weather stations?

1. TRANSOBUOY, AN/WMT-1
2. NOMAD, AN/SMT-1
3. PAWS, AN/GMT-4

A. 1, 2, and 3
B. 1 and 2 only
C. 2 and 3 only
D. 3 only

LESSON 9

SURFACE WEATHER OBSERVATION AND METEOROLOGICAL CODES AND PLOTTING

FIRST ASSIGNMENT

In Pamphlet No. 464 read from page 1 to Observations of Visibility on page 9 and answer questions 1 through 14.

1. When the dry-bulb and the dew-point temperatures are the same, the air is said to be ________.

A. mixing
B. ambient
C. saturated
D. in equilibrium

2. How many minutes before ventilation must the bulb of a wet-bulb thermometer be moistened if the dry-bulb temperature is 34°F.?

A. 5
B. 10
C. 15
D. 20

3. To obtain the best results when using the sling psychrometer, whirl the psychrometer to produce an air flow of not less than ______ feet per second.

A. 30
B. 25
C. 20
D. 15

4. Which of the following wind speeds meets the criteria for reporting a wind gust?

A. Lulls of 4 kts with peaks to 13 kts
B. Lulls of 9 kts with peaks to 19 kts
C. Lulls of 10 kts with peaks to 15 kts
D. Lulls of 16 kts with peaks to 24 kts

5. A wind shift, regardless of the magnitude, will always be reported if associated with a ______.

A. sea breeze
B. foehn wind
C. thunderstorm
D. frontal passage

6. What barometer should you normally use for observing pressure when taking a surface observation?

A. Microbarograph
B. Fortin mercurial
C. Tonnelot mercurial
D. Precision aneroid

7. If a ship's barometer is located 37 feet above the loadline, what correction must be applied to determine sea level pressure?

A. +1.4 mb
B. +1.40 in
C. -1.4 mb
D. -1.40 in

8. A trace of precipitation is less than ______ of an inch.

A. 0.01
B. 0.05
C. 0.001
D. 0.005

9. What is a cloud layer termed when a blue sky or higher clouds can be seen through the layer?

A. Opaque
B. Transparent
C. Thin
D. Partially obscured

10. If a cloud layer covers 0.6 of the sky and 0.3 is classified as opaque, the layer is termed ________.

A. transparent sky cover
B. opaque sky cover
C. thin sky cover
D. a ceiling

11. A variable ceiling's height cannot exceed ________ feet.

A. 100
B. 500
C. 1,000
D. 3,000

12. What is the tenths of sky cover if a layer extends from the horizon to 76 degrees above the horizon?

A. 0.3
B. 0.4
C. 0.5
D. 0.6

13. The height value of a layer of clouds at 11,150 feet would be entered in column 6 (sky and ceiling) as ________.

A. 110
B. 111
C. 112
D. 120

14. What color balloon is preferable to obtain the height of a thin cloud layer?

A. Red
B. Black
C. White
D. Natural

SECOND ASSIGNMENT

In Pamphlet No. 464 read from Observations of Visibility on page 9 to General Observation Procedures on page 16 and answer questions 15 through 24.

15. If a shipboard observer's eyes are 35 feet above the water surface, how many miles away is the horizon?

A. 6.6
B. 7.1
C. 13.1
D. 14.0

16. In order for visibility to be termed variable, it must rapidly increase and decrease by one or more tabular values and be less than ________ mile(s).

A. 1/2
B. 5/8
C. 1
D. 3

17. The intensity of which of the following types of precipitation is determined by visibility?

A. Hail
B. Rain
C. Snow
D. Sleet

18. Which of the following is classified as a lithometeor?

A. Fog
B. Dew
C. Haze
D. Drizzle

19. If snow reduces visibility to 1/2 mile, the precipitation intensity is ________.

A. heavy
B. moderate
C. light
D. slight

20. When will the true wind speed be greater than the apparent wind speed when you compute true wind at sea?

A. When the ship is hove to
B. When the apparent wind is on the same side as the true wind
C. When the apparent wind is forward of the beam
D. When the apparent wind is aft of the beam

21. How often should the muslin wick on a psychrometer aboard ship be changed?

A. Daily
B. Weekly
C. Semimonthly
D. Monthly

22. When, if ever, is it unnecessary to whirl the sling psychrometer when making a shipboard observation?

A. When dry-bulb temperature is above 32°F.
B. When precipitation is occurring
C. When the apparent wind speed is 9 kts or more
D. It must always be whirled

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23. When you take a surface weather observation, what method is preferred for obtaining sea water surface temperatures?

A. Bathythermograph
B. Condensor intake
C. Bucket
D. Injector

24. In order for swell to be recorded during a shipboard surface observation, the swell direction must differ from the wind wave direction by at least ________ degrees.

A. 30
B. 45
C. 60
D. 75

## THIRD ASSIGNMENT

In Pamphlet No. 464 read from General Observation Procedures on page 16 through page 28 and answer questions 25 through 37.

25. Which of the below definitions defines the actual time of a surface weather observation?

A. The time the wind is observed
B. The time the last element is observed
C. The time the observation is started
D. The time the observation is disseminated

26. When taking a surface weather observation during unchanging conditions, which of the following elements should you evaluate first?

A. Wind
B. Precipitation
C. Altimeter setting
D. Sea level pressure

27. What is the synoptic code form used for marine surface observations?

A. FM 21.D
B. FM 22.D
C. FM 23.D
D. FM 26.D

28. Which of the following ceiling designators is considered the most reliable?

A. B
B. E
C. M
D. W

29. How would 0.6 of opaque clouds estimated to be at a height of 500 feet be entered in column 6 (sky and ceiling)?

A. **E5⦷**
B. **E50⦷**
C. **50⦷**
D. **5⦷**

30. How would 0.2 of opaque clouds at 1,000 feet be entered in column 6 (sky and ceiling)?

A. **10⌽**
B. **10-⌽**
C. **1000-⌽**
D. **1000⌽**

31. How are heavy thunder and light rain showers occurring at the time of an observation entered in column 8 (weather and obstructions to vision)?

A. TRW-
B. T+R-
C. TR-
D. T+RW-

32. How is very light rain and fog occurring at the time of an observation entered in column 8 (weather and obstructions to vision)?

A. R-F
B. FR-
C. FR--
D. R--F

33. How would 1013.2 mb be entered in column 9 (sea level pressure) of MF1-11?

A. 13.2
B. 132
C. 1013.2
D. 10132

34. What entry, if any, is made in column 12 (wind direction) of MF1-11 for a calm wind?

A. CALM
B. ——
C. OO
D. No entry is made

REFER TO FIGURE 6 OF THE TEXT IN ANSWERING ITEMS 35 THROUGH 37

35. When was the lowest pressure of the day observed?

A. 0000 LST
B. 0000 GMT
C. 0800 LST
D. 0800 GMT

36. What is the sea level pressure recorded in the 0300 observation?

A. 1014.5 mb
B. 996.0 mb
C. 31.45 in
D. 29.96 in

37. What is the sea/air temperature difference encoded for the 0300 observation?

A. 1.5°F
B. 1.5°C
C. 1.7°F
D. 1.7°C

## FOURTH ASSIGNMENT

In Pamphlet No. 464 read from page 29 through 57 and answer questions 38 through 50.

38. Which of the following indicators indicates a ship's synoptic report in reduced form?

A. SHIP
B. SPESH
C. SHRED
D. SPCLI

39. The symbolic figure group that indicates that an analysis message follows is ________.

A. 10001
B. 11111
C. 19991
D. 65556

40. Which of the below symbolic letters indicates air temperature in whole degrees Celsius at the tropopause level?

A. $T_tT_t$
B. $t_Tt_T$
C. TT
D. tt

41. An observer on an icebreaker enroute to the Antarctic by way of South America would be operating in WMO region ________.

A. I
B. III
C. V
D. VI

42. For complete information on all weather codes used in WMO region VI, consult which of the following publications?

A. FMH #2, Synoptic Code Manual
B. Aerographer's Mate 3 and 2
C. Aerographer's Mate 1 and C
D. N. O. 118, Radio Weather Aids

43. Which of the following groups should you always encode when encoding the land station synoptic code?

A. $d_wd_wP_wH_wH_w$
B. 99ppp
C. 7RRjj
D. Nddff

44. Which of the following plain language words can be used at the end of a land station synoptic report?

A. ICE
B. DUST
C. HAIL
D. LIGHTNING

45. If the pressure tendency and the direction and speed that the ship has made good in the past three hours are not reported in the synoptic code, how are they indicated in the ship's synoptic report?

A. 30 is added to the time of the observation
B. 60 is added to the time of the observation
C. $D_sv_s$ is omitted from the report
D. The group $D_sv_s$app is omitted from the report

46. Which of the below indicates that a ship's upper wind code follows?

A. TT
B. VV
C. PILOT SHIP
D. PILOT

47. Which of the following symbolic letters indicates that Part "A" of the radiosonde code follows?

A. TT
B. YY
C. GG
D. WW

48. How is a wind velocity of 48 knots plotted on a surface synoptic chart?

A. 

B. 

C. 

D. 

49. When plotting a surfaoe synoptic chart, you should plot the pressure in the ______ quadrant.

A. NW
B. SW
C. SE
D. NE

50. Which of the following messages contain(s) information of fallout data?

1. UF
2. RADFO
3. UA

A. 1 and 2
B. 1 and 3
C. 1 only
D. 2 only

## LESSON 10

## ICE AND BATHYTHERMOGRAPH OBSERVATIONS; NANSEN AND STD CASTS; AND SAFETY PROCEDURES FOR OCEANOGRAPHIC OBSERVATIONS

### FIRST ASSIGNMENT

In Pamphlet No. 464 read from page 59 through page 71 and answer questions 1 through 8.

1. The size of a growler approximates the size of a ____________.

   A. volleyball court
   B. city block
   C. small cottage
   D. piano

2. Which of the following approximates the size of a medium floe?

   A. Aircraft carrier
   B. Golf course
   C. Small city
   D. City block

3. "Close pack" describes how many oktas of ice coverage?

   A. Two
   B. Four
   C. Six
   D. Eight

4. Any sea ice attached to the shore by stranding or by other means is called ________ ice.

   A. glacier
   B. field
   C. close
   D. fast

5. The term "spot," as used in the ice code refers to a circular area with a radius of _____.

   A. 1 nm.
   B. 2 nm.
   C. 1 km.
   D. 2 km.

6. A special ice observation must be taken when there is a change of at least ______ in concentration.

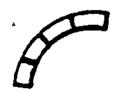
   A. 1/8
   B. 2/8
   C. 3/8
   D. 4/8

7. Which of the following symbolic letters indicate first-year ice over 120 cm. thick?

   A. VF
   B. FT
   C. GF
   D. FL

8. How is a lead indicated on an ice plot?

A. 

C. 

B. 

D. 

### SECOND ASSIGNMENT

In Pamphlet No. 464 read from page 73 through page 88 and answer questions 9 through 15.

9. When commencing a mechanical BT observation, hold the BT just under the surface of the water for 30 seconds in order to ____________.

   A. check cable fittings
   B. ascertain whether the ship is not turning
   C. check winch operation
   D. bring the instrument to water temperature

10. What information must be recorded on the BT slide?

   A. Slide number, date, BT serial number
   B. Time, date, BT serial number
   C. Slide number, time, date, BT serial number
   D. Slide number, time, date

11. What is the allowable error for depth on a mechanical BT observation?

A. 2 ft.
B. 3 ft.
C. 4 ft.
D. 5 ft.

12. During a high sea condition, at what point, if any, should an XBT probe be released?

A. At the bottom of a wave crest
B. Between wave crests
C. At the top of a wave crest
D. The probe should not be released

13. What code figures can be used to indicate that no sea surface reference temperature is encoded for a BT observation?

A. 11 or 22
B. 33 or 44
C. 66 or 77
D. 98 or 99

14. When must you include the group 999NN in a BAXBT message?

A. When terminating the message
B. When you consider the information doubtful.
C. When recording depth increments of 1,000 feet
D. When the sea surface reference temperature exceeds 3°F.

15. In what units of measurements are the temperature and depth readings in the BATHY message in figure 41 expressed?

A. 0.1°F and feet
B. 0.1°C and feet
C. 0.1°C and meters
D. 0.1°F and meters

## THIRD ASSIGNMENT

In Pamphlet No. 464 read from page 89 through page 108 and answer questions 16 through 31.

16. In cold temperatures, how long should the winch be warmed prior to commencing a Nansen cast?

A. 10 minutes
B. 15 minutes
C. 30 minutes
D. 60 minutes

17. Who performs the last check on Nansen bottles before they are lowered into the water?

A. Oceanographic supervisor
B. Platform man
C. Winch operator
D. Bottle passer

18. What must be done when the cable of a shallow Nansen cast has been lowered past a planned depth?

A. The cable must be raised to the planned depth and the bottle hung
B. The bottle must be left off, and the fact that the bottle was not hung must be noted in the oceanographic logbook
C. The bottle must be hung at the depth to which the cable has been lowered, and this depth must be entered in the oceanographic logbook
D. The cast must be aborted

19. How many minutes must be allowed for a messenger to reach 1,950 meters?

A. 12
B. 13
C. 14
D. 15

20. What must be done if a pre-trip of more than one bottle occurs during a Nansen cast?

1. The bottles in question must be disregarded
2. The cast must be retaken
3. The bottle numbers must be noted in the remarks section of the log and temperature message

A. 1 only
B. 2 only
C. 1 and 3
D. 2 and 3

21. What is the proper procedure for drawing salinity samples?

A. Rinse bottle twice, rinse stopper, fill bottle to shoulder
B. Rinse bottle once, rinse stopper, fill bottle to overflowing
C. Rinse bottle once, rinse stopper, fill bottle to shoulder
D. Rinse bottle twice, rinse stopper, fill bottle to overflowing

22. How long should salinity samples be allowed to come to equilibrium before a salinity analysis can be run?

A. 3 hours
B. 6 hours
C. 12 hours
D. 24 hours

23. What information does the winch operator require from the winch card?

A. Actual wire angle
B. Estimated wire angle
C. Actual wire length
D. Estimated wire length

24. How can you determine the meter wheel reading for a particular bottle of a shallow Nansen cast?

A. Add the wire length for the bottle to the maximum wire length
B. Subtract the wire length for the bottle from the minimum wire length
C. Subtract the wire length for the bottle from the maximum wire length
D. Add the wire length for the bottle to the minimum wire length

25. When the meter wheel counter is being set, what is used as the reference for all of the Nansen bottles?

A. Surface of the water
B. Platform
C. Oceanographic weight
D. Last bottle of the cast

26. What is the MAXIMUM allowable variance for the wire-out and wire-in meter readings?

A. 0 meter
B. 1 meter
C. 2 meters
D. 3 meters

27. What is the most important restriction placed on a deep Nansen cast?

A. The wire length must not exceed the depth of the water
B. The wire angle must not exceed 15 degrees
C. The bottom bottle must not be within 100 meters of the bottom.
D. The number of bottles placed on the cable must not exceed 10

28. The weather observation taken during a Nansen cast should always be entered on the ________________.

A. Weather page of the ship's log
B. Nansen salinity sheet
C. Nansen summary sheet
D. Oceanographic Deck Log

29. When more than one Nansen cast is taken on an ocean station, the last group of the oceanographic message for the first cast will always be __________.

A. 11111
B. 19991
C. 55555
D. 99999

30. What is entered for missing data in the Nansen temperature message?

A. A zero
B. A dash
C. The letter "M"
D. A slant bar

31. What are the symbolic letters that represent Nansen bottle location (wire length)?

A. $B_nB_nB_nB_nB_n$
B. DDDDD
C. $D_nD_nD_nD_nD_n$
D. BBBBB

## FOURTH ASSIGNMENT

In Pamphlet No. 464 read from page 109 through page 118 and answer questions 32 through 44.

32. What should an ocean-station vessel do if its STD system fails along a Standard Monitoring Section?

A. Replace the STD casts with BT observations and Nansen casts
B. Replace the STD casts with only BT observations
C. Replace the STD casts with only Nansen casts
D. Discontinue oceanographic observations and return to port

33. How many protected thermometers are used in the surface quality control Nansen bottle?

A. 1
B. 2
C. 3
D. 4

34. What setting, if any, is required for the pens of the 9040 STD recorder before the fish is lowered?

A. Reset both the pens to zero
B. Set the salinity pen 1 division above the temperature pen
C. Set the salinity pen 1 division below the temperature pen
D. No adjustment to the pens is required

35. On a 9040 STD system, the underwater unit may be lowered through the thermocline at a MAXIMUM speed of ______ meters per minute.

A. 50
B. 60
C. 70
D. 80

36. On an STD cast of 2,200 meters, the 1,500-meter QC bottle will be hung when the recorder reads __________ meters.

A. 200
B. 700
C. 1,500
D. 2,200

37. Which of the below depths is NOT a standard depth?

A. 75 m
B. 750 m
C. 1,000 m
D. 2,000 m

38. Temperature is read from the STD recorder's trace to the nearest _______.

A. 0.001°C
B. 0.01°C
C. 0.1°C
D. 1.0°C

39. Which of the following deviations defines a significant depth?

A. 0.1°C.
B. 0.01°C.
C. 0.001 ‰
D. 0.005 ‰

40. STD analog traces are submitted to _______.

A. NAVOCEANO
B. FNWF
C. CGOU
D. NODC

41. How often are Conductivity-Messages required?

A. Each cast
B. Daily
C. Every 5 days
D. Weekly

42. The end-of-message indicator for an STD Data Message is _________.

A. 10001
B. 19991
C. 55555
D. 99999

43. What symbolic figures are used to record the sonic depth to the ocean's bottom?

A. $S_j S_j S_j S_j S_j$
B. BBBBB
C. DDDDD
D. $D_B D_B D_B D_B D_B$

44. How often is the STD Quality Control Data Message sent?

A. Daily, after the last cast of the day
B. After each cast
C. Every 5 days
D. Weekly

## FIFTH ASSIGNMENT

In Pamphlet No. 464 read from page 119 through page 124 and answer questions 45 through 50.

45. In what unit of measurement is the line of the Secchi disc marked?

A. Feet
B. Inches
C. Centimeters
D. Meters

46. How often are Secchi disc readings taken?

A. Every 6 hours
B. Once daily
C. Twice weekly
D. Once weekly

47. How far under the surface of the water must the Secchi disc be when the Forel scale is being used?

A. One meter
B. Two meters
C. Three meters
D. Four meters

48. What is done to prevent a cast from striking the platform?

A. The platform man fends off the cable by using his leather arm guard
B. The winch operator stops the winch
C. The winch operator immediately lowers the cast to its lowest depth
D. The platform man rigs a fender outboard of the platform

49. Who determines the winch speed during the STD cast?

A. Oceanographic supervisor
B. Recorder operator
C. Safety officer
D. Platform man

50. Who directs the winch operator by use of hand signals during Nansen casts?

A. Oceanography officer
B. Oceanographic supervisor
C. Safety officer
D. Platform man

LESSON 11

# DATA PROCESSING AND ANALYSIS

## FIRST ASSIGNMENT

In Pamphlet No. 465 read from page 1 through 17 and answer questions 1 through 10.

1. Winds can blow across isobars over ocean areas at angles of as much as ______ degrees.

   A. 20
   B. 30
   C. 40
   D. 50

2. Which of the below pressure values would be correct for an isobar at 60 degrees north latitude?

   A. 1038
   B. 1022
   C. 982
   D. 976

3. When using the two-station method of analysis, begin the analysis over ____________.

   A. ocean areas with few reports
   B. land areas with many reports
   C. ocean areas with many reports
   D. land areas with few reports

4. Which of the below cloud types will usually be found 600 miles in advance of a warm front?

   A. Stratus
   B. Nimbostratus
   C. Altostratus
   D. Cirrostratus

5. The most important fact to consider when starting a surface analysis is the _________.

   A. corrected past history
   B. location of fronts
   C. location of pressure centers
   D. wind field

6. A line drawn on a surface chart as brown dashes would indicate a __________ line.

   A. convergence
   B. shear
   C. ridge
   D. trough

7. The direction of movement of surface pressure systems and fronts depends upon the ________________.

   A. wind flow at the surface
   B. topography
   C. wind flow aloft
   D. temperature field

8. Which of the below charts would be drawn for contour intervals of 120 meters?

   A. 300-mb
   B. 400-mb
   C. 500-mb
   D. 600-mb

9. Lines of equal temperature drawn on an upper air chart are ____________.

   A. isobars
   B. isotherms
   C. isallobars
   D. isoheights

10. Short dashed green lines drawn on an upper air chart are _________.

   A. isobars
   B. isodrosotherms
   C. isotachs
   D. isoheights

## SECOND ASSIGNMENT

In Pamphlet No. 465 read from page 18 to Communications Systems on page 26 and answer questions 11 through 17.

11. When drawing the "DP" curve on the AROWAGRAM, indicate a stratum of missing data with ________________.

   A. the letters "MB" plotted in the center of the stratum
   B. the letter "M" plotted in the center of the stratum
   C. a dashed line
   D. a wavy line

12. On an AROWAGRAM, one degree of temperature change is equivalent to a height change of ________ feet.

A. 5,000
B. 1,500
C. 500
D. 150

13. Referring to figure 19, determine the height of the freezing level.

A. 4,400 ft.
B. 7,000 ft.
C. 11,600 ft.
D. 12,300 ft.

14. Referring to figure 19, determine the average mixing ratio used to determine the lifting condensation level.

A. 12.9
B. 13.4
C. 14.0
D. 14.6

15. What should you use as the average mixing ratio if there is a surface-based inversion?

A. The average of all dew points in the first 100 millibars of the sounding
B. The dew point from the top of the inversion
C. The surface dew point
D. The average of the dew points from the top and the bottom of the inversion

16. What level is found by extending the average mixing ratio line upwards until it intersects the temperature curve?

A. Convective condensation level
B. Lifting condensation level
C. Level of free convection
D. Freezing level

17. Referring to figure 23, determine the height of the 650-mb level.

A. 11,500 ft.
B. 12,500 ft.
C. 13,500 ft.
D. 14,500 ft.

## THIRD ASSIGNMENT

In Pamphlet No. 465 read from Communications Systems on page 26 through page 46 and and answer questions 18 through 29.

18. Over which of the below teletype circuits would aviation area forecasts be disseminated?

A. Comet I
B. Comet IIA
C. Service A
D. Service C

19. What type of weather message is used to fill in areas of sparse data on a synoptic weather chart?

A. Recco reports
B. Specials
C. Airways
D. Pilot reports

20. In the radar message in table 3, the movement of the area of echoes is from ________ degrees at ________ knots.

A. 160 - 12
B. 270 - 30
C. 316 - 30
D. 316 - 83

21. An area of related or similar echoes covering less than 0.1 of the reported area is a/an ________.

A. fine line
B. scattered area
C. isolated echo
D. widely scattered area

22. In figure 31, what are the weather and obstructions to vision forecasted for the period?

A. Light rain, fog, and smoke
B. Light rain showers, fog, and smoke
C. Very light rain showers, fog, and smoke
D. Very light rain, fog, and smoke

23. In figure 33, what is the surface wind forecast after 0100Z?

A. Less than 10 knots
B. 180 degrees, 15 knots
C. 330 degrees, 15 knots
D. 330 degrees, 20 knots

24. In figure 33, what is the height (in feet) of the lowest ceiling forecasted for the period?

A. 3,400
B. 2,500
C. 1,500
D. 1,000

25. Icing in clouds and in precipitation would appear on a chart area as ________.

A. ICICIP
B. ICGCIP
C. ICGCP
D. ICGICIP

26. If an area forecast states there will be few thunderstorms, what will the areal coverage of these thunderstorms be?

A. 15% or less of the area
B. 16 to 30% of the area
C. 31 to 45% of the area
D. 46% or more of the area

27. In figure 37, what is the height of the freezing level east of the front?

A. 10,000 feet ASL
B. 10,000 feet AGL
C. 6,000 feet ASL
D. 6,000 feet AGL

28. In figure 37, what is the maximum tops forecasted for the entire period?

A. 18,000 feet ASL
B. 18,000 feet AGL
C. 20,000 feet ASL
D. 20,000 feet AGL

29. What would be the heading of a weather message that contained a weather warning other than a hurricane for the North Atlantic?

A. WHNA
B. WWNA
C. WHNT
D. WWNT

FOURTH ASSIGNMENT

In Pamphlet No. 465 read from page 48 through page 63 and answer questions 30 through 39.

30. The portion of a weather depiction chart enclosed by solid lines indicates areas with either visibility below 3 miles or a ceiling less than ____________ feet.

A. 100
B. 500
C. 1,000
D. 3,000

31. What is indicated when no visibility value is entered on a weather depiction station model?

A. Visibility data is missing
B. Visibility is 7 miles or greater
C. An error has been made in plotting
D. Weather and obstructions to vision data are missing

32. Which of the below symbols indicates an overcast with breaks on a weather depiction chart?

A. 
C. 
B. 
D. 

33. If a station reported light rain, light snow, and fog, how would this be entered on a weather depiction chart?

A. R-S-
B. RS
C. RSF
D. R-S-F

34. Which of the below symbols indicates solid stratified echoes on a radar summary chart?

A. 
C. 
B. 
D. 

35. Moderate rain showers increasing in intensity would be indicated by which of the following symbols on a radar summary?

A. RW
B. R/+
C. RW+
D. RW/+

36. In figure 44, the line of echoes located in eastern Texas and western Louisiana is moving east at _______ knots.

A. 20
B. 25
C. 30
D. 35

37. In figure 44, the maximum tops of all cloud echoes on the chart is __________ feet MSL.

A. 45,000
B. 40,000
C. 4,500
D. 4,000

38. How is an instability line indicated on a facsimile chart?

A. 

B. 

C. 

D. 

39. Which of the below symbols indicates moderate icing on a facsimile chart?

A. 

B. 

C. 

D. 

FIFTH ASSIGNMENT

In Pamphlet No. 465 read from page 65 to Oxygen Analysis on page 72 and answer questions 40 through 48.

40. The degree of conformity of a measure to a standard or true value is the definition of _____________.

A. precision
B. accuracy
C. sensitivity
D. discrete measurement

41. What must be checked prior to applying power to the salinometer?

A. Conductivity reads exactly zero
B. Standardization dial reads 5,000
C. Meter sensitivity is within limits
D. Null indicator reads exactly zero

42. Why should the salinometer cell be rinsed and drained several times prior to standardizing the instrument?

A. To allow for cell temperature equilibrium
B. To check the quality of the Standard Water
C. To test various functions of the instrument
D. To familiarize the operator with correct procedures

43. During standardization of the salinometer, how many sample readings must be obtained?

A. 2
B. 3
C. 4
D. 5

44. Which of the below would necessitate a new standardization of the model 6220 salinometer?

A. Power cord is accidentally unplugged
B. Sample temperature differs by 2.4°C. from standardization temperatures
C. Standard water conductivity ratio differs from the standardization conductivity by +0.00025
D. Standard water conductivity ratio differs from the standardization conductivity by -0.00025

45. What should you do to eliminate bubbles in the salinometer cell?

A. Fill the cell rapidly
B. Use care not to shake the sample
C. Turn on the stirrer prior to filling the cell
D. Shake the sample vigorously prior to filling the cell

46. How many samples are run after standardization before a Standard Water sample is run as an unknown?

A. 1
B. 2
C. 3
D. 4

47. Assume that the salinity value for the original standardization is 35.012 ‰ and that the first Standard Water run as an unknown is 35.014 ‰. The correction for shear to be applied to the first salinity value is __________.

A. ± .000
B. + .001
C. - .001
D. - .002

48. Using the salinity values from question 47, determine the shear correction to be applied to the fourth salinity value.

A. - .001
B. + .001
C. - .002
D. + .002

SIXTH ASSIGNMENT

In Pamphlet No. 465 read from Oxygen Analysis on page 72 to Processing Station Data on page 82 and answer questions 49 through 55.

49. The white precipitate of manganous hydroxide rapidly turns brown in the presence of ________.

A. sulfuric acid
B. dissolved oxygen
C. alkaline iodide
D. sodium thiosulfate

50. What should you do with the droplet hanging from the tip of a volumetric pipet after draining the pipet?

A. Transfer the drop to the rest of the liquid by touching it against the side of the container
B. Wipe off the drop with a Chem-wipe
C. Immerse the tip into the liquid
D. Shake the pipet vigorously to drain

51. The chemical reagent that is highly viscous and slippery is __________.

A. potassium biiodate
B. hydrochloric acid
C. alkaline iodide
D. sodium thiosulfate

52. After you have added a reagent to a sea water sample and the precipitate has settled to the bottom of the bottle, the sample should NOT stand for more than ______ hour(s) before acidification.

A. 1/2
B. 1
C. 2
D. 3

53. How often is the sodium thiosulfate solution standardized when ocean stations are taken?

A. At the beginning of each station
B. Once every other day
C. Every five days
D. Once a week

54. During oxygen titration the second end point must agree to within ± ________ ml of the first end point.

A. 0.01
B. 0.02
C. 0.03
D. 0.04

55. A periodic check of the quality of the oxygen analysis reagents is accomplished by __________.

A. making a blank determination
B. standardizing the sodium thiosulfate solution
C. computing the normality of the solution
D. checking the shelf life date of the chemicals

SEVENTH ASSIGNMENT

In Pamphlet No. 465 read from Processing Station Data on page 82 through page 95 and and answer questions 56 through 60.

56. What is the advantage of processing oceanographic data aboard ship instead of at a land station?

A. It provides more stable conditions
B. It provides an immediate guide for future observations
C. There is more work space available
D. Quality control is easier to maintain

61

57. The calibration sheet of a reversing thermometer provides which of the below factors?

1. $V_o$
2. Q-factor
3. $\rho$m

A. 1 and 2
B. 1 and 3
C. 1 only
D. 2 only

58. How can you determine accepted depth from the L-Z graph?

A. Divide the wire length by the L-Z value
B. Multiply the L-Z value by the wire length
C. Subtract the L-Z value from the wire length
D. Add the wire length to the L-Z value

59. In figure 58, what is the density value of the water at point 00?

A. 15.5
B. 24.7
C. 27.4
D. 33.5

60. In figure 61, what is the current direction and velocity in cm/sec at a point of 33° latitude, 118° longitude? 3

A. NE-6
B. SW-6
C. NE-13
D. SW-13

MODIFICATIONS

Lessons 12 and 13 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

ALL U. S. COAST GUARD INSTITUTE COURSES ARE NOW SELF-SCORING

Do Not Send Any Answer Sheets To The Institute

Use the enclosed answer key to determine the correct answer to the questions in your course book, study guide, or course pamphlet. THE LATEST REVISIONS OF COURSE PAMPHLETS WILL HAVE THE ANSWER KEY FOR THE PAMPHLET IN THE BACK OF THE PAMPHLET. IF ANSWERS ARE PROVIDED IN THE PAMPHLET, DISREGARD THE PART OF THIS KEY THAT COVERS THAT LESSON.

When you have completed all the lesson assignments and feel that you are ready for the end-of-course test ask your Educational Services Officer to send for your test. The test will not be sent from the Institute until the ESO requests it. THERE IS NO CHANGE IN THE REQUIREMENT TO PASS THE CLOSED-BOOK END-OF-COURSE TEST.

The answer key has been arranged so that you may look up the answer to any item without seeing the answer to the next item at the same time. This has been done so that you will get the greatest benefit from the self-scoring process. The chart below shows you how to read the answer key.

| | | | REF. | |
|---|---|---|---|---|
| ITEM | LESSON | ANS. | PAM | PG. |
| 1 | 1 | D | 218 | 2 |
| | 2 | A | 312 | 2&3 |
| | 3 | B | 573 | 1 |
| | 4 | D | 574 | 2 |
| | 5 | C | 575 | 1 |
| | 6 | B | 576 | 2 |
| | 7 | A | 577 | 1 |
| | 8 | C | 578 | 2 |

Column 1 shows the item.

Column 2 shows the lesson number.

Column 3 lists the answers.

Column 4 lists the pamphlet number and 5 lists the page number of the reference to the question.

INSTRUCTIONS FOR USING THE LESSON ANSWER KEY

The answer key has been provided so that you will be able to know at the end of each lesson how well you did on it. Read the text material, then answer all the questions for the lesson. Check the answer key to see if you did well enough to go to the next lesson. If you did not do well enough, you should review the text references for the items you missed. When you are sure of the correct answers, continue on to the next lesson. Use the table below as a guide to help you decide how well you did on each lesson.

| Number of items | Number of items you answered CORRECTLY | | |
|---|---|---|---|
| | Go to the next lesson | Restudy the items you missed | Restudy the entire lesson |
| 100 | 88-100 | 70-87 | less than 70 |
| 90 | 79-90 | 63-78 | less than 63 |
| 80 | 70-80 | 56-69 | less than 56 |
| 70 | 62-70 | 49-61 | less than 49 |
| 60 | 53-60 | 42-52 | less than 42 |
| 50 | 44-50 | 35-43 | less than 35 |
| 40 | 35-40 | 28-34 | less than 28 |
| 30 | 26-30 | 21-25 | less than 21 |
| 20 | 17-20 | 14-16 | less than 14 |

NOTE: Before beginning the first lesson, review the answer key to find the items which are marked by "X." All items marked by "X" have been deleted from the lesson. You should not attempt to answer those questions. When all items in a lesson have been marked by "X," you should not read the text material for that lesson. Items on the end-of-course test which are based on lessons which have been deleted will not be counted in your score on the end-of-course test. You will get credit on your score for any answer you select on those items.

F - Figure
T - Table

ANSWER KEY FOR MST2 COURSE, EDITION 1

| Item No. | Les No. | Ans | Ref Pam | Page |
|---|---|---|---|---|
| 1 | 1 | D | 460 | 1 |
| | 2 | D | 460 | 79 |
| | 3 | D | 461 | 1 |
| | 4 | D | 461 | 42 |
| | 5 | B | 462 | 1 |
| | 6 | B | 462 | 39 |
| | 7 | D | 463 | 1 |
| | 8 | A | 463 | 74 |
| | 9 | C | 464 | 1 |
| | 10 | D | 464 | 60 |
| | 11 | A | 465 | F.15 2/3 |
| | 12 | A | 96 | 1 |
| | 13 | D | 160 | 2 |
| 2 | 1 | A | 460 | 1 |
| | 2 | A | 460 | 79 |
| | 3 | C | 461 | 2 |
| | 4 | C | 461 | 42 |
| | 5 | C | 462 | 2 |
| | 6 | B | 462 | 39 |
| | 7 | B | 463 | 2 |
| | 8 | B | 463 | 76 |
| | 9 | C | 464 | 2 |
| | 10 | A | 464 | 61 |
| | 11 | D | 465 | F.16 5 |
| | 12 | D | 96 | 1 |
| | 13 | A | 160 | 5 |
| 3 | 1 | B | 460 | 2 |
| | 2 | A | 460 | 80 |
| | 3 | B | 461 | 2 |
| | 4 | B | 461 | 42 |
| | 5 | D | 462 | 2 |
| | 6 | A | 462 | 40 |
| | 7 | C | 463 | 3 |
| | 8 | A | 463 | 77 |
| | 9 | D | 464 | 2 |
| | 10 | C | 464 | 62 |
| | 11 | B | 465 | F.17 5 |
| | 12 | B | 96 | 1 |
| | 13 | B | 160 | 11 |
| 4 | 1 | A | 460 | 3 |
| | 2 | C | 460 | 80 |
| | 3 | C | 461 | 2 |
| | 4 | B | 461 | 43 |
| | 5 | C | 462 | 2 |
| | 6 | C | 462 | 40 |
| | 7 | C | 463 | 5 |
| | 8 | C | 463 | 80 |
| | 9 | B | 464 | 4 |
| | 10 | D | 464 | 60 |
| | 11 | D | 465 | 7 |
| | 12 | B | 96 | 2 |
| | 13 | C | 160 | 13 |
| 5 | 1 | B | 460 | 3 |
| | 2 | A | 460 | 80 |
| | 3 | B | 461 | 3 |
| | 4 | D | 461 | 43/44 |
| | 5 | B | 462 | 3 |
| | 6 | C | 462 | 45 |
| | 7 | C | 463 | 6 |
| | 8 | C | 463 | T.1 81 |
| | 9 | D | 464 | 5 |
| | 10 | C | 464 | 63 |
| | 11 | A | 465 | 10 |
| | 12 | B | 96 | 3 |
| | 13 | C | 160 | 15 |
| 6 | 1 | D | 460 | 5 |
| | 2 | C | 460 | 81 |
| | 3 | C | 461 | 3 |
| | 4 | C | 461 | 44/46 |
| | 5 | C | 462 | 3 |
| | 6 | A | 462 | 45 |
| | 7 | A | 463 | 5 |
| | 8 | B | 463 | 83 |
| | 9 | D | 464 | 5 |
| | 10 | B | 464 | 67 |
| | 11 | D | 465 | F.20 11 |
| | 12 | B | 96 | F.12 3 |
| | 13 | B | 160 | 21 |
| 7 | 1 | C | 460 | 6 |
| | 2 | A | 460 | 81 |
| | 3 | D | 461 | 4 |
| | 4 | C | 461 | 47 |
| | 5 | A | 462 | 3 |
| | 6 | D | 462 | 47 |
| | 7 | A | 463 | 6/7 |
| | 8 | C | 463 | 87 |
| | 9 | A | 464 | 5 |
| | 10 | B | 464 | 72 |
| | 11 | C | 465 | F.24 10 |
| | 12 | X | X | X |
| | 13 | D | 160 | 23 |
| 8 | 1 | B | 460 | 6 |
| | 2 | B | 460 | 81 |
| | 3 | B | 461 | 4 |
| | 4 | B | 461 | 47 |
| | 5 | A | 462 | 4 |
| | 6 | D | 462 | 47 |
| | 7 | D | 463 | 9 |
| | 8 | B | 463 | 87 |
| | 9 | D | 464 | 6 |
| | 10 | A | 464 | 72 |
| | 11 | A | 465 | F.24 15 |
| | 12 | D | 96 | 4 |
| | 13 | A | 160 | 23 |
| 9 | 1 | A | 460 | 6 |
| | 2 | B | 460 | 82 |
| | 3 | B | 461 | 5 |
| | 4 | B | 461 | 48 |
| | 5 | D | 462 | 5 |
| | 6 | D | 462 | 48 |
| | 7 | B | 463 | 9 |
| | 8 | A | 463 | 88 |
| | 9 | B | 464 | 6 |
| | 10 | D | 464 | 74 |
| | 11 | B | 465 | 16 |
| | 12 | C | 96 | T.2 6 |
| | 13 | D | 160 | 23 |
| 10 | 1 | C | 460 | 7 |
| | 2 | A | 460 | 82 |
| | 3 | A | 461 | 5 |
| | 4 | A | 461 | 48 |
| | 5 | B | 462 | 6 |
| | 6 | B | 462 | 49 |
| | 7 | D | 463 | 10 |
| | 8 | C | 463 | 88 |
| | 9 | C | 464 | 6 |
| | 10 | C | 464 | 76 |
| | 11 | C | 465 | 16 |
| | 12 | B | 96 | T.2 9 |
| | 13 | B | 160 | 24 |
| 11 | 1 | B | 460 | 9 |
| | 2 | B | 460 | 82 |
| | 3 | D | 461 | 7 |
| | 4 | A | 461 | 49 |
| | 5 | B | 462 | 7 |
| | 6 | A | 462 | 49 |
| | 7 | A | 463 | 12 |
| | 8 | B | 463 | 89 |
| | 9 | D | 464 | 7 |
| | 10 | B | 464 | 78 |
| | 11 | B | 465 | 21 |
| | 12 | D | 96 | 9 |
| | 13 | C | 160 | 26 |
| 12 | 1 | D | 460 | 10 |
| | 2 | D | 460 | 83 |
| | 3 | C | 461 | 9 |
| | 4 | D | 461 | 52 |
| | 5 | C | 462 | 7 |
| | 6 | B | 462 | 50 |
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| | 12 | A | 96 | 14 |
| | 13 | A | 160 | 42 |
| 19 | 1 | D | 460 | 16 |
| | 2 | C | 460 | 89 |
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| | 4 | C | 461 | 63 |
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| 48 | 1 | C | 460 | 67 |
| | 2 | C | 460 | 111 |
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# REVIEW OF MATHEMATICS AND BASIC PHYSICS

15-2

A correspondence course pamphlet consisting of excerpts from:

| | |
|---|---|
| American Practical Navigator (Bowditch) | N.O. PUB. 9 |
| Mathematics, Vol. 1 | NAVPERS 10069-C |
| Digital Computer Basics | NAVPERS 10088 |
| Aerographer's Mate 1 & C | NAVPERS 10362-A |
| Aerographer's Mate 3 & 2 | NAVPERS 10363-C |

U.S. COAST GUARD INSTITUTE
OKLAHOMA CITY, OKLAHOMA

JANUARY 1972

PAMPHLET NO. **460**

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WARNING

THE MATERIAL IN THIS PAMPHLET IS FOR TRAINING ONLY. IT SHOULD NEVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, OR OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. ALWAYS CHECK THE LATEST DIRECTIVES AND PUBLICATIONS ON THE JOB.

# INTRODUCTION

You are on your way to advancement as a Marine Science Technician. Most of you, if not all of you, are graduates of MST "A" School and have a good working knowledge of your rate as a whole. In this course there will be areas of review as well as areas of new material.

In this first pamphlet of your course, you will find a review of basics that are vital to the accomplishment of the varied tasks that you will encounter both afloat and ashore. The pamphlet is constructed so that those of you who may be hazy in math might dig a little deeper to find understanding in those areas where you may feel weak. On the other hand, some of you will find that you can breeze right through the math with minimum study. The purpose of the lesson on math is to increase your understanding of basics and not to burden you in the drudgery of problem solving.

Because of the complexity of physics, this pamphlet deals with the application of physics rather than with the broad scope of physics. In most cases the laws of motion, force, and energy apply equally well to both the atmosphere and the hydrosphere. Even though the atmosphere and the hydrosphere are both fluids, this pamphlet deals with the application of physics to meteorology in more detail than to oceanography. At times, reference is made to the application of a law or theory in a controlled environment in order to produce ideas that we, as Marine Science Technicians, might apply to the problems we encounter on a daily basis.

# NUMBER SYSTEMS

## COUNTING

Counting is such a basic and natural process that we rarely stop to think about it. The process is based on the idea of ONE-TO-ONE CORRESPONDENCE, which is easily demonstrated by using the fingers. When children count on their fingers, they are placing each finger in one-to-one correspondence with one of the objects being counted. Having outgrown finger counting, we use numerals.

## NUMERALS

Numerals are number symbols. One of the simplest numeral systems is the Roman numeral system, in which tally marks are used to represent the objects being counted. Roman numerals appear to be a refinement of the tally method still in use today. By this method, one makes short vertical marks until a total of four is reached; when the fifth tally is counted, a diagonal mark is drawn through the first four marks. Grouping by fives in this way is reminiscent of the Roman numeral system, in which the multiples of five are represented by special symbols.

A number may have many "names." For example, the number 6 may be indicated by any of the following symbols: 9 - 3, 12/2, 5 + 1, or 2 x 3. The important thing to remember is that a number is an idea; various symbols used to indicate a number are merely different ways of expressing the same idea.

## POSITIVE WHOLE NUMBERS

The numbers which are used for counting in our number system are sometimes called natural numbers. They are the positive whole numbers, or to use the more precise mathematical term, positive INTEGERS. The Arabic numerals from 0 through 9 are called digits, and an integer may have any number of digits. For example, 5, 32, and 7,049 are all integers. The number of digits in an integer indicates its rank; that is, whether it is "in the hundreds," "in the thousands," etc. The idea of ranking numbers in terms of tens, hundreds, thousands, etc., is based on the PLACE VALUE concept.

## PLACE VALUE

Although a system such as the Roman numeral system is adequate for recording the results of counting, it is too cumbersome for purposes of calculation. Before arithmetic could develop as we know it today, the following two important concepts were needed as additions to the counting process:

1. The idea of 0 as a number.
2. Positional notation (place value).

Positional notation is a form of coding in which the value of each digit of a number depends upon its position in relation to the other digits of the number. The convention used in our number system is that each digit has a higher place value than those digits to the right of it.

The place value which corresponds to a given position in a number is determined by the BASE of the number system. The base which is most commonly used is ten, and the system with ten as a base is called the decimal system (decem is the Latin word for ten). Any number is assumed to be a base-ten number, unless some other base is indicated. One exception to this rule occurs when the subject of an entire discussion is some base other than ten. For example, in the discussion of binary (base two) numbers later in this section, all numbers are assumed to be binary numbers unless some other base is indicated.

DECIMAL SYSTEM

In the decimal system, each digit position in a number has ten times the value of the position adjacent to it on the right. For example, in the number 11, the 1 on the left is said to be in the "tens place," and its value is 10 times as great as that of the 1 on the right. The 1 on the right is said to be in the "units place," with the understanding that the term "unit" in our system refers to the numeral 1. Thus the number 11 is actually a coded symbol which means "one ten plus one unit." Since ten plus one is eleven, the symbol 11 represents the number eleven.

Figure 1 shows the names of several digit positions in the decimal system. If we apply this nomenclature to the digits of the integer 235, then this number symbol means "two hundreds plus three tens plus five units." This number may be expressed in mathematical symbols as follows:

$$2 \times 10 \times 10 + 3 \times 10 \times 1 + 5 \times 1$$

Notice that this bears out our earlier statement: each digit position has 10 times the value of the position adjacent to it on the right.

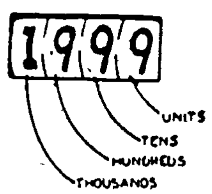


Figure 1.—Names of digit positions.

The integer 4,372 is a number symbol whose meaning is "four thousands plus three hundreds plus seven tens plus two units." Expressed in mathematical symbols, this number is as follows:

$$4 \times 1000 + 3 \times 100 + 7 \times 10 + 2 \times 1$$

This presentation may be broken down further, in order to show that each digit position has 10 times the place value of the position on its right, as follows:

$$4 \times 10 \times 100 + 3 \times 10 \times 10 + 7 \times 10 \times 1 + 2 \times 1$$

The comma which appears in a number symbol such as 4,372 is used for "pointing off" the digits into groups of three beginning at the right-hand side. The first group of three digits on the right is the units group; the second group is the thousands group; the third group is the millions group; etc. Some of these groups are shown in table 1.

Table 1.—Place values and grouping.

| Billions group | Millions group | Thousands group | Units group |
|---|---|---|---|
| Hundred billions<br>Ten billions<br>Billions | Hundred millions<br>Ten millions<br>Millions | Hundred thousands<br>Ten thousands<br>Thousands | Hundreds<br>Tens<br>Units |

By reference to table 1, we can verify that 5,432,786 is read as follows: five million, four hundred thirty-two thousand, seven hundred eighty-six. Notice that the word "and" is not necessary when reading numbers of this kind.

Practice problems:

1. Write the number symbol for seven thousand two hundred eighty-one.
2. Write the meaning, in words, of the symbol 23,469.
3. If a number is in the millions, it must have at least how many digits?
4. If a number has 10 digits, to what number group (thousands, millions, etc.) does it belong?

Answers:

1. 7,281
2. Twenty-three thousand, four hundred sixty-nine.
3. 7
4. Billions

BINARY SYSTEM

The binary number system is constructed in the same manner as the decimal system. However, since the base in this system is two, only two digit symbols are needed for writing numbers. These two digits are 1 and 0. In order to understand why only two digit symbols are needed in the binary system, we may make some observations about the decimal system and then generalize from these.

One of the most striking observations about number systems which utilize the concept of place value is that there is no single-digit symbol for the base. For example, in the decimal system the symbol for ten, the base, is 10. This symbol is compounded from two digit symbols, and its meaning may be interpreted as "one base plus no units." Notice the implication of this where other bases are concerned: Every system uses the same symbol for the base, namely 10. Furthermore, the symbol 10 is not called "ten" except in the decimal system.

Suppose that a number system were constructed with five as a base. Then the only digit symbols needed would be 0, 1, 2, 3, and 4. No single-digit symbol for five is needed, since the symbol 10 in a base-five system with place value means "one five plus no units." In general, in a number system using base N, the largest number for which a single-digit symbol is needed is N minus 1. Therefore, when the base is two, the only digit symbols needed are 1 and 0.

An example of a binary number is the symbol 101. We can discover the meaning of this symbol by relating it to the decimal system. Figure 2 shows that the place value of each digit position in the binary system is two times the place value of the position adjacent to it on the right. Compare this with figure 1, in which the base is ten rather than two.

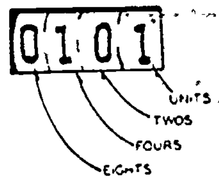


Figure 2.—Digit positions in the binary system.

Placing the digits of the number 101 in their respective blocks on figure 2, we find that 101 means "one four plus no twos plus one unit." Thus 101 is the binary equivalent of decimal 5. If we wish to convert a decimal number, such as 7, to its binary equivalent, we must break it into parts which are multiples of 2. Since 7 is equal to 4 plus 2 plus 1, we say that it "contains" one 4, one 2, and one unit. Therefore, the binary symbol for decimal 7 is 111.

The most common use of the binary number system is in electronic digital computers. All data fed to a typical electronic digital computer is converted to binary form and the computer performs its calculations using binary arithmetic rather than decimal arithmetic. One of the reasons for this is the fact that electrical and electronic equipment utilizes many switching circuits in which there are only two operating conditions. Either the circuit is "on" or it is "off," and a two-digit number system is ideally suited for symbolizing such a situation.

Further information on number systems and their application to the problems of Marine Science will be given in Section 5.

Practice problems:

1. Write the decimal equivalents of the binary numbers 1101, 1010, 1001, and 1111.
2. Write the binary equivalents of the decimal numbers 12, 7, 14, and 3.

Answers:

1. 13, 10, 9, and 15
2. 1100,111,1110,and 11

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# ARITHMETIC

## DEFINITIONS

### ARITHMETIC

That branch of mathematics dealing with computation by numbers is arithmetic. The principal processes involved are addition, subtraction, multiplication, and division. Any number that can be stated or indicated, however large or small, is called a finite number; one too large to be stated or indicated is called an infinite number; and one too small to be stated or indicated is called an infinitesimal number.

The sign of a number is the indication of whether it is a positive (+) or negative (-). A positive number is one having a positive sign (+); a negative number is one having a negative sign (-). The absolute value of a number is that number without regard to sign. Thus, the absolute value of both (+)8 and (-)8 is 8. Generally, a number without a sign can be considered positive.

### EXPRESSING NUMBERS

In Marine Science, fractions are usually expressed as decimals. Thus, 1/4 is expressed as 0.25 and 1/3 as 0.33. To determine the decimal equivalent of a fraction, divide the numerator (the number above the line) by the denominator (the number below the line). When a decimal is less than 1, as in the examples above, it is good practice to show the zero at the left of the decimal point (0.25, not .25).

A number should not be expressed to a greater precision than justified. The precision of a decimal is indicated by the number of digits shown to the right of the decimal point. Thus, the expression "14 miles" indicates a precision to the nearest whole mile, or any value between 13.5 and 14.5 miles. The expression "14.0 miles" indicates a precision of a tenth of a mile, or any value between 13.95 and 14.05 miles.

In a number without a decimal, there is sometimes doubt as to the degree of precision indicated. For example, the number 186,000 may indicate a precision to three, four, five, or six places. This ambiguity is sometimes avoided by expressing numbers as powers of 10. Thus $18.6 \times 10^4$ ($18.6 \times 10{,}000$) indicates precision to the nearest thousand (three places), $18.60 \times 10^4$ to the nearest hundred (four places), $18.600 \times 10^4$ to the nearest ten (five places), and $18.6000 \times 10^4$ to the nearest unit (six places). The position of the decimal is not important if the correct power of 10 is given. For example, $18.6 \times 10^4$ is the same as $1.86 \times 10^5$, $186 \times 10^3$, etc.

The small number above and to the right of 10 (the exponent) indicates the number of places the decimal point is to be moved to the right. If the exponent is negative, it indicates a reciprocal, and the decimal point is moved to the left. Thus, $1.86 \times 10^{-6} = 0.00000186$. This system is sometimes used to avoid long numbers.

Another way of indicating degree of precision is to state the number of significant digits. These are the digits in a number, excluding zeros at the left and sometimes those at the right. Thus, 1,325, 1,001, 1.408, 0.00005926, 625.0, and 0.04000 have four significant digits each. But in the number 312,600 there may be four, five, or six significant digits. Any doubt may be removed by expressing the number times a power of 10, as explained above.

If there are no more significant digits, regardless of how far a computation is carried, this may be indicated by use of the word "exactly." Thus, $12 \div 4 = 3$ exactly, and one nautical mile = 1,852 meters exactly; but $12 \div 7 = 1.7$ approximately, the word "approximately" indicating that additional decimal places might be computed. Another way of indicating an approximate relationship is by placing a positive or negative sign after the number. Thus, $12 \div 7 = 1.7+$, and $11 \div 7 = 1.6-$. This system has the advantage of showing whether the approximation



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is too great or too small.

In any arithmetical computation the answer is no more accurate than the least precise value used. Thus, if it is desired to add 16.4 and 1.88, the answer might be given as 18.28, but since the first term might be anything from 16.35 to 16.45, the answer is anything from 18.23 to 18.33. Hence, to retain the second decimal place in the answer is to give a false indication of accuracy, for the number 18.28 indicates a value between 18.275 and 18.285. However, additional places are sometimes retained until the end of a computation to avoid an accumulation of small errors due to rounding off.

In general, a value obtained by interpolation in a table should not be expressed to more decimal places than given in the table.

## PRECISION AND ACCURACY

The word "precision" as used above is not the same as "accuracy," although the two are sometimes confused. A quantity may be expressed to a greater precision than is justified by the accuracy of the information from which the quantity is derived. For instance, if a ship steams one mile in $3^m21^s$, its speed is $60^m \div 3^m21^s = 60 \div 3.35 = 17.910447761194$ knots, approximately. The division can be carried to as many places as desired; but if the time is measured only to the nearest second, the speed is accurate only to one decimal place in this example, because an error of 0.5 second introduces an error of more than 0.05 knot in the speed. Hence, the additional places are meaningless and possibly misleading, unless more accurate time is available. In general, it is not good practice to state a quantity to greater precision than justified by its accuracy.

The absolute precision of a number is indicated by its number of decimal places; its relative precision by its number of significant digits. Although "absolute" and "relative" are indications of the degree of precision, they may also be measures of accuracy. Thus the expressions absolute accuracy and relative accuracy are used. However, the term "accuracy" should not be used when "precision" only is intended. Thus, the values 186,000 and 0.00000186 may each have three significant digits, or "be correct to three digits," although the first value may be accurate ("absolute accuracy") only to the nearest 1,000, and the second to the nearest 0.00000001. If the numbers are accurate to the number of significant digits shown, each has an error ("relative accuracy") of less than "one part in 186."

Unless all numbers are exact, doubt exists as to the accuracy of the last digit in a computation. Thus, 12.3+9.4+4.6=26.3. But if the three terms to be added have been rounded off from 12.26, 9.38, and 4.57, the correct answer is 26.2. It is obtained by rounding off the answer of 26.21 found by retaining the second decimal place until the end. It is good practice to work with one more place than needed in the answer, when the information is available. In computations involving a large number of terms, or if great accuracy is desired, it is sometimes advisable to retain two or more additional places until the end.

## ROUNDING OFF

In rounding off numbers to the number of places desired, one should take the nearest value. Thus, the number 6.5049 is rounded to 6.505, 6.50, 6.5, or 7, depending upon the number of places desired. If the number to be rounded off ends in 5, the nearer even number is taken. Thus, 1.55 and 1.65 are both rounded to 1.6. Likewise, 12.750 is rounded to 12.8 if only one decimal place is desired. However, 12.749 is rounded to 12.7. That is, 12.749 is not first rounded to 12.75 and then to 12.8, but the entire number is rounded in one operation. When a number ends in 5, the computation can sometimes be carried to additional places to determine whether the correct value is more or less than 5.

## RECIPROCALS

The reciprocal of a number is 1 divided by that number. The reciprocal of a fraction is obtained by interchanging the numerator and denominator. Thus, the reciprocal of 3/5 is 5/3. A whole number may be considered a fraction with 1 as the denominator. Thus, 54 is the same as 54/1, and its reciprocal is 1/54. Division by a number produces the same result as multiplying by its reciprocal, or vice versa. Thus, $12 \div 2 = 12 \times 1/2 = 6$, and $12 \times 2 = 12 \div 1/2 = 24$.

ADDITION

When two or more numbers are to be added, it is generally most convenient to write them in a column, with the decimal points in line. Thus, if 31.2, 0.8874, and 168.14 are to be added, this may be indicated by means of the addition sign (+): 31.2+0.8874+168.14=200.2. But the addition can be performed more conveniently by arranging the numbers as follows:

```
  31.2
   0.8874
 168.14
 200.2
```

The answer is given only to the first decimal place, because the answer is no more accurate than the least precise number among those to be added, as indicated previously. Often it is preferable to state all numbers in a problem to the same precision before starting the addition, although this may introduce a small error as indicated previously:

```
  31.2
   0.9
 168.1
 200.2
```

If there are no decimals, the last digit to the right is aligned:

```
    166
      2
 96,758
 96,926
```

Numbers to be added should be given to the same absolute accuracy, when available, to avoid a false impression of accuracy in the result. Consider the following:

```
 186,000
  71,832
   9,614
     728
 268,174
```

The answer would imply an accuracy to six places. If the first number given is accurate to only three places, or to the nearest 1,000, the answer is not more accurate, and hence the answer should be given as 268,000. Approximately the same answer would be obtained by rounding off at the start:

```
 186,000
  72,000
  10,000
   1,000
 269,000
```

If numbers are added arithmetically, their absolute values are added without regard to signs; but if they are added algebraically, due regard is given to signs. If two numbers to be added algebraically have the same sign, their absolute values are added and given their common sign. If two numbers to be added algebraically have unlike signs, the smaller absolute value is subtracted from the larger, and the sign of the value having the larger absolute value is given to the result. Thus, if +8 and -7 are added arithmetically, the answer is 15, but if they are added algebraically, the answer is +1.

An answer obtained by addition is called a sum.

SUBTRACTION

The inverse of addition is subtraction. Stated differently, the addition of a negative number is the same as the subtraction of a positive number. That is, if a number is to be subtracted from another, the sign ( + or - ) of the subtrahend (the number to be subtracted) is reversed and the result added algebraically to the minuend (the number from which the subtrahend is to be subtracted). Thus, 6-4=2. This may be written +6 -(+4)=+2, which yields the same result as +6 +(-4). For solution, larger numbers are often conveniently arranged in a column with decimal points in a vertical column, as in addition. Thus, 3,728.41-1,861.16 may be written

```
(+)3,728.41
(+)1,861.16 (subtract)
(+)1,867.25
```

This is the same as

```
(+)3,728.41
(-)1,861.16 (add algebraically)
(+)1,867.25
```

The rule of sign reversal applies likewise to negative numbers. Thus, if -3 is to be subtracted from +5, this may be written +5-(-3)= 5+3=8.

In the algebraic addition of two numbers of opposite sign (numerical subtraction), the smaller number is subtracted from the larger and the result is given the sign of the larger number. Thus, +7-4=+3, and -7+4=-3, which is the same as +4-7=-3.

The symbol ∼ indicates that an absolute difference is required without regard to sign of the answer. Thus, 28∼13=15, and 13∼28=15. In both of these solutions 13 and 28 are positive and 15 is an absolute value without sign. If the signs or names of both numbers are the same, either positive or negative, the smaller is subtracted from the larger, but if they are of opposite sign or name, they are numerically added. Thus, (+)16∼(+)21=5 and (-)16∼(-)21=5, but (+)16∼(-)21=37 and (-)16∼(+)21=37.

If numbers are subtracted arithmetically, they are subtracted without regard to sign; but if they are subtracted algebraically, positive (+) numbers are subtracted and negative (-) numbers are added.

An answer obtained by subtraction is called a difference.

MULTIPLICATION

Multiplication may be indicated by the multiplication sign (x), as 154x28=4,312. For solution, the problem is conveniently arranged thus:

```
    154
 (x) 28
   1232
   308
   4312
```

Either number may be given first, but it is generally more convenient to perform the multiplication if the larger number is placed on top, as shown. In this problem, 154 is first multiplied by 8 and then by 2. The second answer is placed under the first, but set one place to the left, so that the right-hand digit is directly below the 2. These steps might be reversed, multiplication by 2 being performed first. This procedure is sometimes used in estimating.

When one number is placed below another for multiplication, as shown above, it is usually best to align the right-hand digits without regard for the position of the decimal point. The number of decimal places in the answer is the sum of the decimal places in the multiplicand (the number to be multiplied) and the multiplier (the second number):

```
      163.27
   (x) 263.9
      146943
      48981
     97962
    32654
   43086.953
```

However, when a number ends in one or more zeros, these may be ignored until the end and then added on to the number:

```
    1924
 (x) 1800
   15392
   1924
   3463200
```

This is also true if both multiplicand and multiplier end in zeros:

```
    1924000
 (x) 1800
   15392
   1924
   3463200000
```

When negative values are to be multiplied, the sign of the answer is positive if an even number of negative signs appear, and negative if there are an odd number. Thus, 2x3=6, 2x(-3)= -6, -2x3=-6, -2x(-3)=(+6). Also, 2x3x8x(-2)x5= -480, 2x(-3)x8x(-2)x5=480, 2x(-3)x(-8)x(-2)x5= -480, 2x(-3)x(-8)x(-2)x(-5)=480, and (-2)x(-3)x (-8)x(-2)x(-5)=-480.

An answer obtained by multiplication is called a product. Any number multiplied by 1 is the number itself. Thus, 125x1=125. Any number multiplied by 0 is 0. Thus, 125x0=0 and 1x0=0.

DIVISION

Division is the inverse of multiplication. It may be indicated by the division sign (÷), as

$376 \div 21 = 18$ approximately; or by placing the number to be divided, called the dividend (376), over the other number, called the divisor (21), as $\frac{376}{21} = 18$ approximately. The expression $\frac{376}{21}$ may be written 376/21 with the same meaning. Such a problem is conveniently arranged for solution as follows:

$$\begin{array}{r} 17 \\ 21 \overline{)376} \\ \underline{21} \\ 166 \\ \underline{147} \\ 19 \end{array}$$

Since the remainder is 19, or more than half of the divisor (21), the answer to the nearest whole number is 18.

An answer obtained by division is called a quotient. Any number divided by 1 is the number itself. Thus, $65 \div 1 = 65$. A number cannot be divided by 0.

If the numbers involved are accurate only to the number of places given, the answer should not be carried to additional places. However, if the numbers are exact, the answer might be carried to as many decimal places as desired. Thus, $374 \div 21 = 17.809523809523809523809523809523809523 \ldots$. When a series of digits repeat themselves with the same remainder, as 809523 (with remainder 17) in the example given above, an exact answer will not be obtained regardless of the number of places to which the division is carried. The series of dots (. . . .) indicates a repeating decimal. In a nonrepeating decimal, a plus sign (+) may be given to indicate a remainder, and a minus sign (-) to indicate that the last digit has been rounded to the next higher value. Thus, 18.68761 may be written 18.6876+ or 18.688-. If the last digit given is rounded off, the word "approximately" may be used instead of dots or a plus or minus sign.

If the divisor is a whole number, the decimal point in the quotient is directly above that of the dividend when the work form shown above is used. Thus, in the example given above, if the dividend had been 37.6 instead of 376, the quotient would have been 1.8 approximately. If the divisor is a decimal, both it and the dividend are multiplied by the power of 10 having an exponent equal to the number of decimal places in the divisor, and the division is then carried out as explained above. Thus, if there are two decimal places in the divisor, both divisor and dividend are multiplied by $10^2 = 100$. This is done by moving the decimal to the right until the divisor is a whole number. If necessary, zeros are added to the dividend. Thus, if 3.7 is to be divided by 2.11, both quantities are first multiplied by $10^2$, and 370 is divided by 211. This is usually performed as follows:

$$\begin{array}{r} 1.75 \\ 2{,}11 \overline{)3{,}70.00} \\ \underline{211} \\ 1590 \\ \underline{1477} \\ 1130 \\ \underline{1055} \\ 75 \end{array}$$

If both the dividend and divisor are positive, or if both are negative, the quotient is positive; but if either is negative, the quotient is negative. Thus, $6 \div 3 = 2$, $(-6) \div (-3) = +2$, $(-6) \div 3 = -2$, and $6 \div (-3) = -2$.

## FRACTIONS

The simplest type of number other than an integer is a COMMON FRACTION. The two terms of a common fraction are the numerator and the denominator. Common fractions and integers together comprise a set of numbers called the RATIONAL NUMBERS.

Fractions are often classified as proper or improper. A proper fraction is one in which the numerator is numerically smaller than the denominator. An improper fraction has a numerator which is larger than its denominator.

When the denominator of an improper fraction is divided into its numerator, a remainder is produced along with the quotient, unless the numerator happens to be an exact multiple of the denominator. For example, 7/5 is equal to 1 plus a remainder of 2. This remainder may be shown as a dividend with 5 as its divisor, as follows:

$$\frac{7}{5} = \frac{5+2}{5} = 1 + \frac{2}{5}$$

The expression 1 + 2/5 is a MIXED NUMBER. Mixed numbers are usually written without showing the plus sign; that is, 1 + 2/5 is the same as $1\frac{2}{5}$ or 1 2/5. When a mixed number is written as 1 2/5, care must be taken to insure that there is a space between the 1 and the 2; otherwise, 1 2/5 might be taken to mean 12/5.

FUNDAMENTAL RULE OF FRACTIONS

Multiplying or dividing both terms of a fraction by the same number does not change the value of the fraction. This is one of the most important rules used in dealing with fractions.

The following examples show how the fundamental rule is used:

1. Change 1/4 to twelfths. This problem is set up as follows:

$$\frac{1}{4} = \frac{?}{12}$$

The first step is to determine how many 4's are contained in 12. The answer is 3, so we know that the multiplier for both terms of the fraction is 3, as follows:

$$\frac{3}{3} \cdot \frac{1}{4} = \frac{3}{12}$$

2. What fraction with a numerator of 6 is equal to 3/4?

SOLUTION: $\frac{6}{?} = \frac{3}{4}$

We note that 6 contains 3 twice; therefore, we need to double the numerator of the right-hand fraction to make it equivalent to the numerator of the fraction we seek. We multiply both terms of 3/4 by 2, obtaining 8 as the denominator of the new fraction, as follows:

$$\frac{6}{8} = \frac{3}{4} \cdot \frac{2}{2}$$

3. Change 6/16 to eighths.

SOLUTION: $\frac{6}{16} = \frac{?}{8}$

We note that the denominator of the fraction which we seek is 1/2 as large as the denominator of the original fraction. Therefore the new fraction may be formed by dividing both terms of the original fraction by 2, as follows:

$$\frac{6 \div 2}{16 \div 2} = \frac{3}{8}$$

Practice problems. Supply the missing number in each of the following:

1. $\frac{3}{8} = \frac{30}{?}$
2. $\frac{44}{48} = \frac{?}{12}$
3. $\frac{?}{90} = \frac{3}{10}$
4. $\frac{1}{6} = \frac{6}{?}$
5. $\frac{1}{?} = \frac{12}{72}$
6. $\frac{3}{5} = \frac{?}{25}$

Answers:

1. 80
2. 11
3. 27
4. 36
5. 6
6. 15

REDUCTION TO LOWEST TERMS

It is frequently desirable to change a fraction to an equivalent fraction with the smallest possible terms; that is, with the smallest possible numerator and denominator. This process is called REDUCTION. Thus, 6/30 reduced to lowest terms is 1/5. Reduction can be accomplished by finding the largest factor that is common to both the numerator and denominator and dividing both of these terms by it. Dividing both terms of the preceding example by 6 reduces the fraction to lowest terms. In computation, fractions should usually be reduced to lowest terms where possible.

If the greatest common factor cannot readily be found, any common factor may be removed and the process repeated until the fraction is in lowest terms. Thus, $\frac{18}{48}$ could first be divided by 2 and then by 3.

$$\frac{18 \div 2}{48 \div 2} = \frac{9}{24}$$

$$\frac{9 \div 3}{24 \div 3} = \frac{3}{8}$$

Practice problems. Reduce the following fractions to lowest terms:

1. $\frac{18}{48}$
2. $\frac{15}{20}$
3. $\frac{35}{56}$
4. $\frac{12}{60}$
5. $\frac{18}{24}$
6. $\frac{9}{144}$

Answers:

1. $\frac{3}{8}$
2. $\frac{3}{4}$
3. $\frac{5}{8}$
4. $\frac{1}{5}$
5. $\frac{3}{4}$
6. $\frac{1}{16}$

## LOWEST COMMON DENOMINATOR

To change unlike fractions to like fractions, it is necessary to find a COMMON DENOMINATOR and it is usually advantageous to find the LOWEST COMMON DENOMINATOR (LCD). This is nothing more than the least common multiple of the denominators.

### Least Common Multiple

If a number is a multiple of two or more different numbers, it is called a COMMON MULTIPLE. Thus, 24 is a common multiple of 6 and 2. There are many common multiples of these numbers. The numbers 36, 48, and 54, to name a few, are also common multiples of 6 and 2.

The smallest of the common multiples of a set of numbers is called the LEAST COMMON MULTIPLE. It is abbreviated LCM. The least common multiple of 6 and 2 is 6. To find the least common multiple of a set of numbers, first separate each of the numbers into prime factors:

Suppose that we wish to find the LCM of 14, 24, and 30. Separating these numbers into prime factors we have:

$$14 = 2 \cdot 7$$
$$24 = 2^3 \cdot 3$$
$$30 = 2 \cdot 3 \cdot 5$$

The LCM will contain each of the various prime factors shown. Each prime factor is used the greatest number of times that it occurs in any one of the numbers. Notice that 3, 5, and 7 each occur only once in any one number. On the other hand, 2 occurs three times in one number. We get the following result:

$$\begin{aligned} LCM &= 2^3 \cdot 3 \cdot 5 \cdot 7 \\ &= 840 \end{aligned}$$

Thus, 840 is the least common multiple of 14, 24, and 30.

### Greatest Common Divisor

The largest number that can be divided into each of two or more given numbers without a remainder is called the GREATEST COMMON DIVISOR of the given numbers. It is abbreviated GCD. It is also sometimes called the HIGHEST COMMON FACTOR.

In finding the GCD of a set of numbers, separate the numbers into prime factors just as for LCM. The GCD is the product of only those factors that appear in all of the numbers. Notice in the example of the previous heading that 2 is the greatest common divisor of 14, 24, and 30.

Find the GCD of 650, 900, and 700. The procedure is as follows:

$$650 = 2 \,.\, 5^2 \,.\, 13$$
$$900 = 2^2 \,.\, 3^2 \,.\, 5^2$$
$$700 = 2^2 \,.\, 5^2 \,.\, 7$$
$$GCD = 2 \,.\, 5^2 = 50$$

Notice that 2 and $5^2$ are factors of each number. The greatest common divisor is 2 x 25=50.

## USING THE LCD

Consider the example

$$\frac{1}{2} + \frac{1}{3}$$

The numbers 2 and 3 are both prime; so the LCD is 6.

Therefore $\quad \frac{1}{2} = \frac{3}{6}$

and $\quad \frac{1}{3} = \frac{2}{6}$

Thus, the addition of 1/2 and 1/3 is performed as follows:

$$\frac{1}{2} + \frac{1}{3} = \frac{3}{6} + \frac{2}{6} = \frac{5}{6}$$

## CANCELLATION

Computation can be considerably reduced by dividing out (CANCELLING) factors common to both the numerator and the denominator. We recognize a fraction as an indicated division. Thinking of 6/9 as an indicated division, we re-

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member that we can simplify division by showing both dividend and divisor as the indicated products of their factors and then dividing like factors, or canceling. Thus,

$$\frac{6}{9} = \frac{2 \times 3}{3 \times 3}$$

Dividing the factor 3 in the numerator by 3 in the denominator gives the following simplified result:

$$\frac{2 \times \overset{1}{\cancel{3}}}{3 \times \underset{1}{\cancel{3}}} = \frac{2}{3}$$

This method is most advantageous when done before any other computation. Consider the example:

$$\frac{1}{3} \times \frac{3}{2} \times \frac{2}{5}$$

The product in factored form is

$$\frac{1 \times 3 \times 2}{3 \times 2 \times 5}$$

Rather than doing the multiplying and then reducing the result 6/30, it is simpler to cancel like factors first, as follows:

$$\frac{1 \times \overset{1}{\cancel{3}} \times \overset{1}{\cancel{2}}}{\underset{1}{\cancel{3}} \times \underset{1}{\cancel{2}} \times 5} = \frac{1}{5}$$

## PERCENT

The word "percent" is derived from Latin. It was originally "per centum," which means "by the hundred." Thus the statement is often made that "percent means hundredths."

Percentage deals with the group of decimal fractions whose denominators are 100—that is, fractions of two decimal places. Since hundredths were used so frequently, the decimal point was dropped and the symbol % was placed after the number and read "percent" (per 100). Thus, 0.15 and 15% represent the same value, 15/100. The first is read "15 hundredths," and the second is read "15 percent." Both mean 15 parts out of 100.

Ordinarily, percent is used in discussing relative values. For example, 25 percent may convey an idea of relative value or relationship. To say "25 percent of the crew is ashore" gives an idea of what part of the crew is gone, but it does not tell how many. For example, 25 percent of the crew would represent vastly different numbers if the comparison were made between a WAGB and a WPB. When it is necessary to use a percent in computation, the number is written in its decimal form to avoid confusion.

By converting all decimal fractions so that they had the common denominator 100, men found that they could mentally visualize the relative size of the part of the whole that was being considered.

## CHANGING DECIMALS TO PERCENT

Since percent means hundredths, any decimal may be changed to percent by first expressing it as a fraction with 100 as the denominator. The numerator of the fraction thus formed indicates how many hundredths we have, and therefore it indicates "how many percent" we have. For example, 0.36 is the same as 36/100. Therefore, 0.36 expressed as a percentage would be 36 percent. By the same reasoning, since 0.052 is equal to 5.2/100, 0.052 is the same as 5.2 percent.

In actual practice, the step in which the denominator 100 occurs is seldom written down. The expression in terms of hundredths is converted mentally to percent. This results in the following rule: To change a decimal to percent, multiply the decimal by 100 and annex the percent sign (%). Since multiplying by 100 has the effect of moving the decimal point two places to the right, the rule is sometimes stated as follows: To change a decimal to percent, move the decimal point two places to the right and annex the percent sign.

## CHANGING COMMON FRACTIONS AND WHOLE NUMBERS TO PERCENT

Common fractions are changed to percent by first expressing them as decimals. For example, the fraction 1/4 is equivalent to the decimal 0.25. Thus, 1/4 is the same as 25 percent.

Whole numbers may be considered as special types of decimals (for example, 4 may be written as 4.00) and thus may be expressed in terms of percentage. The meaning of an expression such as 400 percent is vague unless we keep in mind that percentage is a form of comparison. For example, a question which often arises is, "How can I have more than 100 percent of something if 100 percent means all of it?"

This question seems reasonable, if we limit our attention to such quantities as test scores. However, it is also reasonable to use percentage in comparing a current set of data with a previous set. For example, if the amount of electrical power used by a facility this year is double the amount used last year, then this year's power usage is 200 percent of last year's usage.

The meaning of a phrase such as "200 percent of last year's usage" is often misinterpreted. A total amount that is 200 percent of the previous amount is not the same as an increase of 200 percent. The increase in this case is only 100 percent, for a total of 200. If the increase had been 200 percent, then the new usage figure would be 300 percent of the previous figure.

Baseball batting averages comprise a special case in which percentage is used with only occasional reference to the word "percent." The percentages in batting averages are expressed in their decimal form, with the figure 1 000 representing 100 percent. Although a batting average of 0.300 is referred to as "batting 300," this is actually erroneous nomenclature from the strictly mathematical standpoint. The correct statement, mathematically, would be "batting point three zero zero" or "batting 30 percent."

Practice problems. Change each of the following numbers to percent:

| | | |
|---|---|---|
| 1. 0.0065 | 3. 0.363 | 5. 7 |
| 2. 1.25 | 4. 3/4 | 6. 1/2 |

Answers:

| | | |
|---|---|---|
| 1. 0.65% | 3. 36.3% | 5. 700% |
| 2. 125% | 4. 75% | 6. 50% |

CHANGING A PERCENT TO A DECIMAL

Since we do not compute with numbers in the percent form, it is often necessary to change a percent back to the decimal form. The procedure is just opposite to that used in changing decimals to percents: To change a percent to a decimal, drop the percent sign and divide the number by 100. Mechanically, the decimal point is simply shifted two places to the left and the percent sign is dropped. For example, 25 percent is the same as the decimal 0.25. Percents larger than 100 percent are changed to decimals by the same procedure as ordinary percents. For example, 125 percent is equivalent to 1.25.

Practice problems. Change the following percents to decimals:

| | | |
|---|---|---|
| 1. 2.5% | 3. 125% | 5. $5\frac{3}{4}$% |
| 2. 0.63% | 4. 25% | 6. $9\frac{1}{2}$ % |

Answers:

| | | |
|---|---|---|
| 1. 0.025 | 3. 1.25 | 5. 5.75% = 0.0575 |
| 2. 0.0063 | 4. 0.25 | 6. 9.50% = 0.095 |

THE THREE PERCENTAGE CASES

To explain the cases that arise in problems involving percents, it is necessary to define the terms that will be used. Rate (r) is the number of hundredths parts taken. This is the number followed by the percent sign. The base (b) is the whole on which the rate operates. Percentage (p) is the part of the base determined by the rate. In the example

5% of 40 = 2

5% is the rate, 40 is the base, and 2 is the percentage.

There are three cases that usually arise in dealing with percentage, as follows:

Case I—To find the percentage when the base and rate are known.

EXAMPLE: What number is 6% of 50?

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Case II—To find the rate when the base and percentage are known.

EXAMPLE: 20 is what percent of 60?

Case III—To find the base when the percentage and rate are known.
EXAMPLE: The number 5 is 25% of what number?

Case I

In the example

$$6\% \text{ of } 50 = ?$$

the "of" has the same meaning as it does in fractional examples, such as

$$\frac{1}{4} \text{ of } 16 = ?$$

In other words, "of" means to multiply. Thus, to find the percentage, multiply the base by the rate. Of course the rate must be changed from a percent to a decimal before multiplying can be done. Rate times base equals percentage. Thus,

$$6\% \text{ of } 50 = ?$$

$$0.06 \times 50 = 3$$

The number that is 6% of 50 is 3.

FRACTIONAL PERCENTS

A fractional percent represents a part of 1 percent. In a case such as this, it is sometimes easier to find 1 percent of the number and then find the fractional part. For example, we would find 1/4 percent of 840 as follows:

$$1\% \text{ of } 840 = 0.01 \times 840$$
$$= 8.40$$

Therefore, $\frac{1}{4}\%$ of $840 = 8.40 \times \frac{1}{4}$
$= 2.10$

Case II

To explain case II and case III, we notice in the foregoing example that the base corresponds to the multiplicand, the rate corresponds to the multiplier, and the percentage corresponds to the product.

$$\begin{array}{rl} 50 & \text{(base or multiplicand)} \\ \underline{.06} & \text{(rate or multiplier)} \\ 3.00 & \text{(percentage or product)} \end{array}$$

Recalling that the product divided by one of its factors gives the other factor, we can solve the following problem:

$$?\% \text{ of } 60 = 20$$

We are given the base (60) and percentage (20).

$$\begin{array}{rl} 60 & \text{(base)} \\ \underline{?} & \text{(rate)} \\ 20 & \text{(percentage)} \end{array}$$

We then divide the product (percentage) by the multiplicand (base) to get the other factor (rate). Percentage divided by base equals rate. The rate is found as follows:

$$\frac{20}{60} = \frac{1}{3}$$

$$= .33\frac{1}{3}$$

$$= 33\frac{1}{3}\% \text{ (rate)}$$

The rule for case II, as illustrated in the foregoing problem, is as follows: To find the rate when the percentage and base are known, divide the percentage by the base. Write the quotient in the decimal form first, and finally as a percent.

Case III

The unknown factor in case III is the base, and the rate and percentage are known.

EXAMPLE: 25% of ? = 5

$$\begin{array}{rl} ? & \text{(base)} \\ \underline{.25} & \text{(rate)} \\ 5.00 & \text{(percentage)} \end{array}$$

We divide the product by its known factor to find the other factor. Percentage divided by rate equals base. Thus,

$$\frac{5}{.25} = 20 \text{ (base)}$$

The rule for case III may be stated as follows: To find the base when the rate and percentage are known, divide the percentage by the rate.

Practice problems. In each of the following problems, first determine which case is involved; then find the answer.

1. What is $\frac{3}{4}$% of 740?

2. 7.5% of 2.75 = ?

3. 8 is 2% of what number?

4. ?% of 18 = 15.

5. 12% of ? = 12.

6. 8 is what percent of 32?

Answers:

1. Case I; 5.55

2. Case I; 0.20625

3. Case III; 400

4. Case II; $83\frac{1}{3}$%

5. Case III; 100

6. Case II; 25%

## RATIO AND PROPORTION

The solution of problems based on ratio, proportion, and variation involves no new principles. However, familiarity with these topics will often lead to quick and simple solutions to problems that would otherwise be more complicated.

### RATIO

The results of observation or measurement often must be compared with some standard value in order to have any meaning. For example, to say that a man can read 400 words per minute has little meaning as it stands. However, when his rate is compared to the 250 words per minute of the average reader, one can see that he reads considerably faster than the average reader. How much faster? To find out, his rate is divided by the average rate, as follows:

$$\frac{400}{250} = \frac{8}{5}$$

Thus, for every 5 words read by the average reader, this man reads 8. Another way of making this comparison is to say that he reads $1\frac{3}{5}$ times as fast as the average reader.

When the relationship between two numbers is shown in this way, they are compared as a RATIO. A ratio is a comparison of two like quantities. It is the quotient obtained by dividing the first number of a comparison by the second.

Comparisons may be stated in more than one way. For example, if one gear has 40 teeth and another has 10, one way of stating the comparison would be 40 teeth to 10 teeth. This comparison could be shown as a ratio in four ways as follows:

1. 40:10.

2. 40 ÷ 10

3. $\frac{40}{10}$

4. The ratio of 40 to 10.

When the emphasis is on "ratio," all of these expressions would be read "the ratio of 40 to 10." The form 40 ÷ 10 may also be read "40 divided by 10." The form $\frac{40}{10}$ may also be read "40 over 10."

Comparison by means of a ratio is limited to quantities of the same kind. For example, in order to express the ratio between 6 ft. and 3 yd., both quantities must be written in terms of the same unit. Thus the proper form of this ratio is 2 yd : 3 yd, not 6 ft : 3 yd. When the parts of the ratio are expressed in terms of the same unit, the units cancel each other and the ratio consists simply of two numbers. In this example, the final form of the ratio is 2 : 3.

Since a ratio is also a fraction, all the rules that govern fractions may be used in working with ratios. Thus, the terms may be reduced, increased, simplified, and so forth, according to the rules for fractions. To reduce the ratio 15:20 to lowest terms, write the ratio as a fraction and then proceed as for fractions. Thus, 15:20 becomes

$$\frac{15}{20} = \frac{3}{4}$$

Hence the ratio of 15 to 20 is the same as the ratio of 3 to 4.

Notice the distinction in thought between $\frac{3}{4}$ as a fraction and $\frac{3}{4}$ as a ratio. As a fraction we think of $\frac{3}{4}$ as the single quantity "three-fourths." As a ratio, we think of $\frac{3}{4}$ as a comparison between the two numbers, 3 and 4. For example, the lengths of two sides of a triangle are $1\frac{9}{16}$ ft. and 2 ft. To compare these lengths by means of a ratio, divide one number by the other and reduce to lowest terms, as follows:

$$\frac{1\frac{9}{16}}{2} = \frac{\frac{25}{16}}{2} = \frac{25}{32}$$

The two sides of the triangle compare as 25 to 32.

## INVERSE RATIO

It is often desirable to compare the numbers of a ratio in the inverse order. To do this, we simply interchange the numerator and the denominator. Thus, the inverse of 15:20 is 20:15. When the terms of a ratio are interchanged, the INVERSE RATIO results.

Practice problems. In problems 1 through 6, write the ratio as a fraction and reduce to lowest terms. In problems 7 through 10, write the inverse of the given ratio.

1. The ratio of 5 lb to 15 lb
2. \$16 : \$12
3. 16 ÷ 4
4. One quart to one gallon
5. 5x to 10x
6. $3\frac{1}{3} : 4\frac{1}{2}$
7. The ratio of 6 ft to 18 ft
8. $\frac{4}{8}$
9. 5 : 8
10. 15 to 21

Answers:

| | |
|---|---|
| 1. $\frac{1}{3}$ | 6. $\frac{20}{27}$ |
| 2. $\frac{4}{3}$ | 7. $\frac{3}{1}$ |
| 3. $\frac{4}{1}$ | 8. $\frac{2}{1}$ |
| 4. $\frac{1}{4}$ | 9. $\frac{8}{5}$ |
| 5. $\frac{1}{2}$ | 10. $\frac{7}{5}$ |

## PROPORTION

Closely allied with the study of ratio is the subject of proportion. A PROPORTION is nothing more than an equation in which the members are ratios. In other words, when two ratios are set equal to each other, a proportion is formed. The proportion may be written in three different ways as in the following examples:

$$15:20 :: 3 : 4$$

$$15:20 = 3 : 4$$

$$\frac{15}{20} = \frac{3}{4}$$

The last tow forms are the most common. ALL these forms are read, "15 is to 20 as 3 is to 4." In other words, 15 has the same ratio to 20 as 3 has to 4.

One reason for the extreme importance of proportions is that if any three of the terms are given, the fourth may be found by solving a simple equation. In science many chemical and physical relations are expressed as proportions. Consequently, a familiarity with proportions will provide one method for solving many applied problems. It is evident from the last form shown, $\frac{15}{20} = \frac{3}{4}$, that a proportion is really a fractional equation. Therefore, all the rules for fraction equations apply.

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## TERMS OF A PROPORTION

Certain names have been given to the terms of the two ratios that make up a proportion. In a proportion such as 3:8 = 9:24, the first and the last terms (the outside terms) are called the EXTREMES. In other words, the numerator of the first ratio and the denominator of the second are called the extremes. The second and third terms (the inside terms) are called the MEANS. The means are the denominator of the first ratio and the numerator of the second. In the example just given, the extremes are 3 and 24; the means are 8 and 9.

Four numbers, such as 5, 8, 15, and 24, form a proportion if the ratio of the first two in the order named equals the ratio of the second two. When these numbers are set up as ratios with the equality sign between them, the members will reduce to an identity if a true proportion exists. For example, consider the following proportion:

$$\frac{5}{8} = \frac{15}{24}$$

In this proportion, $\frac{15}{24}$ must reduce to $\frac{5}{8}$ for the proportion to be true. Removing the same factor from both members of $\frac{15}{24}$ we have

$$\frac{5}{8} = \frac{3(5)}{3(8)}$$

The number 3 is the common factor that must be removed from both the numerator and the denominator of one fraction in order to show that the expression

$$\frac{5}{8} = \frac{15}{24}$$

is a true proportion. To say this another way, it is the factor by which both terms of the ratio $\frac{5}{8}$ must be multiplied in order to show that this ratio is the same as $\frac{15}{24}$.

Practice problems. For each of the following proportions, write the means, the extremes, and the factor of proportionality.

1. $\frac{3}{16} = \frac{15}{80}$
2. 4:5 = 12 : 15
3. $\frac{25}{75} = \frac{1}{3}$
4. 12:3 : : 4:1

Answers:

1. Means: 16 and 15
   Extremes: 3 and 80
   Factor of proportionality: 5

2. M: 5 and 12
   E: 4 and 15
   FP: 3

3. M: 75 and 1
   E: 25 and 3
   FP: 25

4. M: 3 and 4
   E: 12 and 1
   FP: 3

# EXPONENTS AND RADICALS

The operation of raising a number to a power is a special case of multiplication in which the factors are all equal. In examples such as $4^2 = 4 \times 4 = 16$ and $5^3 = 5 \times 5 \times 5 = 125$, the number 16 is the second power of 4 and the number 125 is the third power of 5. The expression $5^3$ means that three 5's are to be multiplied together. Similarly, $4^2$ means $4 \times 4$. The first power of any number is the number itself. The power is the number of times the number itself is to be taken as a factor.

The process of finding a root is the inverse of raising a number to a power. A root is a special factor of a number, such as 4 in the expression $4^2 = 16$. When a number is taken as a factor two times, as in the expression $4 \times 4 = 16$, it is called a square root. Thus, 4 is a square root of 16. By the same reasoning, 2 is a cube root of 8, since $2 \times 2 \times 2$ is equal to 8. This relationship is usually written as $2^3 = 8$.

## POWERS AND ROOTS

A power of a number is indicated by an EXPONENT, which is a number in small print placed to the right and toward the top of the number. Thus, in $4^3 = 64$, the number 3 is the EXPONENT of the number 4. The exponent 3 indicates that the number 4, called the BASE, is to be raised to its third power. The expression is read "4 to the third power (or 4 cubed) equals 64." Similarly, $5^2 = 25$ is read "5 to the second power (or 5 squared) equals 25." Higher powers are read according to the degree indicated; for example, "fourth power," "fifth power," etc.

When an exponent occurs, it must always be written unless its value is 1. The exponent 1 usually is not written but is understood. For example, the number 5 is actually $5^1$. When we work with exponents, it is important to remember that any number that has no written exponent really has an exponent equal to 1.

A root of a number can be indicated by placing a radical sign, $\sqrt{\ }$, over the number and showing the root by placing a small number within the notch of the radical sign. Thus, $\sqrt[3]{64}$ indicates the cube root of 64, and $\sqrt[5]{32}$ indicates the fifth root of 32. The number that indicates the root is called the INDEX of the root. In the case of the square root, the index, 2, usually is not shown. When a radical has no index, the square root is understood to be the one desired. For example, $\sqrt{36}$ indicates the square root of 36. The line above the number whose root is to be found is a symbol of grouping called the vinculum. When the radical symbol is used, a vinculum, long enough to extend over the entire expression whose root is to be found, should be attached.

Practice problems. Raise to the indicated power or find the root indicated.

| | | | |
|---|---|---|---|
| 1. $2^3$ | 2. $6^2$ | 3. $4^3$ | 4. $25^3$ |
| 5. $\sqrt{16}$ | 6. $\sqrt[3]{8}$ | 7. $\sqrt[3]{125}$ | 8. $\sqrt[5]{32}$ |

Answers:

| | | | |
|---|---|---|---|
| 1. 8 | 2. 36 | 3. 64 | 4. 15,625 |
| 5. 4 | 6. 2 | 7. 5 | 8. 2 |

## NEGATIVE INTEGERS

Raising to a power is multiplication in which all the numbers being multiplied together are equal. The sign of the product is determined, as in ordinary multiplication, by the number of minus signs. The number of minus signs is odd or even, depending on whether the exponent of the power is odd or even. For example, in the problem

$$(-2)^3 = (-2)(-2)(-2) = -8$$

there are three minus signs. The result is negative. In

$$(-2)^6 = 64$$

there are six minus signs. The result is positive.

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Thus, when the exponent of a negative number is odd, the power is negative; when the exponent is even, the power is positive.

As other examples, consider the following:

$$(-3)^4 = 81$$

$$\left(-\frac{2}{5}\right)^3 = -\frac{8}{125}$$

$$(-2)^8 = 256$$

$$(-1)^5 = -1$$

Positive and negative numbers belong to the class called REAL NUMBERS. The square of a real number is positive. For example, $(-7)^2 = 49$ and $7^2 = 49$. The expression $(-7)^2$ is read "minus seven squared." Note that either seven squared or minus seven squared gives us +49. We cannot obtain -49 or any other negative number by squaring any real number, positive or negative.

Since there is no real number whose square is a negative number, it is sometimes said that the square root of a negative number does not exist. However, an expression under a square root sign may take on negative values. While the square root of a negative number cannot actually be found, it can be indicated.

The indicated square root of a negative number is called an IMAGINARY NUMBER. The number $\sqrt{-7}$, for example, is said to be imaginary. It is read "square root of minus seven." Imaginary numbers are discussed in Section 5 of this course.

## FRACTIONS

We recall that the exponent of a number tells the number of times that the number is to be taken as a factor. A fraction is raised to a power by raising the numerator and the denominator separately to the power indicated. The expression $\left(\frac{3}{7}\right)^2$ means $\frac{3}{7}$ is used twice as a factor. Thus,

$$\left(\frac{3}{7}\right)^2 = \frac{3}{7} \times \frac{3}{7} = \frac{3^2}{7^2}$$

$$= \frac{9}{49}$$

Similarly,

$$\left(-\frac{1}{5}\right)^2 = \frac{1}{25}$$

Since a minus sign can occupy any one of three locations in a fraction, notice that evaluating $\left(-\frac{1}{5}\right)^2$ is equivalent to

$$(-1)^2 \left(\frac{1}{5}\right)^2 \text{ or } \frac{(-1)^2}{5^2} \text{ or } \frac{1^2}{(-5)^2}$$

The process of taking a root of a number is the inverse of the process of raising the number to a power, and the method of taking the root of a fraction is similar. We may simply take the root of each term separately and write the result as a fraction. Consider the following examples:

1. $\sqrt{\frac{36}{49}} = \frac{\sqrt{36}}{\sqrt{49}} = \frac{6}{7}$

2. $\sqrt[3]{\frac{8}{125}} = \frac{\sqrt[3]{8}}{\sqrt[3]{125}} = \frac{2}{5}$

Practice problems. Find the values for the indicated operations:

| | | | |
|---|---|---|---|
| 1. $\left(\frac{1}{3}\right)^2$ | 2. $\left(\frac{3}{4}\right)^2$ | 3. $\left(\frac{6}{5}\right)^2$ | 4. $\left(\frac{2}{3}\right)^3$ |
| 5. $\sqrt{\frac{16}{36}}$ | 6. $\sqrt{\frac{16}{25}}$ | 7. $\sqrt[3]{\frac{8}{27}}$ | 8. $\sqrt{\frac{9}{49}}$ |

Answers:

| | | | |
|---|---|---|---|
| 1. 1/9 | 2. 9/16 | 3. 36/25 | 4. 8/27 |
| 5. 4/6 | 6. 4/5 | 7. 2/3 | 8. 3/7 |

## DECIMALS

When a decimal is raised to a power, the number of decimal places in the result is equal to the number of places in the decimal multiplied by the exponent. For example, consider $(0.12)^3$. There are two decimal places in 0.12 and 3 is the exponent. Therefore, the number of places in the power will be 3(2) = 6. The result is as follows:

$$(0.12)^3 = 0.001728$$

The truth of this rule is evident when we recall the rule for multiplying decimals. Part of the rule states: Mark off as many decimal places in the product as there are decimal places in the factors together. If we carry out the multiplication, $(0.12) \times (0.12) \times (0.12)$, it is obvious that there are six decimal places in the three factors together. The rule can be shown for any decimal raised to any power by simply carrying out the multiplication indicated by the exponent.

Consider these examples:

$$(1.4)^2 = 1.96$$
$$(0.12)^2 = 0.0144$$
$$(0.4)^3 = 0.064$$
$$(0.02)^2 = 0.0004$$
$$(0.2)^2 = 0.04$$

Finding a root of a number is the inverse of raising a number to a power. To determine the number of decimal places in the root of a perfect power, we divide the number of decimal places in the radicand by the index of the root. Notice that this is just the opposite of what was done in raising a number to a power.

Consider $\sqrt{0.0625}$. The square root of 625 is 25. There are four decimal places in the radicand, 0.0625, and the index of the root is 2. Therefore, $4 \div 2 = 2$ is the number of decimal places in the root. We have

$$\sqrt{0.0625} = 0.25$$

Similarly,

$$\sqrt{1.69} = 1.3$$
$$\sqrt[3]{0.027} = 0.3$$
$$\sqrt[3]{1.728} = 1.2$$
$$\sqrt[4]{0.0001} = 0.1$$

## LAWS OF EXPONENTS

All of the laws of exponents may be developed directly from the definition of exponents. Separate laws are stated for the following five cases:

1. Multiplication.
2. Division.
3. Power of a power.
4. Power of a product.
5. Power of quotient.

### MULTIPLICATION

To illustrate the law of multiplication, we examine the following problem:

$$4^3 \times 4^2 = ?$$

Recalling that $4^3$ means $4 \times 4 \times 4$ and that $4^2$ means $4 \times 4$, we see that 4 is used as a factor five times. Therefore $4^3 \times 4^2$ is the same as $4^5$. This result could be written as follows:

$$\begin{aligned} 4^3 \times 4^2 &= 4 \times 4 \times 4 \times 4 \times 4 \\ &= 4^5 \end{aligned}$$

Notice that three of the five 4's came from the expression $4^3$, and the other two 4's came from the expression $4^2$. Thus we may rewrite the problem as follows:

$$\begin{aligned} 4^3 \times 4^2 &= 4^{(3+2)} \\ &= 4^5 \end{aligned}$$

The law of exponents for multiplication may be stated as follows: To multiply two or more powers having the same base, add the exponents and raise the common base to the sum of the exponents. This law is further illustrated by the following examples:

$$2^3 \times 2^4 = 2^7$$
$$3 \times 3^2 = 3^3$$
$$15^4 \times 15^2 = 15^6$$
$$10^2 \times 10^{0.5} = 10^{2.5}$$

### Common Errors

It is important to realize that the base must be the same for each factor in order to apply the laws of exponents. For example, $2^3 \times 3^2$ is neither $2^5$ nor $3^5$. There is no way to apply the law of exponents to a problem of this kind. Another common mistake is to multiply the bases together. For example, this kind of error in the foregoing problem would imply that $2^3 \times 3^2$ is equivalent to $6^5$, or 7776. The error of this may be proved as follows:

$$\begin{aligned} 2^3 \times 3^2 &= 8 \times 9 \\ &= 72 \end{aligned}$$

### DIVISION

The law of exponents for division may be developed from the following example:

$$\begin{aligned} 6^7 \div 6^5 &= \frac{\cancel{6} \times \cancel{6} \times \cancel{6} \times \cancel{6} \times \cancel{6} \times 6 \times 6}{\cancel{6} \times \cancel{6} \times \cancel{6} \times \cancel{6} \times \cancel{6}} \\ &= 6^2 \end{aligned}$$

Cancellation of the five 6's in the divisor with five of the 6's in the dividend leaves only two 6's, the product of which is $6^2$.

This result can be reached directly by noting that $6^2$ is equivalent to $6^{(7-5)}$. In other words, we have the following:

$$
\begin{aligned}
6^7 \div 6^5 &= 6^{(7-5)} \\
&= 6^2
\end{aligned}
$$

Therefore the law of exponents for division is as follows: To divide one power into another having the same base, subtract the exponent of the divisor from the exponent of the dividend. Use the number resulting from this subtraction as the exponent of the base in the quotient.

Use of this rule sometimes produces a negative exponent or an exponent whose value is 0. These two special types of exponents are discussed later in this section.

## POWER OF A POWER

Consider the example $(3^2)^4$. Remembering that an exponent shows the number of times the base is to be taken as a factor and noting in this case that $3^2$ is considered the base, we have

$$(3^2)^4 = 3^2 \cdot 3^2 \cdot 3^2 \cdot 3^2$$

Also in multiplication we add exponents. Thus,

$$3^2 \cdot 3^2 \cdot 3^2 \cdot 3^2 = 3^{(2+2+2+2)} = 3^8$$

Therefore,

$$
\begin{aligned}
(3^2)^4 &= 3^{(4 \times 2)} \\
&= 3^8
\end{aligned}
$$

The laws of exponents for the power of a power may be stated as follows: To find the power of a power, multiply the exponents. It should be noted that this case is the only one in which multiplication of exponents is performed.

## POWER OF A PRODUCT

Consider the example $(3 \cdot 2 \cdot 5)^3$. We know that

$$(3 \cdot 2 \cdot 5)^3 = (3 \cdot 2 \cdot 5)(3 \cdot 2 \cdot 5)(3 \cdot 2 \cdot 5)$$

Thus 3, 2, and 5 appear three times each as factors, and we can show this with exponents as $3^3$, $2^3$, and $5^3$. Therefore,

$$(3 \cdot 2 \cdot 5)^3 = 3^3 \cdot 2^3 \cdot 5^3$$

The law of exponents for the power of a product is as follows: The power of a product is equal to the product obtained when each of the original factors is raised to the indicated power and the resulting powers are multiplied together.

## POWER OF A QUOTIENT

The law of exponents for a power of an indicated quotient may be developed from the following example:

$$
\begin{aligned}
\left(\frac{2}{3}\right)^3 &= \frac{2}{3} \cdot \frac{2}{3} \cdot \frac{2}{3} \\
&= \frac{2 \cdot 2 \cdot 2}{3 \cdot 3 \cdot 3} \\
&= \frac{2^3}{3^3}
\end{aligned}
$$

Therefore,

$$\left(\frac{2}{3}\right)^3 = \frac{2^3}{3^3}$$

The law is stated as follows: The power of a quotient is equal to the quotient obtained when the dividend and divisor are each raised to the indicated power separately, before the division is performed.

Practice problems. Raise each of the following expressions to the indicated power:

1. $(3^2 \cdot 2^3)^2$
2. $3^5 \div 3^2$
3. $\left(\frac{3 \cdot 2}{5 \cdot 6}\right)^3$
4. $(-3^2)^3$
5. $\frac{5^3}{5}$
6. $(3 \cdot 2 \cdot 7)^2$

Answers:

1. $3^4 \times 2^6 = 5{,}184$
2. 27
3. $\frac{1}{125}$
4. $[(-3)^2]^3 = 729$
5. 25
6. $9 \cdot 4 \cdot 49 = 1{,}764$

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## SPECIAL EXPONENTS

Thus far in this discussion of exponents, the emphasis has been on exponents which are positive integers. There are two types of exponents which are not positive integers, and two which are treated as special cases even though they may be considered as positive integers.

## ZERO AS AN EXPONENT

Zero occurs as an exponent in the answer to a problem such as $4^3 - 4^3$. The law of exponents for division states that the exponents are to be subtracted. This is illustrated as follows:

$$\frac{4^3}{4^3} = 4^{(3-3)} = 4^0$$

Another way of expressing the result of dividing $4^3$ by $4^3$ is to use the fundamental axiom which states that any number divided by itself is 1. In order for the laws of exponents to hold true in all cases, this must also be true when any number raised to a power is divided by itself. Thus, $4^3/4^3$ must equal 1.

Since $4^3/4^3$ has been shown to be equal to both $4^0$ and 1, we are forced to the conclusion that $4^0 = 1$.

By the same reasoning,

$$\frac{5}{5} = 5^{1-1} = 5^0$$

Also,

$$\frac{5}{5} = 1$$

Therefore,

$$5^0 = 1$$

Thus we see that any number divided by itself results in a 0 exponent and has a value of 1. By definition then, any number (other than zero) raised to the zero power equals 1. This is further illustrated in the following examples.

$$3^0 = 1$$

$$400^0 = 1$$

$$0.02^0 = 1$$

$$\left(\frac{1}{5}\right)^0 = 1$$

$$(\sqrt{3})^0 = 1$$

## ONE AS AN EXPONENT

The number 1 arises as an exponent sometimes as a result of division. In the example $\frac{5^3}{5^2}$ we subtract the exponents to get

$$5^{3-2} = 5^1$$

This problem may be worked another way as follows:

$$\frac{5^3}{5^2} = \frac{\cancel{5} \cdot \cancel{5} \cdot 5}{\cancel{5} \cdot \cancel{5}} = 5$$

Therefore,

$$5^1 = 5$$

We conclude that any number raised to the first power is the number itself. The exponent 1 usually is not written but is understood to exist.

## NEGATIVE EXPONENTS

If the law of exponents for division is extended to include cases where the exponent of the denominator is larger, negative exponents arise. Thus,

$$\frac{3^2}{3^5} = 3^{2-5} = 3^{-3}$$

Another way of expressing this problem is as follows:

$$\frac{3^2}{3^5} = \frac{\cancel{3} \cdot \cancel{3}}{\cancel{3} \cdot \cancel{3} \cdot 3 \cdot 3 \cdot 3} = \frac{1}{3^3}$$

Therefore,

$$3^{-3} = \frac{1}{3^3}$$

We conclude that a number N with a negative exponent is equivalent to a fraction having the following form: Its numerator is 1; its denominator is N with a positive exponent whose absolute value is the same as the absolute value of the original exponent. In symbols, this rule may be stated as follows:

$$N^{-a} = \frac{1}{N^a}$$



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Also,

$$\frac{1}{N^{-a}} = N^a$$

The following examples further illustrate the rule:

$$5^{-1} = \frac{1}{5}$$

$$6^{-2} = \frac{1}{6^2}$$

$$4^{-12} = \frac{1}{4^{12}}$$

$$\frac{1}{3^{-2}} = 3^2$$

Notice that the sign of an exponent may be changed by merely moving the expression which contains the exponent to the other position in the fraction. The sign of the exponent is changed as this move is made. For example,

$$\frac{1}{10^{-2}} = 1 \div \frac{1}{10^2}$$

$$= 1 \times \frac{10^2}{1}$$

Therefore,

$$\frac{1}{10^{-2}} = \frac{10^2}{1}$$

By using the foregoing relationship, a problem such as $3 \div 5^{-4}$ may be simplified as follows:

$$\frac{3}{5^{-4}} = 3 \times \frac{1}{5^{-4}}$$

$$= 3 \times \frac{5^4}{1}$$

$$= 3 \times 5^4$$

## FRACTIONAL EXPONENTS

Fractional exponents obey the same laws as do integral exponents. For example,

$$4^{1/2} \times 4^{1/2} = 4^{(1/2 + 1/2)}$$

$$= 4^{2/2}$$

$$= 4^1 = 4$$

Another way of expressing this would be

$$4^{1/2} \times 4^{1/2} = (4^{1/2})^2$$

$$= 4^{(1/2 \times 2)}$$

$$= 4^1 = 4$$

Observe that the number $4^{1/2}$, when squared in the foregoing example, produced the number 4 as an answer. Recalling that a square root of a number N is a number x such that $x^2 = N$, we conclude that $4^{1/2}$ is equivalent to $\sqrt{4}$. Thus we have a definition, as follows: A fractional exponent of the form 1/r indicates a root, the index of which is r. This is further illustrated in the following examples:

$$2^{1/2} = \sqrt{2}$$

$$4^{1/3} = \sqrt[3]{4}$$

$$6^{2/3} = (6^{1/3})^2 = (\sqrt[3]{6})^2$$

Also,

$$6^{2/3} = (6^2)^{1/3} = \sqrt[3]{36}$$

Notice that in an expression such as $8^{2/3}$ we can either find the cube root of 8 first or square 8 first, as shown by the following example:

$$(8^{1/3})^2 = 2^2 = 4 \text{ and } (8^2)^{1/3} = \sqrt[3]{64} = 4$$

All the numbers in the evaluation of $8^{2/3}$ remain small if the cube root is found before the number is raised to the second power. This order of operation is particularly desirable in evaluating a number like $64^{5/6}$. If 64 were first raised to the fifth power, a large number would result. It would require a great deal of unnecessary effort to find the sixth root of $64^5$. The result is obtained easily, if we write

$$64^{5/6} = (64^{1/6})^5 = 2^5 = 32$$

If an improper fraction occurs in an exponent, such as 7/3 in the expression $2^{7/3}$, it is customary to keep the fraction in that form rather than express it as a mixed number. In fraction form, an exponent shows immediately what power is intended and what root is intended. However, $2^{7/3}$ can be expressed in another form and simplified by changing the improper fraction to a mixed number and writing the fractional part in the radical form as follows:

$$2^{7/3} = 2^{2 + 1/3} = 2^2 \cdot 2^{1/3} = 4\sqrt[3]{2}$$

The law of exponents for multiplication may be combined with the rule for fractional exponents to solve problems of the following type.

PROBLEM: Evaluate the expression $4^{2.5}$.

SOLUTION: $4^{2.5} = 4^2 \times 4^{0.5}$

$= 16 \times 4^{1/2}$

$= 16 \times 2$

$= 32$

Practice problems:

1. Perform the indicated division: $\frac{2}{2^{1/3}}$
2. Find the product: $7^{2/5} \times 7^{1/10} \times 7^{3/10}$
3. Rewrite with a positive exponent and simplify: $9^{-1/2}$
4. Evaluate $100^{3/2}$
5. Evaluate $(8^0)^5$

Answers:

1. $2^{3/3} \div 2^{1/3} = \sqrt[3]{4}$
2. $7^{8/10}$
3. $\frac{1}{9^{1/2}} = \frac{1}{3}$
4. 1,000
5. 1

## SCIENTIFIC NOTATION AND POWERS OF 10

Technicians, engineers, and others engaged in scientific work are often required to solve problems involving very large and very small numbers. Problems such as

$$\frac{22,684 \times 0.00189}{0.0713 \times 83 \times 7}$$

are not uncommon. Solving such problems by the rules of ordinary arithmetic is laborious and time consuming. Moreover, the tedious arithmetic process lends itself to operational errors. Also there is difficulty in locating the decimal point in the result. These difficulties can be greatly reduced by a knowledge of the powers of 10 and their use.

The laws of exponents form the basis for calculation using powers of 10. The following list includes several decimals and whole numbers expressed as powers of 10:

$$10,000 = 10^4$$
$$1,000 = 10^3$$
$$100 = 10^2$$
$$10 = 10^1$$
$$1 = 10^0$$
$$0.1 = 10^{-1}$$
$$0.01 = 10^{-2}$$
$$0.001 = 10^{-3}$$
$$0.0001 = 10^{-4}$$

The concept of scientific notation may be demonstrated as follows:

$$60,000 = 6.0000 \times 10,000$$
$$= 6 \times 10^4$$
$$538 = 5.38 \times 100$$
$$= 5.38 \times 10^2$$

Notice that the final expression in each of the foregoing examples involves a number between 1 and 10, multiplied by a power of 10. Furthermore, in each case the exponent of the power of 10 is a number equal to the number of digits between the new position of the decimal point and the original position (understood) of the decimal point.

We apply this reasoning to write any number in scientific notation; that is, as a number between 1 and 10 multiplied by the appropriate power of 10. The appropriate power of 10 is found by the following mechanical steps:

1. Shift the decimal point to standard position, which is the position immediately to the right of the first nonzero digit.

2. Count the number of digits between the new position of the decimal point and its original position. This number indicates the value of the exponent for the power of 10.

3. If the decimal point is shifted to the left, the sign of the exponent of 10 is positive; if the decimal point is shifted to the right, the sign of the exponent is negative.

The validity of this rule, for those cases in which the exponent of 10 is negative, is demonstrated as follows:

$$0.00657 = 6.57 \times 0.001 = 6.57 \times 10^{-3}$$

$$0.348 = 3.48 \times 0.1 = 3.48 \times 10^{-1}$$

Further examples of the use of scientific notation are given as follows:

$$543{,}000{,}000 = 5.43 \times 10^{8}$$

$$186 = 1.86 \times 10^{2}$$

$$243.01 = 2.4301 \times 10^{2}$$

$$0.0000007 = 7 \times 10^{-7}$$

$$0.00023 = 2.3 \times 10^{-4}$$

Multiplication Using Powers of 10

From the law of exponents for multiplication we recall that to multiply two or more powers to the same base we add their exponents. Thus,

$$10^{4} \times 10^{2} = 10^{6}$$

We see that multiplying powers of 10 together is an application of the general rule. This is demonstrated in the following examples.

1. $10{,}000 \times 100 = 10^{4} \times 10^{2} = 10^{4+2} = 10^{6}$

2. $0.0000001 \times 0.001 = 10^{-7} \times 10^{-3} = 10^{-7+(-3)} = 10^{-10}$

3. $10{,}000 \times 0.001 = 10^{4} \times 10^{-3} = 10^{4-3} = 10$

4. $23{,}000 \times 500 = ?$

$$23{,}000 = 2.3 \times 10^{4}$$

$$500 = 5 \times 10^{2}$$

Therefore,

$$23{,}000 \times 500 = 2.3 \times 10^{4} \times 5 \times 10^{2} = 2.3 \times 5 \times 10^{4} \times 10^{2} = 11.5 \times 10^{6} = 11{,}500{,}000$$

5. $62{,}000 \times 0.003 \times 4{,}600 = ?$

$$62{,}000 = 6.2 \times 10^{4}$$

$$0.0003 = 3 \times 10^{-4}$$

$$4{,}600 = 4.6 \times 10^{3}$$

Therefore,

$$62{,}000 \times 0.0003 \times 4{,}600 = 6.2 \times 3 \times 4.6 \times 10^{4} \times 10^{-4} \times 10^{3} = 85.56 \times 10^{3} = 85{,}560$$

Practice problems. Multiply, using powers of 10. For the purposes of this exercise, treat all numbers as exact numbers:

1. $10{,}000 \times 0.001 \times 100$
2. $0.000350 \times 5{,}000{,}000 \times 0.0004$
3. $3{,}875 \times 0.000032 \times 3{,}000{,}000$
4. $7{,}000 \times 0.015 \times 1.78$

Answers:

1. $1.0 \times 10^{3}$
2. $7.0 \times 10^{-1}$
3. $3.72 \times 10^{5}$
4. $1.869 \times 10^{2}$

Division Using Powers of 10

The rule of exponents for division states that, for powers of the same base, the exponent of the denominator is subtracted from the exponent of the numerator. Thus,

$$\frac{10^{7}}{10^{3}} = 10^{7-3} = 10^{4}$$

It should be remembered that powers may be transferred from numerator to denominator or from denominator to numerator by simply changing the sign of the exponent. The following examples illustrate the use of this rule for powers of 10:

1. $$\frac{72{,}000}{0.0012} = \frac{7.2 \times 10^{4}}{1.2 \times 10^{-3}} = \frac{7.2}{1.2} \times 10^{4} \times 10^{3} = 6 \times 10^{7}$$

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2. $\frac{44 \times 10^{-4}}{11 \times 10^{-5}} = \frac{44}{11} \times 10^{-4} \times 10^{5}$

$= 4 \times 10$

Combined Multiplication and Division

Using the rules already shown, multiplication and division involving powers of 10 may be combined. The usual method of solving such problems is to multiply and divide alternately until the problem is completed. For example,

$$\frac{36{,}000 \times 1.1 \times 0.06}{0.012 \times 2{,}200}$$

Rewriting this problem in scientific notation, we have

$$\frac{3.6 \times 10^{4} \times 1.1 \times 6 \times 10^{-2}}{1.2 \times 10^{-2} \times 2.2 \times 10^{3}} = \frac{3.6 \times 1.1 \times 6}{1.2 \times 2.2} \times 10$$

$$= 9 \times 10$$

$$= 90$$

Notice that the elimination of 0's, wherever possible, simplifies the computation and makes it an easy matter to place the decimal point.

SIGNIFICANT DIGITS.—One of the most important advantages of scientific notation is the fact that it simplifies the task of determining the number of significant digits in a number. For example, the fact that the number 0.00045 has two significant digits is sometimes obscured by the presence of the 0's. The confusion can be avoided by writing the number in scientific notation, as follows:

$$0.00045 = 4.5 \times 10^{-4}$$

Practice problems. Express the numbers in the following problems in scientific notation and round off before performing the calculation. In each problem, round off calculation numbers to one more digit than the number of significant digits in the least accurate number; round the answer to the number of significant digits in the least accurate number:

1. $\frac{0.000063 \times 50.4 \times 0.007213}{780 \times 0.682 \times 0.018}$

2. $\frac{0.015 \times 216 \times 1.78}{72 \times 0.0624 \times 0.0353}$

3. $\frac{0.000079 \times 0.00036}{29 \times 10^{-8}}$

Answers:

1. $2.38 \times 10^{-6}$
2. $3.64 \times 10$
3. $9.8 \times 10^{-2}$

Other Applications

The applications of powers of 10 may be broadened to include problems involving reciprocals and powers of products.

RECIPROCALS.—The following example illustrates the use of powers of 10 in the formation of a reciprocal:

$$\frac{1}{250{,}000 \times 300 \times 0.02}$$

$$= \frac{1}{2.5 \times 10^{5} \times 3 \times 10^{2} \times 2 \times 10^{-2}}$$

$$= \frac{10^{-5}}{2.5 \times 3 \times 2}$$

$$= \frac{10^{-5}}{15}$$

Rather than write the numerator as 0.00001, write it as the product of two factors, one of which may be easily divided, as follows:

$$\frac{10^{-5}}{15} = \frac{10^{2} \times 10^{-7}}{15}$$

$$= \frac{100}{15} \times 10^{-7}$$

$$= 6.67 \times 10^{-7}$$

$$= 0.000000667$$

POWER OF A PRODUCT.—The following example illustrates the use of powers of 10 in finding the power of a product:

$$(80{,}000 \times 2 \times 10^{5})^{2} = (8 \times 10^{4} \times 2 \times 10^{5})^{2}$$

$$= 8^{2} \times 2^{2} \times (10^{4+5})^{2}$$

$$= 64 \times 4 \times 10^{18}$$

$$= 256 \times 10^{18}$$

$$= 2.56 \times 10^{20}$$

## RADICALS

An expression such as $\sqrt{2}$, $\sqrt[3]{5}$, or $\sqrt{a + b}$ that exhibits a radical sign, is referred to as a

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RADICAL. We have already worked with radicals in the form of fractional exponents, but it is also frequently necessary to work with them in the radical form. The word "radical" is derived from the Latin word "radix," which means "root." The word "radix" itself is more often used in modern mathematics to refer to the base of a number system, such as the base 2 in the binary system. However, the word "radical" is retained with its original meaning of "root."

The radical symbol ($\sqrt{}$) appears to be a distortion of the initial letter "r" from the word "radix." With long usage, the r gradually lost its significance as a letter and became distorted into the symbol as we use it. The vinculum helps to specify exactly which of the letters and numbers following the radical sign actually belong to the radical expression.

The number under a radical sign is the RADICAND. The index of the root (except in the case of a square root) appears in the trough of the radical sign. The index tells what root of the radicand is intended. For example, in $\sqrt[5]{32}$, the radicand is 32 and the index of the root is 5. The fifth root of 32 is intended. In $\sqrt{50}$, the square root of 50 is intended. When the index is 2, it is not written but is understood.

If we can find one square root of a number, we can always find two of them. Remember $(3)^2$ is 9 and $(-3)^2$ is also 9. Likewise, $(4)^2$ and $(-4)^2$ both equal 16, and $(5)^2$ and $(-5)^2$ both equal 25. Conversely, $\sqrt{9}$ is +3 or -3, $\sqrt{16}$ is +4 or -4, and $\sqrt{25}$ is +5 or -5. When we wish to show a number that may be either positive or negative, we may use the symbol $\pm$, which is read "plus or minus." Thus $\pm 3$ means "plus or minus 3." Usually when a number is placed under the radical sign, only its positive root is desired and, unless otherwise specified, it is the only root that need be found.

## COMBINING RADICALS

A number written in front of another number and intended as a multiplier is called a COEFFICIENT. The expression 5x means 5 times x; ay means a times y; and 7 $\sqrt{2}$ means 7 times $\sqrt{2}$. In these examples, 5 is the coefficient of x, a is the coefficient of y, and 7 is the coefficient of $\sqrt{2}$.

Radicals having the same index and the same radicand are SIMILAR. Similar radicals may have different coefficients in front of the radical sign. For example, $3\sqrt{2}$, $\sqrt{2}$, and $\frac{1}{5}\sqrt{2}$ are similar radicals. When a coefficient is not written, it is understood to be 1. Thus, the coefficient of $\sqrt{2}$ is 1. The rule for adding radicals is the same as that stated for adding denominate numbers: Add only units of the same kind. For example, we could add $2\sqrt{3}$ and $4\sqrt{3}$ because the "unit" in each of these numbers is the same ($\sqrt{3}$). By the same reasoning, we could not add $2\sqrt{3}$ and $4\sqrt{5}$ because these are not similar radicals.

### Addition and Subtraction

When addition or subtraction of similar radicals is indicated, the radicals are combined by adding or subtracting their coefficients and placing the result in front of the radical. Adding $3\sqrt{2}$ and $5\sqrt{2}$ is similar to adding 3 bolts and 5 bolts. The following examples illustrate the addition and subtraction of similar radical expressions:

1. $3\sqrt{2} + 5\sqrt{2} = 8\sqrt{2}$
2. $1/2\,(\sqrt[4]{3}) + 1/3\,(\sqrt[4]{3}) = 5/6\,(\sqrt[4]{3})$
3. $\sqrt{5} - 6\sqrt{5} + 2\sqrt{5} = -3\sqrt{5}$
4. $-5\sqrt[3]{7} - 2\sqrt[3]{7} + 7\sqrt[3]{7} = 0$

Example 4 illustrates a case that is sometimes troublesome. The sum of the coefficients, -5, -2, and 7, is 0. Therefore, the coefficient of the answer would be 0, as follows:

$$0(\sqrt[3]{7}) = 0 \times \sqrt[3]{7}$$

Thus the final answer is 0, since 0 multiplied by any quantity is still 0.

Practice problems. Perform the indicated operations:

1. $4\sqrt{3} - \sqrt{3} + 5\sqrt{3}$
2. $\frac{1}{2}\sqrt{6} + \sqrt{6}$
3. $\sqrt[3]{5} - 6\sqrt[3]{5}$
4. $-2\sqrt{10} - 7\sqrt{10}$

Answers

1. $8\sqrt{3}$
2. $\frac{3}{2}\sqrt{6}$
3. $-5\sqrt[3]{5}$
4. $-9\sqrt{10}$

### Multiplication and Division

If a radical is written immediately after another radical, multiplication is intended. Sometimes a dot is placed between the radicals, but not always. Thus, either $\sqrt{7} \cdot \sqrt{11}$ or $\sqrt{7}\,\sqrt{11}$ means multiplication.

When multiplication or division of radicals is indicated, several radicals having the same index can be combined into one radical if desired. Radicals having the same index are said to be of the SAME ORDER. For example, $\sqrt{2}$ is a radical of the second order. The radicals $\sqrt{2}$ and $\sqrt{5}$ are of the same order.

If radicals are of the same order, the radicands can be multiplied or divided and placed under one radical symbol. For example, $\sqrt{5}$ multiplied by $\sqrt{3}$ is the same as $\sqrt{5 \times 3}$. Also, $\sqrt{6}$ divided by $\sqrt{3}$ is the same as $\sqrt{6 \div 3}$. If coefficients appear before the radicals, they also must be included in the multiplication or division. This is illustrated in the following examples:

1. $$\begin{aligned} 2\sqrt{2} \cdot 3\sqrt{5} &= 2 \cdot \sqrt{2} \cdot 3 \cdot \sqrt{5} \\ &= 2 \cdot 3\,\sqrt{2} \cdot \sqrt{5} \\ &= 2 \cdot 3\,\sqrt{2 \cdot 5} \\ &= 6\sqrt{10} \end{aligned}$$

2. $$\begin{aligned} \frac{15\sqrt{6}}{3\sqrt{3}} &= \frac{15}{3} \times \sqrt{\frac{6}{3}} \\ &= 5 \times \sqrt{2} \\ &= 5\sqrt{2} \end{aligned}$$

It is important to note that what we have said about multiplication and division does not apply to addition. A typical error is to treat the expression $\sqrt{9 + 4}$ as if it were equivalent to $\sqrt{9} + \sqrt{4}$. These expressions cannot be equivalent, since 3 + 2 is not equivalent to $\sqrt{13}$.

FACTORING RADICALS.—A radical can be split into two or more radicals of the same order if the radicand can be factored. This is illustrated in the following examples:

1. $\sqrt{20} = \sqrt{4} \cdot \sqrt{5} = 2\sqrt{5}$
2. $\sqrt[3]{54} = \sqrt[3]{27 \cdot 2}$
   $= \sqrt[3]{27} \cdot \sqrt[3]{2} = 3\sqrt[3]{2}$
3. $\dfrac{\sqrt{20}}{\sqrt{5}} = \dfrac{\sqrt{4} \cdot \sqrt{5}}{\sqrt{5}}$
   $= \sqrt{4} = 2$

## SIMPLIFYING RADICALS

Some radicals may be changed to an equivalent form that is easier to use. A radical is in its simplest form when no factor can be removed from the radical, when there is no fraction under the radical sign, and when the index of the root cannot be reduced. A factor can be removed from the radical if it occurs a number of times equal to the index of the root. The following examples illustrate this:

1. $\sqrt{28} = \sqrt{2^2 \cdot 7} = 2\sqrt{7}$
2. $\sqrt[3]{54} = \sqrt[3]{3^3 \cdot 2} = 3(\sqrt[3]{2})$
3. $\sqrt[5]{160} = \sqrt[5]{2^5 \cdot 5} = 2(\sqrt[5]{5})$

Removing a factor that occurs a number of times equal to the index of the root is equivalent to separating a radical into two radicals so that one radicand is a perfect power. The radical sign can be removed from the number that is a perfect square, cube, fourth power, etc. The root taken becomes the coefficient of the remaining radical.

In order to simplify radicals easily, it is convenient to know the squares of whole numbers up to about 25 and a few of the smaller powers of the numbers 2, 3, 4, 5, and 6. Table 2 shows some frequently used powers of numbers.

Table 2.—Powers of numbers.

| | |
|---|---|
| $1^2 = 1$ | $14^2 = 196$ |
| $2^2 = 4$ | $15^2 = 225$ |
| $3^2 = 9$ | $16^2 = 256$ |
| $4^2 = 16$ | $17^2 = 289$ |
| $5^2 = 25$ | $18^2 = 324$ |
| $6^2 = 36$ | $19^2 = 361$ |
| $7^2 = 49$ | $20^2 = 400$ |
| $8^2 = 64$ | $21^2 = 441$ |
| $9^2 = 81$ | $22^2 = 484$ |
| $10^2 = 100$ | $23^2 = 529$ |
| $11^2 = 121$ | $24^2 = 576$ |
| $12^2 = 144$ | $25^2 = 625$ |
| $13^2 = 169$ | |

(A)

Table 2.—Powers of numbers—continued.

| (B) |
|---|
| $2^1 = 2$ |
| $2^2 = 4$ |
| $2^3 = 8$ |
| $2^4 = 16$ |
| $2^5 = 32$ |
| $2^6 = 64$ |
| $2^7 = 128$ |
| $2^8 = 256$ |

| (C) |
|---|
| $3^1 = 3$ |
| $3^2 = 9$ |
| $3^3 = 27$ |
| $3^4 = 81$ |
| $3^5 = 243$ |

| (D) |
|---|
| $4^1 = 4$ |
| $4^2 = 16$ |
| $4^3 = 64$ |
| $4^4 = 256$ |

| (E) |
|---|
| $5^1 = 5$ |
| $5^2 = 25$ |
| $5^3 = 125$ |
| $5^4 = 625$ |

| (F) |
|---|
| $6^1 = 6$ |
| $6^2 = 36$ |
| $6^3 = 216$ |

Referring to table 2 (A), we see that the series of numbers

$$1, 4, 9, 16, 25, 36, 49, 64, 81, 100$$

comprises all the perfect squares from 1 to 100 inclusive. If any one of these numbers appears under a square root symbol, the radical sign can be removed immediately. This is illustrated as follows:

$$\sqrt{25} = 5$$
$$\sqrt{81} = 9$$

A radicand such as 75, which has a perfect square (25) as a factor, can be simplified as follows:

$$\begin{aligned}\sqrt{75} &= \sqrt{25 \cdot 3}\\ &= \sqrt{25} \cdot \sqrt{3}\\ &= 5\sqrt{3}\end{aligned}$$

This procedure is further illustrated in the following problems:

1. $\sqrt{8} = \sqrt{4 \cdot 2}$
   $= \sqrt{4} \cdot \sqrt{2}$
   $= 2\sqrt{2}$
2. $\sqrt{72} = \sqrt{36 \cdot 2}$
   $= \sqrt{36} \cdot \sqrt{2}$
   $= 6\sqrt{2}$

By reference to the perfect fourth powers in table 2, we may simplify a radical such as $\sqrt[4]{405}$. Noting that 405 has the perfect fourth power 81 as a factor, we have the following:

$$\begin{aligned}\sqrt[4]{405} &= \sqrt[4]{81 \cdot 5}\\ &= \sqrt[4]{81} \cdot \sqrt[4]{5}\\ &= 3(\sqrt[4]{5})\end{aligned}$$

As was shown with fractional exponents, taking a root is equivalent to dividing the exponent of a power by the index of the root. If a factor of the radicand has an exponent that is not a multiple of the index of the root, the factor may be separated so that one exponent is divisible by the index, as in

$$\sqrt{3^7} = \sqrt{3^6 \cdot 3} = 3^{6/2} \cdot 3^{1/2} = 3^3 \cdot \sqrt{3} = 27\sqrt{3}$$

Consider also

$$\begin{aligned}\sqrt{2^3 \cdot 3^7 \cdot 5} &= \sqrt{2^2 \cdot 2 \cdot 3^6 \cdot 3 \cdot 5}\\ &= 2 \cdot 3^3(\sqrt{2 \cdot 3 \cdot 5})\\ &= 54\sqrt{30}\end{aligned}$$

If the radicand is a large number, the perfect powers that are factors are not always obvious. In such a case the radicand can be separated into prime factors. For example,

$$\begin{aligned}\sqrt{8{,}820} &= \sqrt{2^2 \cdot 3^2 \cdot 5 \cdot 7^2}\\ &= 2 \cdot 3 \cdot 7\sqrt{5}\\ &= 42\sqrt{5}\end{aligned}$$

Practice problems. Simplify the radicals and reduce to lowest terms:

1. $\dfrac{\sqrt{3} \cdot \sqrt{15}}{\sqrt{5}}$
2. $\dfrac{\sqrt[3]{81}}{\sqrt[3]{27}}$
3. $\dfrac{18(\sqrt[3]{30})}{3(\sqrt[3]{10})}$
4. $\dfrac{\sqrt{8{,}820}}{\sqrt{180}}$

Answers:

1. 3
2. $\sqrt[3]{3}$
3. $6(\sqrt[3]{3})$
4. 7

## RATIONAL AND IRRATIONAL NUMBERS

Real and imaginary numbers make up the number system of algebra. Imaginary numbers are discussed in section 5 of this pamphlet. Real numbers are either rational or irrational. The word RATIONAL comes from the word "ratio." A number is rational if it can be expressed as the quotient, or ratio, of two whole numbers. Rational numbers include fractions like 2.7, whole numbers, and radicals if the radical sign is removable.

Any whole number is rational. Its denominator is 1. For instance, 8 equals $\frac{8}{1}$, which is the quotient of two integers. A number like $\sqrt{16}$ is rational, since it can be expressed as the quotient of two integers in the form $\frac{4}{1}$. The following are also examples of rational numbers:

1. $\sqrt{\frac{25}{9}}$, which equals $\frac{5}{3}$
2. $-6$, which equals $\frac{-6}{1}$
3. $5\frac{2}{7}$, which equals $\frac{37}{7}$

Any rational number can be expressed as the quotient of two integers in many ways. For example,

$$7 = \frac{7}{1} = \frac{14}{2} = \frac{21}{3} \ldots$$

An IRRATIONAL number is a real number that cannot be expressed as the ratio of two integers. The numbers $\sqrt{3}$, $5\sqrt{2}$, $\sqrt{7}$, $\frac{3}{8}\sqrt{20}$, and $\frac{2}{\sqrt{5}}$ are examples of irrational numbers.

### Rationalizing Denominators

Expressions such as $\frac{7}{\sqrt{2}}$ and $\frac{\sqrt{2}}{5\sqrt{3}}$ have irrational numbers in the denominator. If the denominators are changed immediately to decimals, as in

$$\frac{7}{\sqrt{2}} = \frac{7}{1.4142}$$

the process of evaluating a fraction becomes an exercise in long division. Such a fraction can be evaluated quickly by first changing the denominator to a rational number. Converting a fraction with an irrational number in its denominator to an equivalent fraction with a rational number in the denominator is called RATIONALIZING THE DENOMINATOR.

Multiplying a fraction by 1 leaves the value of the fraction unchanged. Since any number divided by itself equals 1, it follows, for example, that

$$\frac{\sqrt{2}}{\sqrt{2}} = 1$$

If the numerator and denominator of $\frac{7}{\sqrt{2}}$ are each multiplied by $\sqrt{2}$, another fraction having the same value is obtained. The result is

$$\frac{7}{\sqrt{2}} = \frac{7}{\sqrt{2}} \cdot \frac{\sqrt{2}}{\sqrt{2}} = \frac{7\sqrt{2}}{2}$$

The denominator of the new equivalent fraction is 2, which is rational. The decimal value of the fraction is

$$\frac{7\sqrt{2}}{2} = \frac{7(1.4142)}{2} = 7(0.7071) = 4.9497$$

To rationalize the denominator in $\frac{\sqrt{2}}{5\sqrt{3}}$ we multiply the numerator and denominator by $\sqrt{3}$. We get

$$\frac{\sqrt{2}}{5\sqrt{3}} = \frac{\sqrt{2}}{5\sqrt{3}} \cdot \frac{\sqrt{3}}{\sqrt{3}} = \frac{\sqrt{6}}{5(3)} = \frac{\sqrt{6}}{15} \text{ or } \frac{1}{15}\sqrt{6}$$

Practice problems. Rationalize the denominator in each of the following:

1. $\frac{6}{\sqrt{2}}$
2. $\frac{\sqrt{5}}{\sqrt{3}}$
3. $\frac{2}{\sqrt{6}}$
4. $\frac{6}{\sqrt{y}}$

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Answers:

1. $3\sqrt{2}$
2. $\frac{\sqrt{15}}{3}$
3. $\frac{\sqrt{6}}{3}$
4. $\frac{6\sqrt{y}}{y}$

## EVALUATING RADICALS

Any radical expression has a decimal equivalent which may be exact if the radicand is a rational number. If the radicand is not rational, the root may be expressed as a decimal approximation, but it can never be exact. A procedure similar to long division may be used for calculating square root and cube root; and higher roots may be calculated by means of methods based on logarithms and higher mathematics. Tables of powers and roots have been calculated for use in those scientific fields in which it is frequently necessary to work with roots.

### SQUARE ROOT PROCESS

The arithmetic process for calculation of square root is outlined in the following paragraphs:

1. Begin at the decimal point and mark the number off into groups of two digits each, moving both to the right and to the left from the decimal point. This may leave an odd digit at the right-hand or left-hand end of the number, or both. For example, suppose that the number whose square root we seek is 9025. The number marked off as specified would be as follows:

$$\sqrt{90'25.}$$

2. Find the greatest number whose square is contained in the left-hand group (90). This number is 9, since the square of 9 is 81. Write 9 above the first group. Square this number (9), place its square below the left-hand group, and subtract, as follows:

$$\begin{array}{r} 9\phantom{25.} \\ \sqrt{90'25.} \\ \underline{81}\phantom{25.} \\ 9\ 25\phantom{.} \end{array}$$

Bring down the next group (25) and place it beside the 9, as shown. This is the new dividend (925).

3. Multiply the first digit in the root (9) by 20, obtaining 180 as a trial divisor. This trial divisor is contained in the new dividend (925) five times; thus the second digit of the root appears to be 5. However, this number must be added to the trial divisor to obtain a "true divisor." If the true divisor is then too large to use with the second quotient digit, this digit must be reduced by 1. The procedure for step 3 is illustrated as follows:

$$\begin{array}{rr} & 9\ \ 5. \\ & \sqrt{90'25.} \\ & \underline{81}\phantom{25.} \\ \cancel{180} & 9\ 25\phantom{.} \\ 185 & \underline{9\ 25}\phantom{.} \\ & 0\ 00\phantom{.} \end{array}$$

The number 180, resulting from the multiplication of 9 by 20, is written as a trial divisor beside the new dividend (925), as shown. The quotient digit (5) is then recorded and the trial divisor is adjusted, becoming 185. The trial quotient (180) is crossed out.

4. The true divisor (185) is multiplied by the second digit (5) and the product is placed below the new dividend (925). This step is shown in the illustration for step 3. When the product in step 4 is subtracted from the new dividend, the difference is 0; thus, in this example, the root is exact.

5. In some problems, the difference is not 0 after all of the digits of the original number have been used to form new dividends. Such problems may be carried further by adding 0's on the right-hand end of the original number, just as in normal long division. However, in the square root process, the 0's must be added and used in groups of 2.

Practice problems. Find the square root of each of the following numbers:

1. 9.61
2. 123.21
3. 0.0025

Answers:

1. 3.1
2. 11.1
3. 0.05

### TABLES OF ROOTS

The decimal values of square roots and cube roots of numbers with as many as 3 or 4 digits can be found from tables. The table in appendix I of this pamphlet gives the square roots and cube roots of numbers from 1 to 100. Most of the values given in such tables are approximate numbers which have been rounded off.

For example, the fourth column in appendix I shows that $\sqrt{72} = 8.4853$, to 4 decimal places. By shifting the decimal point, we can obtain other square roots. A shift of two places in the decimal point in the radicand corresponds to a shift of one place in the same direction in the square root.

The following examples show the effect, as reflected in the square root, of shifting the location of the decimal point in the number whose square root we seek:

$$\sqrt{72} = 8.4853$$
$$\sqrt{0.72} = 0.84853$$
$$\sqrt{0.0072} = 0.084853$$
$$\sqrt{7,200} = 84.853$$

Cube Root

The fifth column in appendix I shows that the cube root of 72 is 4.1602. By shifting the decimal point we immediately have the cube roots of certain other numbers involving the same digits. A shift of three places in the decimal point in the radicand corresponds to a shift of one place in the same direction in the cube root:

Compare the following examples:

$$\sqrt[3]{72} = 4.1602$$
$$\sqrt[3]{0.072} = 0.41602$$
$$\sqrt[3]{72,000} = 41.602$$

Many irrational numbers in their simplified forms involve $\sqrt{2}$ and $\sqrt{3}$. Since these radicals occur often, it is convenient to remember their decimal equivalents as follows:

$$\sqrt{2} = 1.4142 \text{ and } \sqrt{3} = 1.7321$$

Thus any irrational numbers that do not contain any radicals other than $\sqrt{2}$ or $\sqrt{3}$ can be converted to decimal forms quickly without referring to tables.

For example, consider

$$\sqrt{72} = 6\sqrt{2} = 6(1.4142) = 8.485$$
$$\sqrt{27} = 3\sqrt{3} = 3(1.7321) = 5.196$$

Keep in mind that the decimal equivalents of $\sqrt{2}$ and $\sqrt{3}$ as used in the foregoing examples are not exact numbers and the results obtained with them are approximate in the fourth decimal place.

# LOGARITHMS AND THE SLIDE RULE

Logarithms represent a specialized use of exponents. By means of logarithms, computation with large masses of data can be greatly simplified. For example, when logarithms are used, the process of multiplication is replaced by simple addition and division is replaced by subtraction. Raising to a power by means of logarithms is done in a single multiplication, and extracting a root reduces to simple division.

## DEFINITIONS

In the expression $2^3 = 8$, the number 2 is the base (not to be confused with the base of the number system), and 3 is the exponent which must be used with the base to produce the number 8. The exponent 3 is the logarithm of 8 when the base is 2. This relationship is usually stated as follows: The logarithm of 8 to the base 2 is 3. In general, the logarithm of a number N with respect to a given base is the exponent which must be used with the base to produce N. Table 3 illustrates this.

Table 3.—Logarithms with various bases.

| Exponential form | Logarithmic form |
|---|---|
| $2^3 = 8$ | $\log_2 8 = 3$ |
| $4^2 = 16$ | $\log_4 16 = 2$ |
| $5^0 = 1$ | $\log_5 1 = 0$ |
| $27^{2/3} = 9$ | $\log_{27} 9 = 2/3$ |

Table 3 shows that the logarithmic relationship may be expressed equally well in either of two forms: these are the exponential form and the logarithmic form. Observe, in table 3 that the base of a logarithmic expression is indicated by placing a subscript just below and to the right of the abbreviation "log." Observe also that the word "logarithm" is abbreviated without using a period.

The equivalency of the logarithmic and exponential forms may be used to restate the fundamental definition of logarithms in its most useful form, as follows:

$$b^x = N \text{ implies that } \log_b N = x$$

In words, this definition is stated as follows: If the base b raised to the x power equals N, then x is the logarithm of the number N to the base b.

One of the many uses of logarithms may be shown by an example in which the base is 2. Table 4 shows the powers of 2 from 0 through 20. Suppose that we wish to use logarithms to multiply the numbers 512 and 256, as follows:

From table 4, $512 = 2^9$

$256 = 2^8$

Then $512 \times 256 = 2^9 \times 2^8$

$= 2^{17}$

and from the table again $2^{17} = 131072$

It is seen that the problem of multiplication is reduced to the simple addition of the exponents 9 and 8 and finding the corresponding power in the table.

Table 4 (A) shows the base 2 in the exponential form with its corresponding powers. The actual computation in logarithmic work does not require that we record the exponential form. All that is required is that we add the appropriate exponents and have available a table in which we can look up the number corresponding to the new exponent after adding. Therefore, table 4 (B) is adequate for our purpose. Solving the foregoing example by this table, we have the following:

$$\log_2 512 = 9$$

$$\log_2 256 = 8$$

$$\log_2 \text{ of the product} = 17$$

Therefore, the number we seek is the one in the table whose logarithm is 17. This number is 131,072. In this example, we found the exponents directly, added them since this was a

Table 4.—Exponential and logarithmic tables for the base 2.

| (A) Powers of 2 from 0 through 20 | (B) Logarithms for the base 2 and corresponding powers: Log | Number |
|---|---|---|
| $2^0 = 1$ | 0 | 1 |
| $2^1 = 2$ | 1 | 2 |
| $2^2 = 4$ | 2 | 4 |
| $2^3 = 8$ | 3 | 8 |
| $2^4 = 16$ | 4 | 16 |
| $2^5 = 32$ | 5 | 32 |
| $2^6 = 64$ | 6 | 64 |
| $2^7 = 128$ | 7 | 128 |
| $2^8 = 256$ | 8 | 256 |
| $2^9 = 512$ | 9 | 512 |
| $2^{10} = 1024$ | 10 | 1024 |
| $2^{11} = 2048$ | 11 | 2048 |
| $2^{12} = 4096$ | 12 | 4096 |
| $2^{13} = 8192$ | 13 | 8192 |
| $2^{14} = 16384$ | 14 | 16384 |
| $2^{15} = 32768$ | 15 | 32768 |
| $2^{16} = 65536$ | 16 | 65536 |
| $2^{17} = 131072$ | 17 | 131072 |
| $2^{18} = 262144$ | 18 | 262144 |
| $2^{19} = 524288$ | 19 | 524288 |
| $2^{20} = 1048576$ | 20 | 1048576 |

multiplication problem, and located the corresponding power. This avoided the unnecessary step of writing the base 2 each time.

Practice problems. Use the logarithms in table 4 to perform the following multiplication:

1. 64 x 128
2. 1,024 x 256
3. 128 x 4,096
4. 512 x 2,048

Answers:

1. 8,192
2. 262,144
3. 524,288
4. 1,048,576

NATURAL AND COMMON LOGARITHMS

Many natural phenomena, such as rates of growth and decay, are most easily described in terms of logarithmic or exponential formulas. Furthermore, the geometric patterns in which certain seeds grow (for example, sunflower seeds) is a logarithmic spiral. These facts explain the name "natural logarithms." Natural logarithms use the base e, which is an irrational number approximately equal to 2.71828. This system is sometimes called the Napierian system of logarithms, in honor of John Napier, who is credited with the invention of logarithms.

To distinguish natural logarithms from other logarithmic systems, the abbreviation ln is sometimes used. When ln appears, the base is understood to be e and need not be shown. For example, either $\log_e 45$ or ln 45 signifies the natural logarithm of 45.

COMMON LOGARITHMS

As has been shown in preceding paragraphs, any number may be used as a base for a system of logarithms. The selection of a base is a matter of convenience. Briggs in 1617 found that base 10 possessed many advantages not obtainable in ordinary calculations with other bases. The selection of 10 as a base proved so satisfactory that today it is used almost exclusively for ordinary calculations. Logarithms with 10 as a base are therefore called COMMON LOGARITHMS.

When 10 is used as a base, it is not necessary to indicate it in writing logarithms. For example,

$$\log 100 = 2$$

is understood to mean the same as

$$\log_{10} 100 = 2$$

If the base is other than 10, it must be specified by the use of a subscript to the right and below the abbreviation "log." As noted in the foregoing discussion of natural logarithms, the use of the distinctive abbreviation ln eliminates the need for a subscript when the base is e.

It is relatively easy to convert common logarithms to natural logarithms or vice versa, if necessary. It should be noted further that each system has its peculiar advantages, but for most everyday work, the common system is more often used. A simple relation connects the two systems. If the common logarithm of a number can be found, multiplying by 2.3026 gives the natural logarithm of the number. For example,

$$\log 1.60 = 0.2041$$
$$\ln 1.60 = 2.3026 \times 0.2041$$
$$\doteq 0.4700$$

Thus the natural logarithm of 1.60 is 0.4700, correct to four significant digits.

Conversely, multiplying the natural logarithm by 0.4343 gives the common logarithm of a number. As might be expected, the conversion factor 0.4343 is the reciprocal of 2.3026. This is shown as follows:

$$\frac{1}{2.3026} = 0.4343$$

Positive Integral Logarithms

The derivation of positive whole logarithms is readily apparent. For example, we see in table 5 (B) that the logarithm of 10 is 1. The number 1 is simply the exponent of the base 10 which yields 10. This is shown in table 5 (A) opposite the logarithmic equation. Similarly,

$10^0 = 1$ . . . . . . . . . . . . log 1 = 0

$10^2 = 100$ . . . . . . . . . . log 100 = 2

$10^3 = 1{,}000$ . . . . . . . log 1,000 = 3

$10^4 = 10{,}000$ . . . . . log 10,000 = 4

Table 5.—Exponential and corresponding logarithmic notations using base 10.

| A | | | | B | | |
|---|---|---|---|---|---|---|
| $10^{-4}$ | $= \frac{1}{10^4}$ | = | 0.0001 | log | 0.0001 | = -4 |
| $10^{-3}$ | $= \frac{1}{10^3}$ | = | 0.001 | log | 0.001 | = -3 |
| $10^{-2}$ | $= \frac{1}{10^2}$ | = | 0.01 | log | 0.01 | = -2 |
| $10^{-1}$ | $= \frac{1}{10}$ | = | 0.1 | log | 0.1 | = -1 |
| $10^{-1/2}$ | $= \frac{1}{\sqrt{10}} \doteq \frac{\sqrt{10}}{10}$ | = | 0.31623 | log | 0.31623 | = -0.5 |
| | | | | | | = 0.5 -1 |
| $10^0$ | | = | 1 | log | 1 | = 0 |
| $10^{1/2}$ | $= \sqrt{10}$ | = | 3.1623 | log | 3.1623 | = 0.5 |
| $10^1$ | | = | 10 | log | 10 | = 1 |
| $10^{3/2}$ | $= 10\sqrt{10}$ | = | 31.623 | log | 31.623 | = 1.5 |
| $10^2$ | | = | 100 | log | 100 | = 2 |
| $10^{5/2}$ | $= 10^2(\sqrt{10})$ | = | 316.23 | log | 316.23 | = 2.5 |
| $10^3$ | | = | 1,000 | log | 1,000 | = 3 |
| $10^{7/2}$ | $= 10^3(\sqrt{10})$ | = | 3162.3 | log | 3162.3 | = 3.5 |
| $10^4$ | | = | 10,000 | log | 10,000 | = 4 |

### Positive Fractional Logarithms

Referring to table 5, notice that the logarithm of 1 is 0 and the logarithm of 10 is 1. Therefore, the logarithm of a number between 1 and 10 is between 0 and 1. An easy way to verify this is to consider some numbers between 1 and 10 which are powers of 10; the exponent in each case will then be the logarithm we seek. Of course, the only powers of 10 which produce numbers between 1 and 10 are fractional powers.

EXAMPLE: $10^{1/2} = 3.1623$ (approximately)

$10^{0.5} = 3.1623$

Therefore, $\log 3.1623 = 0.5$

Other examples are shown in the table for $10^{3/2}$, $10^{5/2}$, and $10^{7/2}$. Notice that the number that represents $10^{3/2}$, 31.623, logically enough lies between the numbers representing $10^1$ and $10^2$—that is, between 10 and 100. Notice also that $10^{5/2}$ appears between $10^2$ and $10^3$, and $10^{7/2}$ lies between $10^3$ and $10^4$.

### Negative Logarithms

Table 5 shows that negative powers of 10 may be fitted into the system of logarithms. We recall that $10^{-1}$ means $\frac{1}{10}$, or the decimal fraction 0.1. What is the logarithm of 0.1?

SOLUTION: $10^{-1} = 0.1$; $\log 0.1 = -1$

Likewise $10^{-2} = 0.01$; $\log 0.01 = -2$

### Negative Fractional Logarithms

Notice in table 5 that negative fractional exponents present no new problem in logarithmic notation. For example, $10^{-1/2}$ means $\frac{1}{\sqrt{10}}$

$$\frac{1}{\sqrt{10}} = \frac{\sqrt{10}}{10} = 0.31623$$

What is the logarithm of 0.31623?

SOLUTION:

$$10^{-1/2} = 0.31623; \log 0.31623 = -\frac{1}{2}$$

$$= -0.5$$

Table 5 shows logarithms for numbers ranging from 0.0001 to 10,000. Notice that there are only 8 integral logarithms in the entire range. Excluding zero logarithms, the logarithms for all other numbers in the range are fractional or contain a fractional part. By the year 1628, logarithms for all integers from 1 to 100,000 had been computed. Practically all of these logarithms contain a fractional part. It should be remembered that finding the logarithm of a number is nothing more than expressing the number as a power of 10. Table 6 shows the numbers 1 through 10 expressed as powers of 10. Most of the exponents which comprise logarithms are found by methods beyond the scope of this text. However, it is not necessary to know the process used to obtain logarithms in order to make use of them.

Table 6.—The numbers 1 through 10 expressed as powers of 10.

| | |
|---|---|
| $1 = 10^0$ | $6 = 10^{0.77815}$ |
| $2 = 10^{0.30103}$ | $7 = 10^{0.84510}$ |
| $3 = 10^{0.47712}$ | $8 = 10^{0.90309}$ |
| $4 = 10^{0.60206}$ | $9 = 10^{0.95424}$ |
| $5 = 10^{0.69897}$ | $10 = 10^1$ |

## COMPONENTS OF LOGARITHMS

The fractional part of a logarithm is usually written as a decimal. The whole number part of a logarithm and the decimal part have been given separate names because each plays a special part in relation to the number which the logarithm represents. The whole number part of a logarithm is called the CHARACTERISTIC. This part of the logarithm shows the position of the decimal point in the associated number. The decimal part of a logarithm is called the MANTISSA.

For a particular sequence of digits making up a number, the mantissa of a common logarithm is always the same regardless of the position of the decimal point in that number. For example, $\log 5270 = 3.72181$; the mantissa is 0.72181 and the characteristic is 3.

### CHARACTERISTIC

The characteristic of a common logarithm shows the position of the decimal point in the associated number. The characteristic for a given number may be determined by inspection. It will be remembered that a common logarithm is simply an exponent of the base 10.

When we write log 360 = 2.55630, we understand this to mean $10^{2.55630} = 360$. We know that the number is 360 and not 36 or 3,600 because the characteristic is 2. We know $10^1$ is 10, $10^2$ is 100, and $10^3$ is 1,000. Therefore, the number whose value is $10^{2.55630}$ must lie between 100 and 1,000 and of course any number in that range has 3 digits.

Suppose the characteristic had been 1: where would the decimal point in the number be placed? Since $10^1$ is 10 and $10^2$ is 100, any number whose logarithm is between 1 and 2 must lie between 10 and 100 and will have 2 digits. Notice how the position of the decimal point changes with the value of the characteristic in the following examples:

log 36,000 = 4.55630

log 3,600 = 3.55630

log 360 = 2.55630

log 36 = 1.55630

log 3.6 = 0.55630

Note that it is only the characteristic that changes when the decimal point is moved. An advantage of using the base 10 is thus revealed. If the characteristic is known, the decimal point may easily be placed. If the number is known, the characteristic may be determined by inspection: that is, by observing the location of the decimal point.

Although an understanding of the relation of the characteristic to the powers of 10 is necessary for thorough comprehension of logarithms, the characteristic may be determined mechanically by application of the following rules:

1. For a number greater than 1, the characteristic is positive and is one less than the number of digits to the left of the decimal point in the number.

2. For a positive number less than 1, the characteristic is negative and has an absolute value one more than the number of zeros between the decimal point and the first nonzero digit of the number.

**Table 7 contains** examples of each type of characteristic.

Practice problems. In problems 1 through 4, write the characteristic of the logarithm for each number. In 5 through 8, place the decimal

Table 7.—Positive and negative characteristics.

| Number | Power of 10 | Digits in number to the left of decimal point | Characteristic |
|---|---|---|---|
| | Between: | | |
| 134 | $10^2$ and $10^3$ | 3 | 2 |
| 13.4 | $10^1$ and $10^2$ | 2 | 1 |
| 1.34 | $10^0$ and $10^1$ | 1 | 0 |
| | | Zeros between decimal point and first nonzero digit | |
| 0.134 | $10^{-1}$ and $10^0$ | 0 | -1 |
| 0.0134 | $10^{-2}$ and $10^{-1}$ | 1 | -2 |
| 0.00134 | $10^{-3}$ and $10^{-2}$ | 2 | -3 |

point in each number as indicated by the characteristic (c) given for each.

1. 4,321 2. 1.23 3. 0.05 4. 12

5. 123: c = 4 6. 8,210; c = 0

7. 8: c = -1 8. 321: c = -2

Answers:

1. 3 2. 0 3. -2 4. 1

5. 12,300 6. 8.210 7. 0.8 8. 0.0321

### Negative Characteristics

When a characteristic is negative, such as -2, we do not carry out the subtraction since this would involve a negative mantissa. There are several ways of indicating a negative characteristic. Mantissas as presented in appendix I are always positive and the sign of the characteristic is indicated separately. For example, where log 0.023 = $\bar{2}.36173$, the bar over the 2 indicates that only the characteristic is negative—that is, the logarithm is -2 + 0.36173.

Another way to show the negative characteristic is to place it after the mantissa. In this case we write 0.36173-2.

A third method, which is used where possible throughout this section, is to add a certain quantity to the characteristic and to subtract the same quantity to the right of the mantissa. In the case of the example, we may write:

$$\begin{array}{r} \bar{2}.36173 \\ \underline{10 \quad -10} \\ 8.36173-10 \end{array}$$

In this way the value of the logarithm remains the same, but we now have a positive characteristic as well as a positive mantissa.

### MANTISSA

The mantissa is the decimal part of a logarithm. Tables of logarithms usually contain only mantissas since the characteristic can be readily determined as explained previously. Table 8 shows the characteristic, mantissa, and logarithm for several positions of the decimal point using the sequence of digits 4, 5, 6. It will be noted that the mantissa remains the same for that particular sequence of digits, regardless of the position of the decimal point.

Table 8.—Effect of changes in the location of the decimal point.

| Number | Characteristic | Mantissa | Logarithm |
|---|---|---|---|
| 45,600 | 4 | 0.6590 | 4.6590 |
| 4,560 | 3 | 0.6590 | 3.6590 |
| 456 | 2 | 0.6590 | 2.6590 |
| 45.6 | 1 | 0.6590 | 1.6590 |
| 4.56 | 0 | 0.6590 | 0.6590 |
| 0.456 | -1 | 0.6590 | 0.6590-1 |
| 0.0456 | -2 | 0.6590 | 0.6590-2 |
| 0.00456 | -3 | 0.6590 | 0.6590-3 |

Appendix I of this pamphlet is a table which includes the logarithms of numbers from 1 to 134. For our present purpose in using this table, we are concerned only with the first and sixth columns.

The first column contains the number and the sixth column contains its logarithm. For example, if it is desired to find the logarithm of 45, we would find the number 45 in the first column, look horizontally across the page to column 6 and read the logarithm, 1.65321. A glance down the logarithm column will reveal that the logarithms increase in value as the numbers increase in value.

It must be noted in this particular table that both the mantissa and the characteristic are given for the number in the first column. This is simply an additional aid since the characteristic can easily be determined by inspection.

Suppose that we wish to use the table of Appendix I to find the logarithm of a number not shown in the "number" column. By recalling that the mantissa does not change when the decimal point moves, we may be able to determine the desired logarithm. For example, the number 450 does not appear in the number column of the table. However, the number 45 has the same mantissa as 450; the only difference between the two logs is in their characteristics. Thus the logarithm of 450 is 2.65321.

Practice problems. Find the logarithms of the following numbers:

1. 64 2. 98 3. 6400 4. 9.8

Answers:

1. 1.80618 2. 1.99123

3. 3.80618 4. 0.99123

## THE SLIDE RULE

In 1620, not long after the invention of logarithms, Edmond Gunter showed how logarithmic calculations could be carried out mechanically. This is done by laying off lengths on a rule, representing the logarithms of numbers, and by combining these lengths in various ways. The idea was developed, and with the contributions of Mannheim in 1851 the slide rule came into being as we know it today.

The slide rule is a mechanical device by which we can carry out any arithmetic calculation with the exception of addition and subtraction. The most common operations with the slide rule are multiplication, division, finding the square or cube of a number, and finding the square root or cube root of a number. Also trigonometric operations are frequently performed. The advantage of the slide rule is that it can be used with relative ease to solve complicated problems. One limitation is that it will give results with a maximum of only three accurate significant digits. This is sufficient in most calculations, however, since most physical constants are only correct to two or three significant digits. When greater accuracy is required, other methods must be used.

A simplified diagram of a slide rule is pictured in figure 3. The sliding, central part of the rule is called the SLIDE. The movable glass or plastic runner with a hairline imprinted on it is called the INDICATOR. There is a C scale printed on the slide, and a D scale exactly the same as the C scale printed on the BODY or STOCK of the slide rule. The mark that is associated with the primary number 1 on any slide rule scale is called the INDEX. There is

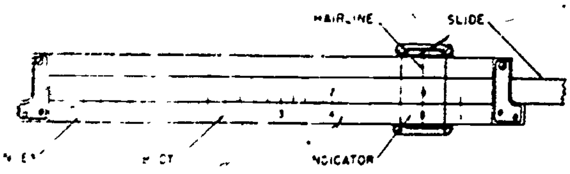


Figure 3.—Simplified diagram of a slide rule.

an index at the extreme left and at the extreme right on both the C and D scales. There are other scales, each having a particular use. Some of these will be mentioned later.

## SLIDE RULE THEORY

We have mentioned that the slide rule is based on logarithms. Recall that, to multiply two numbers, we simply add their logarithms. Previously we found these logarithms in tables, but if the logarithms are laid off on scales such as the C and D scale of the slide rule, we can add the lengths, which represent these logarithms. To make such a scale we could mark off mantissas ranging from 0 to 1 on a rule as in figure 4. We then find in the tables the logarithms for numbers ranging from 1 to 10 and write the number opposite its corresponding logarithm on the scale.

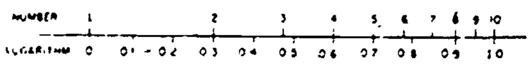


Figure 4.—Logarithms and corresponding numbers on a scale.

Table 9 lists the numbers 1 through 10 and their corresponding logarithms to three places. These numbers are written opposite their logarithms on the scale shown in figure 4. If we have two such scales, exactly alike, arranged so that one of them is free to slide along the other, we can perform the operation of multiplication, for example, by ADDING LENGTHS; that is, by adding logarithms. For example, if we wish to multiply 2 x 3, we find the logarithm of 2 on the stationary scale and move the sliding scale so that its index is over that mark. We then add the logarithm of 3 by finding that logarithm on the sliding scale and by reading below it, on the stationary scale, the logarithm that is the sum of the two.

Since we are not interested in the logarithms themselves, but rather in the numbers they represent, it is possible to remove the logarithmic notation on the scale in figure 4, and leave only the logarithmically spaced number scale. The C and D scales of the ordinary slide rule are made up in this manner. Figure 5 shows the multiplication of 2 x 3. Although the logarithm scales have been removed, the numbers 2 and 3 in reality signify the logarithms of

Table 9.—Numbers and their corresponding logarithms.

| Number | Logarithm | Number | Logarithm |
|---|---|---|---|
| 1 | 0.000 | 6 | 0.778 |
| 2 | 0.301 | 7 | 0.845 |
| 3 | 0.477 | 8 | 0.903 |
| 4 | 0.602 | 9 | 0.954 |
| 5 | 0.699 | 10 | 1.000 |

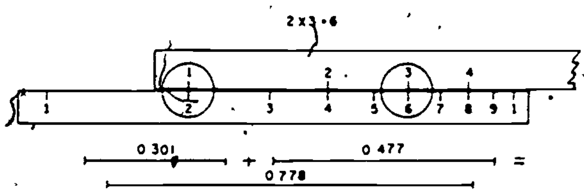


Figure 5.—Multiplication by use of the slide rule.

2 and 3, namely, 0.301 and 0.477; the product 6 on the scale really signifies the logarithm of 6, that is, 0.778. Thus, although logarithms are the underlying principle, we are able to work with the numbers directly.

It should be noted that the scale is made up from mantissas only. The characteristic must be determined separately as in the case where tables are used. Since mantissas identify only the digit sequence, the digit 3 on the slide rule represents not only 3 but 30, 300, 0.003, 0.3, and so forth. Thus, the divisions may represent the number multiplied or divided by any power of 10. This is true also for numbers that fall between the divisions. The digit sequence, 1001, could represent 100.1, 1.001, 0.01001, and so forth. The following example shows the use of the same set of mantissas which appear in the foregoing example, but with a different characteristic and, therefore, a different answer:

EXAMPLE: Use logs (positions on the slide rule) to multiply 20 times 30.

SOLUTION:

log 20 = 1.301 (2 on the slide rule)

log 30 = 1.477 (3 on the slide rule)

log of answer = 2.778 (6 on the slide rule)

Since the 2 in the log of the answer is merely the indicator of the position of the decimal point in the answer itself, we do not expect to find it on the slide rule scale. As in the foregoing example, we find the digit 6 opposite the multiplier 3. This time, however, the 6 represents 600, because the characteristic of the log represented by 6 in this problem is 2.

## READING THE SCALES

Reading a slide rule is no more complicated than reading a yard stick or ruler, if the differences in its markings are understood.

Between the two indices of the C or D scales (the large digit 1 at the extreme left and right of the scales) are divisions numbered 2, 3, 4, 5, 6, 7, 8, and 9. Each length between two consecutive divisions is divided into 10 sections and each section is divided into spaces. (See figure 6.)

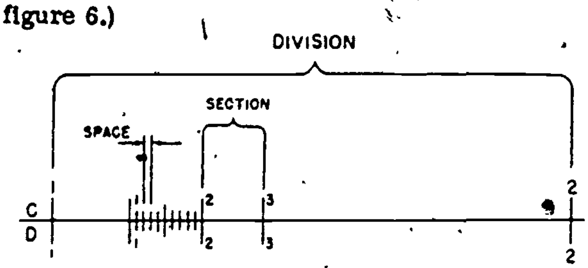


Figure 6.—Division, section, and space of a slide rule scale.

Notice that the division between 1 and 2 occupies about one-third of the length of the rule. This is sufficient space in which to write a number for each of the section marks. The sections in the remaining divisions are not numbered, because the space is more limited. Notice also that in the division between 1 and 2, the sections are each divided into 10 spaces. The sections of the divisions from 2 to 4 are subdivided into only 5 spaces, and those from 4 to the right index are subdivided into only 2 spaces. These subdivisions are so arranged because of the limits of space.

Only the sequence of significant digits is read on the slide rule. The position of the decimal point is determined separately. For example, if the hairline of the indicator is in the left-hand position shown in figure 7, the significant digits are read as follows:

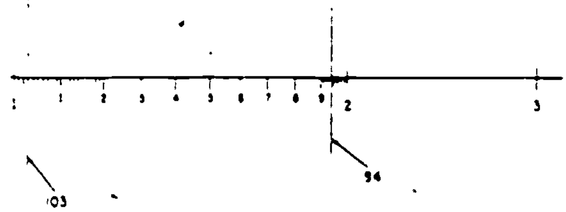


Figure 7.—Readings in the first division of a slide rule.

1. Any time the hairline falls in the first division, the first significant digit is 1.
2. Since the hairline lies between the index and the first section mark, we know the number lies between 1.0 and 1.1, or 10 and 11, or 100 and 110, etc. The second significant digit is 0.
3. We next find how far from the index the hairline is located. It lies on the marking for the third space.
4. The three significant digits are 103.

In the second example shown in figure 7, the hairline is located in the first division, the ninth section, and on the fourth space mark of that section. Therefore, the significant digits are 194.

Thus, we see that any number falling in the first division of the slide rule will always have 1 as its first significant digit. It can have any number from 0 through 9 as its second digit, and any number from 0 through 9 as its third digit. Sometimes a fourth digit can be roughly approximated in this first division, but the number is really accurate to only three significant digits.

In the second and third divisions, each section is divided into only 5 spaces. (See fig. 8). Thus, each space is equal to 0.2 of the section. Suppose, for example, that the hairline lies on the third space mark after the large 2 indicating the second division. The first significant digit is 2. Since the hairline lies between 2 and the first section mark, the second digit is 0. The hairline lies on the third space mark or 0.6 of the way between the division mark and the first section mark, so the third digit is 6. Thus, the significant digits are 206. Notice that if the hairline lies on a space mark the third digit can be written accurately; otherwise it must be approximated.

From the fourth division to the right index, each section is divided into only two spaces. Thus, if the hairline is in the fourth division and lies on the space mark between the sixth and seventh sections, we would read 465. If the hairline did not fall on a space mark, the third digit would have to be approximated.

## OPERATIONS WITH THE SLIDE RULE

There are two parts in solving problems with a slide rule. In the first part the slide rule is used to find the digit sequence of the final result. The second part is concerned with the placing of the decimal point in the result. Let us consider first the digit sequence in multiplication and division.

### Multiplication

Multiplication is performed on the C and D scales of the slide rule. The following procedure is used:

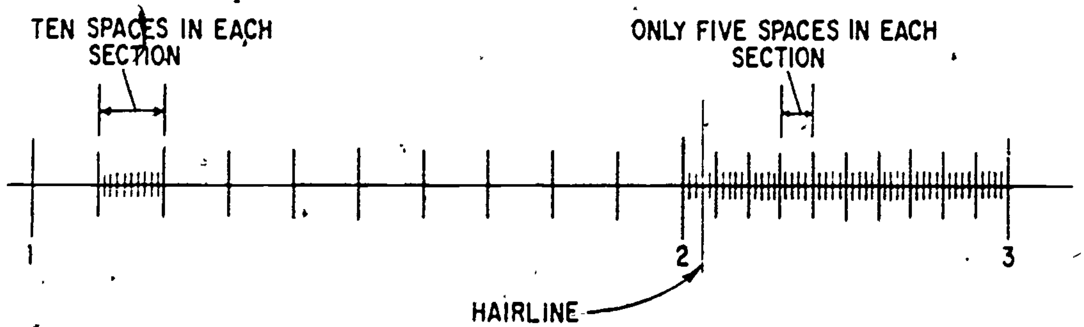


Figure 8.—Reading in the second division of a slide rule.

1. Locate one of the factors to be multiplied on the D scale, disregarding the decimal point.

2. Place the index of the C scale opposite that number.

3. Locate the other factor on the C scale and move the hairline of the indicator to cover this factor.

4. The product is on the D scale under the hairline.

Sometimes in multiplying numbers, such as 25 x 6, the number on the C scale extends to the right of the stock and the product cannot be read. In such a case, we simply shift indices. Instead of the left-hand index of the C scale, the right-hand index is placed opposite the factor on the D scale. The rest of the problem remains the same. By shifting indices, we are simply multiplying or dividing by 10, but this plays no part in reading the significant digits. Shifting indices affects the characteristic only.

EXAMPLE: 252 x 3 = 756

1. Place the left index of the C scale over 252.

2. Locate 3 on the C scale and set the hairline of the indicator over it.

3. Under the hairline on the D scale read the product, 756.

EXAMPLE: 4 x 64 = 256

1. Place the right index of the C scale over 4.

2. Locate 64 on the C scale and set the hairline of the indicator over it.

3. Under the hairline on the D scale read the product, 256.

Practice problems. Determine the following products by slide rule to three significant digits:

| | |
|---|---|
| 1. 2.8 x 16 | 3. 6 x 85 |
| 2. 7 x 1.3 | 4. 2.56 x 3.5 |

Answers:

| | |
|---|---|
| 1. 44.8 | 3. 510 |
| 2. 9.10 | 4. 8.96 |

Division

Division being the inverse of multiplication, the process of multiplication is reversed to perform division on a slide rule. We subtract the length representing the logarithm of the divisor from the length representing the logarithm of the dividend to get the logarithm of the quotient.

The procedure is as follows:

1. Locate the dividend on the D scale and place the hairline of the indicator over it.

2. Move the slide until the divisor (on the C scale) lies under the hairline.

3. Read the quotient on the D scale opposite the C scale index.

If the divisor is greater numerically than the dividend, the slide will extend to the left. If the divisor is less, the slide will extend to the right. In either case, the quotient is the number on the D scale that lies opposite the C scale index, falling within the limits of the D scale.

EXAMPLE: 6 ÷ 3 = 2

1. Locate 6 on the D scale and place the hairline of the indicator over it.

2. Move the slide until 3 on the C scale is under the hairline.

3. Opposite the left C scale index, read the quotient, 2, on the D scale.

EXAMPLE: 378 ÷ 63 = 6

1. Locate 378 on the D scale and move the hairline of the indicator over it.

2. Move the slide to the left until 63 on the C scale is under the hairline.

3. Opposite the right-hand index of the C scale, read the quotient, 6, on the D scale.

Practice problems. Determine the following quotients by slide rule.

| | |
|---|---|
| 1. 126 ÷ 3 | 3. 142 ÷ 71 |
| 2. 960 ÷ 15 | 4. 459 ÷ 17 |

Answers:

| | |
|---|---|
| 1. 42 | 3. 2 |
| 2. 64 | 4. 27 |

## PLACING THE DECIMAL POINT

Various methods have been advanced regarding the placement of the decimal point in numbers derived from slide rule computations. Probably the most universal and most easily remembered method is that of approximation.

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The method of approximation means simply the rounding off of numbers and the mechanical shifting of decimal points in the numbers of the problem so that the approximate size of the solution and the exact position of the decimal point will be seen from inspection. The slide rule may then be used to derive the correct sequence of significant digits. The method may best be demonstrated by a few examples. Remember, shifting the decimal point in a number one place to the left is the same as dividing by 10. Shifting it one place to the right is the same as multiplying by 10. Every shift must be compensated for in order for the solution to be correct.

EXAMPLE: 0.573 x 1.45

SOLUTION: No shifting of decimals is necessary here. We see that approximately 0.6 is to be multiplied by approximately 1-1/2. Immediately, we see that the solution is in the neighborhood of 0.9. By slide rule we find that the significant digit sequence of the product is 832. From our approximation we know that the decimal point is to the immediate left of the first significant digit, 8. Thus,

$0.573 \times 1.45 = 0.832$

EXAMPLE: 239 x 52.3

SOLUTION: For ease in multiplying, we shift the decimal point in 52.3 one place to the left, making it 5.23. To compensate, the decimal point is shifted to the right one place in the other factor. The new position of the decimal point is indicated by the presence of the caret symbol.

$$239.0_{\wedge} \times 5_{\wedge}2.3$$

Our problem is approximately the same as

$$2,400 \times 5 = 12,000$$

By slide rule the digit sequence is 125. Thus,

$$239 \times 52.3 = 12,500$$

EXAMPLE: 0.000134 x 0.092

SOLUTION:

Shifting decimal points, we have

$$0_{\wedge}00.000134 \times 0.09_{\wedge}2$$

Approximation: $9 \times 0.0000013 = 0.0000117.$ By slide rule the digit sequence is 123. From approximation the decimal point is located as follows:

0.0000123

Thus,

$$0.000134 \times 0.092 = 0.0000123$$

EXAMPLE: $\dfrac{53.1}{42.4}$

SOLUTION: The decimal points are shifted so that the divisor becomes a number between 1 and 10. The method employed is cancellation.

Shifting decimal points, we have

$$\frac{5_{\wedge}3.1}{4_{\wedge}2.4}$$

Approximation: $\frac{5}{4} = 1.2$

Digit sequence by slide rule:

1255

Placing the decimal point from the approximation:

1.255

Thus,

$$\frac{53.1}{42.4} = 1.255$$

EXAMPLE: $\dfrac{0.00645}{0.0935}$

SOLUTION:

Shifting decimal points, we have

$$\frac{0.00_{\wedge}645}{0.09_{\wedge}35}$$

Approximation:

$$\frac{0.6}{9} = 0.07$$

Digit sequence by slide rule: 690

Placing the decimal point from the approximation:

0.0690

Thus,

$$\frac{0.00645}{0.0935} = 0.0690$$

Practice problems. Solve the following problems with the slide rule and use the method of approximation to determine the position of the decimal point:

1. 0.00453 x 0.1645
2. 531 ÷ 1.255
3. 0.0362 x 1.21
4. 67 ÷ 316

Answers:

1. 0.000745
2. 42.4
3. 0.0438
4. 0.212

MULTIPLICATION AND DIVISION COMBINED

In problems such as

$$\frac{0.644 \times 330}{161 \times 12}$$

it is generally best to determine the position of the decimal point by means of the method of approximation and to determine the significant digit sequence from the slide rule. Such problems are usually solved by dividing and multiplying alternately throughout the problem. That is, we divide 0.644 by 161, multiply the quotient by 330, and divide that product by 12.

Shifting decimal points, we have

$$\frac{0_\wedge 0.644 \times 3_\wedge 30}{1_\wedge 61 \times 1_\wedge 2}$$

Since there is a combined shift of three places to the left in the divisor, there must also be a combined shift of three places to the left in the dividend.

Approximation: $\frac{0.06 \times \cancel{3}^{2}}{\cancel{1.5}} = 0.06 \times 2 - 0.12$

The step-by-step process of determining the significant digit sequence of this problem is as follows:

1. Place the hairline over 644 on the D scale.
2. Draw the slide so that 161 of the C scale lies under the hairline opposite 644.
3. Opposite the C scale index (on the D scale) is the quotient of 644 ÷ 161. This is to be multiplied by 330, but 330 projects beyond the rule so the C scale indices must be shifted.
4. After shifting the indices, find 330 on the C scale and place the hairline over it. Opposite 330 under the hairline on the D scale is the product of $\frac{644}{161} \times 330$.
5. Next, move the C scale until 12 is under the hairline. Opposite the C scale index (on the D scale) is the final quotient. The digit sequence is 110.

The decimal point is then placed according to our approximation: 0.11. Thus,

$$\frac{0.644 \times 330}{161 \times 12} = 0.11$$

Practice problems. Solve the following problems, using a slide rule:

1. $\frac{22 \times 78.5 \times 157}{17 \times 18.3 \times 85}$
2. $\frac{432 \times 9{,}600}{25{,}600 \times 198}$
3. $\frac{2.77 \times 0.064}{0.17 \times 1.97}$

Answers:

1. 10.2
2. 0.817
3. 0.529

SQUARES

Squares of numbers are found by reference to the A scale. The numbers on the A scale are the squares of those on the D Scale. The A scale is really a double scale, each division being one-half as large as the corresponding division on the D scale. The use of a double scale for squaring is based upon the fact that the logarithm of the square of a number is twice as large as the logarithm of the number itself. In other words,

$$\log N^2 = 2 \log N$$

This is reasonable, since

$$\log N^2 = \log (N \times N)$$
$$= \log N + \log N$$

For a numerical example, suppose that we seek to square 2 by means of logarithms.

$$\log 2 = 0.301$$
$$\log 2^2 = 2 \log 2$$
$$= 2 \times 0.301$$
$$= 0.602$$

Since each part of the A scale is half as large as the corresponding part of the D scale, the logarithm 0.602 on the A scale will be the same length as the logarithm 0.301 on the D scale. That is, these logarithms will be opposite on the A and D scales. On the A scale as on the D scale, the numbers are written rather than their logarithms. Select several numbers on the D scale, such as 2, 4, 8, 11, and read their squares on the A scale, namely, 4, 16, 64, 121.

Notice also that the same relation exists for the B and C scales as for the A and D scales. Of interest, also, is the fact that since the A and B scales are made up as are the C and D scales, they too could be used for multiplying or dividing.

Placing the Decimal Point

Usually the decimal may be placed by the method of approximation. However, close observation will reveal certain facts that eliminate the need for approximations in squaring numbers. Two rules suffice for squaring whole or mixed numbers, as follow:

1. When the square of a number is read on the left half of the A scale, that number will contain twice the number of digits to the left of the decimal point in the original number, less 1.

2. When the square of a number is read on the right half of the A scale, that number will contain twice the number of digits to the left of the decimal point in the original number.

EXAMPLE: Square 2.5.

SOLUTION: Place the hairline over 25 on the D scale. Read the digit sequence, 625, under the hairline in the left half of the A scale.

By rule 1: (2 x number of digits) - 1 = 2(1)-1=1. There is one digit to the left of the decimal point. Thus,

$$(2.5)^2 = 6.25$$

EXAMPLE: Square 6,340.

SOLUTION:

Digit sequence, right half A scale: 402.

By rule 2: 2 x number of digits = 2 x 4 = 8 (digits in answer). Thus,

$$(6,340)^2 = 40,200,000$$

Positive Numbers Less Than One

If positive numbers less than one are to be squared, a slightly different version of the preceding rules must be employed. Count the zeros between the decimal point and the first nonzero digit. Consider this count negative. Then the number of zeros between the decimal point and the first significant digit of the squared number may be found as follows:

1. Left half A scale: Multiply the zeros counted by 2 and subtract 1.

2. Right half A scale: Multiply the zeros counted by 2.

EXAMPLE: Square 0.0045

SOLUTION:

Digit sequence, right half A scale: 2025.

By rule 2: 2(-2) = -4. (Thus, 4 zeros between the decimal point and the first digit.)

$$(0.0045)^2 = 0.00002025$$

EXAMPLE: Square 0.0215

SOLUTION:

Digit sequence, left half A scale: 462.

By rule 1: 2(-1) -1 = -3

$$(0.0215)^2 = 0.000462$$

SQUARE ROOTS

Taking the square root of a number with the slide rule is the inverse process of squaring a number. We find the number on the A scale, set the hairline of the indicator over it, and read the square root on the D scale under the hairline.

Positioning Numbers on the A Scale

Since there are two parts of the A scale exactly alike and the digit sequence could be found on either part, a question arises as to which section to use. Generally, we think of the left half of the rule as being numbered from 1 to 10 and the right half as being numbered from 10 to 100. The numbering continues—left half 100 to 1,000, right half 1,000 to 10,000, and so forth.

A simple process provides a check of the location of the number from which the root is to be taken. For whole or mixed numbers, begin at the decimal point of the number and mark off the digits to the left (including end zeros) in groups of two. This is illustrated in the following two examples:

1. $\sqrt{40,300.21}$

   $\sqrt{4'03'00.21}$

2. $\sqrt{2,034.1}$

   $\sqrt{20'34.1}$

Look at the left-hand group. If it is a 1-digit number, use the left half of the A scale. If it is a 2-digit number, use the right half of the A scale. The number in example 1 is thus located in the left half of the A scale and the number in example 2 is located in the right half.

## Numbers Less Than One

For positive numbers less than one, begin at the decimal point and mark off groups of two to the right. This is illustrated as follows:

1. $\sqrt{0.000245}$

   $\sqrt{0.00'02'45}$

2. $\sqrt{0.00402}$

   $\sqrt{0.00'40'2}$

Looking from left to right, locate the first group that contains a digit other than zero. If the first figure in this group is zero, locate the number in the left half of the A scale. If the first figure is other than zero, locate the number in the right half of the A scale. Thus,

$\sqrt{0.00'02'45}$ is located left

and

$\sqrt{0.00'40'2}$ is located right

## Powers of 10

When the square root of 10, 1,000, 100,000, and so forth, is desired, the center index is used. That is, when the number of digits in a power of 10 is even, use the center index.

The slide rule uses only the first three significant digits of a number. Thus, if the rule is used, $\sqrt{23451.6}$ must be considered as $\sqrt{23400.0}$. Likewise, 1.43567 would be considered 1.43000, and so forth. For greater accuracy, other methods must be used.

Practice problems. State which half of the A scale should be used for each of the following:

| | |
|---|---|
| 1. $\sqrt{432}$ | 5. $\sqrt{4,320}$ |
| 2. $\sqrt{0.014}$ | 6. $\sqrt{0.00301}$ |
| 3. $\sqrt{241.67}$ | 7. $\sqrt{0.0640}$ |
| 4. $\sqrt{0.00045}$ | 8. $\sqrt{9.41}$ |

Answers:

| | |
|---|---|
| 1. Left | 5. Right |
| 2. Left | 6. Right |
| 3. Left | 7. Left |
| 4. Left | 8. Left |

## Placing the Decimal Point

To place the decimal point in the square root of a number, mark off the original number in groups of two as explained previously.

For whole or mixed numbers, the number of groups marked off is the number of digits including end zeros to the left of the decimal point in the root. The following problems illustrate this:

| | | |
|---|---|---|
| 1. $\sqrt{23,415}$ | | |
| | $\sqrt{2'34'15}$ | Three digits to left of decimal point in square root |
| 2. $\sqrt{421,562.4}$ | | |
| | $\sqrt{42'15'62.4}$ | Three digits to left of decimal point in square root |
| 3. $\sqrt{231.321}$ | | |
| | $\sqrt{2'31.321}$ | Two digits to left of decimal point in square root |



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For positive numbers less than one, there will be one zero in the square root between the decimal point and the first significant digit for every pair of zeros counted between the decimal point and the first significant digit of the original number. This is illustrated as follows:

1. $\sqrt{0.0004}$

| | |
|---|---|
| $\sqrt{0.00'04}$ | One zero before first digit in square root |

2. $\sqrt{0.00008}$

| | |
|---|---|
| $\sqrt{0.00'00'8}$ | Two zeros before first digit in square root |

3. $\sqrt{0.08'}$ No zeros before first digit in square root

EXAMPLE: $\sqrt{4,521}$

$\sqrt{45'21}$

(Two digits in left-hand group)

Place the hairline over 452 on the right half of the A scale. Read the digit sequence of the root, 672, on the D scale under the hairline. Since there are two groups in the original number, there are two digits to the left of the decimal point in the root. Thus,

$$\sqrt{4,521} = 67.2$$

EXAMPLE: $\sqrt{0.000741}$

$\sqrt{0.00'07'41}$

(First figure is zero in this group)

Place the hairline over 741 on the left half of the A scale. Read the digit sequence of the root, 272, under the hairline on the D scale. Since there is one pair of zeros to the left of the group containing the first digit, there is one zero between the decimal point and the first significant digit of the root. Thus,

$$\sqrt{0.000741} = 0.0272$$

Practice problems. Evaluate each of the following by means of a slide rule:

1. $(17.75)^2$
2. $(0.65)^2$
3. $\sqrt{9.42}$
4. $\sqrt{0.074}$

Answers:

1. 315
2. 0.422
3. 3.07
4. 0.272

## CUBES AND CUBE ROOTS

Cubes and cube roots are read on the D and K scales of the slide rule. On the K scale are compressed three complete logarithmic scales in the same space as that of the D scale. Thus, any logarithm on the K scale is three times the logarithm opposite it on the D scale. To cube a number by logarithms, we multiply its logarithm by three. Therefore, the logarithms of cubed numbers will lie on the K scale opposite the numbers on the D scale.

As with the other slide rule scales mentioned, the numbers the logarithms represent, rather than the logarithmic notations, are printed on the rule. In the left-hand third of the K scale, the numbers range from 0 to 10; in the middle third they range from 10 to 100; and in the right-hand third, they range from 100 to 1,000.

To cube a number, find the number on the D scale, place the hairline over it, and read the digit sequence of the cubed number on the K scale under the hairline.

### Placing the Decimal Point

The decimal point of a cubed whole or mixed number may be easily placed by application of the following rules:

1. If the cubed number is located in the left third of the K scale, its number of digits to the left of the decimal point is 3 times the number of digits to the left of the decimal point in the original number, less 2.
2. If the cubed number is located in the middle third of the K scale, its number of digits is 3 times the number of digits of the original number, less 1.
3. If the cubed number is located in the right third of the K scale, its number of digits is 3 times the number of digits of the original number.

EXAMPLE: $(1.6)^3$

SOLUTION: Place the hairline over 16 on D scale. Read the digit sequence, 409, on the K scale under the hairline.

The number of digits to the left of the decimal point in the number 1.6 is 1, and the cubed number is in the left-hand third of the K scale.

$$3 \times (\text{No. of digits})-2 = (3 \times 1)-2$$
$$= 1$$

Therefore,

$$(1.6)^3 = 4.09$$

EXAMPLE: $(4.1)^3$

Digit sequence = 689.

SOLUTION: The number of digits to the left of the decimal point in the number 4.1 is 1, and the cubed number is in the middle third of the K scale.

$$3 \times (\text{No. of digits})-1 = (3 \times 1)-1$$
$$= 2$$

Therefore,

$$(4.1)^3 = 68.9$$

EXAMPLE: $(52)^3$

SOLUTION: Digit sequence = 141.

The number of digits to the left of the decimal point in the number 52 is 2, and the cubed number is in the right-hand third of the K scale.

$$3 \times \text{No. of digits} = 3 \times 2$$
$$= 6$$

Therefore,

$$(52)^3 = 141{,}000$$

Positive Numbers Less Than One

If positive numbers less than one are to be cubed, count the zeros between the decimal point and the first nonzero digit. Consider the count negative. Then the number of zeros between the decimal point and the first significant digit of the cubed number may be found as follows:

1. Left third of K scale: Multiply the zeros counted by 3 and subtract 2.
2. Middle third of K scale: Multiply the zeros counted by 3 and subtract 1.
3. Right third of K scale: Multiply the zeros counted by 3.

EXAMPLE: Cube 0.034

SOLUTION: Digit sequence = 393

Zero count of 0.034 = -1, and 393 is in the middle third of the K scale.

$$3 \times (\text{No. of zeros})-1 = (3 \times -1)-1 = -4$$

Therefore,

$$(0.034)^3 = 0.0000393$$

Practice problems. Cube the following numbers using the slide rule.

1. 21  2. 0.7  3. 0.0128  4. 404

Answers:

1. 9260  3. 0.0000021
2. 0.342  4. 66,000,000

Cube Roots

Taking the cube root of a number on the slide rule is the inverse process of cubing a number. To take the cube root of a number, find the number on the K scale, set the hairline over it, and read the cube root on the D scale under the hairline.

POSITIONING NUMBERS ON THE K SCALE.—Since a given number can be located in three positions on the K scale, the question arises as to which third of the K scale to use when you locate a number. Generally, the left index, the left middle index, the right middle index, and the right index are considered to be numbered as shown in figure 9.

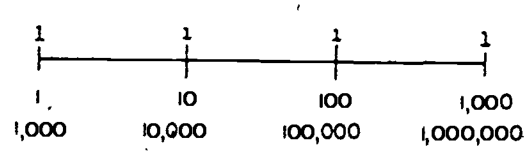


Figure 9.—Powers of 10 associated with K-scale indices.

A system similar to that used with square roots may be used to locate the position of a number on the K scale. Groups of three are used rather than groups of two. The grouping for cube root is illustrated as follows:

1. $\sqrt[3]{40,531.6}$
   $\sqrt[3]{40'531.6}$

2. $\sqrt[3]{4,561.43}$
   $\sqrt[3]{4'561.43}$

3. $\sqrt[3]{0.000043}$
   $\sqrt[3]{0.000'043}$

For whole or mixed numbers, the following rules apply:

1. If the left-hand group contains one digit, locate the number in the left third of the K scale.
2. If the left group contains two digits, locate the number in the middle third of the K scale.
3. If the left group contains three digits, locate the number in the right third of the K scale.

The following examples illustrate the foregoing rules:

1. $\sqrt[3]{4'561.43}$

   (One digit)– left third of K scale.

2. $\sqrt[3]{40'531.6}$

   (Two digits)– middle third of K scale.

3. $\sqrt[3]{453'361}$

   (Three digits)—right third of K scale.

For positive numbers less than one, look from left to right and find the first group that contains a digit other than zero.

1. If the first two figures in this group are zeros, locate the number in the left third of the K scale.
2. If only the first figure in this group is zero, locate the number in the middle third of the K scale.
3. If the first figure of the group is not zero, locate the number in the right third of the K scale.

The following examples illustrate these rules:

1. $\sqrt[3]{0.000'004'53}$

   (Two zeros)– left third of K scale.

2. $\sqrt[3]{0.000'050'43}$

   (One zero)– middle third of K scale.

3. $\sqrt[3]{0.000'000'430}$

   (No zero)– right third of K scale.

PLACING THE DECIMAL POINT.—To place the decimal point in the cube root of a number, we use the system of marking off in groups of three as shown above.

For whole or mixed numbers, there is one digit in the root to the left of the decimal point for every group marked in the original number. Thus,

$$\sqrt[3]{4'531.6}$$

(Two digits in root to left of decimal point.)

For positive numbers less than one, there will be one zero in the root between the decimal point and the first significant digit for every three zeros counted between the decimal point and the first significant digit of the original number. Thus,

$$\sqrt[3]{0.000'000'004}$$

(Two zeros between decimal point and first significant digit of root.)

EXAMPLE: $\sqrt[3]{216000.4}$
$\sqrt[3]{216'000.4}$

(Three digits in left group)

Place the hairline over 216 in the right third of the K scale. Read the digit sequence, 6, under the hairline on the D scale. Since there are two groups in the original number, there are two digits to the left of the decimal point in the root. Thus,

$$\sqrt[3]{216000.4} = 60$$

EXAMPLE: $\sqrt[3]{0.0000451}$
$\sqrt[3]{0.000'045'1}$

(Only first figure is zero in this group)

Place the hairline over 451 in the middle third of the K scale. Read the digit sequence, 357, under the hairline on the D scale. Since there is one group of three zeros, there is one zero between the decimal point and the first significant digit of the root. Thus,

$$\sqrt[3]{0.0000451} = 0.0357$$

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POWERS OF 10.—To take the cube root of a power of 10, mark it off as explained in the preceding paragraphs. The number in the left group will then be 1, 10, or 100. We know that the cube root of 10 is a number between 2 and 3. Thus, for the cube root of any number whose left group is 10, use the K scale index which lies between 2 and 3 on the D scale. The cube root of 100 lies between 4 and 5. Therefore, for a number whose left group is 100, use the K scale index between 4 and 5 on the D scale.

Practice problems. Following are some problems and the digit sequence (d. s.) of the roots. Locate the decimal point for each root.

1. $\sqrt[3]{0.000023}$ d. s. 2844
2. $\sqrt[3]{0.051}$ d. s. 371
3. $\sqrt[3]{127}$ d. s. 5026
4. $\sqrt[3]{204,000}$ d. s. 589
5. $\sqrt[3]{734,000,000}$ d. s. 902
6. $\sqrt[3]{4,913}$ d. s. 17

Answers:

1. 0.02844
2. 0.371
3. 5.026
4. 58.9
5. 902
6. 17

# WORKING WITH NUMBERS

## COMPLEX NUMBERS

In certain calculations in mathematics and related sciences, it is necessary to perform operations with numbers unlike any mentioned thus far in this pamphlet. These numbers, unfortunately called "imaginary" numbers by early mathematicians, are quite useful and have a very real meaning in the physical sense. The number system, which consists of ordinary numbers and imaginary numbers, is called the COMPLEX NUMBER system. Complex numbers are composed of a "real" part and an "imaginary" part.

## REAL NUMBERS

The concept of number, as has been noted previously, has developed gradually. At one time the idea of number was limited to positive whole numbers.

The concept was broadened to include positive fractions, numbers that lie between the whole numbers. At first, fractions included only those numbers which could be expressed with terms that were integers. Since any fraction may be considered as a ratio, this gave rise to the term RATIONAL NUMBER, which is defined as any number which can be expressed as the ratio of two integers. (Remember that any whole number is an integer.)

It soon became apparent that these numbers were not enough to complete the positive number range. The ratio, $\pi$, of the circumference of a circle to its diameter, did not fit the concept of number thus far advanced, nor did such numbers as $\sqrt{2}$ and $\sqrt{3}$. Although decimal values are often assigned to these numbers, they are only approximations. That is, $\pi$ is not exactly equal to 22/7 or to 3.142. Such numbers are called IRRATIONAL to distinguish them from the other numbers of the system. With rational and irrational numbers, the positive number system includes all the numbers from zero to infinity in a positive direction.

Since the number system was not complete with only positive numbers, the system was expanded to include negative numbers. The idea of negative rational and irrational numbers to minus infinity was an easy extension of the system.

Rational and irrational numbers, positive and negative to $\pm$ infinity as they have been presented in this pamphlet, comprise the REAL NUMBER system. The real number system is pictured in figure 10.

## OPERATORS

As shown in a previous section, the plus sign in an expression such as $5 + 3$ can stand for either of two separate things: It indicates the positive number 3, or it indicates that +3 is to be added to 5; that is, it indicates the operation to be performed on +3.

Likewise, in the problem $5 - 3$, the minus sign may indicate the negative number -3, in which case the operation would be addition; that is, $5 + (-3)$. On the other hand, it may indicate the sign of operation, in which case +3 is to be subtracted from 5; that is, $5 - (+3)$.

Thus, plus and minus signs may indicate positive and negative numbers, or they may indicate operations to be performed.

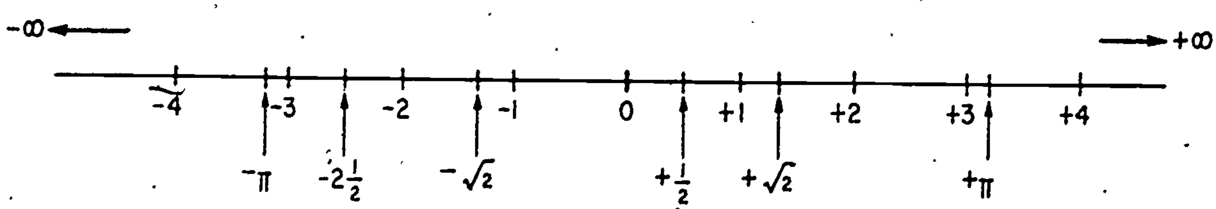


Figure 10.—The real number system.

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IMAGINARY NUMBERS

The number line pictured in figure 10 represents all positive and negative numbers from plus infinity to minus infinity. However, there is a type of number which does not fit into the picture. Such a number occurs when we try to solve the following equation:

$$x^2 + 4 = 0$$
$$x^2 = -4$$
$$x = \pm\sqrt{-4}$$

Notice the distinction between this use of the radical sign and the manner in which it was used in section 3. Here, the $\pm$ symbol is included with the radical sign to emphasize the fact that two values of x exist. Although both roots exist, only the positive one is usually given. This is in accordance with usual mathematical convention.

The equation

$$x = \pm\sqrt{-4}$$

raises an interesting question:

What number multiplied by itself yields -4? The square of -2 is +4. Likewise, the square of +2 is +4. There is no number in the system of real numbers that is the square root of a negative number. The square root of a negative number came to be called an IMAGINARY NUMBER. When this name was assigned the square roots of negative numbers, it was natural to refer to the other known numbers as the REAL numbers.

IMAGINARY UNIT

To reduce the problem of imaginary numbers to its simplest terms, we proceed as far as possible using ordinary numbers in the solution. Thus, we may write $\sqrt{-4}$ as a product

$$\sqrt{-1 \times 4} = \sqrt{4}\sqrt{-1}$$
$$= \pm 2\sqrt{-1}$$

Likewise,

$$\sqrt{-5} = \sqrt{5}\sqrt{-1}$$

Also,

$$3\sqrt{-7} = 3\sqrt{7}\sqrt{-1}$$

Thus, the problem of giving meaning to the square root of any negative number reduces to that of finding a meaning for $\sqrt{-1}$.

The square root of minus 1 is designated i by mathematicians. When it appears with a coefficient, the symbol i is written last unless the coefficient is in radical form. This convention is illustrated in the following examples:

$$\pm 2\sqrt{-1} = \pm 2i$$
$$\sqrt{5}\sqrt{-1} = i\sqrt{5}$$
$$3\sqrt{7}\sqrt{-1} = 3i\sqrt{7}$$

The symbol i stands for the imaginary unit $\sqrt{-1}$. An imaginary number is any real multiple, positive or negative, of i. For example, -7i, +7i, $i\sqrt{15}$, and bi are all imaginary numbers.

In electrical formulas the letter i denotes current. To avoid confusion, electronic technicians use the letter j to indicate $\sqrt{-1}$ and call it "operator j." The name "imaginary" should be thought of as a technical mathematical term of convenience. Such numbers have a very real purpose in the physical sense. Also it can be shown that ordinary mathematical operations such as addition, multiplication, and so forth, may be performed in exactly the same way as for the so-called real numbers.

Practice problems. Express each of the following as some real number times i:

| | | |
|---|---|---|
| 1. $\sqrt{-16}$ | 3. $\sqrt{-5}$ | 5. $\sqrt{-25}$ |
| 2. $2\sqrt{-1}$ | 4. $\frac{d}{f}\sqrt{-f^2}$ | 6. $\sqrt{-\frac{9}{16}}$ |

Answers:

| | | |
|---|---|---|
| 1. 4i | 3. $i\sqrt{5}$ | 5. 5i |
| 2. 2i | 4. di | 6. $\frac{3}{4}i$ |

Powers of the Imaginary Unit

The following examples illustrate the results of raising the imaginary unit to various powers:

$$i = \sqrt{-1}$$
$$i^2 = \sqrt{-1}\sqrt{-1}, \text{ or } -1$$
$$i^3 = i^2 i = -1i, \text{ or } -i$$
$$i^4 = i^2 i^2 = -1 \cdot -1 = +1$$

$$i^{-1} = \frac{1}{i} = \frac{i}{i^2} = \frac{i}{-1} = -i$$

We see from these examples that an even power of i is a real number equal to +1 or -1. Every odd power of i is imaginary and equal to i or -i. Thus, all powers of i reduce to one of the following four quantities: $\sqrt{-1}$, -1, $-\sqrt{-1}$, or +1.

## FUNDAMENTALS OF ALGEBRA

The numbers and operating rules of arithmetic form a part of a very important branch of mathematics called ALGEBRA.

Algebra extends the concepts of arithmetic so that it is possible to generalize the rules for operating with numbers and use these rules in manipulating symbols other than numbers. It does not involve an abrupt change into a distinctly new field, but rather provides a smooth transition into many branches of mathematics with a continuation of knowledge already gained in basic arithmetic.

The idea of expressing quantities in a general way, rather than in the specific terms of arithmetic, is fairly common. A typical example is the formula for the perimeter of a rectangle, $P = 2L + 2W$, in which the letter P represents perimeter, L represents length, and W represents width. It should be understood that $2L = 2(L)$ and $2W = 2(W)$. If the L and the W were numbers, parentheses or some other multiplication sign would be necessary, but the meaning of a term such as 2L is clear without additional signs or symbols.

All formulas are algebraic expressions, although they are not always identified as such. The letters used in algebraic expressions are often referred to as LITERAL NUMBERS (literal implies "letteral").

Another typical use of literal numbers is in the statement of mathematical laws of operation. For example, the commutative, associative, and distributive laws, may be stated in general terms by the use of algebraic symbols.

### COMMUTATIVE LAWS

The commutative laws refer to those situations in which the factors and terms of an expression are rearranged in a different order.

#### ADDITION

The algebraic form of the commutative law for addition is as follows:

$$a + b + c = a + c + b = c + b + a$$

In words, this law states that the sum of two or more addends is the same regardless of the order in which the addends are arranged.

In the algebraic example, a, b, and c represent any numbers we choose, thus giving a broad inclusive example of the rule. (Note that once a value is selected for a literal number, that value remains the same wherever the letter appears in that particular example or problem. Thus, if we give a the value of 12, in the example just given, a's value is 12 wherever it appears.)

#### MULTIPLICATION

The algebraic form of the commutative law for multiplication is as follows:

$$abc = acb = cba$$

In words, this law states that the product of two or more factors is the same regardless of the order in which the factors are arranged.

### ASSOCIATIVE LAWS

The associative laws of addition and multiplication refer to the grouping (association) of terms and factors in a mathematical expression.

#### ADDITION

The algebraic form of the associative law for addition is as follows:

$$a + b + c = (a + b) + c = a + (b + c)$$

In words, this law states that the sum of three or more addends is the same regardless of the manner in which the addends are grouped.

#### MULTIPLICATION

The algebraic form of the associative law for multiplication is as follows:

$$a \cdot b \cdot c = (a \cdot b) \cdot c = a \cdot (b \cdot c)$$

In words, this law states that the product of three or more factors is the same regardless of the manner in which the factors are grouped.

DISTRIBUTIVE LAW

The distributive law refers to the distribution of factors among the terms of an additive expression. The aigebraic form of this law is as follows:

$$a(b + c + d) = ab + ac + ad$$

In words, this law may be stated as follows: If the sum of two or more quantities is multiplied by a third quantity, the product is found by applying the multiplier to each of the original quantities separately and summing the resulting expressions.

ALGEBRAIC SUMS

The word "sum" has been used several times in this discussion, and it is important to realize the full implication where algebra is concerned. Since a literal number may represent either a positive or a negative quantity, a sum of several literal numbers is always understood to be an ALGEBRAIC SUM. That is, it is the sum that results when the algebraic signs of all the addends are taken into consideration.

The following problems illustrate the procedure for finding an algebraic sum:

Let $a = 3$, $b = -2$, and $c = 4$.

Then $a + b + c = (3) + (-2) + (4)$
$= 5$

Also, $a - b - c = a + (-b) + (-c)$
$= 3 + (+2) + (-4)$
$= 1$

The second problem shows that every expression containing two or more terms to be combined by addition and subtraction may be rewritten as an algebraic sum, all negative signs being considered as belonging to specific terms and all operational signs being positive.

It should be noted, in relation to this subject, that the laws of signs for algebra are the same as those for arithmetic.

ALGEBRAIC EXPRESSIONS

An algebraic expression is made up of the signs and symbols of algebra. These symbols include the Arabic numerals, literal numbers, the signs of operation, and so forth. Such an expression represents one number or one quantity. Thus, just as the sum of 4 and 2 is one quantity, that is, 6, the sum of c and d is one quantity, that is, $c + d$. Likewise $\frac{a}{b}$, $\sqrt{b}$, ab, $a - b$, and so forth, are algebraic expressions each of which represents one quantity or number.

Longer expressions may be formed by combinations of the various signs of operation and the other algebraic symbols; but no matter how complex such expressions are, they still represent one number. Thus, the algebraic expression $\frac{-a + \sqrt{2a + b}}{6} - c$ is one number.

The arithmetic value of any algebraic expression depends on the values assigned to the literal numbers. For example, in the expression $2x^2 - 3ay$, if $x = -3$, $a = 5$, and $y = 1$, then we have the following:

$$2x^2 - 3ay = 2(-3)^2 - 3(5)(1)$$
$$= 2(9) - 15 = 18 - 15 = 3$$

Notice that the exponent is an expression such as $2x^2$ applies only to the x. If it is desired to indicate the square of 2x, rather than 2 times the square of x, then parentheses are used and the expression becomes $(2x)^2$.

Practice problems. Evaluate the following algebraic expressions when $a = 4$, $b = 2$, $c = 3$, $x = 7$, and $y = 5$. Remember that the order of operation is multiplication, division, addition, and subtraction.

1. $3x + 7y - c$
2. $xy - 4a^2$
3. $\frac{ax}{b} + y$
4. $c + \frac{ay^2}{b}$

Answers:

1. 53
2. -29
3. 19
4. 53

TERMS AND COEFFICIENTS

The terms of an algebraic expression are the parts of the expression that are connected by plus and minus signs. In the expression $3abx + cy - k$, for example, 3abx, cy, and k are the terms of the expression.

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An expression containing only one term, such as 3ab, is called a monomial (mono means one). A binomial contains two terms; for example, $2r + by$. A trinomial consists of three terms. Any expression containing two or more terms may also be called by the general name, polynomial (poly means many). Usually special names are not given to polynomials of more than three terms. The expression $x^3 - 3x^2 + 7x + 1$ is a polynomial of four terms. The trinomial $x^2 - 2x + 1$ is an example of a polynomial which has a special name.

Practice problems. Identify each of the following expressions as a monomial, binomial, trinomial, or polynomial. (Some expressions may have two names.)

| | | |
|---|---|---|
| 1. $x$ | 3. $abx$ | 5. $3y^2 + 4$ |
| 2. $3y + a + b$ | 4. $4 + 2b + y + z$ | 6. $\frac{2y}{6} + 1$ |

Answers:

| | |
|---|---|
| 1. Monomial | 2. Trinomial (also polynomial) |
| 3. Monomial | 4. Polynomial |
| 5. Binomial (also polynomial) | 6. Binomial (also polynomial) |

In general, a COEFFICIENT of a term is any factor or group of factors of a term by which the remainder of the term is to be multiplied. Thus in the term $2axy$, $2ax$ is the coefficient of $y$, $2a$ is the coefficient of $xy$, and 2 is the coefficient of $axy$. The word "coefficient" is usually used in reference to that factor which is expressed in Arabic numerals. This factor is sometimes called the NUMERICAL COEFFICIENT. The numerical coefficient is customarily written as the first factor of the term. In $4x$, 4 is the numerical coefficient, or simply the coefficient, of $x$. Likewise, in $24xy^2$, 24 is the coefficient of $xy^2$ and in $16(a + b)$, 16 is the coefficient of $(a + b)$. When no numerical coefficient is written it is understood to be 1. Thus in the term $xy$, the coefficient is 1.

## COMBINING TERMS

When arithmetic numbers are connected by plus and minus signs, they can always be combined into one number. Thus,

$$5 - 7\frac{1}{2} + 8 = 5\frac{1}{2}$$

Here three numbers are added algebraically (with due regard for sign) to give one number. The terms have been combined into one term.

Terms containing literal numbers can be combined only if their literal parts are the same. Terms containing literal factors in which the same letters are raised to the same power are called like terms. For example, $3y$ and $2y$ are like terms since the literal parts are the same. Like terms are added by adding the coefficients of the like parts. Thus, $3y + 2y = 5y$ just as 3 bolts + 2 bolts = 5 bolts. Also $3a^2b$ and $a^2b$ are like; $3a^2b + a^2b = 4a^2b$ and $3a^2b - a^2b = 2a^2b$. The numbers $ay$ and $by$ are like terms with respect to $y$. Their sum could be indicated in two ways: $ay + by$ or $(a + b)y$. The latter may be explained by comparing the terms to denominate numbers. For instance, a bolts + b bolts = (a + b) bolts.

Like terms are added or subtracted by adding or subtracting the numerical coefficients and placing the result in front of the literal factor, as in the following examples:

$$7x^2 - 5x^2 = (7 - 5)x^2 = 2x^2$$

$$5b^2x - 3ay^2 - 8b^2x + 10ay^2 = -3b^2x + 7ay^2$$

Dissimilar or unlike terms in an algebraic expression cannot be combined when numerical values have not been assigned to the literal factors. For example, $-5x^2 + 3xy - 8y^2$ contains three dissimilar terms. This expression cannot be further simplified by combining terms through addition or subtraction. The expression may be rearranged as $x(3y - 5x) - 8y^2$ or $y(3x - 8y) - 5x^2$, but such a rearrangement is not actually a simplification.

Practice problems. Combine like terms in the following expression:

| | |
|---|---|
| 1. $2a + 4a$ | 4. $2ay^2 - ay^2$ |
| 2. $y + y^2 + 2y$ | 5. $bx^2 + 2bx^2$ |
| 3. $4\frac{ay}{c} - \frac{ay}{c}$ | 6. $2y + y^2$ |

Answers:

| | |
|---|---|
| 1. $6a$ | 4. $ay^2$ |
| 2. $y^2 + 3y$ | 5. $3bx^2$ |
| 3. $3\frac{ay}{c}$ | 6. $2y + y^2$ |

NUMBER SYSTEMS FOR COMPUTERS

Now consider a few basic definitions that pertain to number systems.

1. Unit — A single thing
2. Number — An arbitrary symbol representing an amount of units.
3. Number System — A method of indicating the amount of units counted.
   a. All modern number systems include the zero.
   b. The radix, or base, of a number system is the amount of characters or symbols it possesses, including the zero.
4. Quantity — A number of units (implies both a unit and a number).
5. Modulus — The total number of different numbers or stable conditions that a counting device can indicate. (For example, the odometer on most automobiles has a modulus of 100,000 since it indicates all numbers from 00,000 to 99,999. The modulus of the hour hand on most watches is 12, and that of the minute hand is 60.)

POSITIONAL NOTATION

The standard shorthand form of writing numbers is known as positional notation. As mentioned before concerning this subject, the value of a particular digit depends not only on the digit value, but also on the position of the digit within the number. Consequently, the decimal number 9751.68 is the standard shorthand form of the quantity nine thousand seven hundred fifty-one and sixty-eight hundredths. What the shorthand form really states is best illustrated by an example as follows:

$$9751.68 = (9 \times 10^3) + (7 \times 10^2) + (5 \times 10^1) + (1 \times 10^0) + (6 \times 10^{-1}) + (8 \times 10^{-2}).$$

A quantity can be expressed in the positional notation (standard shorthand) form in any numbering system. The general form is:

$$Q = (d_n \times r^n) + \dots + (d_2 \times r^2) + (d_1 \times r^1) + (d_0 \times r^0) + (d_{-1} \times r^{-1}) + (d_{-2} \times r^{-2}) + \dots + (d_{-n} \times r^{-n})$$

where: Q is the quantity expressed in positional notation form; r is the base or radix of the number system raised to a power; and $d_2$, $d_1$, $d_0$, $d_{-1}$, $d_{-2}$, etc. .... are the characters of the radix.

Note that the radix point in the general expression (known as the decimal point in the decimal system) is not required because the exponent goes negative. In the shorthand form the radix point is placed between the $d_0 \times r^0$ and $d_{-1} \times r^{-1}$ values.

THE RADIX

Every number system has a radix, or base. When the radix is ten, the decimal system is indicated; when r is eight, the octal system is indicated; and when r is two, the binary system is indicated. The division between integers and fractions is recognized by the position of the radix point. Additional characteristics of the radix are as follows:

1. The radix of a numbering system is equal to the sum of the different characters which are necessary to indicate all the various magnitudes a digit may represent. For example, the decimal system, with a radix ten, has ten digits of magnitudes 0 through 9.

2. The value of the radix is always one unit greater than the largest basic character being used. This is because the radix is equal to the number of characters, whereas the characters themselves start from zero. Thus, the octal system (discussed later) has a radix of eight and uses digits 0 through 7.

3. The positional notation does not, in itself, indicate the radix. The symbol "312" could represent a number written in the quartic (base four), octal, or decimal system, or in any system having a radix of four or greater. Binary numbers are usually recognizable from their string of ones and zeros. To avoid confusion, numbers written in systems other than the decimal system should have the radix noted as a subscript, i.e.,

$$315.72_8$$

The radix subscript is always written as a decimal (base ten) number.

4. Any number can easily be multiplied or divided by the radix of its number system. In decimal notation, to multiply a number by ten, move the decimal (radix) point one digit to the right of its former position, as follows:

$$\begin{array}{r} 34.564 \\ \underline{\text{x ten}} \\ 345.64 \end{array}$$

The following statement brings out a fact often overlooked. The radix point could remain stationary and the digits could move as follows:

$$\begin{array}{r} 034.564 \\ \underline{\text{x ten}} \\ 345.640 \end{array}$$

This is reasonable when one considers that the radix is fixed and the number represented in that radix is changed.

To divide a number by ten, move the decimal (radix) point one digit to the left of its former position or move the digits one digit space to the right relative to the radix point as follows:

$$\frac{34.564}{(\text{ten})} = 3.4564$$

In the same fashion, a binary number is multiplied by two when the binary (radix) point is moved to the right one position value or the number is shifted to the left, as follows:

$$10101.01 \text{ x (two)} = 101010.1$$

COUNTING

The rules for counting numbers written in a system of positional notation are the same for every radix. The octal system is used in the following example to illustrate these rules.

1. Starting from zero, add "one" to the least significant digit until all basic characters have been used:

0, 1, 2, 3, 4, 5, 6, 7, . . . .

2. Since seven is the largest character in this system, a larger number requires two digits. Start the series of two-digit numbers with zero as the least significant digit and a "1" to left of the zero:

. . . . 6, 7, 10, 11, 12, 13, 14, 15, 16, 17, . . .

3. Whenever any digit reaches its maximum value (seven, in this case), replace it with zero and add "1" to its next more significant digit:

. . . 16, 17, 20, 21, . . . 26, 27, 30, 31, . . . 66, 67, 70, 71

4. When two or more consecutive digits reach the maximum value, replace them with zeros and add "1" to the next more significant digit:

. . . 76, 77, 100, 101, . . . 176, 177, 200, . . . 776, 777, 1000

NOTE: The symbol "10" always represents the radix in its own system. This is true because the radix is one unit larger than the largest character, and by the rules of counting, this value is written as "10."

For example:

Binary "10" = two (the radix of the binary system)
Octal "10" = eight (the radix of the octal system)
Decimal "10" = ten (the radix of the decimal system)

Binary System

The simplest possible number system is based on powers of two and is known as the binary system. This system, keyed to the decimal and octal systems, is used in the majority of modern computers and in all digital devices. By applying the rules of counting, an example of binary and octal counting evolves, as shown in Table 10.

By a convenient coincidence, the two binary conditions (1 and 0) can be easily represented by many electrical/electronic components if the 1 binary state is indicated when the component is conductive and the 0 state is indicated when the component is nonconductive. The reverse of this will work equally as well, i.e., the nonconducting state of a component can be used to represent a 1 binary condition and a conducting state the 0 condition. Both procedures are used in digital computer applications and frequently within a single computer. Numerous devices are used to provide representation of binary conditions. These include switches, transistors, relays, and diodes.

Table 10. —Counting

| Decimal | Binary | Octal |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 1 | 1 |
| 2 | 10 | 2 |
| 3 | 11 | 3 |
| 4 | 100 | 4 |
| 5 | 101 | 5 |
| 6 | 110 | 6 |
| 7 | 111 | 7 |
| 8 | 1000 | 10 |
| 9 | 1001 | 11 |
| 10 | 1010 | 12 |
| 11 | 1011 | 13 |
| 12 | 1100 | 14 |

The quantity represented using binary characters (or the characters in any numbering system) cannot be determined without knowing the positional weighting value of each character (digit). The positional value of binary characters from $2^0$ (1) to $2^9$ ($512_{10}$, or 512 base ten) are illustrated in Table 11.

Consider the following hypothetical example. A number of flip-flops (multivibrators) arranged in a chain to form a "register" can be gated by incoming pulses to some or all of the flip-flops so that some are driven to produce a SET or 1 output while others receive no input pulse and produce a CLEAR or 0 output. **If it is assumed that there are ten flip-flops in the chain, a binary condition (number) represented could be 0000010101. The value of this number can be determined by simply summing the positional values as indicated by 1's in the table. By this procedure, the top number in the table yields:**

$$(1 \times 2^4) + (1 \times 2^2) + (1 \times 2^0) = 21$$

Thus,

$$0000010101_2 = 21_{10},$$

and it is now known that the flip-flop chain is storing the decimal equivalent of 21.

The values of the other binary numbers in Table 11 are determined in the same manner.

By convention, weighting values are always arranged in the same manner. The highest one is on the extreme left and the lowest one is on the extreme right. Thus, the position coefficient begins at 1 and increases from right to left.

The leftmost 1 in any binary number (fig. 11) **is always referred to as the "most significant digit."** This is often abbreviated MSD. It is the "most significant" because it is multiplied by the highest valued position coefficient. The "least significant digit," or LSD, is always on the extreme right. It may be a 1 or a 0, and, when a 1, it has the lowest weighting value (1).

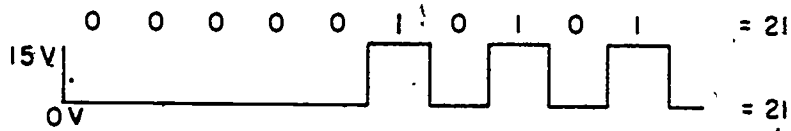
The terms most significant digit and least significant digit have the same meaning in any numbering system. The MSD of the decimal number 43,096 is 4, while the LSD is 6. When 43,096 is multiplied, divided, subtracted, or added to another number, the 4, being in the 10,000 place, will produce the greatest change in the answer. Thus, it is the MSD. The 6, being in the units place, will produce the least change in the answer. It is the least significant digit. In most practical computation, an error in the LSD has little significant effect. An MSD error, however, can result in an incorrect answer of more consequence.

## Binary Coded Decimal

Each of the binary numbers that is shown **in table 12 is called a "binary-coded decimal digit" or "coded digit." One can see that** without using any other binary numbers, it is possible to represent any desired quantity by means of these coded digits. For example, in order to represent 736, we simply write the coded digit for each decimal, and then we place the digit in the same order as the decimals. **Thus, we arrive at 011100110110.**

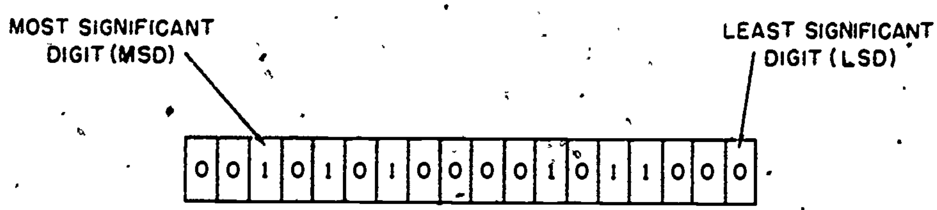
Binary coded decimal digits need not be spaced because we know that each one is composed of four binary digits. For easier reading, however, a space usually will be placed between each coded digit, thus: 0111 0011 0110. Note that this number is not pure binary; it is, instead, a binary-coded decimal number.

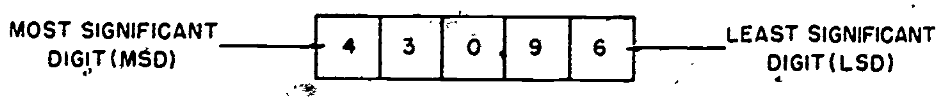
Table 11. —Positional Weighting Value.




| QUANTITIES IN BINARY | $2^9$ | $2^8$ | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| POSITION COEFFICIENT | 512 | 256 | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 | | |
| | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | = | 21 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = | 0 |
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | = | 1023 |
| | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | = | 568 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | = | 5 |
| | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | = | 133 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | = | 1 |

164.64




164.3

Figure 11. —Positional Value.

Table 12. —Binary-coded decimal digits.

| Decimal Digit | Binary - Coded Decimal Digit | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 0 | 0 | 1 |
| 2 | 0 | 0 | 1 | 0 |
| 3 | 0 | 0 | 1 | 1 |
| 4 | 0 | 1 | 0 | 0 |
| 5 | 0 | 1 | 0 | 1 |
| 6 | 0 | 1 | 1 | 0 |
| 7 | 0 | 1 | 1 | 1 |
| 8 | 1 | 0 | 0 | 0 |
| 9 | 1 | 0 | 0 | 1 |

### Octal System

The octal system has eight distinct characters; hence its radix is eight. The octal system is quite useful as an accessory to the binary system, because eight is an integral power of two ($8_{10} = 2^3_{10}$). One octal digit is always equal to three binary and vice versa.

| Octal to Binary | | | Binary to Octal | | |
|---|---|---|---|---|---|
| 2 | 2 | 5 | 010 | 010 | 101 |
| 010 | 010 | 101 | 2 | 2 | 5 |

By breaking a binary number into groups of three bits (BInary digiTs), starting from the radix point and working outwards to the left and right, the binary number may be written in a manner which is called BINARY CODED OCTAL (BCO). This makes the confusing string of 1's and 0's more understandable and facilitates the conversion of the binary number to an octal number. Such numbers would appear with the subscript $_{BCO}$; for example, $010010101_2$ becomes $010\ 010\ 101_{BCO}$ and from there to $225_8$. The binary number 010110.0111 becomes $010\ 110.011\ 100_{BCO}$ and $26.34_8$.

Arithmetic operations in the octal system (or any numbering system) use the same basic procedures as does the decimal system. That is, carry and borrow quantities (in addition and subtraction) are treated identically; a multiplicand is multiplied by each digit of the multiplier, etc. However, the basic rules for the addition or subtraction of one digit to or from another digit, or the multiplication or division of one digit by another, are different for each number system. That is, two digits added in one system will give an answer; the same two digits, added in a different system may give a "different" answer. (The "different" answers are actually equivalent numbers.) The example below shows the results of an addition and a multiplication of the same digits in three systems.

(Note that $11_{10}$, $13_8$, and $14_7$ are equivalent and that $30_{10}$, $36_8$ and $42_7$ are equivalent.)

Each system requires its own addition and multiplication tables. These tables may be constructed by performing the required operation in the decimal system and converting the answer to its equivalent. For example, the addition and multiplication tables for the octal system are shown in Tables 13 and 14, respectively.

The most important point to be remembered when performing arithmetic processes in any number system is to USE ONLY THE CHARACTERS (OR SYMBOLS) WHICH EXIST IN THAT SYSTEM.

| Base 10 (decimal) | Base 8 (octal) | Base 7 (heptal) |
|---|---|---|
| $5_{10} + 6_{10} = 11_{10}$ | $5_8 + 6_8 = 13_8$ $(1 \times 8^1 + 3 \times 8^0)$ | $5_7 + 6_7 = 14_7$ $(1 \times 7^1) + (4 \times 7^0)$ |
| $5_{10} \times 6_{10} = 30_{10}$ | $5_8 \times 6_8 = 36_8$ $(3 \times 8^1 + 6 \times 8^0)$ | $5_7 \times 6_7 = 42_7$ $(4 \times 7^1 + 2 \times 7^0)$ |

Table 13.—Octal Addition.

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 10 |
| 2 | 3 | 4 | 5 | 6 | 7 | 10 | 11 |
| 3 | 4 | 5 | 6 | 7 | 10 | 11 | 12 |
| 4 | 5 | 6 | 7 | 10 | 11 | 12 | 13 |
| 5 | 6 | 7 | 10 | 11 | 12 | 13 | 14 |
| 6 | 7 | 10 | 11 | 12 | 13 | 14 | 15 |
| 7 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |

Table 14.—Octal Multiplication.

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 2 | 2 | 4 | 6 | 10 | 12 | 14 | 16 |
| 3 | 3 | 6 | 11 | 14 | 17 | 22 | 25 |
| 4 | 4 | 10 | 14 | 20 | 24 | 30 | 34 |
| 5 | 5 | 12 | 17 | 24 | 31 | 36 | 43 |
| 6 | 6 | 14 | 22 | 30 | 36 | 44 | 52 |
| 7 | 7 | 16 | 25 | 34 | 43 | 52 | 61 |

## CONVERSION

If two numbers written in different numbering systems represent the same quantity, these numbers are equivalent (the represented quantities are equal although the numbers are not necessarily composed of the same characters). Any change which retains the equivalence of the original numbers results in a new set of equivalent numbers. Therefore, it is possible to convert numbers from one numbering system to another numbering system, that is, to change radices. Prior to discussing the mechanics of conversion, the following point is stated.

To determine the decimal quantitative meaning of a number expressed in a system other than the decimal system, write the number in a power series summation, multiplying each digit of the number by its radix raised to the indicated positional power. The radix and the power must be expressed as a decimal number to obtain the decimal quantity.

Examples:

Problem: For what quantity does the binary number 10101.01 stand?

Solution:

$$\begin{aligned}\text{Quantity} &= (1 \times 2^4) + (0 \times 2^3) + (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) + (0 \times 2^{-1}) + (1 \times 2^{-2}) \\ &= (1 \times 16) + 0 + (1 \times 4) + 0 + (1 \times 1) + 0 + (1 \times 0.25) = 21.25_{10}\end{aligned}$$

Problem: For what quantity does the octal number 25.2 stand?

Solution:

$$\begin{aligned}\text{Quantity} &= (2 \times 8^1) + (5 \times 8^0) + (2 \times 8^{-1}) \\ &= (2 \times 8) + (5 \times 1) + (2 \times 0.125) \\ &= 16 + 5 + 0.25 \\ &= 21.25_{10}\end{aligned}$$

Note that the numbers $21.25_{10}$, $25.2_8$, and $10101.01_2$ are equivalent.

### BINARY - DECIMAL

One of the simplest, most direct, and most easily remembered methods of converting from binary to decimal and vice versa is the table method illustrated in table 15.

NOTE: To find the decimal equivalent of a binary number (10101.01 in this case) by using the table method, insert the binary number in the table, observing its binary positional value and using the radix point as the reference. Then total the decimal values which have the binary character "1" below them. (A similar procedure was discussed earlier.)

Example:

Problem: Convert binary 101001.010 to its decimal equivalent.

Solution: Plugging the binary number into the table and summing

Table 15.—Binary - Decimal Conversion for Decimal Number 41.25

| $2_{10}$ raised to various powers | Continue as high as needed | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^{-1}$ | $2^{-2}$ | Continue as low as needed |
|---|---|---|---|---|---|---|---|---|---|---|
| Equivalent expressed as a decimal | | 32 | 16 | 8 | 4 | 2 | 1 | 0.5 | 0.25 | |
| Quantity expressed as a decimal | | 1<br>MSD | 0 | 1 | 0 | 0 | 1 | 0 | 1<br>LSD | |

Radix point

the decimal values result in:

$$\begin{array}{r} 32.00\ (2^5) \\ 8.00\ (2^3) \\ 1.00\ (2^0) \\ 0.25\ (2^{-2}) \\ \hline 41.25 \end{array}$$

Therefore, binary 101001.010 is equivalent to decimal 41.25. The procedure to find the binary equivalent of a decimal number is as follows:

1. Find the largest whole power of two that may be subtracted from the decimal number and place the binary character "1" underneath the decimal value of this whole power of two in the table.
2. Using the remainder, if any, from step 1, again subtract the largest whole power of two. Place the binary character "1" underneath the decimal value of this whole power of two in the table.
3. Continue until the remainder is zero. Under every decimal value which does not have the binary character "1," place the binary character "0."
4. Rounding-off of fractions is necessary where exact conversions into binary are neither possible nor necessary.

Example:

Problem: Convert decimal 41.25 to its binary equivalent.

Solution: Decimal 32 ($2^5$) is the largest whole power of two (Step (1). A binary character "1" is placed beneath the decimal value 32 ($2^5$) in the table. The remainder (41.25 - 32) is 9.25. Decimal 8 ($2^3$) is the largest whole power of two which fits into 9.25. The remainder (9.25 - 8) is 1.25. A binary character "1" is therefore placed under the decimal 8 ($2^3$) in the table. The process continues until the remainder is zero or rounding-off is indicated. All squares not containing the binary character "1", are assigned the binary character "0".

Therefore, decimal 41.25 is equivalent to binary 101001.01.

## BINARY - OCTAL

Since one octal digit is always equal to three binary digits ($8_{10} = 2^3_{10}$ as previously stated), conversion from binary to octal or octal to binary is quite simple. Binary to octal conversion is accomplished as follows:

1. Beginning at the binary point, mark off the binary number into groups of three digits

to the left and to the right of the binary point. Add the binary character "0" where needed to complete a group of three.

2. Replace each group of three binary characters with its octal equivalent, which is:

$000 = 0_8$
$001 = 1_8$
$010 = 2_8$
$011 = 3_8$
$100 = 4_8$
$101 = 5_8$
$110 = 6_8$
$111 = 7_8$

Example:

Problem: Convert binary 101001.01 to its octal equivalent.

Solution:

| Binary | 101 | 001 | . | 010 |
|---|---|---|---|---|
| Octal | 5 | 1 | . | 2 |

Therefore, binary 101001.010 is equivalent to octal 51.2.

OCTAL - BINARY

Octal to binary conversion is simply the reverse of the above procedure. For each octal digit, write the corresponding three binary digits.

Example:

Problem: Convert octal 51.2 to its binary equivalent.

Solution:

| Octal | 5 | 1 | . | 2 |
|---|---|---|---|---|
| Binary | 101 | 001 | . | 010 |

Therefore, octal 51.2 is equivalent to binary 101001.010.

DECIMAL - OCTAL

Rather than memorize rules and formulas, it is suggested (as a learning procedure) that you accomplish conversion from octal to decimal or decimal to octal by utilizing the binary system as an intermediary. The following examples point out how this is accomplished.

Example:

Problem: What is the decimal equivalent of octal 51.2?

Solution: From octal to binary by groups of three;

| Octal | 5 | 1 | . | 2 |
|---|---|---|---|---|
| Binary | 101 | 001 | . | 010 |

then from binary to decimal by powers of two table and summation;

| Binary | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|
| Powers of two | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ |
| Decimal value | 32 | | 8 | | | 1 | | 0.25 | |

and summation of decimal values; 32 + 8 + 1 + 0.25 = 41.25.

Therefore, octal 51.2 is equivalent to decimal 41.25.

Problem: What is the octal equivalent of decimal 653.21?

Solution: From decimal to binary by whole powers of two and table;

| Powers of two | $2^9$ | $2^8$ | $2^7$ | $2^6$ | $2^5$ | $2^4$ | $2^3$ | $2^2$ | $2^1$ | $2^0$ | $2^{-1}$ | $2^{-2}$ | $2^{-3}$ | $2^{-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Decimal value | 512 | 256 | 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 | 0.5 | 0.25 | 0.125 | 0.0625 |
| Binary | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 |

653.21

| | | |
|---|---|---|
| (–) | 512.00 | (Place a 1 under 512) |
| | 141.21 | Remainder |
| (–) | 128.00 | (Place a 1 under 128) |
| | 13.21 | Remainder |
| (–) | 8.00 | (Place a 1 under 8) |
| | 5.21 | Remainder |
| (–) | 4.00 | (Place a 1 under 4) |
| | 1.21 | Remainder |
| (–) | 1.00 | (Place a 1 under 1) |
| | 0.210 | Remainder |
| (–) | 0.125 | (Place a 1 under 0.125) |
| | 0.0850 | Remainder |
| (–) | 0.0625 | (Place a 1 under 0.0625) |
| | 0.0225 | Remainder |

(The conversion will be stopped at this point for this example.) The binary equivalent of decimal 653.21 is therefore

1010001101.0011,

which is now converted to octal by groups of three (starting at the radix point):

| Binary | 001 | 010 | 001 | 101 | . | 001 | 100 |
|---|---|---|---|---|---|---|---|
| Octal | 1 | 2 | 1 | 5 | . | 1 | 4 |

Therefore, the octal equivalent of decimal 653.21 is 1215.14. With practice, all of the above steps can be done mentally.

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# NUMERICAL TRIGONOMETRY

The word "trigonometry" means "measurement by triangles." As it is presented in many textbooks, trigonometry includes topics other than triangles and measurement. However, this section is intended only as an introduction to the numerical aspects of trigonometry as they relate to measurement of lengths and angles.

## SPECIAL PROPERTIES OF RIGHT TRIANGLES

A RIGHT TRIANGLE has been defined as any triangle containing a right angle. The side opposite the right angle in a right triangle is a HYPOTENUSE. (See fig. 12.) In figure 12, side AC is the hypotenuse.

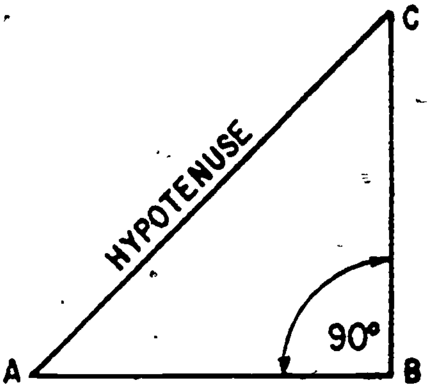


Figure 12.—A right triangle.

An important property of all right triangles, which relates the lengths of the three sides, was discovered by the Greek philosopher Pythagoras.

### PYTHAGOREAN THEOREM

The rule of Pythagoras, or PYTHAGOREAN THEOREM, states that the square of the length of the hypotenuse (in any right triangle) is equal to the sum of the squares of the lengths of the other two sides. For example, if the sides are

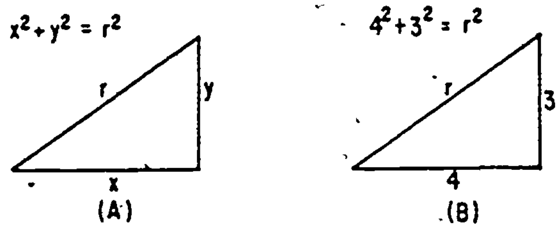


Figure 13.—The Pythagorean Theorem. (A) General triangle; (B) triangle with sides of specific lengths.

labeled as in figure 13 (A), the Pythagorean Theorem is stated in symbols as follows:

$$x^2 + y^2 = r^2$$

An example of the use of the Pythagorean Theorem in a problem follows:

EXAMPLE: Find the length of the hypotenuse in the triangle shown in figure 13 (B).

SOLUTION:
$$r^2 = 3^2 + 4^2$$
$$r = \sqrt{9 + 16}$$
$$= \sqrt{25} = 5$$

EXAMPLE: An observer on a ship at point A, figure 14, knows that his distance from point C is 1,200 yards and that the length of BC is 1,300 yards. He measures angle A and finds that it is 90°. Calculate the distance from A to B.

SOLUTION: By the rule of Pythagoras,

$$(BC)^2 = (AB)^2 + (AC)^2$$
$$(1{,}300)^2 = (AB)^2 + (1{,}200)^2$$
$$(1{,}300)^2 - (1{,}200)^2 = (AB)^2$$
$$(13 \times 10^2)^2 - (12 \times 10^2)^2 = (AB)^2$$
$$(169 \times 10^4) - (144 \times 10^4) = (AB)^2$$
$$25 \times 10^4 = (AB)^2$$
$$500 \text{ yd} = AB$$

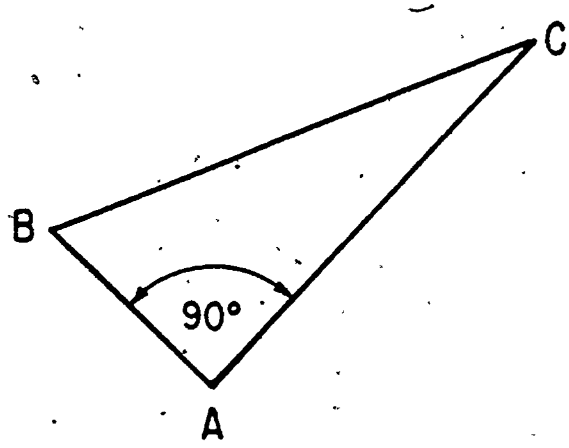


Figure 14.—Using the Pythagorean Theorem.

SIMILAR RIGHT TRIANGLES

Two right triangles are SIMILAR if one of the acute angles of the first is equal to one of the acute angles of the second. This conclusion is supported by the following reasons:

1. The right angle in the first triangle is equal to the right angle in the second since all right angles are equal.
2. The sum of the angles of any triangle is 180°. Therefore, the sum of the two acute angles in a right triangle is 90°.
3. Let the equal acute angles in the two triangles be represented by A and A' respectively. (See fig. 15.) Then the other acute angles, B and B', are as follows:

$$B = 90° - A$$
$$B' = 90° - A'$$

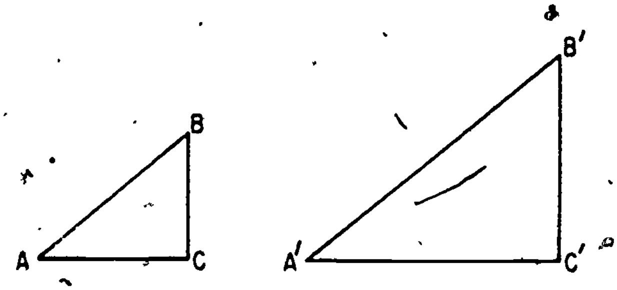


Figure 15.—Similar right triangles.

4. Since angles A and A' are equal, angles B and B' are also equal.
5. We conclude that two right triangles with one acute angle of the first equal to one acute angle of the second have all of their corresponding angles equal. Thus the two triangles are similar.

Practical situations frequently occur in which similar right triangles are used to solve problems. For example, the height of a tree can be determined by comparing the length of its shadow with that of a nearby flagpole, as shown in figure 16.

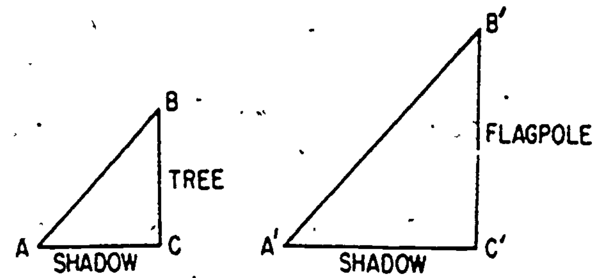


Figure 16.—Calculation of height by comparison of shadows.

Assume that the rays of the sun are parallel and that the tree and flagpole both form 90° angles with the ground. Then triangles ABC and A'B'C' are right triangles, and angle B is equal to angle B'. Therefore, the triangles are similar and their corresponding sides are proportional, with the following result:

$$\frac{BC}{AC} = \frac{B'C'}{A'C'}$$

$$BC = \frac{(AC) \times (B'C')}{A'C'}$$

Suppose that the flagpole is known to be 30 feet high, the shadow of the tree is 12 feet long, and the shadow of the flagpole is 24 feet long. Then

$$BC = \frac{12 \times 30}{24} = 15 \text{ feet}$$

Practice problems.

1. A mast at the top of a building casts a shadow whose tip is 48 feet from the base of the building. If the building is 12 feet high and its shadow is 32 feet long, what is the length of the mast? (NOTE: If the length of the mast is x, then the height of the mast above the ground is x + 12.)

2. Figure 17 represents an L-shaped building with dimensions as shown. On the line of sight from A to D, a stake is driven at C, a point 8 feet from the building and 10 feet from A. If ABC is a right angle, find the length of AB and the length of AD. Notice that AE is 18 feet and ED is 24 feet.

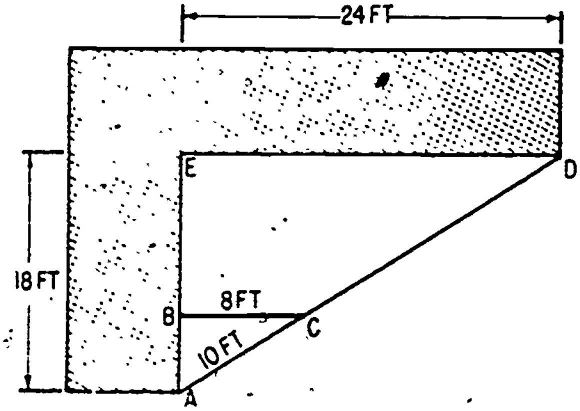


Figure 17.—Using similar triangles.

Answers:

1. 6 feet

2. AB = 6 feet
AD = 30 feet

## TRIGONOMETRIC RATIOS

The relationships between the angles and the sides of a right triangle are expressed in terms of TRIGONOMETRIC RATIOS. For example, in figure 18, the sides of the triangle are named in accordance with their relationship to angle $\theta$. In trigonometry, angles are usually named by means of Greek letters. The Greek name of the symbol $\theta$ is theta.

The six trigonometric ratios for the angle $\theta$ are listed in table 16.

The ratios are defined as follows:

1. $\sin\theta = \dfrac{\text{side opposite } \theta}{\text{hypotenuse}} = \dfrac{y}{r}$

2. $\cos\theta = \dfrac{\text{side adjacent to } \theta}{\text{hypotenuse}} = \dfrac{x}{r}$

3. $\tan\theta = \dfrac{\text{side opposite } \theta}{\text{side adjacent to } \theta} = \dfrac{y}{x}$

4. $\cot\theta = \dfrac{\text{side adjacent to } \theta}{\text{side opposite } \theta} = \dfrac{x}{y}$

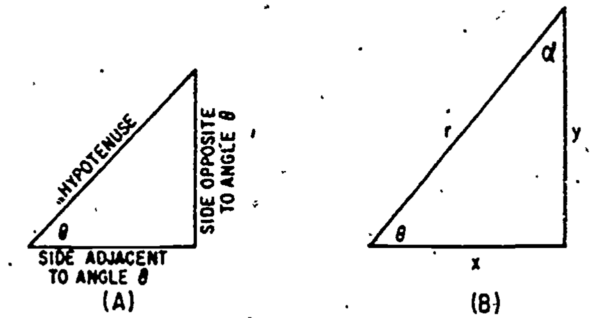


Figure 18.—Relationship of sides and angles in a right triangle. (A) Names of the sides; (B) symbols used to designate the sides.

Table 16.—Trigonometric ratios.

| Name of ratio | Abbreviation |
|---|---|
| sine of $\theta$ | $\sin\theta$ |
| cosine of $\theta$ | $\cos\theta$ |
| tangent of $\theta$ | $\tan\theta$ |
| cotangent of $\theta$ | $\cot\theta$ |
| secant of $\theta$ | $\sec\theta$ |
| cosecant of $\theta$ | $\csc\theta$ |

5. $\sec\theta = \dfrac{\text{hypotenuse}}{\text{side adjacent to } \theta} = \dfrac{r}{x}$

6. $\csc\theta = \dfrac{\text{hypotenuse}}{\text{side opposite to } \theta} = \dfrac{r}{y}$

The other acute angle in figure 18 (B) is labeled $\alpha$ (Greek alpha). The side opposite $\alpha$ is x, and the side adjacent to $\alpha$ is y. Therefore, the six ratios for $\alpha$ are as follows:

1. $\sin\alpha = \dfrac{x}{r}$

2. $\cos\alpha = \dfrac{y}{r}$

3. $\tan\alpha = \dfrac{x}{y}$

4. $\cot\alpha = \dfrac{y}{x}$

5. $\sec\alpha = \dfrac{r}{y}$

6. $\csc\alpha = \dfrac{r}{x}$

Suppose that the sides of triangle (B) in figure 18 are as follows: x = 3, y = 4, r = 5. Then each of the ratios for angles $\theta$ and $\alpha$ may be expressed as a common fraction or as a decimal. For example,

$$\sin \theta = \frac{4}{5} = 0.800$$

$$\sin \alpha = \frac{3}{5} = 0.600$$

Decimal values have been computed for ratios of angles between 0° and 90°, and values for angles above 90° can be expressed in terms of these same values by means of conversion formulas. Appendix II of this training pamphlet gives the sine, cosine, and tangent of angles from 0° to 90°. The secant, cosecant, and cotangent are calculated, when needed, by using their relationships to the three principal ratios. These relationships are as follows:

$$\text{secant } \theta = \frac{1}{\text{cosine } \theta}$$

$$\text{cosecant } \theta = \frac{1}{\text{sine } \theta}$$

$$\text{cotangent } \theta = \frac{1}{\text{tangent } \theta}$$

## TABLES

Tables of decimal values for the trigonometric ratios may be constructed in a variety of ways. Some give the angles in degrees, minutes, and seconds; others in degrees and tenths of a degree. The latter method is more compact and is the method used for appendix II. The "headings" at the bottom of each page in appendix II provide a convenient reference showing the minute equivalents for the decimal fractions of a degree. For example, 12' (12 minutes) is the equivalent of 0.2°.

### Finding the Function Value

The trigonometric ratios are sometimes called FUNCTIONS, because the value of the ratio depends upon (is a function of) the angle size. Finding the function value in appendix II is easily accomplished. For example, the sine 35° is found by looking in the "sin" row opposite the large number 35, which is located in the extreme left-hand column.

Since our angle in this example is exactly 35°, we look for the decimal value of the sine in the column with the 0.0° heading. This column contains decimal values for functions of the angle plus 0.0°; in our example, 35° plus 0.0°, or simply 34.0°. Thus we find that the sine of 35.0° is 0.5736. By the same reasoning, the sine of 42.7° is 0.6782, and the tangent of 32.3° is 0.6322.

A typical problem in trigonometry is to find the value of an unknown side in a right triangle when only one side and one acute angle are known. EXAMPLE: In triangle ABC (fig. 19), find the length of AC if AB is 13 units long and angle CAB is 34.7°.

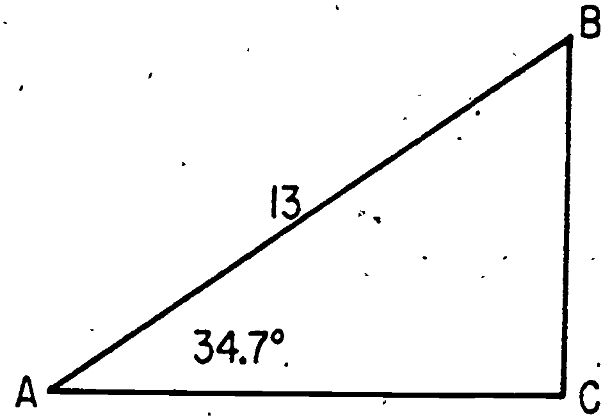


Figure 19.—Using the trigonometric ratios to evaluate the sides.

SOLUTION:

$$\frac{AC}{13} = \cos 34.7°$$

$$AC = 13 \cos 34.7°$$

$$= 13 \times 0.8221$$

$$= 10.69 \text{ (approx.)}$$

The angles of a triangle are frequently stated in degrees and minutes, rather than degrees and tenths. For example, in the foregoing problem, the angle might have been stated as 34°42'. When the stated number of minutes is an exact multiple of 6 minutes, the minute entries at the bottom of each page in appendix II may be used.

### Finding the Angle.

Problems are frequently encountered in which two sides are known in a right triangle, but neither of the acute angles is known. For example, by applying the Pythagorean Theorem we can verify that the triangle in figure 20 is

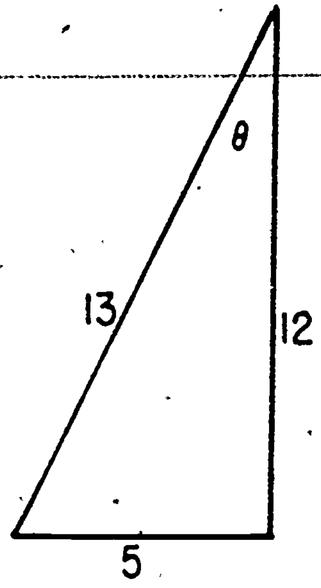


Figure 20.—Using trigonometric ratios to evaluate angles.

a right triangle. The only information given concerning angle $\theta$ is the ratio of sides in the triangle. The size of $\theta$ is calculated as follows:

$$\tan \theta = \frac{5}{12} = 0.4167$$

$\theta$ = the angle whose tangent is 0.4167

Assuming that the sides and angles in figure 20 are in approximately the correct proportions, we estimate that angle $\theta$ is about 20°. The table entries for the tangent in the vicinity of 20° are slightly too small since we need a number near 0.4167. However, the tangent of 22°36' is 0.4163, and the tangent of 22°42' is 0.4183. Therefore, $\theta$ is between 22°36' and 22°42'.

## Interpolation

It is frequently necessary to estimate the value of an angle to a closer approximation than is available in the table. This is equivalent to estimating between table entries, and the process is called INTERPOLATION. For example, in the foregoing problem it was determined that the angle value was between 22°36' and 22°42'. The following paragraphs describe the procedure for interpolating to find a closer approximation to the value of the angle.

The following arrangement of numbers is recommended for interpolation:

$$\begin{array}{cccc} & \text{ANGLE} & \text{TANGENT} & \\ 6' \left\{ \begin{array}{c} 22°36' \\ \theta \\ 22°42' \end{array} \right. & & \left. \begin{array}{c} \left. \begin{array}{c} 0.4163 \\ 0.4167 \end{array} \right\} .0004 \\ 0.4183 \end{array} \right\} .0020 & \end{array}$$

The spread between 22°36' and 22°42' is 6', and we use the comparison of the tangent values to determine how much of this 6' spread is included in $\theta$, the angle whose value is sought. Notice that the tangent of $\theta$ is different from tan 22°36' by only 0.0004, and the total spread in the tangent values is 0.0020. Therefore, the tangent of $\theta$ is $\frac{0.0004}{0.0020}$ of the way between the tangents of the two angles given in the table. This is 1/5 of the total spread, since

$$\frac{0.0004}{0.0020} = \frac{4}{20} = \frac{1}{5}$$

Another way of arriving at this result is to observe that the total spread is 20 ten-thousandths and that the partial spread corresponding to angle $\theta$ is 4 ten-thousandths. Since 4 out of 20 is the same as 1 out of 5, angle $\theta$ is 1/5 of the way between 22°36' and 22°42'.

Taking 1/5 of the 6' spread between the angles, we have the following calculation:

$$\frac{1}{5} \times 6' = \frac{1}{5} \times 5'60''$$

$$= 1'12'' \text{ (1 minute and 12 seconds)}$$

The 12" obtained in this calculation causes our answer to appear to have greater accuracy than the tables from which it is derived. This apparent increase in accuracy is a normal result of interpolation. Final answers based on interpolated data should be rounded off to the same degree of accuracy as that of the original data.

The value of 1 minute and 12 seconds found in the foregoing problem is added to 22°36', as follows:

$$\theta = 22°36' + 1'12'' = 22°37'12''$$

Therefore $\theta$ is 22°37', approximately.

The foregoing problem could have been solved in terms of tenths and hundredths of a degree, rather than minutes, as follows:

$$
\begin{array}{c c c c c c}
 & \text{ANGLE} & \text{TANGENT} & & & \\
\multirow{3}{*}{0.1^\circ} & 22.60^\circ & 0.4163 & \multirow{2}{*}{0.0004} & & \\
 & \theta & 0.4167 & & & 0.0020 \\
 & 22.70^\circ & 0.4183 & & & 
\end{array}
$$

In this example, we are concerned with an angular spread of 0.10° and $\theta$ is located 1/5 of the way through this spread. Thus we have

$$\theta = 22.60^\circ + \left(\frac{1}{5} \times 0.10^\circ\right)$$

$$\theta = 22.60^\circ + 0.02^\circ$$

$$\theta = 22.62^\circ$$

Interpolation must be approached with common sense in order to avoid applying corrections in the wrong direction. For example, the cosine of an angle decreases in value as the angle increases from 0° to 90°. If we need the value of the cosine of an angle such as 22°39', the calculation is as follows:

$$
\begin{array}{c c c c c}
 & \text{ANGLE} & & \text{COSINE} & \\
 & 22^\circ 36' & \multirow{2}{*}{3'} & 0.9232 & \\
6' & 22^\circ 39' & & & 0.0007 \\
 & 22^\circ 42' & & 0.9225 & 
\end{array}
$$

In this example, it is easy to see that 22°39' is halfway between 22°36' and 22°42'. Therefore, the cosine of 22°39' is halfway between the cosine of 22°36' and that of 22°42'. Taking one-half of the spread between these cosines, we then SUBTRACT from 0.9232 to find the cosine of 22°39', as follows:

$$
\begin{aligned}
\cos 22^\circ 39' &= 0.9232 - \left(\frac{1}{2} \times 0.0007\right) \\
&= 0.9232 - 0.00035 \\
&= 0.92285 \\
&= 0.9229 \text{ (approximately)}
\end{aligned}
$$

Practice problems:

1. Use the table in appendix II to find the decimal value of each of the following ratios:

| | |
|---|---|
| a. tan 45° | d. sin 37°14' |
| b. sin 60° | e. cos 51.5° |
| c. cos 42°6' | f. tan 13.75° |

2. Find the angle which corresponds to each of the following decimal values in appendix II:

| | |
|---|---|
| a. sin $\theta$ = 0.2790 | c. tan $\theta$ = 0.7604 |
| b. cos $\theta$ = 0.9018 | d. sin $\theta$ = 0.8142 |

Answers:

| | |
|---|---|
| 1. a. 1 | d. 0.6051 |
| b. 0.8660 | e. 0.6225 |
| c. 0.7420 | f. 0.2447 |
| 2. a. $\theta$ = 16.2° | c. $\theta$ = 37°15' |
| b. $\theta$ = 25°36' | d. $\theta$ = 54°30' |

## RIGHT TRIANGLES WITH SPECIAL ANGLES AND SIDE RATIOS

Three types of right triangles are expecially significant because of their frequent occurrence. These are the 30°-60°-90° triangle, the 45°-90° triangle, and the 3-4-5 triangle.

### THE 30°-60°-90° TRIANGLE

The 30°-60°-90° triangle is so named because these are the sizes of its three angles. The sides of this triangle are in the ratio of 1 to $\sqrt{3}$ to 2, as shown in figure 21.

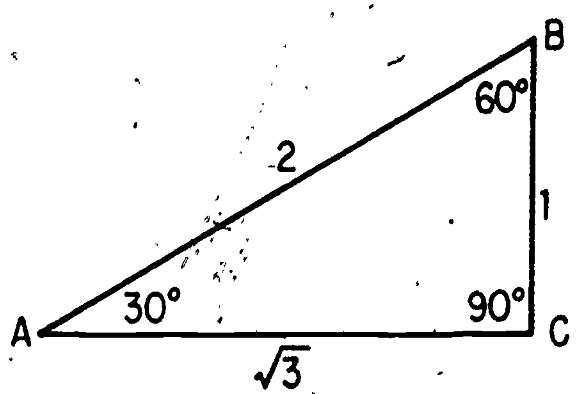


Figure 21.—30°-60°-90° triangle.

The sine ratio for the 30° angle in figure 21 establishes the proportionate values of the sides. For example, we know that the sine of 30° is 1/2; therefore, side AB must be twice as long as BC. If side BC is 1 unit long, then side AB is 2 units long and, by the rule of Pythagoras, AC is found as follows:

$$AC = \sqrt{(AB)^2 - (BC)^2}$$
$$= \sqrt{4 - 1} = \sqrt{3}$$

Regardless of the size of the unit, a 30°-60°-90° triangle has a hypotenuse which is 2 times as long as the shortest side. The shortest side is opposite the 30° angle. The side opposite the 60° angle is $\sqrt{3}$ times as long as the shortest side. For example, suppose that the hypotenuse of a 30°-60°-90° triangle is 30 units long; then the shortest side is 15 units long, and the length of the side opposite the 60° angle is 15 $\sqrt{3}$ units.

Practice problems. Without reference to tables or to the rule of Pythagoras, find the following lengths and angles in figure 22:

1. Length of AC.
2. Size of angle A.
3. Size of angle B.
4. Length of RT.
5. Length of RS.
6. Size of angle T.

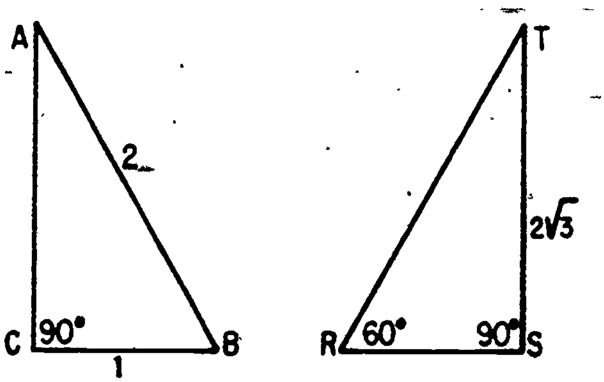


Figure 22.—Finding parts of 30°-60°-90° triangles.

Answers:

1. $\sqrt{3}$
2. 30°
3. 60°
4. 4
5. 2
6. 30°

THE 45°-90° TRIANGLE

Figure 23 illustrates a triangle in which two angles measure 45° and the third angle

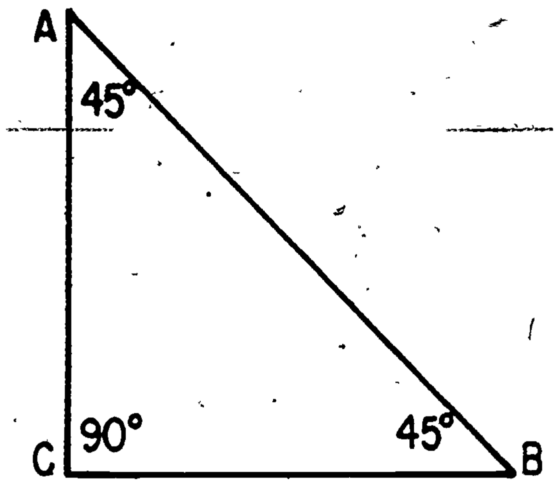


Figure 23.—A 45°-90° triangle.

measures 90°. Since angles A and B are equal, the sides opposite them are also equal. Therefore, AC equals CB. Suppose that CB is 1 unit long; then AC is also 1 unit long, and the length of AB is calculated as follows:

$$(AB)^2 = 1^2 + 1^2 = 2$$
$$AB = \sqrt{2}$$

Regardless of the size of the triangle, if it has two 45° angles and one 90° angle, its sides are in the ratio 1 to 1 to $\sqrt{2}$. For example, if sides AC and CB are 3 units long, AB is 3 $\sqrt{2}$ units long.

Practice problems. Without reference to tables or to the rule of Pythagoras, find the following lengths and angles in figure 24:

1. AB
2. BC
3. Angle B

Answers:

1. 2 $\sqrt{2}$
2. 2
3. 45°

THE 3-4-5 TRIANGLE

The triangle shown in figure 25 has its sides in the ratio 3 to 4 to 5. Any triangle with its sides in this ratio is a right triangle.

It is a common error to assume that a triangle is a 3-4-5 type because two sides are known to be in the ratio 3 to 4, or perhaps 4 to 5. Figure 26 shows two examples of triangles which happen to have two of their sides in the stated ratio, but not the third side. This

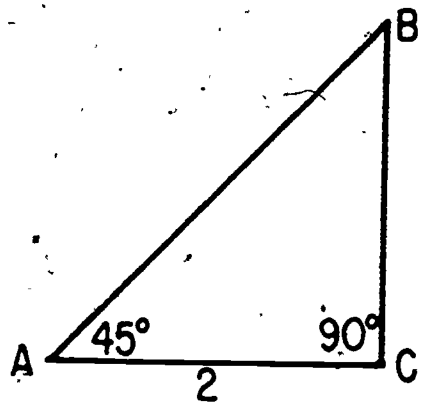


Figure 24.—Finding unknown parts in a 45°-90° triangle.

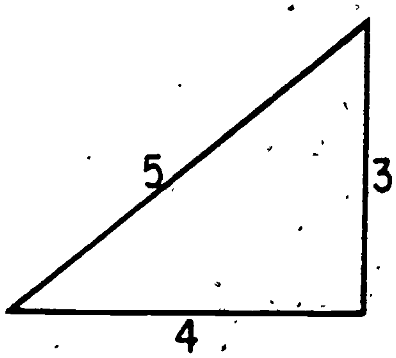


Figure 25.—A 3-4-5 triangle.

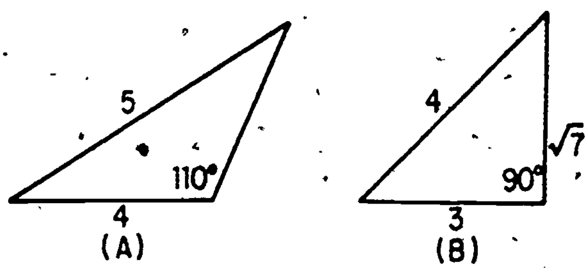


Figure 26.—Triangles which may be mistaken for 3-4-5 triangles.

can be because the triangle is not a right triangle, as in figure 26 (A). On the other hand, even though the triangle is a right triangle its longest side may be the 4-unit side, in which case the third side cannot be 5 units long. (See figure 26 (B).)

It is interesting to note that the third side in figure 26 (B) is $\sqrt{7}$. This is a very unusual coincidence in which one side of a right triangle is the square root of the sum of the other two sides.

Related to the basic 3-4-5 triangle are all triangles whose sides are in the ratio 3 to 4 to 5 but are longer (proportionately) than these basic lengths. For example, the triangle pictured in figure 17 is a 3-4-5 triangle.

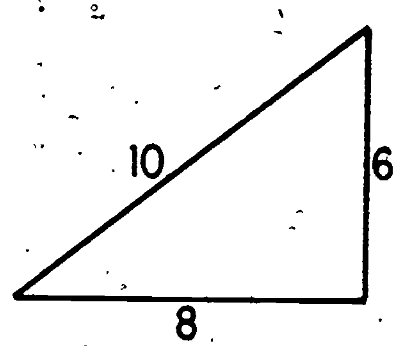


Figure 27.—Triangle with sides which are multiples of 3, 4, and 5.

The 3-4-5 triangle is very useful in calculations of distance. If the data can be adapted to fit a 3-4-5 configuration, no tables or calculation of square root (Pythagorean Theorem) are needed.

EXAMPLE: An observer at the top of a 40-foot vertical tower knows that the base of the tower is 30 feet from a target on the ground. How does he calculate his slant range (direct line of sight) from the target?

SOLUTION: Figure 28 shows that the desired length, AB, is the hypotenuse of a right triangle whose shorter sides are 30 feet and 40 feet long. Since these sides are in the ratio 3 to 4 and angle C is 90°, the triangle is a 3-4-5 triangle. Therefore, side AB represents the 5-unit side of the triangle. The ratio 30 to 40 to 50 is equivalent to 3-4-5, and thus side AB is 50 units long.

Practice problems. Without reference to tables or to the rule of Pythagoras, solve the following problems:

1. An observer is at the top of a 30-foot vertical tower. Calculate his slant range from a target on the ground which is 40 feet from the base of the tower.

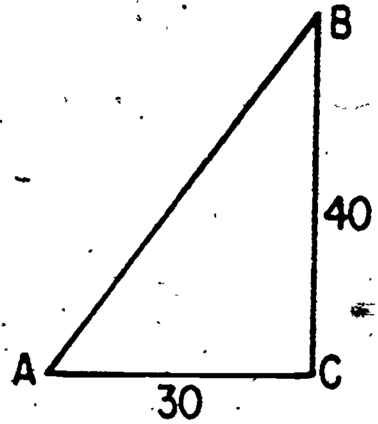


Figure 28.—Solving problems with a 3-4-5 triangle.

2. A guy wire 15 feet long is stretched from the top of a pole to a point on the ground 9 feet from the base of the pole. Calculate the height of the pole.

Answers:

1. 50 feet 2. 12 feet

## OBLIQUE TRIANGLES

Oblique triangles are defined as triangles which contain no right angles. A natural approach to the solution of problems involving oblique triangles is to construct perpendicular lines and form right triangles which subdivide the original triangle. Then the problem is solved by the usual methods for right triangles.

### DIVISION INTO RIGHT TRIANGLES

The oblique triangle ABC in figure 29 has been divided into two right triangles by drawing line BD perpendicular to AC. The length of AC is found as follows:

1. Find the length of AD.

$$\frac{AD}{35} = \cos 40^\circ$$

$$AD = 35 \cos 40^\circ$$

$$= 35\ (0.7660)$$

$$= 26.8 \text{ (approximately)}$$

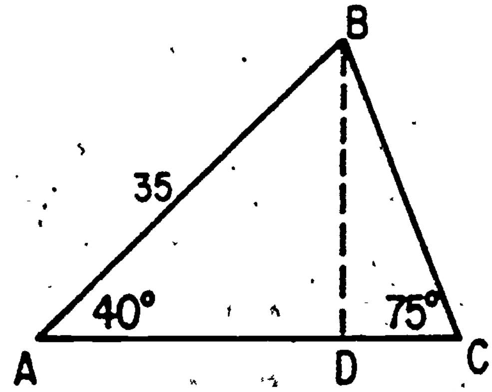


Figure 29.—Finding the unknown parts of an oblique triangle.

CAUTION: A careless appraisal of this problem may lead the unwary trainee to represent the ratio AC/AB as the cosine of 40°. This error is avoided only by the realization that the trigonometric ratios are based on RIGHT triangles.

2. In order to find the length of DC, first calculate BD.

$$\frac{BD}{35} = \sin 40^\circ$$

$$BD = 35 \sin 40^\circ$$

$$= 35\ (0.6428)$$

$$= 22.4 \text{ (approximately)}$$

3. Find the length of DC.

$$\frac{22.4}{DC} = \tan 75^\circ$$

$$DC = \frac{22.4}{\tan 75^\circ} = \frac{22.4}{3.732}$$

$$DC = 6.01 \text{ (approximately)}$$

4. Add AD and DC to find AC.

$$26.8 + 6.01 = 32.81$$

$$AC = 32.8 \text{ (approximately)}$$

### SOLUTION BY SIMULTANEOUS EQUATIONS

A typical problem in trigonometry is the determination of the height of a point such as B in figure 30.

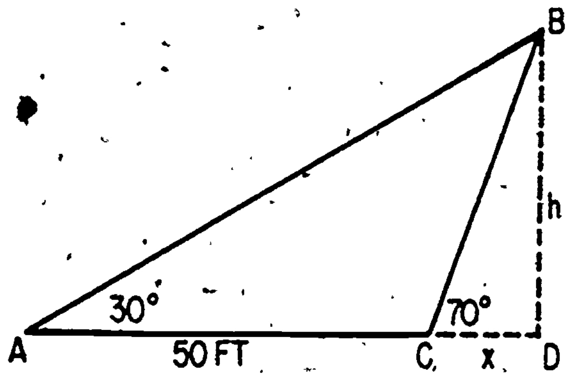


Figure 30.—Calculation of unknown quantities by means of oblique triangles.

Suppose that point B is the top of a hill, and point D is inaccessible. Then the only measurements possible on the ground are those shown in figure 30. If we let h represent BD and x represent CD, we can set up the following system of simultaneous equations:

$$\frac{h}{x} = \tan 70^\circ$$

$$\frac{h}{50 + x} = \tan 30^\circ$$

Solving these two equations for h in terms of x, we have

$$h = x \tan 70^\circ$$

and

$$h = (50 + x) \tan 30^\circ$$

Since the two quantities which are both equal to h must be equal to each other, we have

$$x \tan 70^\circ = (50 + x) \tan 30^\circ$$

$$x\ (2.748) = 50\ (0.5774) + x(0.5774)$$

$$x\ (2.748) - x\ (0.5774) = 28.8$$

$$x\ (2.171) = 28.8$$

$$x = \frac{28.8}{2.171} = 13.3 \text{ feet}$$

Knowing the value of x, it is now possible to compute h as follows:

$$h = x \tan 70^\circ$$

$$= 13.3\ (2.748)$$

$$= 36.5 \text{ feet (approximately)}$$

Practice problems:

1. Find the length of side BC in figure 31 (A).
2. Find the height of point B above line AD in figure 31 (B).

Answers:

1. 21.3 feet
2. 41.7 feet

LAW OF SINES

The law of sines provides a direct approach to the solution of oblique triangles, avoiding the necessity of subdividing into right triangles. Let the triangle in figure 32 (A) represent any oblique triangle with all of its angles acute.

The labels used in figure 32 are standardized. The small letter a is used for the side opposite angle A; small b is opposite angle B; small c is opposite angle C.

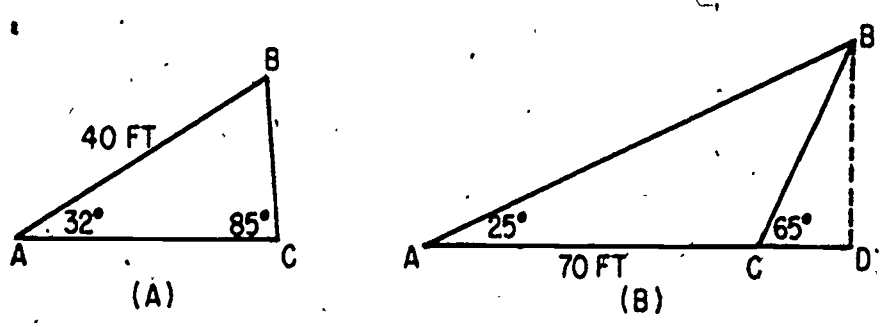


Figure 31 —(A) Oblique triangle with all angles acute; (B) obtuse triangle.

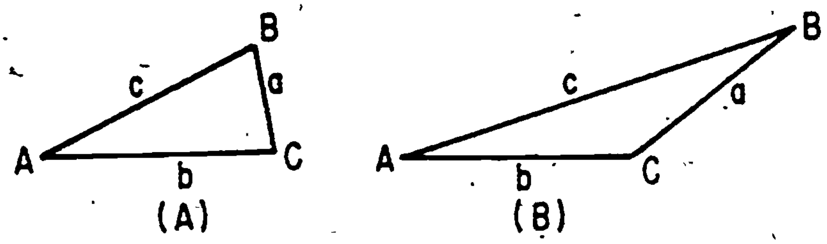


Figure 32.—(A) Acute oblique triangle with standard labels; (B) obtuse triangle with standard labels.

The law of sines states that in any triangle, whether it is acute as in figure 32 (A) or obtuse as in figure 32 (B), the following is true:
true:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

EXAMPLE: In figure 32 (A), let angle A be 15° and let angle C be 85°. If BC is 20 units, find the length of AB.

SOLUTION: By the law of sines,

$$\frac{20}{\sin 15^\circ} = \frac{c}{\sin 85^\circ}$$

$$c = \frac{20 \sin 85^\circ}{\sin 15^\circ}$$

$$c = \frac{20\ (0.9962)}{0.2588} = 77.0$$

# APPLIED PHYSICS

Physics is devoted to finding and defining problems as well as to reaching their solutions. Physics not only teaches a person to be curious about the physical world around him but also gives him a means of satisfying his curiosity. Physics is the basic science that deals with motion, force, and energy as shown in the laws of mechanics, electricity, magnetism, sound, heat, and light.

Your understanding of the weather and the motions of the oceans as well as your ability to analyze the situations that arise in oceanography and meteorology depend upon your knowledge of the application of some of the fundamental principles of physics. This does not mean that you must be able to understand all of the complicated theories of oceanography or meteorology; however, it does mean that you should have a fair working knowledge of some of the more elementary aspects of physics, as applied to the atmosphere and the ocean, as well as other physical laws, in order to perform your duties as a Marine Science Technician in a creditable manner.

## MATTER AND ENERGY

Matter is defined as anything that occupies space and has weight. Matter is around us in some form everywhere in our daily life—the air we breathe, the water we drink, and the food we eat. All of these are various forms of matter. Two basic particles make up the composition of all matter—the atom and the molecule. The molecule is the smallest particle into which matter can be divided without destroying its characteristic properties. In physics, the molecule is the unit of matter. Molecules are composed of one or more atoms. The atom is the smallest particle of certain kinds of matter called chemical elements. The atom, in its simplest form, contains a central part known as the nucleus and has positively charged particles called protons and other particles called neutrons, which have about the same weight as protons, but which have no electrical charge. Surrounding the nucleus and moving about it are negatively charged particles called electrons. Regardless of the number of atoms present, the molecules of any element (an element is a substance that cannot be broken down into anything simpler) always consist of the same kind of atoms. For example, every molecule of oxygen has two atoms of oxygen.

A compound is a substance (or is matter) formed by combining two or more elements. Thus, ordinary table salt is a compound formed by combining two elements—sodium and chlorine. Elements and compounds may exist together without forming new compounds. Their atoms do not combine. This is known as a mixture. Air is a familiar mixture. Every sample of air contains several kinds of molecules which are chiefly molecules of the elements oxygen, nitrogen, and argon, together with the compounds of water vapor and carbon dioxide. Ocean water, too, is another mixture, made up chiefly of water and salt molecules, with a smaller number of molecules of many other compounds as well as molecules of several elements.

Forms of Matter

Matter is found in one or more of the following three states:

1. Solid. Solids are substances which have a definite volume and shape and will retain their original shape and volume after being moved from one container to another. An example is a block of wood or a bar of metal.

2. Liquid. A liquid has a definite volume, because it is almost impossible to pack it into a smaller space. However, when a liquid is moved from one container to another, it will retain its original volume, but will take on the shape of the container into which it is moved. For example, if a glass of water is poured into a larger bucket or pail, the volume remains unchanged but the liquid will occupy a different space in that it conforms to the walls of the container in which it is poured.

3. Gas. Gases have neither a definite shape nor a definite volume. They will not only take on the shape of the container into which they are placed but will expand and fill it, no matter what the volume of the container.

Since gases and liquids flow easily, they are both called fluids. Moreover, many of the laws of physics which apply to liquids apply equally as well to gases.

Matter itself cannot be created or destroyed. It can be changed from one state to another; it can be changed in form and appearance; it can combine with other kinds of matter to form different substances. This fact is called the "Principle of Conservation of Matter."

Changes in Matter

Although matter cannot be created or destroyed, it is constantly undergoing some kind of change. The changes are of three kinds: physical, chemical, and nuclear. In physics we are primarily concerned with the physical change.

1. Physical. In a physical change the molecules remain the same and matter changes only in state or form. Water is a good example. Ordinarily water is a liquid; when the temperature drops to freezing and below, it goes into its solid state (ice); and when the temperature is raised to boiling and above, it becomes steam, which is a gaseous form of water. No new substance is formed. The molecular structure remains the same.

2. Chemical. Chemical change occurs when the composition of the molecules of the substance is changed and a new substance with different properties is produced. For instance, in the example above illustrating physical change, water merely changed its state in the change from liquid to ice or liquid to water vapor. However, when water is changed into hydrogen and oxygen by an electric current, a chemical change has taken place. The water molecules do not now exist, and in their place are three molecules of gas, two of which are hydrogen, and one of which is oxygen.

3. Nuclear. A nuclear change is similar to a chemical change in that new substances with new properties are formed. However, in a chemical change new materials are produced by a rearrangement of the atoms of the original material; in a nuclear change, the changes in the identity of the atoms form new materials. Atom bombs owe their destructive force to the important nuclear changes brought about by man.

Properties and Characteristics of Matter

From our definition of matter (anything that occupies space and has weight), it can be said that all kinds of matter have certain properties in common. Two of these properties are weight and volume. There are several other common properties which are covered briefly in this section. These properties are called general properties of matter.

PERMANANCE.—Matter cannot be manufactured or destroyed. Its form or state can be changed by one of the processes previously mentioned.

IMPENETRABILITY.—Two objects cannot occupy the same space at the same time. For example, a boat pushes aside the water as it travels. Also, when a bottle is filled with water, the air is forced out to make room for the water.

POROSITY.—In all matter there exists minute spaces or pores between the particles. We can cite two examples of extremes in this case. A sponge has pores, or openings, that can readily be seen by the naked eye while a block of metal or wood has very small pores. However, they are still present even though not visible to the naked eye.

INERTIA.—This property of matter is perhaps the most fundamental of all attributes of matter. In short, it is the tendency for an object to stay at rest if it is in a position of rest, or to continue in motion if it is moving. Inertia makes bodies hard to start and hard to stop.

VOLUME.—Since all matter occupies space, it must have volume; that is, it has length, width, and depth. Volume is said to have dimensions of length cubed because it is the product of three linear measurements.

MASS.—Mass is defined as the measure of the quantity of matter contained in a body. This property does not vary. For example, a sponge can be compressed or allowed to expand back to its original shape and size, but the mass does not change. The mass will remain the same on the earth as on the sun or moon, or at the bottom of a valley or the top of a mountain. Only if something is taken away or added to it is the mass changed. Later in the section its meaning will have a slightly different connotation.

GRAVITATION.—We know from our previous studies in science that every body attracts or pulls upon other bodies. In other words, all matter has gravitation. Air masses exert a gravitation attraction. One of Newton's laws states that the force of attraction between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance between their two centers. Therefore, a mass will have less gravitational pull on it at the top of a mountain than it would at sea level because the center is displaced farther away from the gravitational pull of the center of the earth. Gravity also varies with latitude, being less at the Equator than at the poles due to a greater distance from the center of the earth.

WEIGHT.—The weight of an object is a measure of gravitational attraction and depends upon the mass or quantity that it contains and the amount of gravitational attraction the earth has for it. Weight is a force, and as such it should be expressed in units of force, such as the dyne in the cgs system. A dyne is the force that will give to a mass of 1 gram an acceleration of 1 centimeter per second per second. The force necessary to accelerate 1 gram 980.665 cm/sec$^2$ at 45° lat would be 980.665 dynes.

Since gravity varies with latitude and height above sea level, so must weight vary with the same factors. Thus, you will weigh more at the poles than at the Equator and more at sea level than atop a mountain. In a comparison of mass and weight, mass will remain constant no matter where it is, but weight will vary with latitude and height above sea level.

DENSITY.—The mass of a unit volume of a substance or mass per unit volume is called density. Usually we speak of substances being heavier or lighter than another when comparing equal volumes of the two substances.

Since density is a derived quantity, the density of an object can be computed by dividing its mass (or weight) by its volume. The formula for determining the density of a substance is

$$D = \frac{M}{V}$$

where D stands for density, M for mass, and V for volume.

Since mass in the cgs system is measured in grams, and the unit volume in the cgs system is 1 cubic centimeter, density may be expressed as grams per cubic centimeter. We then have the equation

$$D = \frac{g}{cm^3}$$

In the metric system, 1 cubic centimeter of water has a mass of approximately 1 gram; therefore, the density of water is given as 1 gram per cubic centimeter or 1 g/cm$^3$. In the English system, the density of water is 62.4 pounds per cubic foot, or 62.4 lb/ft$^3$.

The density of gases is derived from the same basic formula as the density of a solid.

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Pressure, volume, and temperature all affect the density of gases. This effect is discussed later in this section under gas laws. Another notable effect is the moisture content of a gas.

Helicopters have their greatest lift and attain highest speeds in air of high density. Thus, pilots of these craft prefer to fly under conditions of low temperature and high pressure since this is when the air is most dense. Too, pilots of jet aircraft have a great interest in the density of the air because air density not only affects speed, rate of climb, and fuel consumption, but it also plays an important role in determining the length of runway necessary for takeoff.

SPECIFIC GRAVITY.—The specific gravity of a substance is the ratio of the density of the substance to the density of water—

$$\text{Specific gravity} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number which tells how many times a substance is heavier than water. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 62.4 times 4 or 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density. Because the density of water is 1 gram per cubic centimeter, a substance whose specific gravity is 4 has a density of 4 grams per cubic centimeter. Specific gravity and density are independent of the size of the sample under consideration and depend only on the material of which the substance is made.

The unit of volume most used is a cube with an edge of unit length. In the English system, volume is usually measured in cubic feet or cubic inches. Thus, the unit is a cube 1 foot or 1 inch on each edge. In the metric system, the cubic centimeter or cubic meter is used. Another unit commonly used in the metric system is the LITER. The liter is the volume of a cube 10 centimeters on each edge. The liter, therefore, contains 1,000 cubic centimeters.

Systems of Unit and Measure

From very early times it has been necessary to have some method of weighing and measuring the fundamental quantities in physics. The three customarily chosen in physics are length, mass, and time.

A complete set of units for measurement of both the fundamental and derived quantities is called a system. In order to simplify relationships between different kinds of measurements, scientists have adopted several systems. Each is named in terms of the three fundamental units upon which it is based. The system most widely used in the United States is the FPS, or foot-pound-second system, called the English system.

The system most widely used throughout the civilized world with the exception of the United States, England, Canada, and Russia is the metric system. This system employs the cgs or centimeter-gram-second system. The metric system is most widely used by scientists the world over.

The metric system is a decimal system similar to that used in the money system of the United States, in that each unit is one-tenth the size of the next larger unit of measure. Since it is the system most widely used, and it is not improbable that before many years this system will receive worldwide adoption, it is the system discussed here.

The metric system is not difficult to learn. The meter is the unit of length and the gram is the unit of mass. The common subdivisions of each of these units is then broken down by the use of certain prefixes such as centi—meaning one one-hundredth—and milli—meaning one one-thousandth. The most common multiple for these units is formed by using the prefix kilo which means one thousand. Table 17 shows the measures of length in the metric system. A meter is equivalent to approximately 39.37 inches. Greek and Latin prefixes are used to indicate larger or smaller units of the meter.

Other quantities derived from length are the area and the volume. The standard unit of measure for area is the square centimeter, or $cm^2$. For volume the standard unit of measure is the cubic centimeter, or $cm^3$.

Measures of weight in the metric system are formed by adding the Greek and Latin prefixes to the gram. There are approximately 454 grams to a pound. The kilogram is 1,000 grams and is equivalent to about 2.2 pounds.

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Table 17. —Metric measures of length.

| | |
|---|---|
| Micrometer . . . . . | 1 1/1,000,000 of a meter |
| Millimeter. . . . . | 1 1/1,000 of a meter |
| Centimeter. . . . . | 1 1/100 of a meter |
| Decimeter . . . . . | 1/10 of meter |
| Dekameter . . . . . | 10 meters |
| Hectometer. . . . . | 100 meters |
| Kilometer . . . . . | 1,000 meters |
| Megameter. . . . . | 1,000,000 meters |

In both the English and the metric systems, the second is the standard unit of time.

In the application of physics to Marine Science, we may find that the units of mass, length, and time may be used to express different terms with the use of dimensions as listed in table 18.

Table 18.-Units and Dimensions

| TERM | DIMENSION | UNITS |
|---|---|---|
| Mass | $M$ | g |
| Length | $L$ | cm |
| Time | $T$ | sec |
| Velocity | $LT^{-1}$ | cm/sec |
| Acceleration | $LT^{-2}$ | $cm/sec^2$ |
| Force | $MLT^{-2}$ | $g\ cm/sec^2$ |
| Work | $ML^2T^{-2}$ | $g\ cm^2/sec^2$ |
| Density | $ML^{-3}$ | $g/cm^3$ |
| Pressure | $ML^{-1}T^{-2}$ | $g/cm/sec^2$ |

ENERGY

Energy is defined as the ability to do work. Energy is also something that produces changes in matter. Heat can change water from a liquid to a gas, for example. There are many different kinds of energy, but we are mainly concerned with those kinds which affect the processes in the atmosphere. The energy principle simply stated is that energy is measured by the amount of work a body can do. Work is done only when a force succeeds in moving the body it acts upon. The quantity of work done is equal to the product of the force times the distance moved. Therefore, we derive the formula

$$W=Fd \quad \text{or} \quad ML^2T^{-2} = MLT^{-2} \times L = ML^2T^{-2}$$

where W is the amount of work done, F is the force, and d is the distance.

Work is measured in the English system by the foot-pound; that is, if 1 pound of force acts through a distance of 1 foot, it performs 1 foot-pound of work. In the metric cgs system, if the force is measured in dynes, the distance is measured in centimeters, and the work is denoted in ergs (the work done by a force of 1 dyne exerted for a distance of 1 cm). Another unit used to measure work is the joule. It is simply 10,000,000 ergs, and is equivalent to just under three-fourths of a foot-pound.

Two kinds of energy are important in our study of atmospheric physics. They are potential energy (or energy at rest or of position) and kinetic energy (or the energy of motion), which are discussed under energy considerations later in this section.

## MASS, FORCE, AND MOTION

### MASS AND INERTIA

Any general discussion of the principles of physics would be incomplete without some consideration of the way in which mass, force, and motion are related. Even the tiny particles of atomic physics have mass and motion; in fact, the physical laws relating to mass and motion provide very important clues for use in the difficult task of predicting the behavior of these invisible particles. Some of the same laws governing their motion are also applied to the ordinary objects we encounter every day.

You have probably learned that a body is accelerated (made to move faster) by the application of a force. The acceleration of a body is directly proportional to the force causing that acceleration. This information, however, is not enough to write an equation involving force and acceleration in familiar units. Acceleration depends also upon the mass of the body that is being moved.

The term MASS refers to that property of matter which in ordinary language is described as INERTIA. We know from experience that an object at rest never starts to move by itself; a push or a pull must be exerted on it by some other object. This external force is needed because the body has inertia. To give a numerical value to this inertia, it is compared with

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some standard, the inertia of which is taken as one. When the inertia of other bodies is taken in respect to this standard, it is called mass. Therefore, mass is a measure of inertia. Suppose two objects of identical size and shape are made of different materials. If gravity were not present, masses of the two objects could be judged by their inertia-that is, by their resistance to change in velocity.

The observations that have been made point to a connection between force, mass, and acceleration. It can be shown experimentally that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body or that

$$a = F/m \quad \text{or} \quad LT^{-2} = MLT^{-2} \times M^{-1} = LT^{-2}$$

where a is the acceleration, F is the force exerted, and m is the mass of the body. In the case of falling bodies, the force of gravity for a large mass is greater than that for a small mass, so that the acceleration of gravity becomes a constant. The preceding equation is the mathematical representation of Newton's second law. It is probably the most important equation in mechanics (this is the name given to the branch of physics which deals with force and motion). It is usually stated in the form

$$F = ma \quad \text{or} \quad MLT^{-2} = M \times LT^{-2} = MLT^{-2}$$

When using this equation, be sure to use units of mass and not units of weight.

## FORCE

Force is a push or pull acting upon a body. Many people think that all force comes from muscular effort, such as the effort required to push a box resting on the deck. However, water in a can exerts force on the sides and bottom of the can and an upward force on any object on the surface of the water. A tug exerts force on the ship it is pushing or pulling. In all of these examples, the body exerting the force is in contact with the body on which the force is exerted; forces of this type are called contact forces. There are also forces which act through empty space without contact. The force of gravity exerted on a body by the earth-known as the weight of the body-is one example of this type of force. Forces which act through empty space without contact are called action-at-a-distance forces. Electric and magnetic forces are action-at-a-distance forces.

## VECTORS

Problems arise in which it is necessary to deal with one or more forces acting on a body. To solve problems involving forces, a means of representing forces must be found. A force is completely described when its magnitude, direction, and point of application are given. Because a vector is a line which represents both magnitude and direction, a vector may be used to describe a force. The length of the line represents the magnitude of the force, the direction of the line represents the direction in which the force is being applied, and the starting point of the line represents the point of application of the force. For example, to represent a force of 10 pounds acting due east on point A, draw a line 10 units long, starting at point A and extending in a direction 90° clockwise from north (See fig. 33.).

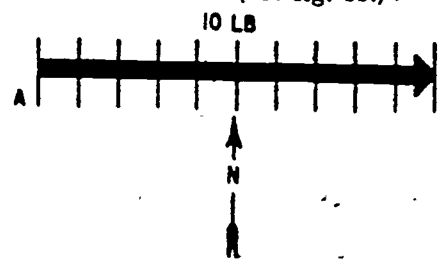


Figure 33.—Example of a vector.

## COMPOSITION OF FORCES

If two or more forces are acting simultaneously at a point, the same effect can be produced by a single force of the proper size and direction. This single force, which is equivalent to the action of two or more forces, is called the resultant. Putting component forces together to find the resultant force is called composition of forces. The vectors representing the forces must be added to find the resultant. Because a vector represents both magnitude and direction, the method for adding vectors differs from the procedure used for scalar quantities, which have no direction.

Consider this example: Find the resultant force when a vertical force of 5 pounds and a horizontal force of 10 pounds are applied at point A. (See fig. 34.) The resultant force may be found as follows: Represent the given forces by vectors AB and AC drawn to a suitable scale, as in figure 34. At points B and C, draw dotted lines perpendicular to AB and AC, respectively. From A draw a line to the point of intersection X of the dotted lines. Vector AX represents the resultant of the two forces. Thus, when two mutually perpendicular forces act on a point, the vector representing the resultant force is the diagonal of a rectangle. The length of AX, on the same scale as that for the two original forces, is the size of the resultant force; the angle $\theta$ gives the direction with respect to the horizontal.

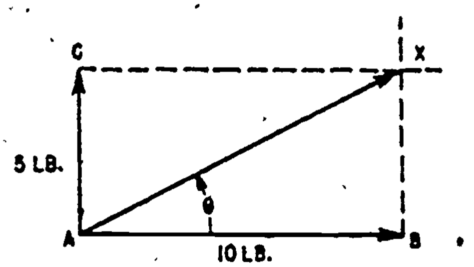


Figure 34.—Composition of two right-angle forces.

When it is desired to find the resultant of two forces which are not at right angles, the following graphic method may be used. Let AB and AC (fig. 35) represent the two forces drawn accurately to scale. From point C draw a line parallel to AB and from point B draw a line parallel to AC. The lines will intersect at a point X, as shown in figure 35. The force AX is the resultant of the two forces AC and AB. Note that the two dotted lines and the two given forces make a parallelogram ACXB. Solving for the resultant in this manner is called the parallelogram method. The size and direction of the resultant may be found by measurement from the figure drawn to scale. This method applies to any two forces acting on a point whether they act at right angles or not. Note that the parallelogram becomes a rectangle for forces acting at right angles.

Consider the following problems as practical examples of combining forces:

1. A supply barge is anchored in a river during a storm. If the wind acts westward on it with a force of 4,000 pounds and the tide acts southward on it with a force of 3,000 pounds, what is the direction and the magnitude of the resultant force acting upon the barge? Figure 36 shows the forces acting upon the barge. If the force vectors have been drawn to scale, the magnitude and direction of the resultant may be obtained by measuring the length of the diagonal of the completed parallelogram and the angle the diagonal makes with a side of the parallelogram. The resultant can be found also by geometry and trigonometry.

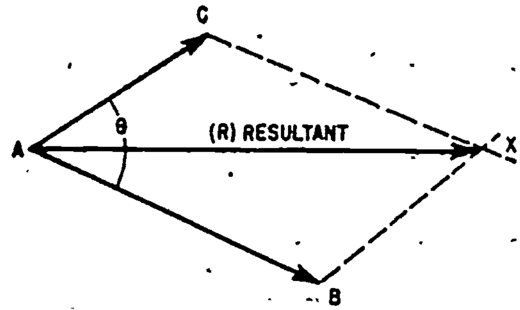


Figure 35.-Graphic method of the composition of forces.

From the Pythagorean relationship:

$$
\begin{aligned}
R^2 &= 3000^2 + 4000^2 \\
R^2 &= (3 \times 1,000)^2 + (4 \times 1,000)^2 \\
R^2 &= (3^2 \times 1,000^2) + (4^2 \times 1,000^2) \\
R^2 &= (1,000^2) \times (3^2 + 4^2) \\
R^2 &= (1,000^2) \times (25) \\
R &= \sqrt{(1,000^2) \times (25)} = (1,000) \times (5) \\
R &= 5,000 \text{ lb}
\end{aligned}
$$

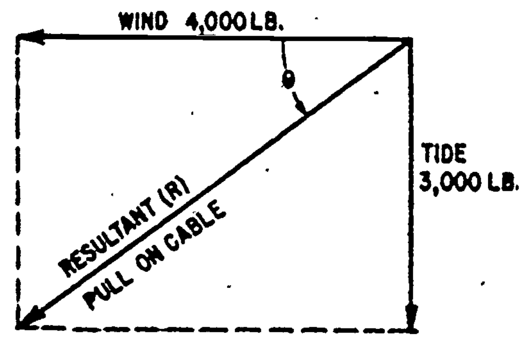


Figure 36.-Problem using the composition of forces.

From trigonometry:

$$
\begin{aligned}
\tan\ \theta &= \frac{\text{opposite side}}{\text{adjacent side}} \\
\tan\ \theta &= \frac{3,000}{4,000} = 0.750 \\
&= 36.9^\circ
\end{aligned}
$$

The resultant is a force of 5,000 pounds acting at an angle of 36.9° with the direction of the wind or in a direction of 233.1° (270°-36.9° = 233.1°).

2. With a slight modification, the parallelogram method of addition applies also to the reverse operation of subtraction. Consider the

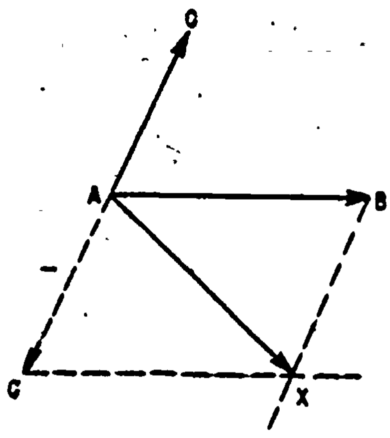


Figure 37.-Parallelogram method of subtracting forces.

problem of subtracting force AC from force AB. (See fig. 37.) First, force AC is reversed in direction giving -AC. Then, forces -AC and AB are added by the parallelogram method, giving the resultant AX, which in this case is the difference between forces AB and AC. A simple check to verify the results consists of adding AX to AC; the sum or resultant should be identical with AB.

## LAWS OF MOTION

The atmosphere and hydrosphere are constantly in motion. This motion does not just happen of its own accord; there are forces at work which cause it to move. Some forces cause it to move from one elevation, or height, to another as convective currents. Other factors cause it to move in various directions with a great range of speed. Still other factors cause it to move in either a clockwise or counterclockwise fashion over wide areas. Perhaps a review of Newton's laws of motion will aid you in understanding some of the reasons why the atmosphere and hydrosphere move as they do.

### NEWTON'S LAWS

Sir Issac Newton, a foremost English physicist, formulated three important laws relative to motion. In his first law, the law of inertia, he stated that every body continues in its state of rest or uniform motion in a straight line unless it is compelled to change by applied forces. Although the atmosphere is a mixture of gases and it has the properties peculiar to gases, it still behaves in many respects as a body when considered in the terms of Newton's law. There would be no movement of great quantities of air unless there was a force to cause it. For instance, air moves from one area to another because there is a force (or forces) great enough to change its direction or to overcome its tendency to remain at rest.

The second of Newton's laws of motion, force and acceleration, states that change of motion of a body is proportional to the applied force and takes place in the direction of the straight line in which that force is applied. In respect to the atmosphere, this means that the change of the motion of the atmosphere is determined by the force acting upon it and takes place in the direction of that force.

Newton's third law of motion, reacting forces, states that to every action there is always an equal and opposite reaction, or the mutual actions of two bodies are always equal and oppositely directed. Consequently, there is never a force acting in nature unless there are two bodies, one impressing, or exerting, the force and the other being impressed by force. Still another aspect of the law is that a force cannot exist by itself; it must exist along with another force. It is clear, then, that there must be at least two bodies and two forces. In the atmosphere there are many masses, or bodies, of air, each exerting a force and having a force exerted against it.

### BALANCE OF FORCES—WINDS

Newton's first two laws of motion indicate that motion tends to be in straight lines and only deviates from such lines when acted upon by another force, or by a combination of forces. The air tends, for instance, to move in a straight line from a high-pressure area to a low-pressure area. However, there are forces which prevent the air from moving in a straight line.

### PRESSURE GRADIENT FORCE

The variation of heating (and consequently the variations of pressure) from one locality to another is the initial factor that produces movement of air or wind. The most direct path from high to low pressure is one along which the pressure is changing most rapidly and is called the pressure gradient. Pressure gradient force is the force that moves air from an area of high pressure to an area of low pressure. The velocity of the wind depends upon the pressure gradient. If the pressure gradient is steep, the wind speed is strong; if the pressure gradient is weak, the wind speed is light.

## CORIOLIS EFFECT

If pressure gradient force were the only force affecting windflow, the wind would blow at right angles across isobars (lines connecting points of equal barometric pressure) from high to low pressure. From observation we know the wind actually blows parallel to isobars above any frictional level. Therefore, other factors must be affecting the windflow, and one of these factors is the rotation of the earth. A particle at rest on the earth's surface is in equilibrium. If the particle starts to move because of a pressure gradient force, its relative motion is affected by the rotation of the earth. If a mass of air from the Equator moves northward, it is deflected to the right, so that a south wind tends to become a southwesterly wind.

An air mass moving from the North Pole tends to become a northeasterly wind. This deflection is known as the Coriolis effect and is stated as a law. (See fig. 38.) This law states that when a mass of air starts to move over the earth's surface, it is deflected to the right of its path in the Northern Hemisphere and to the left of its path in the Southern Hemisphere. Coriolis effect is dependent upon the latitude and speed of the moving air mass. It is greatest at the poles and nonexistent at the Equator. It increases as the speed of the moving air mass increases.

In figure 38, note that if an object at point A in space is moved toward point B in space, an observer in space would see the object move from A to B along a straight line in space. An observer at point C on the rotating plane, however, would find himself under point B when the object arrived at point B in space. It would appear to the observer on the rotating plane that a force D had been acting on the moving object to push it to the right of its path. This effect is the Coriolis

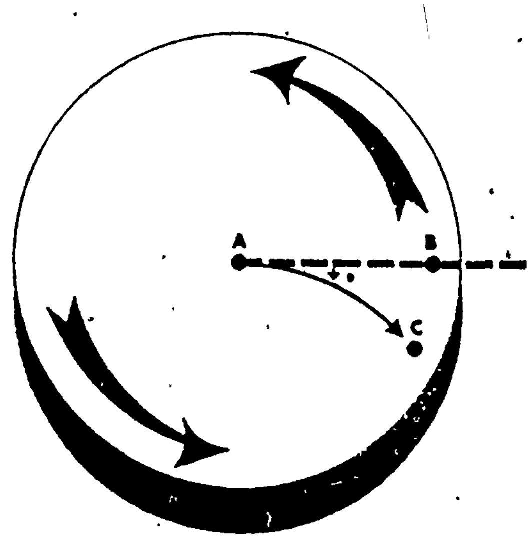


Figure 38.—Coriolis effect.

(or deflecting) effect. Study illustration 38 carefully; note that no actual force is involved and also that no actual deflection has taken place. The deflection is apparent; that is, it appears to be a deflection caused by a force. In Marine Science, we speak of this deflection as the Coriolis effect. This effect can be further illustrated by rotating a piece of paper while trying to draw a straight line between a point on the paper and a fixed point off the paper.

## CENTRIFUGAL EFFECT

According to Newton's first law of motion, a body in motion continues in the same direction in a straight line and with the same speed unless acted upon by some external force. Therefore, for a body to move in a curved path, some force must be continually applied. The force restraining bodies to move in a curved path is called the centripetal force, and it is always directed toward the center of rotation. When a rock is whirled around on a string, the centripetal force is afforded by the tension of the string.

Newton's third law states that for every action there is an equal and opposite reaction. Centrifugal force is the reacting force which is equal to and opposite in direction to the centripetal force. Centrifugal force, then, is a force directed outward from the center of rotation.

As you know, a bucket of water can be swung over your head at a rate such that the water does not come out. This is an example of both centrifugal and centripetal force. The water is being held in the bucket by centrifugal force tending to pull it outward. The centripetal force, the force holding the bucket and water to the center, is your arm swinging the bucket. As soon as you cease swinging the bucket, the forces cease and the water falls out of the bucket. Figure 39 is a simplified illustration of centripetal and centrifugal force.

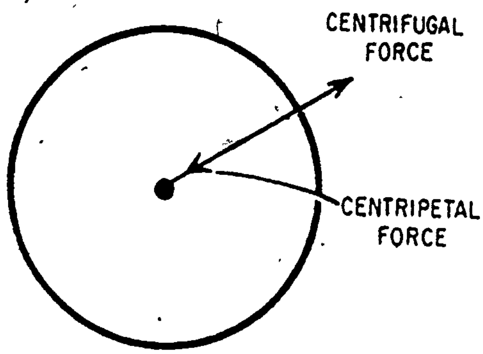


Figure 39.—Simplified illustration of centripetal and centrifugal force.

High- and low-pressure systems can be compared to rotating disks. Centrifugal effect tends to fling air out from the center of rotation of these systems. Therefore, when winds tend to blow in a circular path, centrifugal effect (in addition to pressure gradient and Coriolis effects) influences these winds.

## SPEED AND VELOCITY

The terms "speed" and "velocity" are frequently used interchangeably. However, it should be understood that the two are not the same. Speed is the rate at which a body moves, whereas velocity describes both the RATE at which a body moves and the DIRECTION in which it travels.

In meteorology, speed is the term that should be used when only rate of movement is meant. When direction is involved along with speed, the two should be expressed as "wind direction and speed."

## CIRCULAR MOTION

Motion that takes a circular path is contrary to the natural tendency of motion to be in straight lines. As mentioned earlier, air tends to move from one pressure area to another in straight lines. Air moves in a circular path as a result of the balance of the effective forces or effects—pressure gradient, Coriolis, and centrifugal.

We have applied Newton's Laws of Motion to the atmosphere, but it is easy to relate the same laws of motion to the hydrosphere when we consider both air and water as MASS in motion.

# GAS LAWS

Since the atmosphere is composed of a mixture of gases, familiarity with the fundamental concepts of the most important gas laws and principles will aid you in understanding the effects that temperature, pressure, and volume variations have upon the atmosphere. Besides the basic gas laws, there are other physical aspects of the atmosphere which must be considered.

## ATMOSPHERIC PRESSURE

Pressure is defined as force per unit area. Atmospheric pressure is the force per unit area exerted by the atmosphere in any part of the atmospheric envelope. Therefore, the greater the force exerted by the molecules of the air for any given area, the greater the pressure. Air pressure at any given altitude within the atmosphere is determined by the weight of the atmosphere pressing down from above. Therefore, the pressure decreases with altitude because the weight of the atmosphere decreases. Although the pressure varies on a horizontal plane from day to day, the greatest pressure variations are with changes in altitude. Nevertheless, horizontal variations of pressure are important in meteorology because they cause or help to cause good and bad weather.

At sea level, the average pressure is about 1,013 millibars (14.7 pounds per square inch). It has been found that the pressure decreases by half for each 18,000-foot increase in altitude. Thus, at 18,000 feet one can expect an average pressure of about 500 millibars (7.35 pounds per square inch), and at 36,000 feet a pressure of only 250 millibars (3.68 pounds per square inch), etc. Therefore, it may be concluded that atmospheric pressures are greatest at lower elevations because the total weight of the atmosphere is greatest at these points.

Atmospheric pressure is normally measured in meteorology by the use of a mercurial or aneroid barometer. Pressure is measured in many different units. One atmosphere of pressure is 29.92 inches of mercury, 760 millimeters of mercury, 1,013.25 millibars, 14.7 pounds per square inch, or 1,033 grams per square centimeter. These measurements are made under standard conditions. The U. S. Standard Atmosphere assumes a mean sea level temperature of 15°C, a standard sea level pressure of 1,013.2 millibars or 29.92 inches of mercury, a temperature lapse rate of 0.65°C per 100 meters up to 11 kilometers, and a tropopause and stratosphere temperature of -56.5°C.

STANDARD CONDITIONS

The conditions under which gases must be compared, densities determined, and gas constants derived are known as the standard conditions for gases. The standard conditions are a pressure of 760 millimeters of mercury (1,013.25 mb) and a temperature of 0°C, sometimes referred to as STP (standard temperature and pressure).

KINETIC THEORY OF GASES

The kinetic theory of gases is very heplful in understanding the behavior of gases. Gases, like some other substances, consist of molecules which have no inherent tendency to stay in one place as do the molecules of a solid. Instead, the molecules of gas, since they are smaller than the space between them, move about at random (but in straight lines until they collide with each other or with other obstructions). However, this movement has an average speed. When gas is enclosed, its pressure depends on the number of times the molecules strike the surrounding walls. The number of blows which the molecules strike per second against the walls remains constant as long as the temperature and the volume remain constant.

If the volume (the space occupied by the gas) is decreased, the density of the gas is increased. Density is defined as mass per unit volume. An object that contains more molecules per unit volume is said to be denser than an object that contains less. Since air is easily compressed, density is directly proportional to pressure. With an increase in density, the number of blows against the wall is increased, thereby increasing the pressure, the temperature remaining constant. Temperature is a measure of the molecular activity of the gas molecules and a measure of the internal energy of a gas. When the temperature is increased, there is a corresponding increase in the speed of the molecules; they strike the walls at a faster rate, thereby increasing the pressure, provided the volume remains constant.

Temperature is therefore closely related to the volume, pressure, and density of gases. The earth's atmosphere (the air) is a mixture of gases.

How do heat and humidity influence pressure? Moist air is lighter than dry air and so exerts less pressure. An increase in temperature allows an increase in moisture content and lightens air in that manner. More important, heat expands air, which also makes it lighter per unit volume.

We can summarize this discussion with a few statements as they apply to the atmosphere. They are as follows:

1. An increase in atmospheric pressure results in an increase in atmospheric density. Conversely, a decrease in pressure results in a decrease of density.

2. An increase in moisture in the air decreases atmospheric density. Conversely, a decrease in moisture increases the density.

3. An increase in temperature causes air to expand and lowers its pressure and density. It also increases its capacity to hold moisture. Conversely, a decrease in temperature contracts air and increases its pressure and density; it also decreases the atmosphere's capacity to hold moisture.

The laws governing the behavior of gases and mixtures of gases are given in the following sections.

DALTON'S LAWS

The laws relative to the pressure of a mixture of gases were formulated by the English physicist, John Dalton. One of the laws states that the partial pressures of two or more mixed gases (or vapors) are the same as if each filled the space alone. The other law states that the total pressure is the sum of all the partial pressures of gases and vapors present in an enclosure.

Water vapor, in the atmosphere, for instance, is independent of the presence of other gases; the vapor pressure is independent of the pressure of the dry gases in the atmosphere, and vice versa. The vapor pressure for any given temperature has a maximum limit; this limit is reached when the air is saturated (can hold no more moisture at that temperature and pressure). However, the total atmospheric pressure is found by adding all the pressures—those of the dry air and the water vapor.

## BOYLE'S LAW

Boyle's law states that the volume of a gas is inversely proportional to its pressure, provided the temperature remains constant. This means that if the volume is halved, the pressure is doubled. Boyle's law, as it is applied to atmospheric physics, is a fundamental law. Since in the free atmosphere one is not dealing with controlled volumes of gas, Boyle's law is used in conjunction with other laws to provide the solution to various problems in atmospheric physics. The formula for Boyle's law is as follows:

$$VP = V'P'$$

V—initial volume
P—initial pressure
V′—new volume
P′—new pressure

## CHARLES' LAW

In the section on the kinetic theory of gases, it was explained that the temperature of a gas is a measure of the average speed of the molecules of the gas. It was also shown that the pressure the gas exerts is a measure of the number of times per second that the molecules strike the walls of the container and the speed at which they strike it. It then can easily be seen that if the temperature of a gas in a closed container is raised, the speed of the molecules within the gas increases. This causes the molecules to strike the side of the container more times per second and with more force, since they are moving faster. Thus, by increasing the temperature, the pressure is increased. This is stated by Charles' law in the following manner: If the volume of an enclosed gas remains constant, the pressure is directly proportional to the absolute temperature. Therefore, if the absolute temperature is doubled, the pressure is doubled; if the absolute temperature is halved, the pressure is halved.

Charles' law, as it is applied to atmospheric physics, is one of the foundation laws. The formula for Charles' law is as follows:

$$VT' = V'T, \text{ or it can be written } \frac{V}{V'} = \frac{T}{T'}$$

V—Initial volume
T—Initial temperature (absolute)
V′—New volume
T′—New temperature (absolute)

## UNIVERSAL GAS LAW

The universal gas law is a combination of Boyle's law and Charles' law. It states that the product of the initial pressure, initial volume, and new temperature (absolute scale) of an enclosed gas is equal to the product of the new pressure, new volume, and initial temperature. It is a mathematical statement whereby many gas problems can be solved involving principles of Boyle's law and/or Charles' law. The formula is as follows:

$$PVT' = P'V'T$$

P—initial pressure
V—initial volume
T—initial temperature (absolute)
P′—new pressure
V′—new volume
T′—new temperatue (absolute)

## EQUATION OF STATE

The EQUATION OF STATE is a general formula which gives the same information as Boyle's law and Charles' law. It involves a gas constant, which is a value assigned each gas. For instance, the gas constant of air is 2,870 when the pressure is expressed in millibars and the density is expressed in metric tons per cubic meter. The constant may be expressed differently, depending on the system of units used. The following formula is an expression of the equation:

$$P = \rho RT$$

P—pressure in millibars
$\rho$—density
R—gas constant
T—temperature (absolute)

## PASCAL'S LAW

Pascal's law relative to the behavior of FLUIDS under pressure applies, of course, to GASES under pressure, all of which means that a gas transmits undiminished pressure in all directions and on all parts of the enclosing wall. The law states that when an external pressure is applied to any confined fluid at rest, the pressure is increased at every point in the fluid by the amount of external pressure applied. This means that the pressure of the atmosphere is exerted not only downward on the surface of an object, but also in all directions against a surface which is exposed to the atmosphere.

## BERNOULLI'S THEOREM

According to Bernoulli's theorem, pressures are least where velocities are greatest, and pressures are greatest where velocities are least. This is true of liquids and gases. (See fig. 40.)

One of the practical uses of the theorem as applied to meteorology is for forecasting winds of a certain kind. For the purpose of illustration, the Santa Ana wind is used. The condition which produces this wind is a high-pressure area with a strong pressure gradient situated near Salt Lake City, Utah. This gradient directs the windflow into a valley leading to the town of Santa Ana near the coast of California. As the wind enters the valley, its flow is sharply restricted by the funneling effect of the mountain sides. This restriction causes the wind speed to increase, bringing about a drop in pressure in and near the valley. This pressure drop caused by the Bernoulli effect is a valuable forecasting aid in predicting this type of wind.

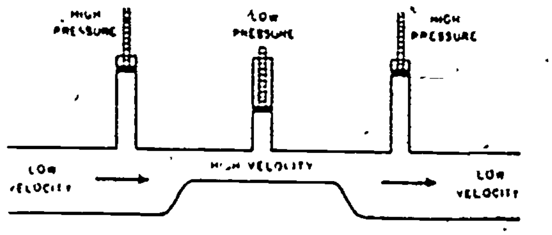

Figure 40.—Example of Bernoulli's theorem.

## ARCHIMEDES' PRINCIPLE

Archimedes' principle states that a body completely or partially submerged in a fluid experiences an upward force equal to the weight of the fluid displaced. Archimedes' principle of buoyancy is also at work in the atmosphere, for the air is a fluid and it has a lifting effect upon everything which it surrounds. This buoyant force is equal to the weight of the air which is displaced. Consequently, the atmosphere, through its buoyancy, exerts a greater pressure upward on the bottom of an object than it does downward on the top of an object. Knowing that the lifting effect of the air is equal to the weight of the air displaced, you may determine the total lift of a balloon as being almost equal to the weight of the air displaced, minus the weight of the gas used for inflation.

## AVOGADRO'S NUMBER

It was the hypothesis of Avogadro that equal volumes of all gases under the same pressure and temperature contain the same number of molecules. The number of molecules in a gram molecule of gas is known as AVOGADRO'S NUMBER; a gram molecule of any gas contains $6.02 \times 10^{23}$ molecules and at 0°C and 76 cm pressure occupies a volume of 22,414 $cm^3$. A gram molecule is the mass of a compound equal numerically to the value of its molecular weight; likewise, a gram atom is the mass of an element numerically equal to the value of its atomic weight.

## HYDROSTATIC EQUATION

The HYDROSTATIC LAW states that the difference in pressure between two points at different levels in a mass of fluid at rest is equal to the weight of a column of the fluid of a unit cross section reaching vertically from one level to another.

For the atmosphere, the hydrostatic law states that the difference in pressure between two points in the atmosphere, one above the other, is equal to the weight of the air column between the two points. Although these two laws are essentially the same, there are two variables which must be considered when applied to the atmosphere. They are temperature and density.

From Charles' law it was learned that when the temperature increases, the volume increases and the density decreases. Therefore, the thickness of a layer of air will be greater when the temperature is increased. To find the height of a pressure surface in the atmosphere (such as in working up an adiabatic chart), you must take these two variables into consideration.

In the computation of a radiosonde observation, a set of tables has been computed and the density has been incorporated in these tables.

The thickness of a layer can be determined by the following formula:

$$Z = (49{,}080 + 107t)\frac{Po - P}{Po + P}$$

Z—altitude difference in feet (thickness of layer)
t—mean temperature in degrees Fahrenheit
Po—pressure at the bottom point of the layer.
P—pressure at the top point of the layer

For example, let us assume that a layer of air between 800 and 700 millibars has a mean temperature of 30°F. Applying the formula, we obtain the following value:

$$Z = (49{,}080 + 107 \times 30)\frac{800 - 700}{800 + 700}$$

$$Z = (49{,}080 + 3{,}210)\frac{100}{1{,}500}$$

$$Z = (52{,}290)\frac{1}{15}$$

$$Z = 3{,}486 \text{ feet } (1{,}063 \text{ meters})$$

We can also apply the HYDROSTATIC EQUATION to the hydrosphere by using the following formula:

$$p = \rho g h$$

p - pressure of the water column

$\rho$ - density of the water column

g - acceleration of gravity

h - height of the water column

## CHANGE OF STATE

A change of state (or change of phase) of a substance describes the change of a substance from a solid to a liquid, liquid to a vapor, vapor to a liquid, liquid to a solid, solid to vapor, or vapor to a solid. In meteorology we are concerned primarily with the change of state of water in the air. Water is present in the atmosphere in any or all of the three states (solid, liquid, and vapor) and changes back and forth from one state to another. The mere presence of water is important, but the change of state of the water in the air is more important because the change of state of water affects the weather directly. The solid state of water is in the form of ice crystals; the liquid state of water is in the form of raindrops; and the vapor state of water is in the form of the unseen gas in the air. Clouds and fogs are composed of tiny droplets of water, not of water vapor.

Energy is involved in the various changes of state which occur in the atmosphere. The energy involved in the various changes of state is primarily in the form of heat. The heat which is used by the substance in changing its state is referred to as the latent heat and is usually stated in calories. The calorie is a unit of heat energy. It is the amount of heat required to raise the temperature of 1 gram of water 1°C. A closer look at some of the major changes of state of the atmosphere helps to clarify latent heat.

## EVAPORATION

Evaporation is the physical process in which a liquid is changed to a gaseous state.

Water undergoes the process of evaporation when changing from the liquid to gaseous state. According to the molecular theory of matter, all matter consists of molecules in motion. The molecules in a bottled liquid are restricted in their motion by the walls of the container. However, on a free surface exposed to the atmosphere, the motion of the molecules in the liquid is restricted by the weight of the atmosphere or, more precisely, by the atmospheric pressure. If the speed of the liquid molecules is sufficiently high, they escape from the surface of the liquid into the atmosphere. As the temperature of the liquid is increased, the speed of the molecules is increased, and the rate at which the molecules escape from the surface also increases. Evaporation takes place only fron the free surface of a substance.

During the process of evaporation, heat is absorbed by the water being vaporized. The amount absorbed is approximately 539 calories per gram of water at a temperature of 100°C. On the other hand, the amount is 597.3 calories if the evaporation takes place at 0°C. This energy is required to keep the molecules in the vapor state and is called the latent heat of vaporization. Since the water needs to absorb heat in order to vaporize, heat must be supplied or else evaporation cannot take place. The air provides this heat. For this reason, evaporation is said to be a cooling process, because by supplying the heat for vaporization, the temperature of the air is lowered.

When evaporation takes place throughout the water, it is called boiling. For water to boil, heat must be added to the water from another source. Since boiling has no application in meteorology, it is not discussed any further.

CONDENSATION

Basically, condensation is the opposite of evaporation, in that water vapor undergoes a change in state from gas to liquid. However, a condition of saturation must be fulfilled before condensation can occur; that is, the air must contain all the water vapor it can hold (100% relative humidity) before any of it can condense from the atmosphere.

In the process of condensation, the heat that was absorbed in evaporation is released from the water vapor into the air and is called the latent heat of condensation.

FUSION

Fusion is the change of state from a solid to a liquid at the same temperature. The number of gram calories of heat necessary to change 1 gram of a substance from the solid to the liquid state is known as the heat of fusion. To change 1 gram of ice to 1 gram of water at a constant temperature and pressure requires roughly 80 calories of heat.

Latent heat of fusion is the heat released by the liquid when a liquid changes into a solid. Since it requires 80 calories to change 1 gram of ice to 1 gram of water, this same amount of heat is released when 1 gram of water is changed to ice; therefore, the latent heat of fusion of water is about 80 calories.

SUBLIMATION

Sublimation is the change of state from a solid to a vapor at the same temperature. The heat of sublimation equals the heat of fusion, plus the heat of vaporization for a substance. The calories required for water to sublime are: 80 + 597.3 = 677.3, if the vapor has a temperature of 0°C. (See figure 41.)

CRYSTALLIZATION

The process of vapor passing directly into the solid form without going through the liquid phase is called crystallization. This process, as well as its reverse, is often called sublimation in meteorology. (See fig. 41.)

The calories liberated by crystallization are the same as those for sublimation. Crystallization frequently takes place in the atmosphere when supercooled water vapor crystallizes directly into ice crystals and forms cirriform clouds.

SPECIFIC HEAT

The specific heat of a substance shows how many calories of heat it takes to raise the temperature of that substance 1°C. Since it takes 1 calorie to raise the temperature of 1 gram of water 1°C, the specific heat of water is 1. The specific heat of a substance plays a tremendous

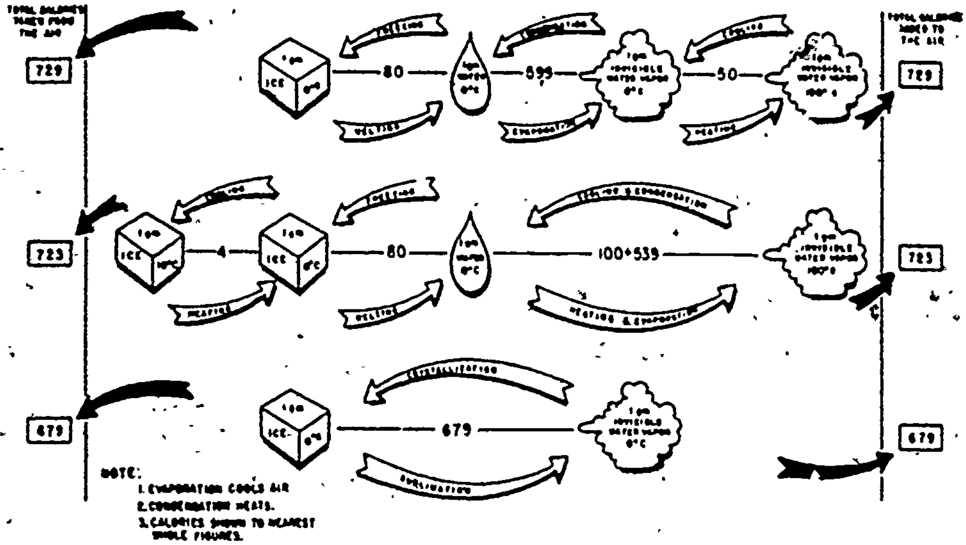


Figure 41.—Thermal history of 1 gram of ice.

role in Marine Science because it is tied directly to temperature changes. For instance, the specific heat of the earth in general is 0.25. This means it takes only 0.25 calorie to raise the temperature of 1 gram of earth 1°C. Stated another way, the earth heats and cools four times as fast as water.

From this you can see that ocean weather is milder and less extreme in temperature than continental weather because it takes four times as long (or four times as much heat/cooling) for water to both heat and cool.

The specific heat of various land surfaces is also different, though the difference between one land surface and another is not as great as between land and water. Dry sand or bare rock has the lowest specific heat. Forest areas have the highest specific heat. This difference in specific heat is another cause for differences in temperature for areas of different types of surfaces which are only a few miles apart.

The specific heat of ice is 0.421 and that of steam is 0.502. These specific heats are reflected in the thermal history of 1 gram of ice as shown in figure 41. They also point out the tremendous amount of energy involved in the fusion, sublimation, and vaporization processes in the atmosphere.

Energy cannot be created or destroyed; however, it can be transformed from one type of energy into another. Even the amount that seems to be lost can be accounted for in the form of light, sound, heat, and the like.

## PRESSURE VERSUS DENSITY

Although very light, air has weight and is affected by gravity. By its weight, air exerts pressure on everything it touches. Since air is a gas, its weight becomes a fluid pressure, exerted in all directions (Pascal's law).

Principal pressure variation comes about with change in altitude. Pressure at any point in a column of water, mercury, or any fluid, depends upon the weight of the column above that point. In the same manner, air pressure at a given altitude is determined by the weight of the air pressing down from above. Air pressure at sea level averages 1,013 millibars (14.7 pounds per square inch).

The weight and compression of the atmosphere cause the molecules of the air to be closer together and more numerous at the bottom of the atmosphere, or where it rests upon the earth's surface. This means that the air at the bottom of the atmosphere is denser than it is at higher

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altitudes.

At the bottom of the atmosphere, where the density of the air is greatest, the greatest amount of atmospheric pressure is exerted. By definition, atmospheric pressure is a force per unit area. Force is equal to mass multiplied by acceleration. There is a change of pressure whenever either the mass of the atmosphere or the accelerations of the molecules within the atmosphere are changed.

Although altitude exerts the dominant control, temperature and moisture alter pressure at any given altitude, especially near the earth's surface where heat and humidity are most abundant. The pressure variations produced by heat and humidity (with heat operating as the senior partner) cause the turbulence and wind that help to make our weather.

## METHODS OF HEAT TRANSFER

The atmosphere is constantly gaining and losing heat, and heat is being transported from one part of the world to the other by wind movements. It is due to the inequalities in gain and loss of heat that the air is almost constantly in motion. The motions and heat transformations are directly expressed by wind and weather. In Marine Science, one is concerned with three methods of heat transfer. They are conduction, convection, and radiation. Heat is transferred from the earth directly to the atmosphere by radiation and conduction, and within the atmosphere by radiation, conduction, and convection. A form of convection, or advection, is used in a special manner in Marine Science; it is discussed as a separate method of heat transfer.

### RADIATION

Radiation refers to the process by which electromagnetic energy is propagated through space. Radiation occurs at the speed of light, that is, about 186,300 miles per second. Radiation travels in straight lines and does not need a material medium through which to pass. It is the most important single means of heat transfer for the earth as a whole. All of the heat the earth receives is by radiation.

### CONDUCTION

Conduction is the transfer of heat from warmer to colder matter by contact. Although of secondary importance in the heating of the atmosphere, it is a means by which air close to the surface of the earth heats during the day and cools during the night. Even if air is a poor conductor (as shown by the use of dead airspace in Thermopane glass and the airspaces used as insulation in buildings), the heating and cooling of air at the immediate surface of the earth are accomplished by conduction.

### CONVECTION

Convection is the transfer of heat from one place to another by bodily transfer of the matter containing it. In Marine Science, the term "convection" is normally applied to vertical transport.

Vertical transfer of heat is accomplished by the motion of warm air to higher levels and the descent of cold air to lower levels where, by radiation and conduction, it can absorb heat from the earth. Convection currents are turbulent and cause bumpiness in the air. On a calm, sunny day, air rises over highways and settles over nearby rivers; this is mainly due to convection.

### ADVECTION

Horizontal transfer of heat is accomplished by motion of the air from one latitude and longitude to another. It is of major importance in the exchange of air between polar and equatorial regions. Much more heat is transported from place to place by the process of advection than by any of the other methods of heat transfer. This can be easily understood when you think of the fact that the air is almost always in motion at all levels of the atmosphere.

Transfer of heat by advection is accomplished not only by the transport of warm air, but also by the transport of warm vapor which releases heat when condensation occurs.

## ENERGY CONSIDERATIONS—STABILITY AND INSTABILITY

### ATMOSPHERIC ENERGY CONSIDERATIONS

ENERGY has previously been defined as the capacity to perform work. There are two basic kinds of energy. They are KINETIC and POTEN-

TIAL. Kinetic energy is ability to perform work due to motion. Potential energy is ability to perform work due to position or condition. The term "kinetic" is used for energy due to present motion, whereas the term "potential" applies to energy stored for later action.

The kinetic theory of gases is very helpful in understanding the behavior of gases. Gases, like other substances, consist of molecules. Unlike solids, molecules of gas have no inherent tendency to stay in one place. Instead, gas molecules, since they are smaller than the space between them, move about at random (but in straight lines until they collide with each other or with other obstructions). Their movement has an average speed at a given temperature. When gas is enclosed, its pressure depends on the number of times the molecules strike the surrounding walls in a unit of time. The number of times the molecules strike per unit of time against the walls remains constant as long as the temperature and the volume remain constant. If the volume (the space occupied by the gas) is decreased, the density of the gas is increased, and the number of blows against the walls is increased, thereby increasing the pressure. When the temperature is increased, there is a corresponding increase in the speed of the molecules; they strike the walls at a faster rate, increasing the pressure, provided that the volume remains constant.

According to the kinetic theory of gases, the temperature of a gas is dependent upon the rate at which the molecules are moving about and is proportional to the kinetic energy of the moving molecules. The kinetic energy of the moving molecules of a gas is the internal energy of the gas, and it follows that an increase in temperature is accompanied by an increase in the internal energy of the gas. Likewise, an increase in the internal energy results in an increase in the temperature of the gas.

An increase in the temperature of a gas or in its internal energy can be produced by the addition of heat or by performing work on the gas. A combination of these can likewise produce an increase in temperature or internal energy. This is in accordance with the first law of thermodynamics.

In the application of the first law of thermodynamics to a gas, it may be said that the two main forms of energy are internal energy and work energy. Internal energy is manifested as sensible heat or temperature; work energy is manifested as pressure changes in the gas. In other words, work is required to increase the pressure of a gas and work is done by the gas when the pressure diminishes. It follows, then that if internal (heat) energy is added to a simple gas, this energy must show up as an increase in either temperature or pressure, or both. Also, if work is performed on the gas, the work energy must show up as an increase in either pressure or temperature, or both.

Consider air in a cylinder, which is enclosed by a piston. In accordance with the first law of thermodynamics, any increase in the pressure exerted by the piston results in work being done on the air. As a consequence, either the temperature and pressure must be increased or the heat equivalent of this work must be transmitted to the surrounding bodies. In the case of a plain compressor, this work done by a piston is changed into an increase in the temperature and the pressure of the air. It also results in some increase in the temperature of the surrounding body.

If the surrounding body is considered to be insulated so that it is not heated, there is no heat transferred, and the air must acquire this additional energy as an increase in temperature and pressure. The process by which a gas, such as air, is heated or cooled without heat being added to the gas or taken away is called an adiabatic process.

In the atmosphere, adiabatic and nonadiabatic processes are taking place continuously. The air near the ground is receiving heat from or giving heat to the ground. These are nonadiabatic processes. However, in the free atmosphere somewhat removed from the earth's surface, the short-period processes are adiabatic. When a parcel of air is lifted in the free atmosphere, it encounters areas of decreasing pressure. To equalize this pressure, the parcel must expand. In expanding, it is doing work. In doing work, it uses heat. This results in a lowering of temperature, as well as a decrease in the pressure and density. When a parcel of air descends in the free atmosphere, it encounters areas of increasing pressure. To equalize the pressure, the parcel must contract. In doing this, work is done on the parcel. This work energy, which is being added to the parcel, shows up as an increase in temperature. The pressure and density increase in this case, too.

## LAPSE RATES

The rate of cooling that a parcel of air undergoes as it ascends in the free atmosphere (or the rate of heating as it descends) is known as the ADIABATIC LAPSE RATE. For unsaturated air the rate of change is 1°C per 100 meters or 5 1/2° F per 1,000 feet. This is known as the DRY ADIABATIC LAPSE RATE. For saturated air the rate of change is different. When a parcel of saturated air ascends in the free atmosphere, the rate of change is known as the SATURATION ADIABATIC LAPSE RATE. (See table 19.)

The saturation adiabatic lapse rate is the result of the condensation that takes place in a saturated parcel of air as it ascends above the condensation level. For each gram of water condensed, about 600 calories of heat are liberated. The latent heat of condensation is absorbed by the air. Consequently, the lapse rate becomes less than the dry adiabatic lapse rate.

The mean slope of the saturation adiabat may be taken as approximately 0.55°C per 100 meters or 3°F per 1,000 feet. The term MEAN SLOPE is used because the saturation adiabatic lapse rate increases with altitude. This is a result of the decrease of water vapor with altitude; consequently, there is a decrease in the total heat of condensation which is liberated.

The normal or average decrease of temperature with height is known as the normal or average lapse rate. The normal lapse rate is about 3 1/2° F per 1,000 feet up to the tropopause. However, the actual lapse rate in the atmosphere at any given time depends on turbulence, radiation processes, conduction of heat near the ground, or the transport of air by horizontal advection in the upper layers. Condensation of moisture or evaporation also affects the lapse rate by the addition or removal of the heat of condensation. Figure 42 shows some of the various types of lapse rates which may be found in the atmosphere.

Table 19.—Lapse rates of temperature.

| Lapse rate | Per 1,000 feet | Per 100 meters |
|---|---|---|
| Dry adiabatic | 5 1/2° F | 1° C |
| Saturation (moist) adiabatic | 2-3° F | .55° C |
| Average | 3.3° F | .65° C |
| Superadiabatic | 5 1/2-15° F | 1-3.42° C |
| Autoconvective | More than 15° F | More than 3.42° C |

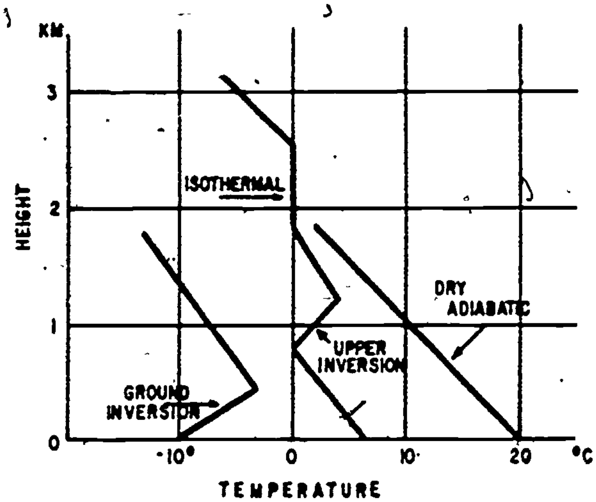


Figure 42.—Lapse rates in the atmosphere.

## Reversible Process

The REVERSIBLE PROCESS is based upon the assumption that no condensed water falls as precipitation, but is carried with the ascending parcel. The ascending parcel undergoes several stages as follows:

1. The dry stage, where the parcel is lifted dry adiabatically to saturation.
2. The rain stage, where all water vapor exceeding the saturation amount is condensed out of the parcel.
3. The hail stage, occurring at 0° C when the parcel rises isothermally because the expansional cooling is offset by the heat of fusion being released when the uncondensed water is frozen.
4. The snow stage, when the excess moisture is changed directly from a vapor to a solid (snow).

The process is reversible, since the parcel reaches the top of the atmosphere with the same water content with which it started. Upon its descent, the same stages will occur in reverse order and the parcel arrives at the original level (pressure) with the same temperature as before.

## Irreversible Process

The IRREVERSIBLE PROCESS is based upon the assumption that all excess water which is condensed from the air will fall immediately as precipitation. The stages in this process are nearly similar to the reversible process.

1. The dry stage is the same as the reversible.
2. The rain stage is the same as the reversible except that moisture falls as rain.
3. The hail stage is eliminated, since there is no liquid to change into ice.
4. The snow stage is the same as the reversible except that excess moisture condenses and falls as snow.

The parcel is dry by the time it reaches the top of the atmosphere; therefore, it must descend dry adiabatically, and the temperature is therefore much higher upon reaching the original level.

The irreversible process closely approximates the actual conditions in the atmosphere; therefore, it is placed upon the AROWAGRAM in the form of saturation adiabats.

Figure 43 shows the various stages during the ascent and descent of air in the irreversible process.

If a parcel of air (A) follows the dry adiabatic lapse rate to the 1,000-mb line, the temperature at that point (P) is the potential temperature. If the parcel continues up the dry adiabat to the saturation point (S), condensation will begin and the parcel will follow the saturation adiabat through the rain stage (S-H). When the temperature falls below freezing, the condensation will be in the form of snow (H-D).

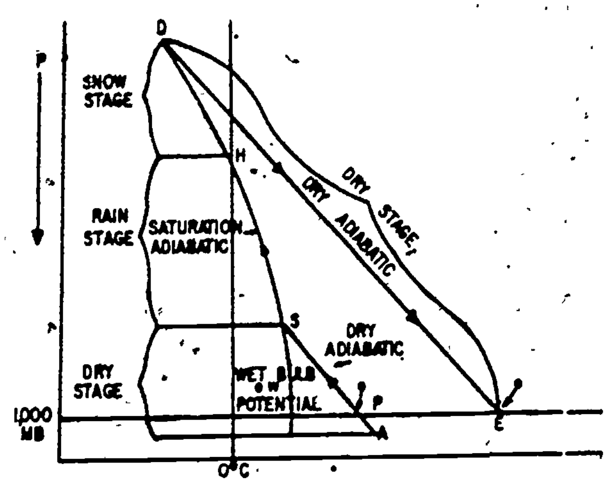


Figure 43.—The irreversible process.

Actually in nature, supercooled water droplets may form even below the freezing point. When all the moisture has condensed, all of the latent heat of condensation has been added to the air, and if the parcel is then brought back to the 1,000-mb level, it will follow the dry adiabatic lapse rate (D-E) and arrive back at this level with a temperature of E. This hypothetical temperature is called the equivalent potential temperature.

## CONDENSATION AND PRECIPITATION

The CLASSIC CONDENSATION THEORY is the theory used when making thermodynamic computations, such as on the AROWAGRAM. It is perfectly valid for these computations. In this theory it is assumed that water is entirely in vapor form until 100 percent relative humidity is reached, and then it changes to liquid or ice. It assumes that liquid drops do not exist at a temperature below freezing; and below freezing only direct crystallization or sublimation occurs.

When attempting to explain the actual process of condensation and precipitation in the atmosphere, the CLASSIC CONDENSATION THEORY is no longer completely valid. These are some of the defects in the theory:

1. Clouds, and especially fog, are likely to occur at less than 100 percent relative humidity. The whole process of formation of a droplet is a continuous one that, however, is most rapid at 100 percent humidity.
2. Liquid droplets supercooled to temperatures several degrees below freezing are so common in the atmosphere as to be regarded as the rule rather than the exception.
3. Liquid drops not only exist at temperatures below freezing, but new condensation occurs at these temperatures as well as direct sublimation.

Before condensation can occur in the free atmosphere, the temperature of the air must be reduced to near the dewpoint, or the moisture content must be increased so as to increase the dewpoint to near the temperature. In laboratory experiments, it has been proved that even these conditions will not induce condensation if the air is pure. It was proved that in pure air a supersaturation of 400 percent was possible before condensation occurred.

There are also several other observations which do not conform to these theories. Drizzle may fall out of stratus or stratocumulus layers that do not extend into the freezing temperatures, particularly at sea and in coastal districts with onshore winds. In the Tropics, and also in warm maritime air masses in temperate latitudes, cumulus has been observed to yield light, moderate, and even heavy rain though the tops did not extend above the freezing level.

The explanation for the latter phenomenon appears to be that in the Tropics, where the freezing level is high, cumulus can develop to such great depths without reaching 0°C and that coalescence between cloud droplets becomes effective enough to result in appreciable rain. When the cloud droplets are of initially different sizes and hence have different settling rates, some of them will collide and coalesce. This increases their settling rate, and consequently, the number of collisions per unit of time. By such a chain reaction, the droplets grow to sufficient size to fall out as precipitation. A cloud of great vertical extent is needed for this process to result in heavy precipitation. This condition is satisfied in the Tropics. The high temperatures found there give a high liquid-water content, which also furthers the coalescence process.

The drizzle which falls out of nonfreezing layer clouds is a more gentle display of the coalescence process. Drizzle appears to be more frequent over the sea and along the sea borders, other things being equal; this fact favors the part played by salt nuclei. Precipitation from nonfreezing clouds has not been noted in continental air masses.

From these observations we may reach the following conclusions. The coalescence process may account for much of the precipitation which falls in the Tropics; the classic theory, on the other hand, applies to most of the precipitation occurring in middle and high latitudes. Whenever moderate or heavy rain falls in the temperate or Arctic regions, it originates mainly in clouds that, in the upper portions at least, have reached negative Celsius temperatures.

A further conclusion based on many studies of temperature of the cloud top as a condition for precipitation reveals that when rain or snow—continuous or intermittent—reaches the ground from stratiform clouds, the clouds—solid or layered—extend in most cases to heights where temperatures are below -12° C or even -20° C.

Nuclei

The foreign particles in the air may be divided into three classes:

1. Hygroscopic nuclei.
2. Sublimation nuclei.
3. Neutral or nonhygroscopic particles.

When air is cooled so that it approaches the dewpoint, the hygroscopic nuclei begin to absorb water from the air. The larger nuclei will then cause condensation to occur even before the saturation point is reached. However, as the drops grow in size they become so diluted that they become less and less active as hygroscopic material. The condensation process can then proceed only when the air is cooled slightly below its dewpoint so that a slight amount of supersaturation is present. It can be seen that condensation on hygroscopic nuclei is a continuous process, beginning at low relative humidities.

The most common hygroscopic nuclei are sea salts, sulfuric acids, and nitric acids. Hygroscopic nuclei vary in number, with the maximum over cities, decreasing in number over rural areas, and at a minimum over the oceans. Annual variations in amounts of hygroscopic nuclei are caused by the increased amount of combustion taking place during the winter months. Diurnal variation is caused by the lack of sunlight at night to oxidize sulfur and nitric dioxides. Since the source region for hygroscopic nuclei is at the surface of the earth, they decrease in number with altitude.

Sublimation nuclei are much smaller and fewer in number than hygroscopic nuclei. They are shaped like an ice crystal. Ice forms on these nuclei below water saturation, but at or above ice saturation. Sublimation nuclei are not very active between 0° C and -10° C; in fact, when considering the entire atmosphere at all temperatures down to about -40° C, there are more liquid droplets than ice particles.

Neutral or nonhygroscopic particles are particles such as ordinary dust. These particles may act as condensation nuclei, but seldom do.

The atmosphere has been described as an AEROSOL, which is a colloidal system in which the dispersed water vapor is composed of either solid or liquid particles; and in which the dispersing medium is the air. A cloud has been described as colloidally unstable by virtue of its position in a turbulent atmosphere.

There have been many theories presented on the processes leading to colloidal instability within a cloud which would cause the growth of raindrops. A few of the more feasible ones are as follows:

1. Electrical attraction.
2. Hydrodynamical attraction.
3. Vapor pressure gradient from smaller to larger drops.
4. Introdution of extremely hygroscopic nuclei.
5. Collision due to turbulence.
6. Vapor pressure gradient from warmer to colder drops.
7. Vapor pressure gradient from liquid to ice (Bergeron-Findeisen Theory).
8. Nonuniform drops in the gravitational field.

The last two theories are considered to be the most important in the formation of raindrops. The liquid-to-ice theory is the most important during the initial formation of the droplet, but once they have grown to such size that they begin to fall, the gravitational field theory becomes the most important.

Cloud and Weather Modification Methods

Activity in cloud and weather modification has been on a sound and realistic basis only since 1958. This opinion was recently expressed by scientists from the National Center for Atmospheric Research in Boulder, Colorado, in an article on the research the center is undertaking to effectively modify weather.

Cloud modification methods have been mainly in the use of dry ice, silver iodide, and water to increase the cloud amount and to possibly trigger precipitation.

The object of seeding with dry ice is to cause the coexistence of ice and water. Seeding with dry ice may be used to dissipate clouds, to precipitate clouds, or to make existing clouds more persistent.

The use of silver iodide has been found to be the most effective source of ice crystal nuclei found to date and is most effective at temperatures below -10°C.

The use of water attempts to employ the principle of nonuniform drops in the gravitational field. It may be used on actively convective portions of large cumulus clouds.

According to Schaefer, the most favorable atmospheric conditions for precipitating clouds by seeding are large cumulus clouds without precipitation already occurring, abundant moisture, a large lapse rate, a low concentration of ice nuclei, the absence of wind shear, and either no inversions or few inversions, or weak ones.

In practical applicaton of this weather modification program, the prevention of thunderstorm formation, hail, windstorms, and torrential rain may be accomplished by either dissipating or overseeding, or increasing precipitation by seeding the clouds with the proper amounts. No evidence appears to exist that clouds can be milked of their moisture in flat regions, but indications are that seeding, especially with silver iodide smoke, can increase precipitation as much as 10 to 15 percent.

Another application of this process is the so-called CLOUDBUSTERS of the Air Force. They have found that holes or windows can be punched in certain clouds which hinder aircraft landings and takeoffs, parachute drops, and rescue and reconnaissance missions. Windows more than 3 miles wide have been created by overseeding such clouds with dry ice pellets.

The dissipation of certain types of fogs can be accomplished by seeding. This is more effective for cold fogs and has little effect on warm or ice crystal fogs.

## STABILITY AND INSTABILITY

Most weather phenomena depend upon whether the air masses are stable or unstable. As stated before, moisture content plays an important part in weather. A parcel of air may be stable when dry and then may become unstable if it is lifted to saturation. An understanding of stability and instability is, therefore, essential to a forecaster.

STABILITY is the state of equilibrium in which a parcel of air has a tendency to resist displacement from the level at which it is in equilibrium with its environment or, if displaced, to return to its original position. INSTABILITY is the state of equilibrium in which a parcel of air when displaced has a tendency to move farther away from its original position.

The stability and instability of air depend a great deal on the moisture content of the air. Therefore, a discussion of equilibrium of air should be separate with respect to dry air and saturated air.

### Equilibrium of Dry Air

The method used for determining the equilibrium of air will be the parcel method, wherein a parcel of air is lifted and then compared to the surrounding air to determine its equilibrium. The dry adiabatic lapse rate is always used as a reference to determine the stability or instability of dry air.

ABSOLUTE INSTABILITY. — Consider a column of air in which the lapse rate is greater than the dry adiabatic lapse rate (the lapse rate is to the left of the dry adiabatic lapse rate on the AROWAGRAM). (See fig. 44.) If the parcel of air at point A were displaced upward to point B, it would cool at the dry adiabatic lapse rate. Upon arriving at point B, it would be warmer than the surrounding air. The parcel would

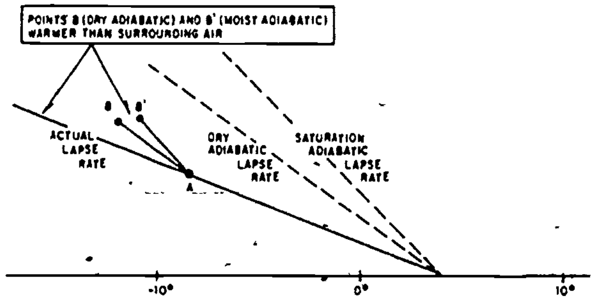


Figure 44. —Absolute instability (any degree of saturation).

therefore have a tendency to continue to rise, seeking air of its own density. Consequently, the column would be unstable. From this, the rule is established that if the lapse rate of a column of air is greater than the dry adiabatic lapse rate, the column is in a state of ABSOLUTE INSTABILITY. The term "absolute" is used because this applies whether the air is dry or saturated, as is evidenced by displacing upward a saturated parcel of air from point A along a saturation adiabat to point B'. The parcel is more unstable than if displaced along a dry adiabat.

STABILITY.—Consider a column of dry air in which the lapse rate is less than the dry adiabatic lapse rate (the lapse rate is to the right of the dry adiabatic lapse rate on the AROWAGRAM). (See fig. 45.) If the parcel at point A were displaced upward to point B, it would cool at the dry adiabatic lapse rate, and upon arriving at point B it would be colder than the surrounding air. It would therefore have a tendency to return to its original level. Consequently, the column of air would be stable.

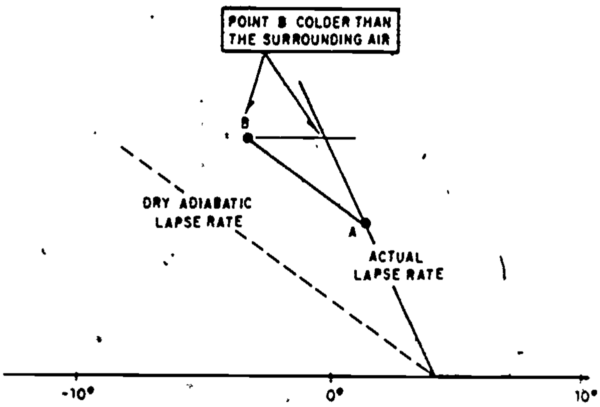


Figure 45.—Stability (dry air).

From this, the rule is established that if the lapse rate of a column of DRY AIR is less than the dry adiabatic lapse rate, the column is stable.

NEUTRAL STABILITY.—Consider a column of DRY AIR in which the lapse rate is equal to the dry adiabatic lapse rate. The parcel would cool at the dry adiabatic lapse rate if displaced upward. It would at all times be at the same temperature and density as the surrounding air and would have a tendency neither to return to nor to move farther away from its original position. The column of dry air, therefore, would be in a state of NEUTRAL STABILITY.

Equilibrium of Saturated Air

When saturated air is lifted, it cools at a rate different from that of dry air. This is due to release of the latent heat of condensation, which is absorbed by the air. The rate of cooling of saturated air is known as the saturation adiabatic lapse rate. This rate is used as a reference for determining the equilibrium of saturated air.

ABSOLUTE STABILITY.—Consider a column of air in which the lapse rate is less than the saturation adiabatic lapse rate (the lapse rate is to the right of the saturation adiabatic lapse rate on the AROWAGRAM). (See fig. 46.) If the parcel of saturated air at point A were displaced upward to point B, it would cool at the saturation adiabatic lapse rate, and upon arriving at point B it would be colder than the surrounding air.

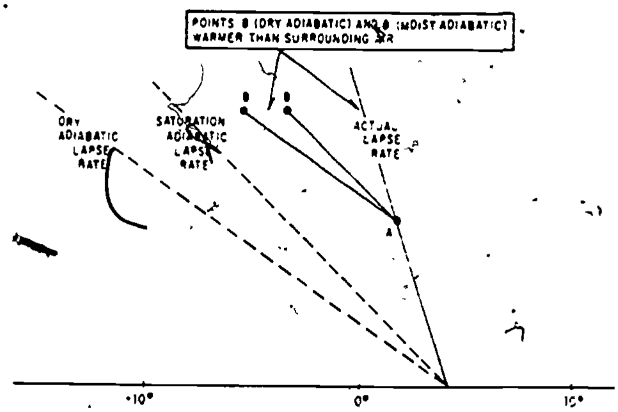


Figure 46.—Absolute stability (any degree of saturation).

The layer, therefore, would be in a state of ABSOLUTE STABILITY. From this, the following rule is established: If the lapse rate for a column of air is less than the saturation adiabatic lapse rate, the column is absolutely stable. Dry air cools dry adiabatically and also would be colder than the surrounding air. Therefore, this rule applies to all air, as is evidenced when an unsaturated parcel of air is displaced upward dry adiabatically to point B', where the parcel is more stable than the parcel displaced along a saturation adiabat.

INSTABILITY.—Consider now a column of air in which the lapse rate is greater than the saturation adiabatic lapse rate. (See fig. 47.) If a parcel of saturated air at point A were displaced upward to point B, it would cool at the saturation adiabatic lapse rate. Upon arriving at point B, the parcel would be warmer than the surrounding air. For this reason, it would have a tendency to continue moving farther from its original position. The parcel, therefore, would be in a state of INSTABILITY. The following rule is applicable: If a lapse rate for a column of SATURATED AIR is greater than the saturation adiabatic lapse rate, the column is unstable.

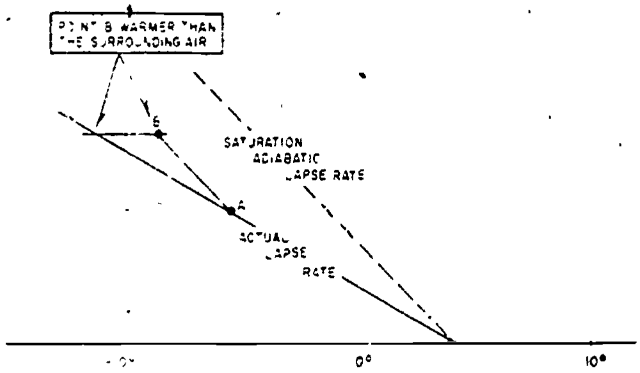


Figure 47.—Instability (saturated air).

NEUTRAL STABILITY.—Consider a column of saturated air in which the lapse rate is equal to the saturation adiabatic lapse rate. A parcel of air displaced upward would cool at the saturation adiabatic lapse rate and would at all times be equal in temperature to the surrounding air. On that account, it would tend neither to move farther away from nor to return to its original level. It, therefore, would be in a state of NEUTRAL STABILITY. The rule for this situation is that if the lapse rate for a column of saturated air is equal to the saturation adiabatic lapse rate, the column is neutrally stable.

## Conditional Instability

In the treatment of stability and instability so far, only air that was either dry or saturated was considered. Under normal atmospheric conditions, natural air is unsaturated to begin with but becomes saturated if lifted far enough. This presents no problem if the lapse rate for the column of air is greater than the dry adiabatic lapse rate (absolutely unstable) or if the lapse rate is less than the saturation adiabatic lapse rate (absolutely stable). However, if the lapse rate for a column of natural air lies between the dry adiabatic lapse rate and the saturation adiabatic lapse rate, the air may be stable or unstable, depending upon the distribution of moisture. When the lapse rate of a column of air lies between the saturation adiabatic lapse rate and the dry adiabatic lapse rate, the equilibrium is termed CONDITIONAL INSTABILITY, because the stability is conditioned by the moisture distribution. The equilibrium of this column of air is determined by the use of positive and negative energy areas. The determination of an area as positive or negative depends upon whether the environment is colder or warmer than the ascending parcel. Positive areas are conducive to instability; negative areas are conducive to stability.

TYPES OF CONDITIONAL INSTABILITY.—Conditional instability may be one of three types. The REAL LATENT type is a condition in which the positive area is larger than the negative area (potentially unstable). The PSEUDO-LATENT type is a condition in which the positive area is smaller than the negative area (potentially stable). The STABLE type is a condition in which there is no positive area.

ENERGY AREAS FOR MECHANICAL LIFTING.—A negative area is the area (on an AROWAGRAM) bounded by the temperature curve; the dry adiabat from the surface point to the lifting condensation level (LCL); and the moist adiabat from the LCL to its intersection with the temperature curve (this point on the temperature curve is termed the level of free convection (LFC)). In figure 48, the negative area is shaded with slanting lines.

A positive area is the area (on an AROWAGRAM) to the right of the temperature curve, bounded by the temperature curve and the saturation adiabat extended upward from the LFC. In figure 48, it is shaded with a dotted pattern.

ENERGY AREAS FOR CONVECTIVE LIFTING.—If lifting by convection is expected, the negative area is determined by locating the intersection of the temperature curve, the average mixing ratio, and a dry adiabat. The average mixing ratio is chosen because more than just surface parcels are involved in convec-

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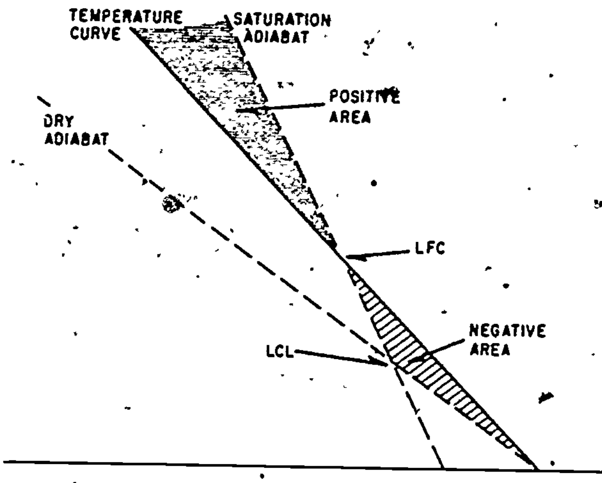


Figure 48. —LCL, LFC, and negative and positive areas—mechanical lifting.

tive activity. The standard practice is to average the mixing ratio for a 100-mb stratum above the surface, or to average the mixing ratio for the moist surface layer when it is less than 100 millibars in vertical extent. In addition, each locality should add a small factor, determined locally, to allow for an increase in moisture; this is especially true on coastlines or near large rivers and lakes. This procedure insures use of a realistic moisture content for the lower layer (which will be thoroughly mixed in the convective process). This level is known as the convective condensation level (CCL). The area downward from this intersection and bounded by the temperature curve and the dry adiabat is the negative area. It represents the energy which must be supplied in order that a parcel of air will rise from the surface to a level where it will continue to rise without a supply of energy from an outside source. The intersection of the dry adiabat drawn from the CCL with the surface level determines the surface temperature necessary for free convection. Notice that in this situation the negative area is to the right of the temperature curve, whereas with mechanical lifting the negative area is to the left of the temperature curve. (See fig. 49.)

The positive area in a situation of convective lifting is the area to the right of the temperature curve, bounded by the temperature curve and the saturation adiabat extended from the intersection of the mixing ratio and the temperature curve; that is, the CCL. (See fig. 49.)

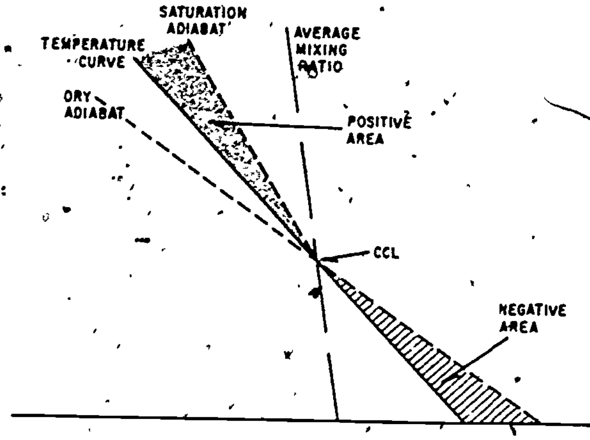


Figure 49. —CCL, and negative and positive areas—convective lifting.

Autoconvection

AUTOCONVECTION is a condition which is started spontaneously by a layer of air when the lapse rate of temperature is such that density increases with elevation. For density to increase with altitude, the lapse rate must be equal to or exceed 3.42° C per 100 meters. (This is the AUTOCONVECTIVE LAPSE RATE.) An example of this condition is found to exist near the surface of the earth in a road mirage or a dust devil. These occur over surfaces which are easily heated, such as the desert, open fields, etc., and are usually found during periods of intense surface heating.

Convection Stability and Instability

So far in the discussion of convection stability and instability, we have considered PARCELS of air. Let us now examine LAYERS of air. A layer of air which is originally stable may become quite unstable due to moisture distribution if the entire layer is lifted.

Convective stability is the condition that occurs when the equilibrium of a layer of air, because of the temperature and humidity distribution, is such that when the entire layer is lifted, its stability is increased.

Convective instability is the condition of equilibrium of a layer of air occurring when the temperature and humidity distribution is such that when the entire layer of air is lifted, its instability is increased.

CONVECTIVE STABILITY. – Consider a layer of air whose humidity distribution is dry at the bottom and moist at the top. If the layer of air is lifted, the top and the bottom will cool at the same rate until the top reaches saturation. Thereafter, the top will cool less rapidly than the bottom. The top will cool saturation adiabatically; the bottom will still continue to cool dry adiabatically. The lapse rate for the layer then will decrease. The stability will increase.

The layer must be unstable at the beginning and may become stable when lifting takes place.

In a layer that is convectively stable, the equivalent potential temperature increases with elevation.

CONVECTIVE INSTABILITY.—Consider a layer of air in which the air at the bottom is moist and the air at the top of the layer is dry. If this layer of air is lifted, the bottom and the top will cool dry adiabatically until the lower portion is saturated. The lower part will then cool saturation adiabatically while the top of the layer is still cooling dry adiabatically. The lapse rate then begins to increase, causing the instability to increase.

In a layer of convectively unstable air, the equivalent potential temperature DECREASES with elevation.

In order to determine the convective stability or instability of a layer of air, you should first know why you expect the lifting of a whole layer. The obvious answer is an orographic barrier or a frontal surface. Next, determine how much lifting is to be expected and at what level does it commence, for you need not necessarily have to lift a layer of air close to the surface of the earth. The amount of lifting will, of course, depend on the situation at hand. In determining the convective stability or instability of a layer of air at a particular locality, proceed as follows:

1. Lift the driest end of the lapse rate dry adiabatically until saturated and then moist adiabatically for a predetermined number of millibars.

2. Lift the moist end of the lapse rate dry adiabatically until saturated, thence moist adiabatically for an equal number of millibars.

3. Connect the upper to the lower point thus formed with a straight line, representing the new lapse rate.

Refer to figures 50 and 51 for a presentation of convective stability and instability.

## Stability Determination from Existing Lapse Rate

We can very simply test the stability conditions of the plotted sounding by observing the observed temperatures and lapse rates in reference to superimposed lines representing the dry and moist adiabatic lapse rates on the AROWAGRAM.

For instance, if we observe that the lapse rate on the actual sounding is to the right of the moist adiabatic rate, the air is absolutely stable. If it lies between the moist and dry adiabatic lapse rates, its stability is dependent on the moisture present, and it is called conditionally stable. If the lapse rate is greater than the dry adiabatic lapse rate, we have absolute instability in the air and can expect vertical currents to cause turbulence in that area.

Figure 52 illustrates the varying degrees of air stability which are directly related to the rate at which the temperature changes with height.

## Determining Bases of Convective Type Clouds

We have seen from our foregoing discussion in an earlier section of this chapter that moisture is important in determining certain stability conditions in the atmosphere. We know, too, that the difference between the temperature and the dewpoint is an indication of the relative humidity, and that when the dewpoint and the temperature are the same, the air is saturated and some form of condensation cloud may be expected. This lends itself to a means of estimating the height of the base of clouds formed by surface heating; that is, cumuliform type clouds, when the surface temperature and dewpoint are known. We know that the dewpoint will decrease in temperature at the rate of 1° F per 1,000 feet during a lifting process. The ascending parcel in the convective current will experience a decrease in temperature of about 5 1/2° F per 1,000 feet. Thus, the dewpoint and the temperature approach each other at the rate of 4 1/2° F per 1,000 feet. As an example,

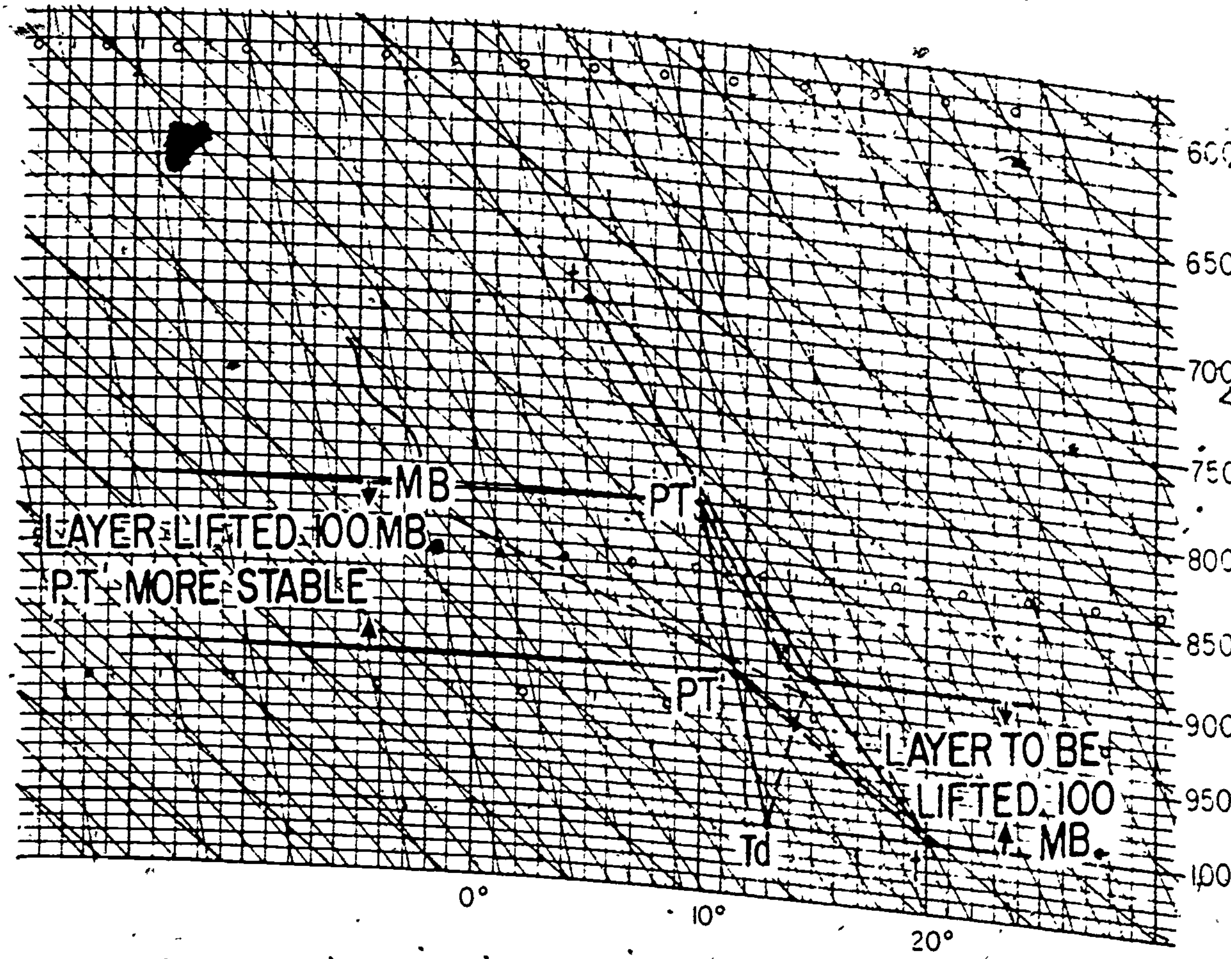


Figure 50.—Convective stability (layer method).

consider the surface temperature to be 80° F and the surface dewpoint 62° F, a difference of 18° F. This difference, divided by the approximate rate that the temperature approaches the dewpoint (4 1/2° F per 1,000 ft) indicates the approximate height of the base of the clouds caused by this lifting process (18 ÷ 4 1/2 = 4,000 feet). This is graphically shown in figure 53. The Marine Science Technician should remember that this method cannot be applied to all cloud types, but is limited to clouds formed by convection currents, such as summertime cumulus clouds, and only in the locality where the clouds form. It is not valid around maritime or mountainous areas.

### Stability in Relation to Cloud Type

When a cloud is formed, the stability of the atmosphere helps to determine the type of cloud formed. For example, if the air is very stable and it is being forced to ascend the side of a mountain (fig. 54), the cloud formed will be layerlike with little vertical development and with little or no turbulence. If, however, the air is unstable in the situation, the clouds formed would have vertical development and turbulence would be expected with them. The base of this type cloud would be determined by mechanical lifting and by the LCL.

## OPTICAL PHENOMENA

Many of our greatest [illegible]s and the greater part of what we kn[illegible]ut our surroundings are gained throug[illegible]e beauties of color. Color is light. Light sent out by such bodies as the sun or the moon or from artificial sources such as lamps and even the light reflected by the objects which it strikes, affect the eye and produce the sensation of vision. Too, much of the world's work and much of our recreation are made possible by the use of light.

Light, too, when acting in conjunction with some of the elements of the atmosphere produces such atmospheric phenomena as halos, coronas, mirages, and rainbows

In this section we will discuss some of the theories of light, even though scientists do not yet have a complete explanation of the nature of light, its properties, what happens to these light rays after they leave their source, and some of the atmospheric phenomena produced by light

LIGHT

Light is known to be a form of energy It is closely related to and travels at the same speed, 186,000 miles per second, as radiant heat, radio, and X-rays. One of the main differences between light rays and sound waves is that light waves can travel through a vacuum, but sound waves cannot. Sound waves require matter for their transmission. Another important difference is the speed with which light waves travel in relation to sound waves. For all practical purposes, the light waves travel so rapidly over the distances with which we are concerned that we think of the waves as being instantaneous, whereas the speed of sound is very slow by comparison and is affected by altitude as well as by the temperature of the medium through which it is traveling.

There are considered to be two sources of light—the natural light, nearly all of which we receive from the sun, and artificial light, such as light from electric lamps, the light of a fire,

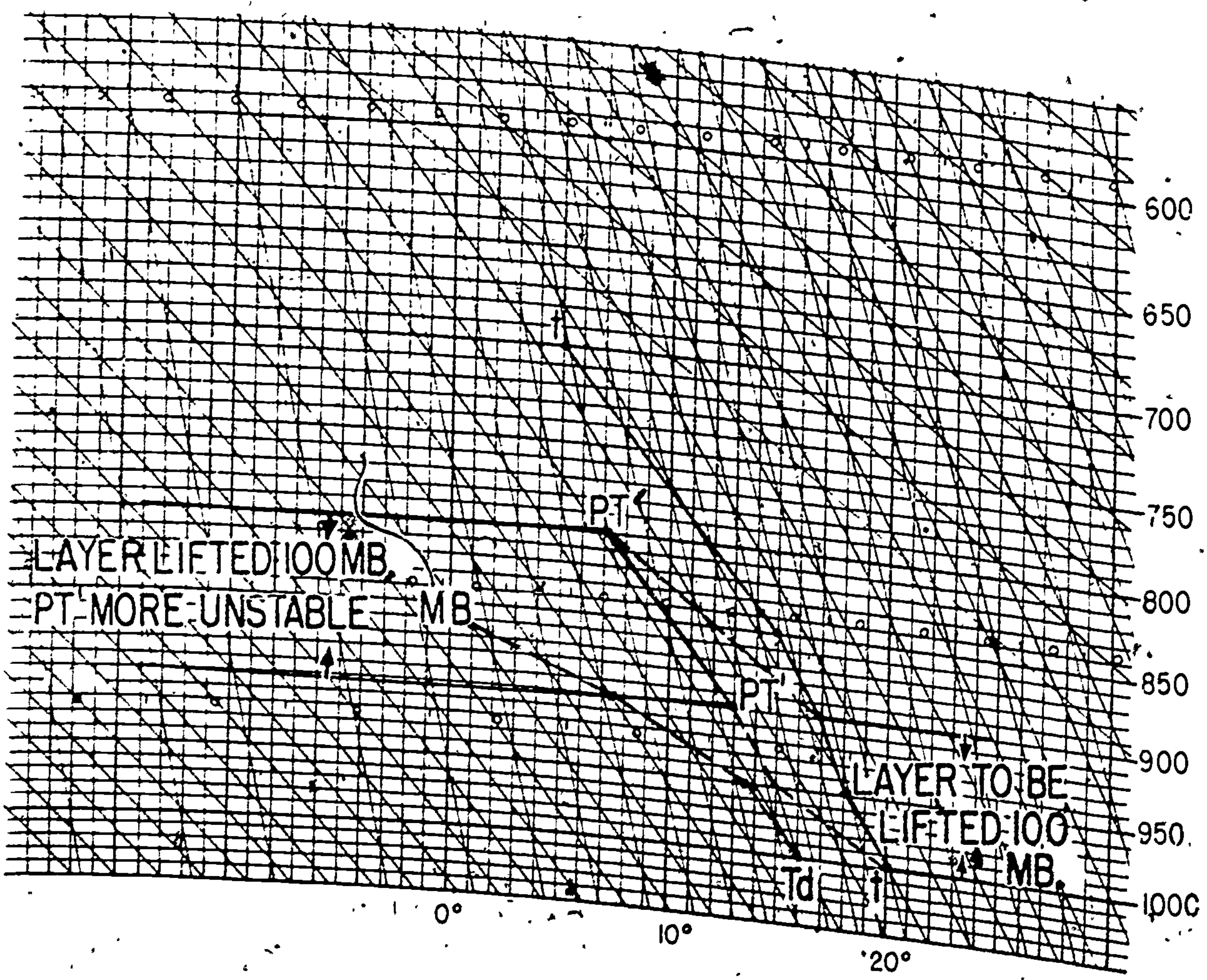


Figure 51.—Convective instability (layer method).

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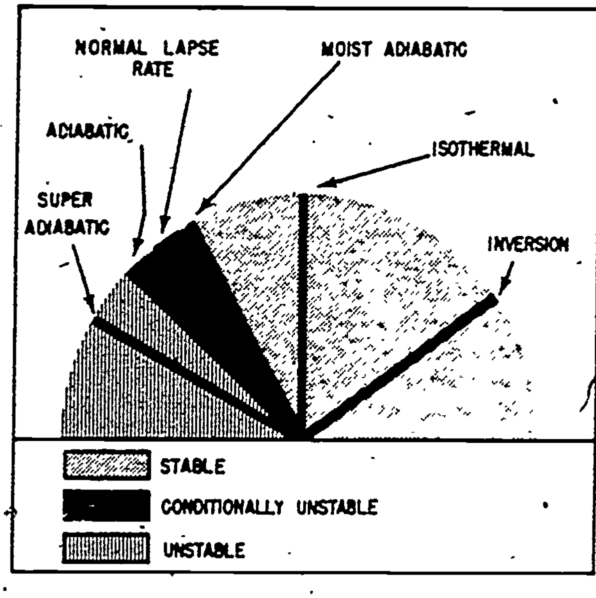


Figure 52.—Degrees of stability in relation to temperature changes with height.

or the light from fluorescent tubes produced by the action of ultraviolet light on chemicals enclosed in the tube.

Luminous bodies are those bodies which produce their own light. We think of the sun and the stars as luminous bodies. Illuminated or nonluminous bodies are those bodies which merely reflect the light they receive and are therefore visible because of this reflection.

Frequencies

The waves which produce the sensation of light are all very short, which means that the frequency of light waves is very high. WAVELENGTH means the distance from the crest of one wave to the crest of the following wave.

In order to measure these wavelengths conveniently, a special unit of measure was devised and has been named for the scientist who devised it. This unit is called an ANGSTROM UNIT, or more usually, an ANGSTROM. In more recent work, these waves are measured in millimicrons which are millionths of millimeters.

A brief study of figure 55 indicates that light with a longer wavelength (such as 700 millimicrons) will be red, and that light with a shorter wavelength (500 millimicrons for example) will be blue-green. From this it could be reasoned that the color of light depends strictly on its wavelength. Actually, the color of light is dependent upon its frequency, just as sound depends upon its pitch, or frequency.

When the wavelength of 700 millimicrons (fig. 56) is measured in a vacuum, it produces the color known as red, but in another medium this wavelength will be other than 700 millimicrons. For example, when red light that has been traveling in air enters glass, which is a medium of different density, it loses speed, and its wavelength becomes shorter, or compressed. The fact that it continues to be red is because the frequency remains the same, thus demonstrating the principle that color depends upon frequency of transmission. It must be kept in mind that the scale in figure 56 refers to wavelengths in air.

Various colors depend on the frequency of transmission of the various component wavelengths of the visible spectrum which are present in equal amounts in white light.

Theory

The exact nature of light is not fully understood, although men who study theoretical physics have been trying to discover its exact nature for many centuries. Some experiments seem to show that light is composed of tiny particles, and some indicate that it is made up of waves.

First one theory and then the other attracted the approval and acceptance of the physicists. Today there are scientific phenomena which can be explained only by the wave theory and another large group of occurrences which can

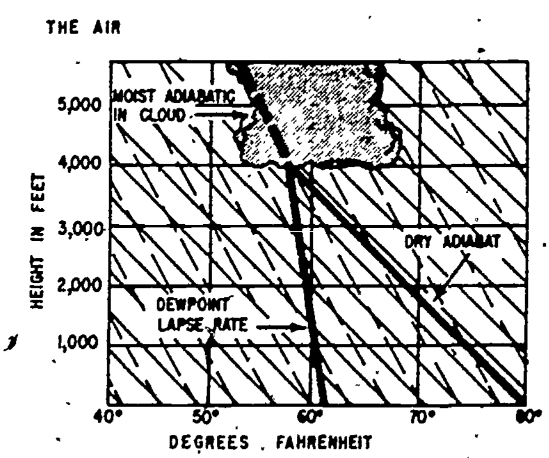


Figure 53.—Determination of a cloud's base when the dewpoint and temperature are known.



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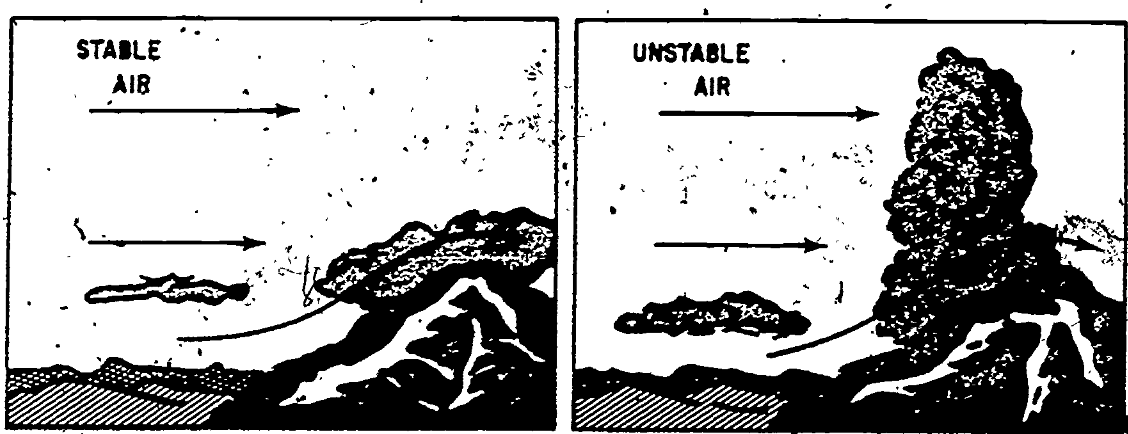


Figure 54.—Illustration showing that very stable air retains its stability even when it is forced upward, forming a flat cloud. Air which is potentially unstable when forced upward becomes turbulent and forms a towering cloud.

be made clear by the particle or corpuscular theory. Physicists, constantly searching for some new discovery which would bring these contradictory theories into agreement, gradually have come to accept a theory concerning light which is a combination of these two views.

According to the view now generally accepted, light is a form of electromagnetic radiation; that is, light and similar forms of radiation are made up of moving electric and magnetic forces. A simple example of motion similar to these radiation waves can be made by dropping a pebble into a pool of water. The waves spread out in expanding circles until they reach the edge of the pool in much the same manner as the rays of light spread from the sun. However, the waves in the pool are very slow and clumsy in comparison with light coming from the sun which travels approximately 186,000 miles per second.

Light radiates from its source in all directions until absorbed or diverted by coming in contact with some substance. Lines drawn from the light source to any point on one of these waves indicate the direction in which the wave fronts are moving. These lines are radii of the spheres formed by the wave fronts. In diagrams of optical and projection equipment and in other illustrations of image formation, these lines show direction of movement and are called light rays. Although single rays of light do not exist, light "rays," as used in illustrations, provide a convenient method of giving the direction in which light is traveling at any point.

A large volume of light is called a beam, a narrow beam is called a pencil, and the smallest portion of a pencil is a light ray. A ray of light, then, can be illustrated as a straight line. This straight line drawn from a light source may represent an infinite number of rays radiating in all directions from the source. (See fig. 57.)

Wave fronts near the light source are sharply curved, while those at a distance are almost flat. Light rays from a distant source or object are considered to be parallel, as illustrated in figure 58.

Characteristics

When light waves, which travel in straight lines, encounter any substance, they are either transmitted, reflected, or absorbed (See fig. 59.) Those substances which permit the

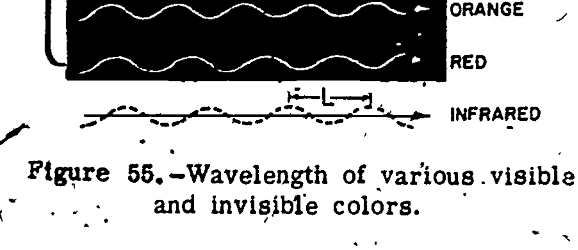


Figure 55.—Wavelength of various visible and invisible colors.



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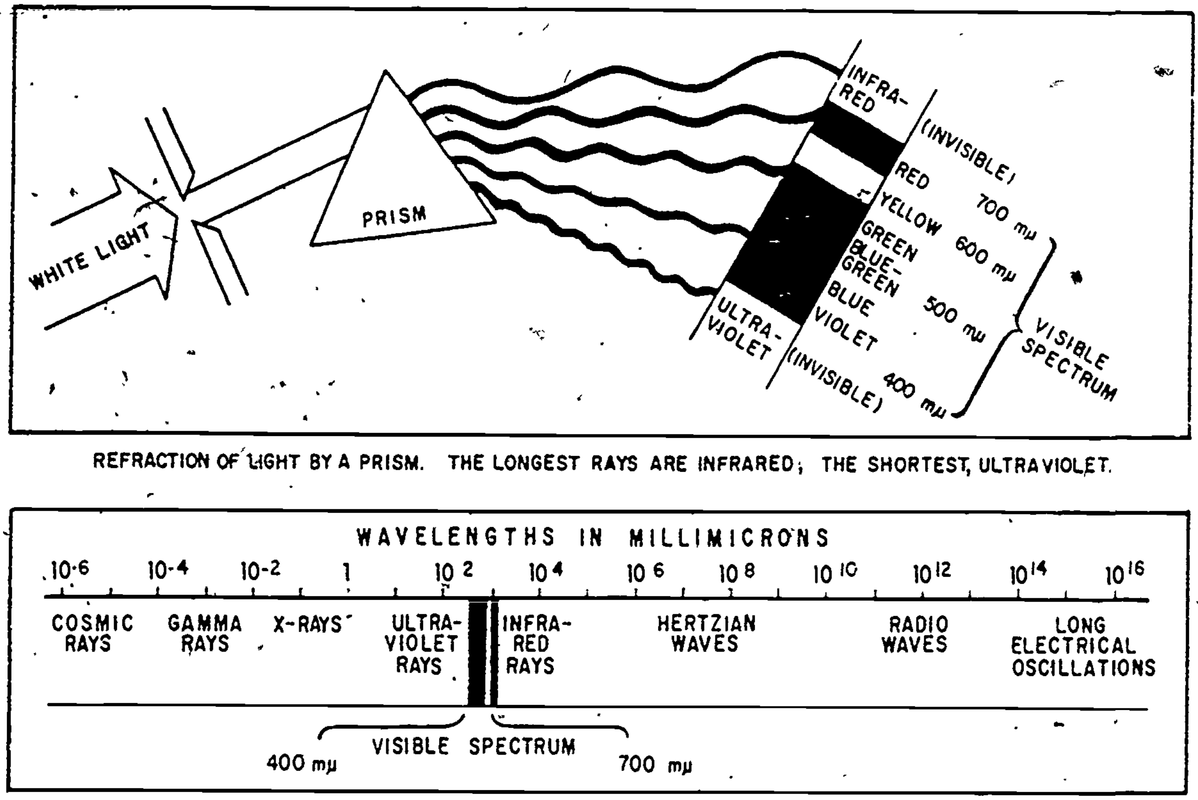

REFRACTION OF LIGHT BY A PRISM. THE LONGEST RAYS ARE INFRARED; THE SHORTEST, ULTRAVIOLET.

Figure 56.—Wavelengths and refraction.

penetration of clear vision through them, and which transmit almost all the light falling upon them are said to be transparent. There is no substance known which is perfectly transparent, but many substances are nearly so. Those substances which allow the passage of part of the light but appear clouded and impair vision substantially, are called translucent. Those substances which do not transmit any light are called opaque.


Figure 57. —Waves and radii from a near-by light source.

All objects which are not light sources are visible only because they reflect all or some part of the light reaching them from some luminous source. If light is neither transmitted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and reflection always take place. No substance completely transmits, reflects, or absorbs all the light which reaches its surface. Figure 59 shows how glass transmits, absorbs, and reflects light.

Candlepower and Foot-Candles

Illumination is the light received from a light source. The intensity of illumination is measured in foot-candles. A foot-candle is the amount of light falling upon a surface 1 square foot in area, 1 foot away from the light source of 1 candlepower.

Law of Inverse Squares

The law of inverse squares states that the amount of light a body receives is inversely proportional to the square of the distance from the source of light. Therefore,

$$\text{foot-candles} = \frac{\text{candlepower}}{\text{distance squared}}, \text{ or}$$

$$\text{foot-candles} = \frac{cp}{d^2}$$

REFLECTION

The term "reflected light" simply refers to those light waves that are neither transmitted nor absorbed, but are thrown back from the surface of the medium they encounter. If a ray of light is directed against a mirror, the light ray that strikes the surface is called the incident ray and the one that bounces off is the reflected ray. The imaginary line perpendicular to the mirror at the point where the ray strikes is the NORMAL. The angle between the incident ray and the normal is the angle of incidence. The angle between the reflected ray and the normal is the angle of reflection. These terms are illustrated in figure 60.

If the surface of the medium contacted by the incident light ray is smooth and polished, such as a mirror, the reflected light will be thrown back at the same angle to the surface as the incident light. The path of the light reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection which states: The angle of incidence is equal to the angle of reflection.

A common application of this law in projection equipment is seen when it is necessary to direct light in a new direction. By using a ray of light with a mirror at a 45° angle and by applying the law of reflection, we can see how this is accomplished. The apparatus would be similar to that shown in figure 61. The light ray striking the 45° mirror will reflect a beam at the same angle as the incident ray, resulting in a change of direction of 90°.

A mirror is an excellent reflecting surface because it is flat and unbroken. The combinations of many incident beams will keep the same relationship between beams even after reflection. This means that all parallel rays will strike at the same angle of incidence and will be reflected at the same angle of reflection. They will remain parallel after reflection. This is called regular (or specular) reflection. (See fig. 62 (A).)

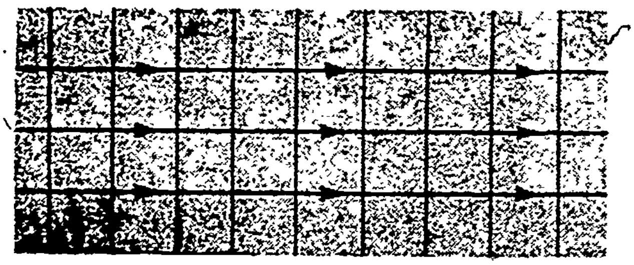

Figure 58.—Waves and radii from a distant light source.

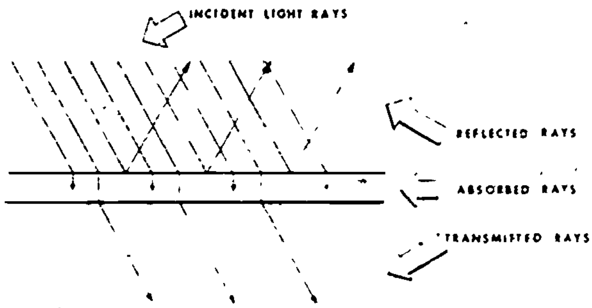


Figure 59.—Light rays reflected, absorbed, and transmitted.

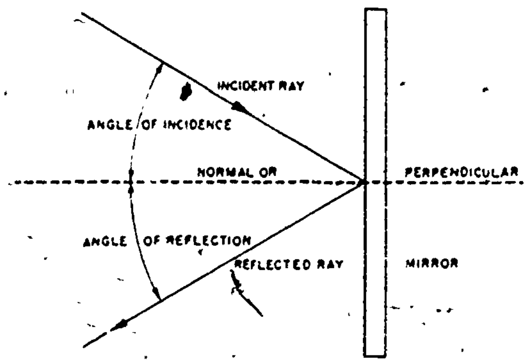


Figure 60.—Terms used to describe the reflection of light.

Reflection from a smooth surfaced object presents few problems. It is a different matter, however, when a rough surface reflects light. The law of reflection still holds; but because the surface is rough, the angle of incidence will be different for each ray of light. The reflected light will be scattered in all directions as shown in figure 62 (B). This form of reflected light is called irregular or diffused light.

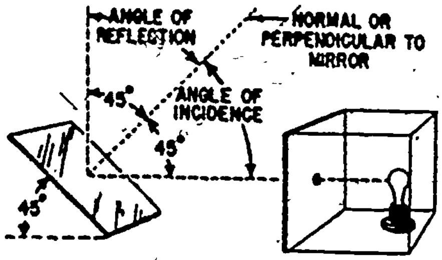


Figure 61. —Applying the law of reflection.

What happens when parallel rays of light strike a curved mirror? Again, we go to the law of reflection for the answer. If the reflecting object is a concave mirror, which is the most common type of curved reflector used, the parallel rays striking its surface will be reflected in the manner shown in figure 63. If this seems to be in error, remember that the normal is perpendicular to the surface of the medium and the normals on a curved surface will not be parallel to one another. The result is that reflected rays come together or converge.

As illustrated in figure 63, when parallel rays are reflected from a concave mirror, they converge almost to a point (if the concavity is parabolic, they converge exactly to a point); they then cross and diverge or spread out again. What would happen if you put a source of light at the point where the rays cross? As you will remember, the rays of light from a nearby object

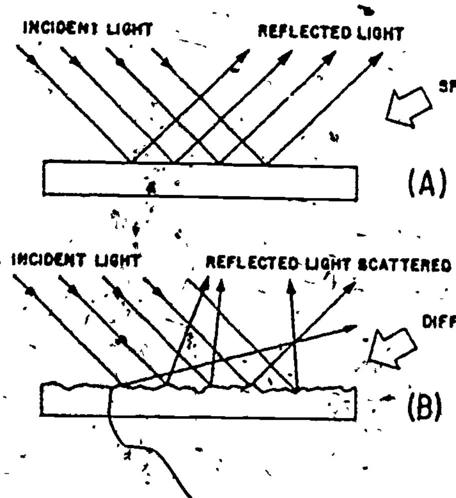


Figure 62. —Reflected light.
(A) Regular (specular); (B) Irregular (diffused).

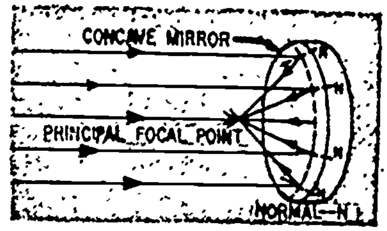


Figure 63. —Reflection from a concave mirror.

are not parallel but radiate out from the source, as shown in figure 57. All the light that strikes a concave mirror in this case is reflected in a narrow beam of parallel rays as shown in figure 64. In this way, the light from a source is intensified because the light that would normally be lost is directed back past the source and is added to the beam.

## REFRACTION

The change of direction which occurs when a ray of light passes from one transparent substance into another of different density is called refraction. This phenomenon enables a lens to form an image. Without refraction, light waves would pass in straight lines through transparent substances without any change of direction. Only shadow patterns could be made with them.

Refraction is due to the fact that light travels at various speeds in different transparent substances. The ratio of the speed of light in air to its speed in each transparent substance is called the index of refraction for that particular substance. For example, light travels about one and one-half times as fast in air as it does in glass, so the index of refraction for glass is about 1.5.

Tables of refractive indices are useful in such specialized tasks as navigation, in which instruments must receive light rays from many different angles.

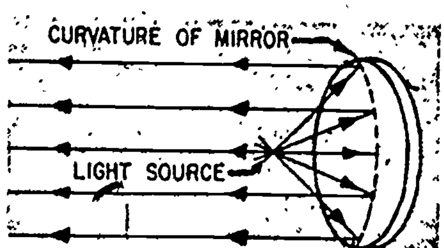


Figure 64. —Projection by a concave mirror.

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Refraction, or change of direction, always follows a simple rule. When the light ray passes from one transparent substance into another of greater density, refraction is toward the normal. (In this rule, the normal means a line perpendicular to the surface of the medium at the point of entrance of the light ray.) In passing from one transparent substance into another of lesser density, refraction is away from the normal.

Refraction through a piece of plate glass is shown in figure 65. The ray of light strikes the glass plate at an oblique angle. If it were to continue in a straight line, it would emerge from the plate at point A. But in accordance with the rule just given, it is bent toward the normal and emerges from the glass at point B. Upon entering the air, the ray does not continue on its path but is bent away from the normal and along the path, BC, in the air. If the two surfaces of the glass are parallel, the ray leaving the glass is parallel to the ray entering the glass. The displacement depends upon the thickness of the glass plate and the angle of entry into it.

All rays striking the glass at any angle other than perpendicular are refracted in the same manner. In the case of a perpendicular ray, which enters the glass normal to the surface, no refraction takes place, and the ray continues through the glass and into the air in a straight line.

When a ray of light passes through a flat sheet of glass, it emerges parallel to the incident ray. This holds true only when the two surfaces of the glass are parallel. When the two surfaces are not parallel, as in a prism, the ray is refracted differently at each surface of the glass and does not emerge parallel to the incident ray.

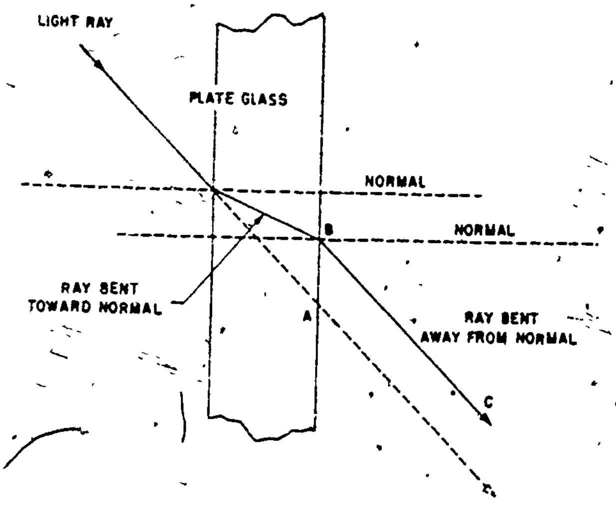


Figure 65.—Refraction through a piece of plate glass.

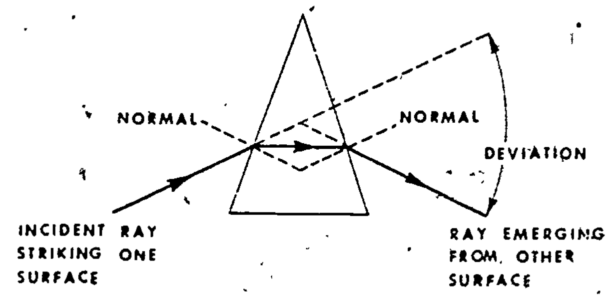


Figure 66.—Path of light ray through a prism.

Figure 66 shows that both refractions are in the same direction, and that the ray coming out of the prism is not parallel to the ray going into it. The law of refraction explains what has happened. When the ray entered the prism, it was bent toward the normal; and when it emerged, it was bent away from the normal. Notice that the deviation is the result of the two normals not being parallel.

If two triangular prisms are placed base-to-base, as in figure 67, parallel incident rays passing through them are refracted and caused to intersect. The rays passing through different parts of the prisms, however, will not intersect at the same point. In the case of two prisms, there are only four refracting surfaces. The light rays from different points on the same plane will not be refracted to a point on the same plane behind the prism. They emerge from the prisms and intersect at different points along an extended common baseline, as illustrated by points A, B, and C of figure 67.

When a beam of white light is passed through a prism, as shown in figure 56, it is refracted and dispersed into its component wavelengths. Each of these wavelengths reacts differently on the eye, which then sees the various colors that compose the visible spectrum. This experiment with the prism was first conducted in 1666 by the same Sir Isaac Newton who formulated the corpuscular theory of light reception.

The visible spectrum is recorded as a mixture of red, orange, yellow, green, blue, indigo, and violet (fig. 56). It can be readily demonstrated that white light results when the



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PRIMARIES (red, green, and blue) are mixed together in overlapping beams of light. (NOTE: These are not the primaries used in mixing pigments.) Furthermore, the COMPLEMENTARY or secondary colors (magenta, yellow, and cyan) may be shown with equal ease by

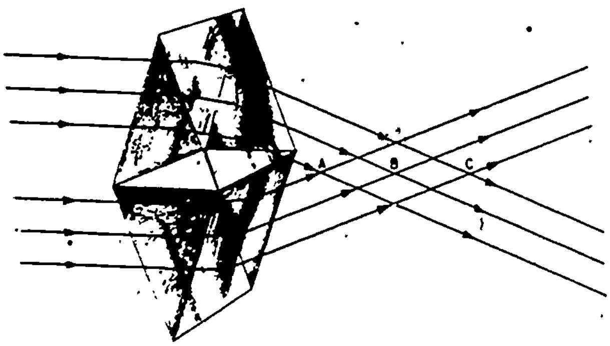


Figure 67.—Refraction of light rays by two prisms base-to-base.

mixing any two of the primary colors in overlapping beams of light. Thus, red and green light mixed in equal intensities will make yellow light; green and blue will produce blue-green light which is termed cyan; and blue and red light correctly mixed will render magenta (a purplish red).

It should be noted that a few modern texts vary the treatment of the color scale slightly from Newton's original seven spectral colors. This is due partly to developments in the mixing value of pigments (paints), and partly to the discoveries of Maxwell and the related theory of Young and Helmholtz. This theory assumes that the retina of the eye is equipped with three varying groups of nerves, sensitive roughly to red, green, and blue-violet light.

## ATMOSPHERIC OPTICAL PHENOMENA

We think of atmospheric optical phenomena as those phenomena of the atmosphere which can be explained in terms of optical laws. Given below is a description of some of the optical phenomena which we commonly observe. Some of the atmospheric elements, such as moisture, serve as a prism to break a light source down into its various component colors.

### Mirages

A mirage is an optical illusion due to the refraction of light as it passes through nonhomogenous layers of the atmosphere. Distant objects are seen in an unnatural position, sometimes elevated, sometimes depressed, and often inverted; this phenomenon occurs most in hot climates over surfaces that are warmed by insolation, such as sandy plains.

Mirages may occur in any region, even a city street. They are generally of three types, the inferior mirage, the superior mirage, and the lateral mirage. These depend, respectively, on whether the spurious image appears below, above, or to one side of the true position of the object. The inferior mirage is the most common and is responsible for the illusion of a body of water in a desert or for the illusion of a wet highway on a hot summer day. The superior mirage, more spectacular but less frequent, causes distant objects, trees, ships, mountains, etc., to apear inverted in the sky. Multiple or complex mirages have been observed, an example of which is the Fata Morgana.

### Corpuscular Rays

These rays are beams of light apparently diverging from the sun, seen both before and after sunrise and sunset, especially in a hazy or humid atmosphere. The beams are rendered luminous by the dust or water vapor. They are especially striking when they shine through rifts in the clouds. They are actually parallel and their apparent divergency is a result of perspective.

### Rainbows

The rainbow is a semicircular arc, usually exhibiting all the primary colors, which appears opposite the sun as a result of reflection, refraction, and diffraction of the sunlight or moonlight by water droplets. Rainbows occur when the sun is near the horizon. The various colors are determined by the waves being reflected or refracted. The coloration depends on the size of the droplets. Large droplets yield brilliant bows, with the limiting color red. Medium drops have a limiting color of orange, and inside the violet there are bands in which pink predominates. With small drops, supernumerary bows appear to be separate from the primary bow. With very small drops, the rainbow degenerates into a white fog with faint traces of color at its edges.

## Halos

A halo is a luminous ring around the sun or the moon caused by refraction of light rays from the sun or moon through an ice crystal cloud or in a sky filled with ice crystals. Halos occur in two sizes, one with a radius of 22 degrees and the other with a radius of 46 degees. The most common is the 22-degree halo or fragment of it in a circle of 22 degrees radius around the sun or moon, red on the inside, followed by yellow and green, to blue on the outside. Whitish halos are caused by the reflection of light from the surface of the ice crystals. A colored halo may be distinguished from a corona by the fact that it has the red nearest the sun or moon, while the corona has the red in the outer ring.

## Coronas

A corona is a luminous ring surrounding the sun or moon caused by the diffraction of light by tiny raindrops. The light source is the sun or the moon. As distinguished from the halo, the color sequence of the corona is opposite that of the halo, since the red is on the outside. The radius of the corona is inversely proportional to the size of the water drops. A small corona indicates large drops; a large corona, small drops. When a corona is observed to be rapidly becoming smaller, it may, in conjunction with other signs, indicate that a storm is imminent, because the more humid the air, the larger the water droplets.

## Cloud Iridescence

Cloud iridescence is actually nothing more than a portion of a corona. It is caused by the diffraction of light from the sun or moon. The particles are so small that no concentricity is noticed.

# APPENDIX I

# SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, LOGARITHMS, AND RECIPROCALS OF NUMBERS

| No. | Square | Cube | Square Root | Cube Root | Log. | 1000 x Recip. | No = Dia. Circum. | No = Dia. Area |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1.0000 | 1 0000 | 0.00000 | 1000 000 | 3 142 | 0 7854 |
| 2 | 4 | 8 | 1 4142 | 1 2599 | 0 30103 | 500 000 | 6 283 | 3.1416 |
| 3 | 9 | 27 | 1 7321 | 1 4422 | 0.47712 | 333 333 | 9.425 | 7 0686 |
| 4 | 16 | 64 | 2.0000 | 1.5874 | 0 60206 | 250 000 | 12 566 | 12 5664 |
| 5 | 25 | 125 | 2 2361 | 1.7100 | 0.69897 | 200.000 | 15 708 | 19 6350 |
| 6 | 36 | 216 | 2 4495 | 1.8171 | 0 77815 | 166 667 | 18 850 | 28.2743 |
| 7 | 49 | 343 | 2 6458 | 1.9129 | 0 84510 | 142 857 | 21.991 | 38 4845 |
| 8 | 64 | 512 | 2 8284 | 2.0000 | 0 90308 | 125 000 | 25 133 | 50 2655 |
| 9 | 81 | 729 | 3 0000 | 2.0801 | 0 95424 | 111.111 | 28 274 | 63 6173 |
| 10 | 100 | 1000 | 3.1623 | 2 1544 | 1 00000 | 100 000 | 31 416 | 78.5398 |
| 11 | 121 | 1331 | 3 3166 | 2 2240 | 1 04139 | 90 9091 | 34.558 | 95.0332 |
| 12 | 144 | 1728 | 3 4641 | 2 2894 | 1.07918 | 83.3333 | 37 699 | 113 097 |
| 13 | 169 | 2197 | 3 6056 | 2.3513 | 1 11394 | 76.9231 | 40 841 | 132.732 |
| 14 | 196 | 2744 | 3.7417 | 2 4101 | 1.14613 | 71 4286 | 43 982 | 153 938 |
| 15 | 225 | 3375 | 3 8730 | 2 4662 | 1 17609 | 66 6667 | 47.124 | 176 715 |
| 16 | 256 | 4096 | 4 0000 | 2 5198 | 1.20412 | 62.5000 | 50 265 | 201 062 |
| 17 | 289 | 4913 | 4 1231 | 2 5713 | 1 23045 | 58.8235 | 53.407 | 226.980 |
| 18 | 324 | 5832 | 4 2426 | 2 6207 | 1.25527 | 55.5556 | 56.549 | 254.469 |
| 19 | 361 | 6859 | 4 3589 | 2 6684 | 1.27875 | 52.6316 | 59 690 | 283.529 |
| 20 | 400 | 8000 | 4 4721 | 2 7144 | 1.30103 | 50.0000 | 62 832 | 314.159 |
| 21 | 441 | 9261 | 4.5826 | 2.7589 | 1.32222 | 47 6190 | 65.973 | 346 361 |
| 22 | 484 | 10648 | 4 6904 | 2 8020 | 1.34242 | 45.4545 | 69.115 | 380 133 |
| 23 | 529 | 12167 | 4 7958 | 2 8439 | 1.36173 | 43.4783 | 72 257 | 415.476 |
| 24 | 576 | 13824 | 4 8990 | 2 8845 | 1.38021 | 41.6667 | 75.398 | 452.389 |
| 25 | 625 | 15625 | 5.0000 | 2.9240 | 1.39794 | 40.0000 | 78.540 | 490 874 |
| 26 | 676 | 17576 | 5 0990 | 2 9625 | 1.41497 | 38.4615 | 81.681 | 530.929 |
| 27 | 729 | 19683 | 5 1962 | 3 0000 | 1.43136 | 37 0370 | 84.823 | 572.555 |
| 28 | 784 | 21952 | 5 2915 | 3 0366 | 1 44716 | 35.7143 | 87.965 | 615.752 |
| 29 | 841 | 24389 | 5.3852 | 3 0723 | 1 46240 | 34.4828 | 91.106 | 660.520 |
| 30 | 900 | 27000 | 5.4772 | 3.1072 | 1.47712 | 33.3333 | 94.248 | 706.858 |
| 31 | 961 | 29791 | 5 5678 | 3 1414 | 1.49136 | 32 2581 | 97.389 | 754 768 |
| 32 | 1024 | 32768 | 5 6569 | 3 1748 | 1.50515 | 31 2500 | 100.531 | 804 248 |
| 33 | 1089 | 35937 | 5 7446 | 3 2075 | 1.51851 | 30.3030 | 103.673 | 855.299 |
| 34 | 1156 | 39304 | 5 8310 | 3 2396 | 1.53148 | 29.4118 | 106 814 | 907 920 |
| 35 | 1225 | 42875 | 5 9161 | 3 2711 | 1 54407 | 28.5714 | 109.956 | 962 113 |
| 36 | 1296 | 46656 | 6 0000 | 3 3019 | 1.55630 | 27.7778 | 113 097 | 1017 88 |
| 37 | 1369 | 50653 | 6 0828 | 3 3322 | 1 56820 | 27 0270 | 116 239 | 1075 21 |
| 38 | 1444 | 54872 | 6 1644 | 3 3620 | 1 57978 | 26.3158 | 119.381 | 1134.11 |
| 39 | 1521 | 59319 | 6 2450 | 3 3912 | 1 59106 | 25 6410 | 122 522 | 1194 39 |
| 40 | 1600 | 64000 | 6 3246 | 3 4200 | 1 60206 | 25 0000 | 125.66 | 1256 64 |
| 41 | 1681 | 68921 | 6 4031 | 3 4482 | 1.61278 | 24 3902 | 128 81 | 1320 25 |
| 42 | 1764 | 74088 | 6 4807 | 3 4760 | 1 62325 | 23 8095 | 131 95 | 1385 44 |
| 43 | 1849 | 79507 | 6 5574 | 3.5034 | 1 63347 | 23 2558 | 135 09 | 1452.20 |
| 44 | 1936 | 85184 | 6.6332 | 3.5303 | 1.64345 | 22.7273 | 138 23 | 1520.53 |

| No. | Square | Cube | Square Root | Cube Root | Log. | 1000 x Recip | No. = Dia. Circum | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Circum | Area |
| 45 | 2025 | 91125 | 6 7082 | 3 5569 | 1 65321 | 22 2222 | 141 37 | 1590 41 |
| 46 | 2116 | 97336 | 6 7823 | 3 5830 | 1 66276 | 21 7391 | 144 51 | 1661 90 |
| 47 | 2209 | 103823 | 6 8557 | 3 6088 | 1 67210 | 21 2766 | 147 65 | 1734 94 |
| 48 | 2304 | 110592 | 6 9282 | 3 6342 | 1 68124 | 20 8333 | 150 80 | 1809 56 |
| 49 | 2401 | 117649 | 7 0000 | 3 6593 | 1 69020 | 20 4082 | 153 94 | 1885 74 |
| 50 | 2500 | 125000 | 7 0711 | 3 6840 | 1 69897 | 20 0000 | 157 08 | 1963 50 |
| 51 | 2601 | 132651 | 7 1414 | 3 7084 | 1 70757 | 19 6078 | 160 22 | 2042 82 |
| 52 | 2704 | 140608 | 7 2111 | 3 7325 | 1 71600 | 19 2308 | 163 36 | 2123 72 |
| 53 | 2809 | 148877 | 7 2801 | 3 7563 | 1 72428 | 18 8679 | 166 50 | 2206 18 |
| 54 | 2916 | 157464 | 7 3485 | 3.7798 | 1 73239 | 18 5185 | 169-65 | 2290 22 |
| 55 | 3025 | 166375 | 7.4162 | 3 8030 | 1 74036 | 18 1818 | 172 79 | 2375 83 |
| 56 | 3136 | 175616 | 7 4833 | 3 8259 | 1 74819 | 17 8571 | 175 93 | 2463 01 |
| 57 | 3249 | 185193 | 7 5498 | 3 8485 | 1 75587 | 17 5439 | 179 07 | 2551 76 |
| 58 | 3364 | 195112 | 7 6158 | 3 8709 | 1 76343 | 17 2414 | 182 21 | 2642 08 |
| 59 | 3481 | 205379 | 7.6811 | 3.8930 | 1 77085 | 16 9492 | 185 35 | 2733 97 |
| 60 | 3600 | 216000 | 7 7460 | 3 9149 | 1 77815 | 16 6667 | 188 50 | 2827 43 |
| 61 | 3721 | 226981 | 7 8102 | 3 9365 | 1 78533 | 16 3934 | 191 64 | 2922 47 |
| 62 | 3844 | 238328 | 7 8740 | 3 9579 | 1 79239 | 16 1290 | 194 78 | 3019 07 |
| 63 | 3969 | 250047 | 7 9373 | 3 9791 | 1 79934 | 15 8730 | 197 92 | 3117 25 |
| 64 | 4096 | 262144 | 8 0000 | 4 0000 | 1 80618 | 15 6250 | 201 06 | 3216 99 |
| 65 | 4225 | 274625 | 8 0623 | 4 0207 | 1 81291 | 15 3846 | 204 20 | 3318 31 |
| 66 | 4356 | 287496 | 8 1240 | 4 0412 | 1 81954 | 15 1515 | 207 35 | 3421 19 |
| 67 | 4489 | 300763 | 8 1854 | 4 0615 | 1 82607 | 14 9254 | 210 49 | 3525 65 |
| 68 | 4624 | 314432 | 8 2462 | 4 0817 | 1 83251 | 14 7059 | 213 63 | 3631 68 |
| 69 | 4761 | 328509 | 8 3066 | 4.1016 | 1 83885 | 14 4928 | 216 77 | 3739 28 |
| 70 | 4900 | 343000 | 8 3666 | 4 1213 | 1 84510 | 14 2857 | 219.91 | 3848 45 |
| 71 | 5041 | 357911 | 8 4261 | 4 1408 | 1 85126 | 14 0845 | 223 05 | 3959 19 |
| 72 | 5184 | 373248 | 8 4853 | 4 1602 | 1 85733 | 13 8889 | 226 19 | 4071 50 |
| 73 | 5329 | 389017 | 8 5440 | 4 1793 | 1 86332 | 13 6986 | 229 34 | 4185 39 |
| 74 | 5476 | 405224 | 8 6023 | 4.1983 | 1 86923 | 13 5135 | 232 48 | 4300 84 |
| 75 | 5625 | 421875 | 8 6603 | 4 2172 | 1 87506 | 13 3333 | 235 62 | 4417 86 |
| 76 | 5776 | 438976 | 8 7178 | 4.2358 | 1 88081 | 13 1579 | 238 76 | 4536 46 |
| 77 | 5929 | 456533 | 8 7750 | 4 2543 | 1 88649 | 12 9870 | 241 90 | 4656 63 |
| 78 | 6084 | 474552 | 8 8318 | 4 2727 | 1 89209 | 12 8205 | 245 04 | 4778 36 |
| 79 | 6241 | 493039 | 8 8882 | 4.2908 | 1 89763 | 12 6582 | 248 19 | 4901 67 |
| 80 | 6400 | 512000 | 8 9443 | 4.3089 | 1 90309 | 12 5000 | 251 33 | 5026 55 |
| 81 | 6561 | 531441 | 9 0000 | 4 3267 | 1 90849 | 12.3457 | 254 47 | 5153 00 |
| 82 | 6724 | 551368 | 9 0554 | 4 3445 | 1 91381 | 12 1951 | 257 61 | 5281 02 |
| 83 | 6889 | 571787 | 9 1104 | 4 3621 | 1 91908 | 12 0482 | 260 75 | 5410 61 |
| 84 | 7056 | 592704 | 9 1652 | 4 3795 | 1 92428 | 11 9048 | 263 89 | 5541 77 |
| 85 | 7225 | 614125 | 9 2195 | 4 3968 | 1 92942 | 11 7647 | 267 04 | 5674 50 |
| 86 | 7396 | 636056 | 9 2736 | 4 4140 | 1 93450 | 11 6279 | 270 18 | 5808 80 |
| 87 | 7569 | 658503 | 9 3274 | 4 4310 | 1 93952 | 11 4943 | 273 32 | 5944 68 |
| 88 | 7744 | 681472 | 9 3808 | 4 4480 | 1 94448 | 11 3636 | 276 46 | 6082 12 |
| 89 | 7921 | 704969 | 9.4340 | 4.4647 | 1 94939 | 11.2360 | 279.60 | 6221.14 |

| No. | Square | Cube | Square Root | Cube Root | Log. | 1000 x Recip. | No. = Dia. Circum. | No. = Dia. Area |
|---|---|---|---|---|---|---|---|---|
| 90 | 8100 | 729000 | 9.4868 | 4.4814 | 1.95424 | 11.1111 | 282.74 | 6361.73 |
| 91 | 8281 | 753571 | 9.5394 | 4.4979 | 1 95904 | 10.9890 | 285.88 | 6503.88 |
| 92 | 8464 | 778688 | 9.5917 | 4.5144 | 1 96379 | 10 8696 | 289.03 | 6647.61 |
| 93 | 8649 | 804357 | 9.6437 | 4.5307 | 1.96848 | 10.7527 | 292.17 | 6792.91 |
| 94 | 8836 | 830584 | 9.6954 | 4.5468 | 1.97313 | 10.6383 | 295.31 | 6939.78 |
| 95 | 9025 | 857375 | 9.7468 | 4.5629 | 1.97772 | 10.5263 | 298.45 | 7088.22 |
| 96 | 9216 | 884736 | 9.7980 | 4.5789 | 1.98227 | 10.4167 | 301.59 | 7238.23 |
| 97 | 9409 | 912673 | 9.8489 | 4.5947 | 1.98677 | 10 3093 | 304.73 | 7389.81 |
| 98 | 9604 | 941192 | 9 8995 | 4 6104 | 1.99123 | 10.2041 | 307.88 | 7542.96 |
| 99 | 9801 | 970299 | 9.9499 | 4.6261 | 1.99564 | 10.1010 | 311.02 | 7697.69 |
| 100 | 10000 | 1000000 | 10 0000 | 4 6416 | 2.00000 | 10.00000 | 314 16 | 7853.98 |
| 101 | 10201 | 1030301 | 10 0499 | 4 6570 | 2 00432 | 9.90099 | 317.30 | 8011.85 |
| 102 | 10404 | 1061208 | 10.0995 | 4.6723 | 2 00860 | 9.80392 | 320 44 | 8171.28 |
| 103 | 10609 | 1092727 | 10 1489 | 4 6875 | 2 01284 | 9.70874 | 323.58 | 8332.29 |
| 104 | 10816 | 1124864 | 10.1980 | 4.7027 | 2.01703 | 9.61538 | 326 73 | 8494.87 |
| 105 | 11025 | 1157625 | 10.2470 | 4.7177 | 2.02119 | 9 52381 | 329 87 | 8659.01 |
| 106 | 11236 | 1191016 | 10 2956 | 4 7326 | 2 02531 | 9.43396 | 333.01 | 8824.73 |
| 107 | 11449 | 1225043 | 10 3441 | 4.7475 | 2.02938 | 9.34579 | 336.15 | 8992.02 |
| 108 | 11664 | 1259712 | 10.3923 | 4 7622 | 2 03342 | 9 25926 | 339.29 | 9160.88 |
| 109 | 11881 | 1295029 | 10.4403 | 4.7769 | 2 03743 | 9.17431 | 342.43 | 9331.32 |
| 110 | 12100 | 1331000 | 10.4881 | 4.7914 | 2 04139 | 9 09091 | 345.58 | 9503.32 |
| 111 | 12321 | 1367631 | 10.5357 | 4 8059 | 2 04532 | 9 00901 | 348.72 | 9676.89 |
| 112 | 12544 | 1404928 | 10.5830 | 4 8203 | 2 04922 | 8.92857 | 351.86 | 9852.03 |
| 113 | 12769 | 1442897 | 10.6301 | 4 8346 | 2.05308 | 8.84956 | 355 00 | 10028.7 |
| 114 | 12996 | 1481544 | 10.6771 | 4 8488 | 2.05690 | 8.77193 | 358.14 | 10207.0 |
| 115 | 13225 | 1520875 | 10.7238 | 4 8629 | 2.06070 | 8.69565 | 361.28 | 10386.9 |
| 116 | 13456 | 1560896 | 10 7703 | 4 8770 | 2 06446 | 8.62069 | 364.42 | 10568.3 |
| 117 | 13689 | 1601613 | 10 8167 | 4.8910 | 2.06819 | 8 54701 | 367.57 | 10751.3 |
| 118 | 13924 | 1643032 | 10.8628 | 4.9049 | 2.07188 | 8.47458 | 370.71 | 10935.9 |
| 119 | 14161 | 1685159 | 10.9087 | 4 9187 | 2.07555 | 8.40336 | 373.85 | 11122.0 |
| 120 | 14400 | 1728000 | 10.9545 | 4.9324 | 2.07918 | 8.33333 | 376.99 | 11309.7 |
| 121 | 14641 | 1771561 | 11.0000 | 4.9461 | 2.08279 | 8.26446 | 380.13 | 11499.0 |
| 122 | 14884 | 1815848 | 11.0454 | 4.9597 | 2 08636 | 8.19672 | 383.27 | 11689.9 |
| 123 | 15129 | 1860867 | 11.0905 | 4.9732 | 2.08991 | 8.13008 | 386.42 | 11882.3 |
| 124 | 15376 | 1906624 | 11.1355 | 4.9866 | 2.09342 | 8.06452 | 389.56 | 12076.3 |
| 125 | 15625 | 1953125 | 11.1803 | 5 0000 | 2.09691 | 8.00000 | 392.70 | 12271.8 |
| 126 | 15876 | 2000376 | 11.2250 | 5.0133 | 2.10037 | 7.93651 | 395.84 | 12469.0 |
| 127 | 16129 | 2048383 | 11.2694 | 5.0265 | 2.10380 | 7.87402 | 398.98 | 12667.7 |
| 128 | 16384 | 2097152 | 11.3137 | 5 0397 | 2.10721 | 7.81250 | 402.12 | 12868.0 |
| 129 | 16641 | 2146689 | 11.3578 | 5.0528 | 2.11059 | 7.75194 | 405.27 | 13069.8 |
| 130 | 16900 | 2197000 | 11.4018 | 5.0653 | 2.11394 | 7.69231 | 408.41 | 13273.2 |
| 131 | 17161 | 2248091 | 11.4455 | 5 0788 | 2.11727 | 7.63359 | 411.55 | 13478.2 |
| 132 | 17424 | 2299968 | 11.4891 | 5.0916 | 2.12057 | 7.57576 | 414.69 | 13684.8 |
| 133 | 17689 | 2352637 | 11.5326 | 5.1045 | 2.12385 | 7.51880 | 417.83 | 13892.9 |
| 134 | 17956 | 2406104 | 11.5758 | 5.1172 | 2.12710 | 7.46269 | 620.97 | 14102.6 |

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# APPENDIX II

# NATURAL SINES, COSINES, AND TANGENTS OF ANGLES FROM 0° to 90°

0°–14.9°

| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | sin | 0.0000 | 0.0017 | 0.0035 | 0.0052 | 0.0070 | 0.0087 | 0.0105 | 0.0122 | 0.0140 | 0.0157 |
| | cos | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.9999 | 0.9999 | 0.9999 | 0.9999 |
| | tan | 0.0000 | 0.0017 | 0.0035 | 0.0052 | 0.0070 | 0.0087 | 0.0105 | 0.0122 | 0.0140 | 0.0157 |
| 1 | sin | 0.0175 | 0.0192 | 0.0209 | 0.0227 | 0.0244 | 0.0262 | 0.0279 | 0.0297 | 0.0314 | 0.0332 |
| | cos | 0.9998 | 0.9998 | 0.9998 | 0.9997 | 0.9997 | 0.9997 | 0.9996 | 0.9996 | 0.9995 | 0.9995 |
| | tan | 0.0175 | 0.0192 | 0.0209 | 0.0227 | 0.0244 | 0.0262 | 0.0279 | 0.0297 | 0.0314 | 0.0332 |
| 2 | sin | 0.0349 | 0.0366 | 0.0384 | 0.0401 | 0.0419 | 0.0436 | 0.0454 | 0.0471 | 0.0488 | 0.0506 |
| | cos | 0.9994 | 0.9993 | 0.9993 | 0.9992 | 0.9991 | 0.9990 | 0.9990 | 0.9989 | 0.9988 | 0.9987 |
| | tan | 0.0349 | 0.0367 | 0.0384 | 0.0402 | 0.0419 | 0.0437 | 0.0454 | 0.0472 | 0.0489 | 0.0507 |
| 3 | sin | 0.0523 | 0.0541 | 0.0558 | 0.0576 | 0.0593 | 0.0610 | 0.0628 | 0.0645 | 0.0663 | 0.0680 |
| | cos | 0.9986 | 0.9985 | 0.9984 | 0.9983 | 0.9982 | 0.9981 | 0.9980 | 0.9979 | 0.9978 | 0.9977 |
| | tan | 0.0524 | 0.0542 | 0.0559 | 0.0577 | 0.0594 | 0.0612 | 0.0629 | 0.0647 | 0.0664 | 0.0682 |
| 4 | sin | 0.0698 | 0.0715 | 0.0732 | 0.0750 | 0.0767 | 0.0785 | 0.0802 | 0.0819 | 0.0837 | 0.0854 |
| | cos | 0.9976 | 0.9974 | 0.9973 | 0.9972 | 0.9971 | 0.9969 | 0.9968 | 0.9966 | 0.9965 | 0.9963 |
| | tan | 0.0699 | 0.0717 | 0.0734 | 0.0752 | 0.0769 | 0.0787 | 0.0805 | 0.0822 | 0.0840 | 0.0857 |
| 5 | sin | 0.0872 | 0.0889 | 0.0906 | 0.0924 | 0.0941 | 0.0958 | 0.0976 | 0.0993 | 0.1011 | 0.1028 |
| | cos | 0.9962 | 0.9960 | 0.9959 | 0.9957 | 0.9956 | 0.9954 | 0.9952 | 0.9951 | 0.9949 | 0.9947 |
| | tan | 0.0875 | 0.0892 | 0.0910 | 0.0928 | 0.0945 | 0.0963 | 0.0981 | 0.0998 | 0.1016 | 0.1033 |
| 6 | sin | 0.1045 | 0.1063 | 0.1080 | 0.1097 | 0.1115 | 0.1132 | 0.1149 | 0.1167 | 0.1184 | 0.1201 |
| | cos | 0.9945 | 0.9943 | 0.9942 | 0.9940 | 0.9938 | 0.9936 | 0.9934 | 0.9932 | 0.9930 | 0.9928 |
| | tan | 0.1051 | 0.1069 | 0.1086 | 0.1104 | 0.1122 | 0.1139 | 0.1157 | 0.1175 | 0.1192 | 0.1210 |
| 7 | sin | 0.1219 | 0.1236 | 0.1253 | 0.1271 | 0.1288 | 0.1305 | 0.1323 | 0.1340 | 0.1357 | 0.1374 |
| | cos | 0.9925 | 0.9923 | 0.9921 | 0.9919 | 0.9917 | 0.9914 | 0.9912 | 0.9910 | 0.9907 | 0.9905 |
| | tan | 0.1228 | 0.1246 | 0.1263 | 0.1281 | 0.1299 | 0.1317 | 0.1334 | 0.1352 | 0.1370 | 0.1388 |
| 8 | sin | 0.1392 | 0.1409 | 0.1426 | 0.1444 | 0.1461 | 0.1478 | 0.1495 | 0.1513 | 0.1530 | 0.1547 |
| | cos | 0.9903 | 0.9900 | 0.9898 | 0.9895 | 0.9893 | 0.9890 | 0.9888 | 0.9885 | 0.9882 | 0.9880 |
| | tan | 0.1405 | 0.1423 | 0.1441 | 0.1459 | 0.1477 | 0.1495 | 0.1512 | 0.1530 | 0.1548 | 0.1566 |
| 9 | sin | 0.1564 | 0.1582 | 0.1599 | 0.1616 | 0.1633 | 0.1650 | 0.1668 | 0.1685 | 0.1702 | 0.1719 |
| | cos | 0.9877 | 0.9874 | 0.9871 | 0.9869 | 0.9866 | 0.9863 | 0.9860 | 0.9857 | 0.9854 | 0.9851 |
| | tan | 0.1584 | 0.1602 | 0.1620 | 0.1638 | 0.1655 | 0.1673 | 0.1691 | 0.1709 | 0.1727 | 0.1745 |
| 10 | sin | 0.1736 | 0.1754 | 0.1771 | 0.1788 | 0.1805 | 0.1822 | 0.1840 | 0.1857 | 0.1874 | 0.1891 |
| | cos | 0.9848 | 0.9845 | 0.9842 | 0.9839 | 0.9836 | 0.9833 | 0.9829 | 0.9826 | 0.9823 | 0.9820 |
| | tan | 0.1763 | 0.1781 | 0.1799 | 0.1817 | 0.1835 | 0.1853 | 0.1871 | 0.1890 | 0.1908 | 0.1926 |
| 11 | sin | 0.1908 | 0.1925 | 0.1942 | 0.1959 | 0.1977 | 0.1994 | 0.2011 | 0.2028 | 0.2045 | 0.2062 |
| | cos | 0.9816 | 0.9813 | 0.9810 | 0.9806 | 0.9803 | 0.9799 | 0.9796 | 0.9792 | 0.9789 | 0.9785 |
| | tan | 0.1944 | 0.1962 | 0.1980 | 0.1998 | 0.2016 | 0.2035 | 0.2053 | 0.2071 | 0.2089 | 0.2107 |
| 12 | sin | 0.2079 | 0.2096 | 0.2113 | 0.2130 | 0.2147 | 0.2164 | 0.2181 | 0.2198 | 0.2215 | 0.2232 |
| | cos | 0.9781 | 0.9778 | 0.9774 | 0.9770 | 0.9767 | 0.9763 | 0.9759 | 0.9755 | 0.9751 | 0.9748 |
| | tan | 0.2126 | 0.2144 | 0.2162 | 0.2180 | 0.2199 | 0.2217 | 0.2235 | 0.2254 | 0.2272 | 0.2290 |
| 13 | sin | 0.2250 | 0.2267 | 0.2284 | 0.2300 | 0.2317 | 0.2334 | 0.2351 | 0.2368 | 0.2385 | 0.2402 |
| | cos | 0.9744 | 0.9740 | 0.9736 | 0.9732 | 0.9728 | 0.9724 | 0.9720 | 0.9715 | 0.9711 | 0.9707 |
| | tan | 0.2309 | 0.2327 | 0.2345 | 0.2364 | 0.2382 | 0.2401 | 0.2419 | 0.2438 | 0.2456 | 0.2475 |
| 14 | sin | 0.2419 | 0.2436 | 0.2453 | 0.2470 | 0.2487 | 0.2504 | 0.2521 | 0.2538 | 0.2554 | 0.2571 |
| | cos | 0.9703 | 0.9699 | 0.9694 | 0.9690 | 0.9686 | 0.9681 | 0.9677 | 0.9673 | 0.9668 | 0.9664 |
| | tan | 0.2493 | 0.2512 | 0.2530 | 0.2549 | 0.2568 | 0.2586 | 0.2605 | 0.2623 | 0.2642 | 0.2661 |
| Degs. | Function | 0′ | 6′ | 12′ | 18′ | 24′ | 30′ | 36′ | 42′ | 48′ | 54′ |

| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | sin | 0.2588 | 0.2605 | 0.2622 | 0.2639 | 0.2656 | 0.2672 | 0.2689 | 0.2706 | 0.2723 | 0.2740 |
| | cos | 0.9659 | 0.9655 | 0.9650 | 0.9646 | 0.9641 | 0.9636 | 0.9632 | 0.9627 | 0.9622 | 0.9617 |
| | tan | 0.2679 | 0.2698 | 0.2717 | 0.2736 | 0.2754 | 0.2773 | 0.2792 | 0.2811 | 0.2830 | 0.2849 |
| 16 | sin | 0.2756 | 0.2773 | 0.2790 | 0.2807 | 0.2823 | 0.2840 | 0.2857 | 0.2874 | 0.2890 | 0.2907 |
| | cos | 0.9613 | 0.9608 | 0.9603 | 0.9598 | 0.9593 | 0.9588 | 0.9583 | 0.9578 | 0.9573 | 0.9568 |
| | tan | 0.2867 | 0.2886 | 0.2905 | 0.2924 | 0.2943 | 0.2962 | 0.2981 | 0.3000 | 0.3019 | 0.3038 |
| 17 | sin | 0.2924 | 0.2940 | 0.2957 | 0.2974 | 0.2990 | 0.3007 | 0.3024 | 0.3040 | 0.3057 | 0.3074 |
| | cos | 0.9563 | 0.9558 | 0.9553 | 0.9548 | 0.9542 | 0.9537 | 0.9532 | 0.9527 | 0.9521 | 0.9516 |
| | tan | 0.3057 | 0.3076 | 0.3096 | 0.3115 | 0.3134 | 0.3153 | 0.3172 | 0.3191 | 0.3211 | 0.3230 |
| 18 | sin | 0.3090 | 0.3107 | 0.3123 | 0.3140 | 0.3156 | 0.3173 | 0.3190 | 0.3206 | 0.3223 | 0.3239 |
| | cos | 0.9511 | 0.9505 | 0.9500 | 0.9494 | 0.9489 | 0.9483 | 0.9478 | 0.9472 | 0.9466 | 0.9461 |
| | tan | 0.3249 | 0.3269 | 0.3288 | 0.3307 | 0.3327 | 0.3346 | 0.3365 | 0.3385 | 0.3404 | 0.3424 |
| 19 | sin | 0.3256 | 0.3272 | 0.3289 | 0.3305 | 0.3322 | 0.3338 | 0.3355 | 0.3371 | 0.3387 | 0.3404 |
| | cos | 0.9455 | 0.9449 | 0.9444 | 0.9438 | 0.9432 | 0.9426 | 0.9421 | 0.9415 | 0.9409 | 0.9403 |
| | tan | 0.3443 | 0.3463 | 0.3482 | 0.3502 | 0.3522 | 0.3541 | 0.3561 | 0.3581 | 0.3600 | 0.3620 |
| 20 | sin | 0.3420 | 0.3437 | 0.3453 | 0.3469 | 0.3486 | 0.3502 | 0.3518 | 0.3535 | 0.3551 | 0.3567 |
| | cos | 0.9397 | 0.9391 | 0.9385 | 0.9379 | 0.9373 | 0.9367 | 0.9361 | 0.9354 | 0.9348 | 0.9342 |
| | tan | 0.3640 | 0.3659 | 0.3679 | 0.3699 | 0.3719 | 0.3739 | 0.3759 | 0.3779 | 0.3799 | 0.3819 |
| 21 | sin | 0.3584 | 0.3600 | 0.3616 | 0.3633 | 0.3649 | 0.3665 | 0.3681 | 0.3697 | 0.3714 | 0.3730 |
| | cos | 0.9336 | 0.9330 | 0.9323 | 0.9317 | 0.9311 | 0.9304 | 0.9298 | 0.9291 | 0.9285 | 0.9278 |
| | tan | 0.3839 | 0.3859 | 0.3879 | 0.3899 | 0.3919 | 0.3939 | 0.3959 | 0.3979 | 0.4000 | 0.4020 |
| 22 | sin | 0.3746 | 0.3762 | 0.3778 | 0.3795 | 0.3811 | 0.3827 | 0.3843 | 0.3859 | 0.3875 | 0.3891 |
| | cos | 0.9272 | 0.9265 | 0.9259 | 0.9252 | 0.9245 | 0.9239 | 0.9232 | 0.9225 | 0.9219 | 0.9212 |
| | tan | 0.4040 | 0.4061 | 0.4081 | 0.4101 | 0.4122 | 0.4142 | 0.4163 | 0.4183 | 0.4204 | 0.4224 |
| 23 | sin | 0.3907 | 0.3923 | 0.3939 | 0.3955 | 0.3971 | 0.3987 | 0.4003 | 0.4019 | 0.4035 | 0.4051 |
| | cos | 0.9205 | 0.9198 | 0.9191 | 0.9184 | 0.9178 | 0.9171 | 0.9164 | 0.9157 | 0.9150 | 0.9143 |
| | tan | 0.4245 | 0.4265 | 0.4286 | 0.4307 | 0.4327 | 0.4348 | 0.4369 | 0.4390 | 0.4411 | 0.4431 |
| 24 | sin | 0.4067 | 0.4083 | 0.4099 | 0.4115 | 0.4131 | 0.4147 | 0.4163 | 0.4179 | 0.4195 | 0.4210 |
| | cos | 0.9135 | 0.9128 | 0.9121 | 0.9114 | 0.9107 | 0.9100 | 0.9092 | 0.9085 | 0.9078 | 0.9070 |
| | tan | 0.4452 | 0.4473 | 0.4494 | 0.4515 | 0.4536 | 0.4557 | 0.4578 | 0.4599 | 0.4621 | 0.4642 |
| 25 | sin | 0.4226 | 0.4242 | 0.4258 | 0.4274 | 0.4289 | 0.4305 | 0.4321 | 0.4337 | 0.4352 | 0.4368 |
| | cos | 0.9063 | 0.9056 | 0.9048 | 0.9041 | 0.9033 | 0.9026 | 0.9018 | 0.9011 | 0.9003 | 0.8996 |
| | tan | 0.4663 | 0.4684 | 0.4706 | 0.4727 | 0.4748 | 0.4770 | 0.4791 | 0.4813 | 0.4834 | 0.4856 |
| 26 | sin | 0.4384 | 0.4399 | 0.4415 | 0.4431 | 0.4446 | 0.4462 | 0.4478 | 0.4493 | 0.4509 | 0.4524 |
| | cos | 0.8988 | 0.8980 | 0.8973 | 0.8965 | 0.8957 | 0.8949 | 0.8942 | 0.8934 | 0.8926 | 0.8918 |
| | tan | 0.4877 | 0.4899 | 0.4921 | 0.4942 | 0.4964 | 0.4986 | 0.5008 | 0.5029 | 0.5051 | 0.5073 |
| 27 | sin | 0.4540 | 0.4555 | 0.4571 | 0.4586 | 0.4602 | 0.4617 | 0.4633 | 0.4648 | 0.4664 | 0.4679 |
| | cos | 0.8910 | 0.8902 | 0.8894 | 0.8886 | 0.8878 | 0.8870 | 0.8862 | 0.8854 | 0.8846 | 0.8838 |
| | tan | 0.5095 | 0.5117 | 0.5139 | 0.5161 | 0.5184 | 0.5206 | 0.5228 | 0.5250 | 0.5272 | 0.5295 |
| 28 | sin | 0.4695 | 0.4710 | 0.4726 | 0.4741 | 0.4756 | 0.4772 | 0.4787 | 0.4802 | 0.4818 | 0.4833 |
| | cos | 0.8829 | 0.8821 | 0.8813 | 0.8805 | 0.8796 | 0.8788 | 0.8780 | 0.8771 | 0.8763 | 0.8755 |
| | tan | 0.5317 | 0.5340 | 0.5362 | 0.5384 | 0.5407 | 0.5430 | 0.5452 | 0.5475 | 0.5498 | 0.5520 |
| 29 | sin | 0.4848 | 0.4863 | 0.4879 | 0.4894 | 0.4909 | 0.4924 | 0.4939 | 0.4955 | 0.4970 | 0.4985 |
| | cos | 0.8746 | 0.8738 | 0.8729 | 0.8721 | 0.8712 | 0.8704 | 0.8695 | 0.8686 | 0.8678 | 0.8669 |
| | tan | 0.5543 | 0.5566 | 0.5589 | 0.5612 | 0.5635 | 0.5658 | 0.5681 | 0.5704 | 0.5727 | 0.5750 |
| Degs. | Function | 0' | 6' | 12' | 18' | 24' | 30' | 36' | 42' | 48' | 54' |

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| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | sin | 0.5000 | 0.5015 | 0.5030 | 0.5045 | 0.5060 | 0.5075 | 0.5090 | 0.5105 | 0.5120 | 0.5135 |
| | cos | 0.8660 | 0.8652 | 0.8643 | 0.8634 | 0.8625 | 0.8616 | 0.8607 | 0.8599 | 0.8590 | 0.8581 |
| | tan | 0.5774 | 0.5797 | 0.5820 | 0.5844 | 0.5867 | 0.5890 | 0.5914 | 0.5938 | 0.5961 | 0.5985 |
| 31 | sin | 0.5150 | 0.5165 | 0.5180 | 0.5195 | 0.5210 | 0.5225 | 0.5240 | 0.5255 | 0.5270 | 0.5284 |
| | cos | 0.8572 | 0.8563 | 0.8554 | 0.8545 | 0.8536 | 0.8526 | 0.8517 | 0.8508 | 0.8499 | 0.8490 |
| | tan | 0.6009 | 0.6032 | 0.6056 | 0.6080 | 0.6104 | 0.6128 | 0.6152 | 0.6176 | 0.6200 | 0.6224 |
| 32 | sin | 0.5299 | 0.5314 | 0.5329 | 0.5344 | 0.5358 | 0.5373 | 0.5388 | 0.5402 | 0.5417 | 0.5432 |
| | cos | 0.8480 | 0.8471 | 0.8462 | 0.8453 | 0.8443 | 0.8434 | 0.8425 | 0.8415 | 0.8406 | 0.8396 |
| | tan | 0.6249 | 0.6273 | 0.6297 | 0.6322 | 0.6346 | 0.6371 | 0.6395 | 0.6420 | 0.6445 | 0.6469 |
| 33 | sin | 0.5446 | 0.5461 | 0.5476 | 0.5490 | 0.5505 | 0.5519 | 0.5534 | 0.5548 | 0.5563 | 0.5577 |
| | cos | 0.8387 | 0.8377 | 0.8368 | 0.8358 | 0.8348 | 0.8339 | 0.8329 | 0.8320 | 0.8310 | 0.8300 |
| | tan | 0.6494 | 0.6519 | 0.6544 | 0.6569 | 0.6594 | 0.6619 | 0.6644 | 0.6669 | 0.6694 | 0.6720 |
| 34 | sin | 0.5592 | 0.5606 | 0.5621 | 0.5635 | 0.5650 | 0.5664 | 0.5678 | 0.5693 | 0.5707 | 0.5721 |
| | cos | 0.8290 | 0.8281 | 0.8271 | 0.8261 | 0.8251 | 0.8241 | 0.8231 | 0.8221 | 0.8211 | 0.8202 |
| | tan | 0.6745 | 0.6771 | 0.6796 | 0.6822 | 0.6847 | 0.6873 | 0.6899 | 0.6924 | 0.6950 | 0.6976 |
| 35 | sin | 0.5736 | 0.5750 | 0.5764 | 0.5779 | 0.5793 | 0.5807 | 0.5821 | 0.5835 | 0.5850 | 0.5864 |
| | cos | 0.8192 | 0.8181 | 0.8171 | 0.8161 | 0.8151 | 0.8141 | 0.8131 | 0.8121 | 0.8111 | 0.8100 |
| | tan | 0.7002 | 0.7028 | 0.7054 | 0.7080 | 0.7107 | 0.7133 | 0.7159 | 0.7186 | 0.7212 | 0.7239 |
| 36 | sin | 0.5878 | 0.5892 | 0.5906 | 0.5920 | 0.5934 | 0.5948 | 0.5962 | 0.5976 | 0.5990 | 0.6004 |
| | cos | 0.8090 | 0.8080 | 0.8070 | 0.8059 | 0.8049 | 0.8039 | 0.8028 | 0.8018 | 0.8007 | 0.7997 |
| | tan | 0.7265 | 0.7292 | 0.7319 | 0.7346 | 0.7373 | 0.7400 | 0.7427 | 0.7454 | 0.7481 | 0.7508 |
| 37 | sin | 0.6018 | 0.6032 | 0.6046 | 0.6060 | 0.6074 | 0.6088 | 0.6101 | 0.6115 | 0.6129 | 0.6143 |
| | cos | 0.7986 | 0.7976 | 0.7965 | 0.7955 | 0.7944 | 0.7934 | 0.7923 | 0.7912 | 0.7902 | 0.7891 |
| | tan | 0.7536 | 0.7563 | 0.7590 | 0.7618 | 0.7646 | 0.7673 | 0.7701 | 0.7729 | 0.7757 | 0.7785 |
| 38 | sin | 0.6157 | 0.6170 | 0.6184 | 0.6198 | 0.6211 | 0.6225 | 0.6239 | 0.6252 | 0.6266 | 0.6280 |
| | cos | 0.7880 | 0.7869 | 0.7859 | 0.7848 | 0.7837 | 0.7826 | 0.7815 | 0.7804 | 0.7793 | 0.7782 |
| | tan | 0.7813 | 0.7841 | 0.7869 | 0.7898 | 0.7926 | 0.7954 | 0.7983 | 0.8012 | 0.8040 | 0.8069 |
| 39 | sin | 0.6293 | 0.6307 | 0.6320 | 0.6334 | 0.6347 | 0.6361 | 0.6374 | 0.6388 | 0.6401 | 0.6414 |
| | cos | 0.7771 | 0.7760 | 0.7749 | 0.7738 | 0.7727 | 0.7716 | 0.7705 | 0.7694 | 0.7683 | 0.7672 |
| | tan | 0.8098 | 0.8127 | 0.8156 | 0.8185 | 0.8214 | 0.8243 | 0.8273 | 0.8302 | 0.8332 | 0.8361 |
| 40 | sin | 0.6428 | 0.6441 | 0.6455 | 0.6468 | 0.6481 | 0.6494 | 0.6508 | 0.6521 | 0.6534 | 0.6547 |
| | cos | 0.7660 | 0.7649 | 0.7638 | 0.7627 | 0.7615 | 0.7604 | 0.7593 | 0.7581 | 0.7570 | 0.7559 |
| | tan | 0.8391 | 0.8421 | 0.8451 | 0.8481 | 0.8511 | 0.8541 | 0.8571 | 0.8601 | 0.8632 | 0.8662 |
| 41 | sin | 0.6561 | 0.6574 | 0.6587 | 0.6600 | 0.6613 | 0.6626 | 0.6639 | 0.6652 | 0.6665 | 0.6678 |
| | cos | 0.7547 | 0.7536 | 0.7524 | 0.7513 | 0.7501 | 0.7490 | 0.7478 | 0.7466 | 0.7455 | 0.7443 |
| | tan | 0.8693 | 0.8724 | 0.8754 | 0.8785 | 0.8816 | 0.8847 | 0.8878 | 0.8910 | 0.8941 | 0.8972 |
| 42 | sin | 0.6691 | 0.6704 | 0.6717 | 0.6730 | 0.6743 | 0.6756 | 0.6769 | 0.6782 | 0.6794 | 0.6807 |
| | cos | 0.7431 | 0.7420 | 0.7408 | 0.7396 | 0.7385 | 0.7373 | 0.7361 | 0.7349 | 0.7337 | 0.7325 |
| | tan | 0.9004 | 0.9036 | 0.9067 | 0.9099 | 0.9131 | 0.9163 | 0.9195 | 0.9228 | 0.9260 | 0.9293 |
| 43 | sin | 0.6820 | 0.6833 | 0.6845 | 0.6858 | 0.6871 | 0.6884 | 0.6896 | 0.6909 | 0.6921 | 0.6934 |
| | cos | 0.7314 | 0.7302 | 0.7290 | 0.7278 | 0.7266 | 0.7254 | 0.7242 | 0.7230 | 0.7218 | 0.7206 |
| | tan | 0.9325 | 0.9358 | 0.9391 | 0.9424 | 0.9457 | 0.9490 | 0.9523 | 0.9556 | 0.9590 | 0.9623 |
| 44 | sin | 0.6947 | 0.6959 | 0.6972 | 0.6984 | 0.6997 | 0.7009 | 0.7022 | 0.7034 | 0.7046 | 0.7059 |
| | cos | 0.7193 | 0.7181 | 0.7169 | 0.7157 | 0.7145 | 0.7133 | 0.7120 | 0.7108 | 0.7096 | 0.7083 |
| | tan | 0.9657 | 0.9691 | 0.9725 | 0.9759 | 0.9793 | 0.9827 | 0.9861 | 0.9896 | 0.9930 | 0.9965 |
| Degs. | Function | 0′ | 6′ | 12′ | 18′ | 24′ | 30′ | 36′ | 42′ | 48′ | 54′ |

| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 45 | sin | 0.7071 | 0.7083 | 0.7096 | 0.7108 | 0.7120 | 0.7133 | 0.7145 | 0.7157 | 0.7169 | 0.7181 |
| | cos | 0.7071 | 0.7059 | 0.7046 | 0.7034 | 0.7022 | 0.7009 | 0.6997 | 0.6984 | 0.6972 | 0.6959 |
| | tan | 1.0000 | 1.0035 | 1.0070 | 1.0105 | 1.0141 | 1.0176 | 1.0212 | 1.0247 | 1.0283 | 1.0319 |
| 46 | sin | 0.7193 | 0.7206 | 0.7218 | 0.7230 | 0.7242 | 0.7254 | 0.7266 | 0.7278 | 0.7290 | 0.7302 |
| | cos | 0.6947 | 0.6934 | 0.6921 | 0.6909 | 0.6896 | 0.6884 | 0.6871 | 0.6858 | 0.6845 | 0.6833 |
| | tan | 1.0355 | 1.0392 | 1.0428 | 1.0464 | 1.0501 | 1.0538 | 1.0575 | 1.0612 | 1.0649 | 1.0686 |
| 47 | sin | 0.7314 | 0.7325 | 0.7337 | 0.7349 | 0.7361 | 0.7373 | 0.7385 | 0.7396 | 0.7408 | 0.7420 |
| | cos | 0.6820 | 0.6807 | 0.6794 | 0.6782 | 0.6769 | 0.6756 | 0.6743 | 0.6730 | 0.6717 | 0.6704 |
| | tan | 1.0724 | 1.0761 | 1.0799 | 1.0837 | 1.0875 | 1.0913 | 1.0951 | 1.0990 | 1.1028 | 1.1067 |
| 48 | sin | 0.7431 | 0.7443 | 0.7455 | 0.7466 | 0.7478 | 0.7490 | 0.7501 | 0.7513 | 0.7524 | 0.7536 |
| | cos | 0.6691 | 0.6678 | 0.6665 | 0.6652 | 0.6639 | 0.6626 | 0.6613 | 0.6600 | 0.6587 | 0.6574 |
| | tan | 1.1106 | 1.1145 | 1.1184 | 1.1224 | 1.1263 | 1.1303 | 1.1343 | 1.1383 | 1.1423 | 1.1463 |
| 49 | sin | 0.7547 | 0.7559 | 0.7570 | 0.7581 | 0.7593 | 0.7604 | 0.7615 | 0.7627 | 0.7638 | 0.7649 |
| | cos | 0.6561 | 0.6547 | 0.6534 | 0.6521 | 0.6508 | 0.6494 | 0.6481 | 0.6468 | 0.6455 | 0.6441 |
| | tan | 1.1504 | 1.1544 | 1.1585 | 1.1626 | 1.1667 | 1.1708 | 1.1750 | 1.1792 | 1.1833 | 1.1875 |
| 50 | sin | 0.7660 | 0.7672 | 0.7683 | 0.7694 | 0.7705 | 0.7716 | 0.7727 | 0.7738 | 0.7749 | 0.7760 |
| | cos | 0.6428 | 0.6414 | 0.6401 | 0.6388 | 0.6374 | 0.6361 | 0.6347 | 0.6334 | 0.6320 | 0.6307 |
| | tan | 1.1918 | 1.1960 | 1.2002 | 1.2045 | 1.2088 | 1.2131 | 1.2174 | 1.2218 | 1.2261 | 1.2305 |
| 51 | sin | 0.7771 | 0.7782 | 0.7793 | 0.7804 | 0.7815 | 0.7826 | 0.7837 | 0.7848 | 0.7859 | 0.7869 |
| | cos | 0.6293 | 0.6280 | 0.6266 | 0.6252 | 0.6239 | 0.6225 | 0.6211 | 0.6198 | 0.6184 | 0.6170 |
| | tan | 1.2349 | 1.2393 | 1.2437 | 1.2482 | 1.2527 | 1.2572 | 1.2617 | 1.2662 | 1.2708 | 1.2753 |
| 52 | sin | 0.7880 | 0.7891 | 0.7902 | 0.7912 | 0.7923 | 0.7934 | 0.7944 | 0.7955 | 0.7965 | 0.7976 |
| | cos | 0.6157 | 0.6143 | 0.6129 | 0.6115 | 0.6101 | 0.6088 | 0.6074 | 0.6060 | 0.6046 | 0.6032 |
| | tan | 1.2799 | 1.2846 | 1.2892 | 1.2938 | 1.2985 | 1.3032 | 1.3079 | 1.3127 | 1.3173 | 1.3222 |
| 53 | sin | 0.7986 | 0.7997 | 0.8007 | 0.8018 | 0.8028 | 0.8039 | 0.8049 | 0.8059 | 0.8070 | 0.8080 |
| | cos | 0.6018 | 0.6004 | 0.5990 | 0.5976 | 0.5962 | 0.5948 | 0.5934 | 0.5920 | 0.5906 | 0.5892 |
| | tan | 1.3270 | 1.3319 | 1.3367 | 1.3416 | 1.3465 | 1.3514 | 1.3564 | 1.3613 | 1.3663 | 1.3713 |
| 54 | sin | 0.8090 | 0.8100 | 0.8111 | 0.8121 | 0.8131 | 0.8141 | 0.8151 | 0.8161 | 0.8171 | 0.8181 |
| | cos | 0.5878 | 0.5864 | 0.5850 | 0.5835 | 0.5821 | 0.5807 | 0.5793 | 0.5779 | 0.5764 | 0.5750 |
| | tan | 1.3764 | 1.3814 | 1.3865 | 1.3916 | 1.3968 | 1.4019 | 1.4071 | 1.4124 | 1.4176 | 1.4229 |
| 55 | sin | 0.8192 | 0.8202 | 0.8211 | 0.8221 | 0.8231 | 0.8241 | 0.8251 | 0.8261 | 0.8271 | 0.8281 |
| | cos | 0.5736 | 0.5721 | 0.5707 | 0.5693 | 0.5678 | 0.5664 | 0.5650 | 0.5635 | 0.5621 | 0.5606 |
| | tan | 1.4281 | 1.4335 | 1.4388 | 1.4442 | 1.4496 | 1.4550 | 1.4605 | 1.4659 | 1.4715 | 1.4770 |
| 56 | sin | 0.8290 | 0.8300 | 0.8310 | 0.8320 | 0.8329 | 0.8339 | 0.8348 | 0.8358 | 0.8368 | 0.8377 |
| | cos | 0.5592 | 0.5577 | 0.5563 | 0.5548 | 0.5534 | 0.5519 | 0.5505 | 0.5490 | 0.5476 | 0.5461 |
| | tan | 1.4826 | 1.4882 | 1.4938 | 1.4994 | 1.5051 | 1.5108 | 1.5166 | 1.5224 | 1.5282 | 1.5340 |
| 57 | sin | 0.8387 | 0.8396 | 0.8406 | 0.8415 | 0.8425 | 0.8434 | 0.8443 | 0.8453 | 0.8462 | 0.8471 |
| | cos | 0.5446 | 0.5432 | 0.5417 | 0.5402 | 0.5388 | 0.5373 | 0.5358 | 0.5344 | 0.5329 | 0.5314 |
| | tan | 1.5399 | 1.5458 | 1.5517 | 1.5577 | 1.5637 | 1.5697 | 1.5757 | 1.5818 | 1.5880 | 1.5941 |
| 58 | sin | 0.8480 | 0.8490 | 0.8499 | 0.8508 | 0.8517 | 0.8526 | 0.8536 | 0.8545 | 0.8554 | 0.8563 |
| | cos | 0.5299 | 0.5284 | 0.5270 | 0.5255 | 0.5240 | 0.5225 | 0.5210 | 0.5195 | 0.5180 | 0.5165 |
| | tan | 1.6003 | 1.6066 | 1.6128 | 1.6191 | 1.6255 | 1.6319 | 1.6383 | 1.6447 | 1.6512 | 1.6577 |
| 59 | sin | 0.8572 | 0.8581 | 0.8590 | 0.8599 | 0.8607 | 0.8616 | 0.8625 | 0.8634 | 0.8643 | 0.8652 |
| | cos | 0.5150 | 0.5135 | 0.5120 | 0.5105 | 0.5090 | 0.5075 | 0.5060 | 0.5045 | 0.5030 | 0.5015 |
| | tan | 1.6643 | 1.6709 | 1.6775 | 1.6842 | 1.6909 | 1.6977 | 1.7045 | 1.7113 | 1.7182 | 1.7251 |
| Degs. | Function | 0′ | 6′ | 12′ | 18′ | 24′ | 30′ | 36′ | 42′ | 48′ | 54′ |

| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 60 | sin | 0.8660 | 0.8669 | 0.8678 | 0.8686 | 0.8695 | 0.8704 | 0.8712 | 0.8721 | 0.8729 | 0.8738 |
| | cos | 0.5000 | 0.4985 | 0.4970 | 0.4955 | 0.4939 | 0.4924 | 0.4909 | 0.4894 | 0.4879 | 0.4863 |
| | tan | 1.7321 | 1.7391 | 1.7461 | 1.7532 | 1.7603 | 1.7675 | 1.7747 | 1.7820 | 1.7893 | 1.7966 |
| 61 | sin | 0.8746 | 0.8755 | 0.8763 | 0.8771 | 0.8780 | 0.8788 | 0.8796 | 0.8805 | 0.8813 | 0.8821 |
| | cos | 0.4848 | 0.4833 | 0.4818 | 0.4802 | 0.4787 | 0.4772 | 0.4756 | 0.4741 | 0.4726 | 0.4710 |
| | tan | 1.8040 | 1.8115 | 1.8190 | 1.8265 | 1.8341 | 1.8418 | 1.8495 | 1.8572 | 1.8650 | 1.8728 |
| 62 | sin | 0.8829 | 0.8838 | 0.8846 | 0.8854 | 0.8862 | 0.8870 | 0.8878 | 0.8886 | 0.8894 | 0.8902 |
| | cos | 0.4695 | 0.4679 | 0.4664 | 0.4648 | 0.4633 | 0.4617 | 0.4602 | 0.4586 | 0.4571 | 0.4555 |
| | tan | 1.8807 | 1.8887 | 1.8967 | 1.9047 | 1.9128 | 1.9210 | 1.9292 | 1.9375 | 1.9458 | 1.9542 |
| 63 | sin | 0.8910 | 0.8918 | 0.8926 | 0.8934 | 0.8942 | 0.8949 | 0.8957 | 0.8965 | 0.8973 | 0.8980 |
| | cos | 0.4540 | 0.4524 | 0.4509 | 0.4493 | 0.4478 | 0.4462 | 0.4446 | 0.4431 | 0.4415 | 0.4399 |
| | tan | 1.9626 | 1.9711 | 1.9797 | 1.9883 | 1.9970 | 2.0057 | 2.0145 | 2.0233 | 2.0323 | 2.0413 |
| 64 | sin | 0.8988 | 0.8996 | 0.9003 | 0.9011 | 0.9018 | 0.9026 | 0.9033 | 0.9041 | 0.9048 | 0.9056 |
| | cos | 0.4384 | 0.4368 | 0.4352 | 0.4337 | 0.4321 | 0.4305 | 0.4289 | 0.4274 | 0.4258 | 0.4242 |
| | tan | 2.0503 | 2.0594 | 2.0686 | 2.0778 | 2.0872 | 2.0965 | 2.1060 | 2.1155 | 2.1251 | 2.1348 |
| 65 | sin | 0.9063 | 0.9070 | 0.9078 | 0.9085 | 0.9092 | 0.9100 | 0.9107 | 0.9114 | 0.9121 | 0.9128 |
| | cos | 0.4226 | 0.4210 | 0.4195 | 0.4179 | 0.4163 | 0.4147 | 0.4131 | 0.4115 | 0.4099 | 0.4083 |
| | tan | 2.1445 | 2.1543 | 2.1642 | 2.1742 | 2.1842 | 2.1943 | 2.2045 | 2.2148 | 2.2251 | 2.2355 |
| 66 | sin | 0.9135 | 0.9143 | 0.9150 | 0.9157 | 0.9164 | 0.9171 | 0.9178 | 0.9184 | 0.9191 | 0.9198 |
| | cos | 0.4067 | 0.4051 | 0.4035 | 0.4019 | 0.4003 | 0.3987 | 0.3971 | 0.3955 | 0.3939 | 0.3923 |
| | tan | 2.2460 | 2.2566 | 2.2673 | 2.2781 | 2.2889 | 2.2998 | 2.3109 | 2.3220 | 2.3332 | 2.3445 |
| 67 | sin | 0.9205 | 0.9212 | 0.9219 | 0.9225 | 0.9232 | 0.9239 | 0.9245 | 0.9252 | 0.9259 | 0.9265 |
| | cos | 0.3907 | 0.3891 | 0.3875 | 0.3859 | 0.3843 | 0.3827 | 0.3811 | 0.3795 | 0.3778 | 0.3762 |
| | tan | 2.3559 | 2.3673 | 2.3789 | 2.3906 | 2.4023 | 2.4142 | 2.4262 | 2.4383 | 2.4504 | 2.4627 |
| 68 | sin | 0.9272 | 0.9278 | 0.9285 | 0.9291 | 0.9298 | 0.9304 | 0.9311 | 0.9317 | 0.9323 | 0.9330 |
| | cos | 0.3746 | 0.3730 | 0.3714 | 0.3697 | 0.3681 | 0.3665 | 0.3649 | 0.3633 | 0.3616 | 0.3600 |
| | tan | 2.4751 | 2.4876 | 2.5002 | 2.5129 | 2.5257 | 2.5386 | 2.5517 | 2.5649 | 2.5782 | 2.5916 |
| 69 | sin | 0.9336 | 0.9342 | 0.9348 | 0.9354 | 0.9361 | 0.9367 | 0.9373 | 0.9379 | 0.9385 | 0.9391 |
| | cos | 0.3584 | 0.3567 | 0.3551 | 0.3535 | 0.3518 | 0.3502 | 0.3486 | 0.3469 | 0.3453 | 0.3437 |
| | tan | 2.6051 | 2.6187 | 2.6325 | 2.6464 | 2.6605 | 2.6746 | 2.6889 | 2.7034 | 2.7179 | 2.7326 |
| 70 | sin | 0.9397 | 0.9403 | 0.9409 | 0.9415 | 0.9421 | 0.9426 | 0.9432 | 0.9438 | 0.9444 | 0.9449 |
| | cos | 0.3420 | 0.3404 | 0.3387 | 0.3371 | 0.3355 | 0.3338 | 0.3322 | 0.3305 | 0.3289 | 0.3272 |
| | tan | 2.7475 | 2.7625 | 2.7776 | 2.7929 | 2.8083 | 2.8239 | 2.8397 | 2.8556 | 2.8716 | 2.8878 |
| 71 | sin | 0.9455 | 0.9461 | 0.9466 | 0.9472 | 0.9478 | 0.9483 | 0.9489 | 0.9494 | 0.9500 | 0.9505 |
| | cos | 0.3256 | 0.3239 | 0.3223 | 0.3206 | 0.3190 | 0.3173 | 0.3156 | 0.3140 | 0.3123 | 0.3107 |
| | tan | 2.9042 | 2.9208 | 2.9375 | 2.9544 | 2.9714 | 2.9887 | 3.0061 | 3.0237 | 3.0415 | 3.0595 |
| 72 | sin | 0.9511 | 0.9516 | 0.9521 | 0.9527 | 0.9532 | 0.9537 | 0.9542 | 0.9548 | 0.9553 | 0.9558 |
| | cos | 0.3090 | 0.3074 | 0.3057 | 0.3040 | 0.3024 | 0.3007 | 0.2990 | 0.2974 | 0.2957 | 0.2940 |
| | tan | 3.0777 | 3.0961 | 3.1146 | 3.1334 | 3.1524 | 3.1716 | 3.1910 | 3.2106 | 3.2305 | 3.2506 |
| 73 | sin | 0.9563 | 0.9568 | 0.9573 | 0.9578 | 0.9583 | 0.9588 | 0.9593 | 0.9598 | 0.9603 | 0.9608 |
| | cos | 0.2924 | 0.2907 | 0.2890 | 0.2874 | 0.2857 | 0.2840 | 0.2823 | 0.2807 | 0.2790 | 0.2773 |
| | tan | 3.2709 | 3.2914 | 3.3122 | 3.3332 | 3.3544 | 3.3759 | 3.3977 | 3.4197 | 3.4420 | 3.4646 |
| 74 | sin | 0.9613 | 0.9617 | 0.9622 | 0.9627 | 0.9632 | 0.9636 | 0.9641 | 0.9646 | 0.9650 | 0.9655 |
| | cos | 0.2756 | 0.2740 | 0.2723 | 0.2706 | 0.2689 | 0.2672 | 0.2656 | 0.2639 | 0.2622 | 0.2605 |
| | tan | 3.4874 | 3.5105 | 3.5339 | 3.5576 | 3.5816 | 3.6059 | 3.6305 | 3.6554 | 3.6806 | 3.7062 |
| Degs. | Function | 0′ | 6′ | 12′ | 18′ | 24′ | 30′ | 36′ | 42′ | 48′ | 54′ |

| Degs. | Function | 0.0° | 0.1° | 0.2° | 0.3° | 0.4° | 0.5° | 0.6° | 0.7° | 0.8° | 0.9° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 75 | sin | 0.9659 | 0.9664 | 0.9668 | 0.9673 | 0.9677 | 0.9681 | 0.9686 | 0.9690 | 0.9694 | 0.9699 |
| | cos | 0.2588 | 0.2571 | 0.2554 | 0.2538 | 0.2521 | 0.2504 | 0.2487 | 0.2470 | 0.2453 | 0.2436 |
| | tan | 3.7321 | 3.7583 | 3.7848 | 3.8118 | 3.8391 | 3.8667 | 3.8947 | 3.9232 | 3.9520 | 3.9812 |
| 76 | sin | 0.9703 | 0.9707 | 0.9711 | 0.9715 | 0.9720 | 0.9724 | 0.9728 | 0.9732 | 0.9736 | 0.9740 |
| | cos | 0.2419 | 0.2402 | 0.2385 | 0.2368 | 0.2351 | 0.2334 | 0.2317 | 0.2300 | 0.2284 | 0.2267 |
| | tan | 4.0108 | 4.0408 | 4.0713 | 4.1022 | 4.1335 | 4.1653 | 4.1976 | 4.2303 | 4.2635 | 4.2972 |
| 77 | sin | 0.9744 | 0.9748 | 0.9751 | 0.9755 | 0.9759 | 0.9763 | 0.9767 | 0.9770 | 0.9774 | 0.9778 |
| | cos | 0.2250 | 0.2232 | 0.2215 | 0.2198 | 0.2181 | 0.2164 | 0.2147 | 0.2130 | 0.2113 | 0.2096 |
| | tan | 4.3315 | 4.3662 | 4.4015 | 4.4374 | 4.4737 | 4.5107 | 4.5483 | 4.5864 | 4.6252 | 4.6646 |
| 78 | sin | 0.9781 | 0.9785 | 0.9789 | 0.9792 | 0.9796 | 0.9799 | 0.9803 | 0.9806 | 0.9810 | 0.9813 |
| | cos | 0.2079 | 0.2062 | 0.2045 | 0.2028 | 0.2011 | 0.1994 | 0.1977 | [illegible] | 0.1942 | 0.1925 |
| | tan | 4.7046 | 4.7453 | 4.7867 | 4.8288 | 4.8716 | 4.9152 | 4.9594 | [illegible] | 5.0504 | 5.0970 |
| 79 | sin | 0.9816 | 0.9820 | 0.9823 | 0.9826 | 0.9829 | 0.9833 | 0.9836 | 0.9839 | 0.9842 | 0.9845 |
| | cos | 0.1908 | 0.1891 | 0.1874 | 0.1857 | 0.1840 | 0.1822 | 0.1805 | 0.1788 | 0.1771 | 0.1754 |
| | tan | 5.1446 | 5.1929 | 5.2422 | 5.2924 | 5.3435 | 5.3955 | 5.4486 | 5.5026 | 5.5578 | 5.6140 |
| 80 | sin | 0.9848 | 0.9851 | 0.9854 | 0.9857 | 0.9860 | 0.9863 | 0.9866 | 0.9869 | 0.9871 | 0.9874 |
| | cos | 0.1736 | 0.1719 | 0.1702 | 0.1685 | 0.1668 | 0.1650 | 0.1633 | 0.1616 | 0.1599 | 0.1582 |
| | tan | 5.6713 | 5.7297 | 5.7894 | 5.8502 | 5.9124 | 5.9758 | 6.0405 | 6.1066 | 6.1742 | 6.2432 |
| 81 | sin | 0.9877 | 0.9880 | 0.9882 | 0.9885 | 0.9888 | 0.9890 | 0.9893 | 0.9895 | 0.9898 | 0.9900 |
| | cos | 0.1564 | 0.1547 | 0.1530 | 0.1513 | 0.1495 | 0.1478 | 0.1461 | 0.1444 | 0.1426 | 0.1409 |
| | tan | 6.3138 | 6.3859 | 6.4596 | 6.5350 | 6.6122 | 6.6912 | 6.7720 | 6.8548 | 6.9395 | 7.0264 |
| 82 | sin | 0.9903 | 0.9905 | 0.9907 | 0.9910 | 0.9912 | 0.9914 | 0.9917 | 0.9919 | 0.9921 | 0.9923 |
| | cos | 0.1392 | 0.1374 | 0.1357 | 0.1340 | 0.1323 | 0.1305 | 0.1288 | 0.1271 | 0.1253 | 0.1236 |
| | tan | 7.1154 | 7.2066 | 7.3002 | 7.3962 | 7.4947 | 7.5958 | 7.6996 | 7.8062 | 7.9158 | 8.0285 |
| 83 | sin | 0.9925 | 0.9928 | 0.9930 | 0.9932 | 0.9934 | 0.9936 | 0.9938 | 0.9940 | 0.9942 | 0.9943 |
| | cos | 0.1219 | 0.1201 | 0.1184 | 0.1167 | 0.1149 | 0.1132 | 0.1115 | 0.1097 | 0.1080 | 0.1063 |
| | tan | 8.1443 | 8.2636 | 8.3863 | 8.5126 | 8.6427 | 8.7769 | 8.9152 | 9.0579 | 9.2052 | 9.3572 |
| 84 | sin | 0.9945 | 0.9947 | 0.9949 | 0.9951 | 0.9952 | 0.9954 | 0.9956 | 0.9957 | 0.9959 | 0.9960 |
| | cos | 0.1045 | 0.1028 | 0.1011 | 0.0993 | 0.0976 | 0.0958 | 0.0941 | 0.0924 | 0.0906 | 0.0889 |
| | tan | 9.5144 | 9.6768 | 9.8448 | 10.02 | 10.20 | 10.39 | 10.58 | 10.78 | 10.99 | 11.20 |
| 85 | sin | 0.9962 | 0.9963 | 0.9965 | 0.9966 | 0.9968 | 0.9969 | 0.9971 | 0.9972 | 0.9973 | 0.9974 |
| | cos | 0.0872 | 0.0854 | 0.0837 | 0.0819 | 0.0802 | 0.0785 | 0.0767 | 0.0750 | 0.0732 | 0.0715 |
| | tan | 11.43 | 11.66 | 11.91 | 12.16 | 12.43 | 12.71 | 13.00 | 13.30 | 13.62 | 13.95 |
| 86 | sin | 0.9976 | 0.9977 | 0.9978 | 0.9979 | 0.9980 | 0.9981 | 0.9982 | 0.9983 | 0.9984 | 0.9985 |
| | cos | 0.0698 | 0.0680 | 0.0663 | 0.0645 | 0.0628 | 0.0610 | 0.0593 | 0.0576 | 0.0558 | 0.0541 |
| | tan | 14.30 | 14.67 | 15.06 | 15.46 | 15.89 | 16.35 | 16.83 | 17.34 | 17.89 | 18.46 |
| 87 | sin | 0.9986 | 0.9987 | 0.9988 | 0.9989 | 0.9990 | 0.9990 | 0.9991 | 0.9992 | 0.9993 | 0.9993 |
| | cos | 0.0523 | 0.0506 | 0.0488 | 0.0471 | 0.0454 | 0.0436 | 0.0419 | 0.0401 | 0.0384 | 0.0366 |
| | tan | 19.08 | 19.74 | 20.45 | 21.20 | 22.02 | 22.90 | 23.86 | 24.90 | 26.03 | 27.27 |
| 88 | sin | 0.9994 | 0.9995 | 0.9995 | 0.9996 | 0.9996 | 0.9997 | 0.9997 | 0.9997 | 0.9998 | 0.9998 |
| | cos | 0.0349 | 0.0332 | 0.0314 | 0.0297 | 0.0279 | 0.0262 | 0.0244 | 0.0227 | 0.0209 | 0.0192 |
| | tan | 28.64 | 30.14 | 31.82 | 33.69 | 35.80 | 38.19 | 40.92 | 44.07 | 47.74 | 52.08 |
| 89 | sin | 0.9998 | 0.9999 | 0.9999 | 0.9999 | 0.9999 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| | cos | 0.0175 | 0.0157 | 0.0140 | 0.0122 | 0.0105 | 0.0087 | 0.0070 | 0.0052 | 0.0035 | 0.0017 |
| | tan | 57.29 | 63.66 | 71.62 | 81.85 | 95.49 | 114.6 | 143.2 | 191.0 | 286.5 | 573.0 |
| Degs. | Function | 0′ | 6′ | 12′ | 18′ | 24′ | 30′ | 36′ | 42′ | 48′ | 54′ |

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# APPENDIX III
# MATHEMATICAL SYMBOLS

| SYMBOL | NAME OR MEANING | |
|---|---|---|
| $+$ | Addition or positive value | |
| $-$ | Subtraction or negative value | |
| $\pm$ | Positive or negative value | |
| $\cdot$ | Multiplication dot (Centered; not to be mistaken for decimal point.) | |
| x | Multiplication symbol | |
| ( ) | Parentheses | Grouping symbols |
| [ ] | Brackets | Grouping symbols |
| { } | Braces | Grouping symbols |
| — | Vinculum (overscore) | Grouping symbols |
| % | Percent | |
| $\div$ | Division symbol | |
| : | Ratio symbol | |
| :: | Proportion symbol | |
| = | Equality symbol | |
| $\neq$ | "Not equal" symbol | |
| < | Less than | |
| $\leq$ | Less than or equal to | |
| > | Greater than | |
| $\geq$ | Greater than or equal to | |
| $\propto$ | "Varies directly as" or "is proportional to" (Not to be mistaken for Greek alpha ($\alpha$).) | |

| SYMBOL | NAME OR MEANING |
|---|---|
| $\sqrt{\ }$ | Square root symbol |
| $\sqrt{\quad}$ | Square root symbol with vinculum. Vinculum is made long enough to cover all factors of the number whose square root is to be taken. |
| $\sqrt[n]{\ }$ | Radical symbol. Letter n represents a number indicating which root is to be taken. |
| i or j | Imaginary unit; operator j for electronics; represents $\sqrt{-1}$. |
| $\infty$ | Infinity symbol. |
| . . . | Ellipsis. Used in series of numbers in which successive numbers are predictable by their conformance to a pattern; meaning is approximated by "etc." |
| $\log_a N$ | Logarithm of N to the base a. |
| log N | Logarithm of N to the base 10. (understood) |
| ln N | Natural or Napierian logarithm of N. Base of the natural or Napierian logarithm system. |
| $\lvert X \rvert$ | Absolute value of X. |
| $\pi$ | Pi. The ratio of the circumference of any circle to its diameter. Approximate numerical value is 22/7. |
| $\therefore$ | Therefore |
| $\angle$ or $\measuredangle$ | Angle |



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## APPENDIX IV

## GREEK ALPHABET

| | | | |
|---|---|---|---|
| Α α | Alpha | Ν ν | Nu |
| Β β | Beta | Ξ ξ | Xi |
| Γ γ | Gamma | Ο ο | Omicron |
| Δ δ | Delta | Π π ϖ | Pi |
| Ε ε | Epsilon | Ρ ρ | Rho |
| Ζ ζ | Zeta | Σ σ ς | Sigma |
| Η η | Eta | Τ τ | Tau |
| Θ θ ϑ | Theta | Υ υ | Upsilon |
| Ι ι | Iota | Φ φ ϕ | Phi |
| Κ κ | Kappa | Χ χ | Chi |
| Λ λ | Lambda | Ψ ψ | Psi |
| Μ μ | Mu | Ω ω | Omega |

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# APPENDIX V
# FORMULAS

### Areas

$A = s^2$ — The area of a square is equal to the square of a side.

$A = \frac{b}{2} h$ — The area of a triangle is equal to one half the base times the height.

$A = \pi r^2$ — The area of a circle is equal to the radius squared times pi.

$A = lw$ — The area of a rectangle is equal to the length times the width.

$A = Ch$ — The lateral area of a cylinder is equal to the circumference of the base times the height.

### Areas

$A = 4\pi r^2$ — The square area of a sphere is equal to 4 times pi times the radius squared.

### Volumes

$V = e^3$ — The volume of a cube equals the cube of an edge.

$V = Bh$ — The volume of a rectangular solid or cylinder equals the area of the base times the height.

$V = \frac{4}{3} \pi r^3$ — The volume of a sphere equals $\frac{4}{3}$ pi times the radius cubed.

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# THE HYDROSPHERE

15-2

A correspondence course pamphlet consisting of original material developed at the Coast Guard Institute and excerpts from:

| | |
|---|---|
| Oceanographic Handbook | CG 401 |
| OSV Oceanography Manual | CG 410 |
| American Practical Navigator | N. O. Pub. 9 |
| Ice Observations | N. O. Pub. 606-d |
| Instruction Manual for Obtaining Oceanographic Data | N. O. Pub. 607 |
| Glossary of Oceanographic Terms | N. O. Pub. SP-35 |
| Handbook of Oceanographic Tables | N. O. Pub. SP-68 |
| Oceanography and Underwater Sound for Naval Applications | N. O. Pub. SP-84 |
| Science and the Sea | NAVOCEANO |
| Aerographer's Mate 1 & C | NAVPERS 10362-A |

U.S. COAST GUARD INSTITUTE
OKLAHOMA CITY, OKLAHOMA

DECEMBER 1971

PAMPHLET NO. 461

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THE MATERIAL IN THIS PAMPHLET IS [illegible] ONLY. IT SHOULD [illegible]EVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, [illegible] OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. [illegible]WAYS CHECK THE LATEST DIRECTIVES AND [illegible] ON THE JOB.

# INTRODUCTION TO OCEANOGRAPHY

Oceanography is the application of the five basic sciences—physics, chemistry, meteorology, biology, and geology—to the phenomena of the ocean. The field of oceanography embraces a variety of widely separated fields such as sedimentation, ecology, bacteriology, biochemistry, hydrodynamics, acoustics, and optics. Studies in each of these fields have been made, but there is still the need for even greater efforts in all of oceanography's related fields. The incentive for study lies in the areas of transportation, climatic control, and the potential source of food, fresh water, mineral substances, and power.

The extent of the ocean alone makes it an important subject for study. The ocean covers 70.8 percent of the surface of the earth. The ocean's divisions comprise this 70.8 percent in the following way: the Atlantic, 16.2 percent; the Pacific, 32.4 percent; the Indian, 14.4 percent; and marginal and adjacent areas, 7.8 percent. (See figure 1.) The Pacific alone covers more of the earth's surface than the entire area covered by land.

Our nation is framed by over 12,000 miles of coastline. Only one other continental nation, the

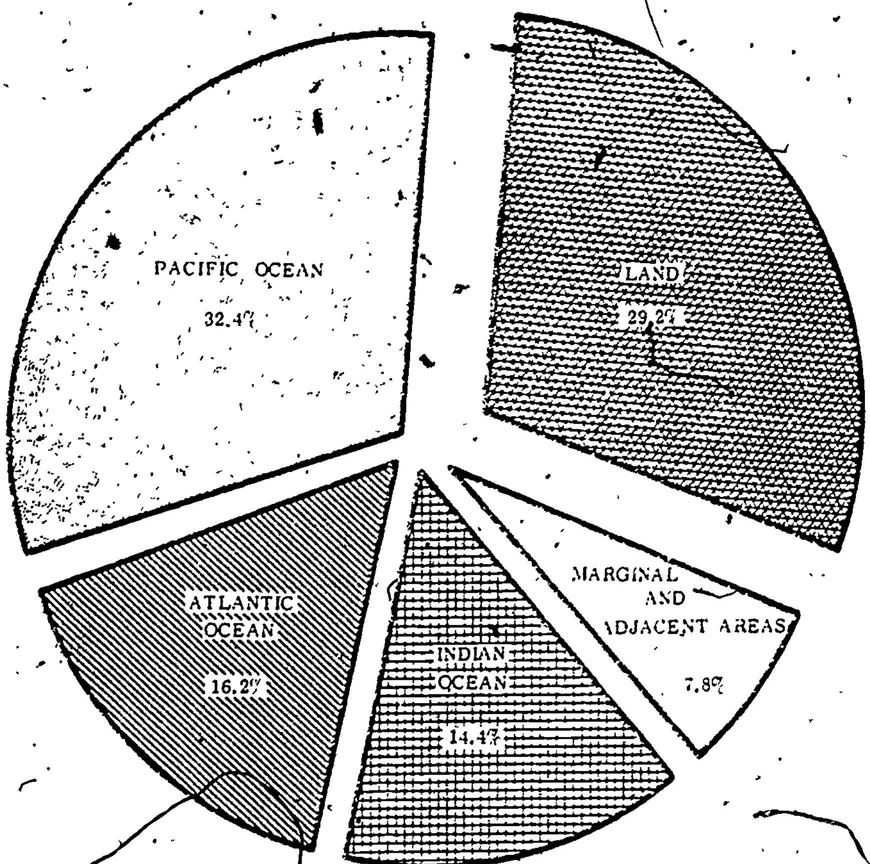


Figure 1.— The Earths's surface— land vs. water.

Soviet Union, has a longer border with the sea. America's growth as an international power has been enhanced by the free flow of thought, talents, and products of industry over the sea. In 1961, President Kennedy wrote to Congress, "Knowledge of the oceans is more than a matter of curiosity. Our very survival may hinge on it." The ocean, from surface to bottom, is a strategic zone for national defense. Our citizens turn to the sea for food, recreation, mineral resources, fresh water, and waste disposal. Today, the sea holds food resources for an expanding world population, two-thirds of which suffer from dietary protein deficiencies.

As the ocean holds one of the keys to existence, it also holds the sword of destruction. The complexities of air-sea interaction spawn devastating hurricanes and storms whose winds and water surges take American lives and destroy our property. Each year thousands of our citizens lose their lives while engaged in the pursuit of employment and recreation on and near our waters.

## THE NATIONAL OBJECTIVE

The federal government has established a broad national objective in oceanography: to comprehend the ocean, its boundaries, its properties, and its processes, and to exploit this comprehension in the public interest and in the enhancement of our security, our culture, our international posture, and our economic growth.

Five subordinate goals support this objective:

1. To strengthen basic science.
2. To improve national defense.
3. To manage resources in the ocean.
4. To manage resources in domestic waters.
5. To protect life and property ashore and to insure the safety and efficiency of operations at sea.

The Interagency Committee on Oceanography (ICO) was established in 1960 as a permanent committee of the Federal Council for Science and Technology. The Committee was charged to provide the essential direction and coordination of the national oceanographic program, incorporating its judgement for [illegible] and emphasis in terms of both long-range scientific needs and the requirements of government agencies. Operating within the framework of the Long Range National Oceanographic Plan (1963-1972), ICO technical panels prepare annual recommendations for the conduct of the federal program. The Committee reviews these recommendations to insure program balance, adequacy of resources, and response to national goals. The Committee's recommended program is submitted to the Federal Council for Science and Technology for final review and approval.

## HISTORY OF OCEANOGRAPHY

In order to fully appreciate the goals of current oceanographic programs, you should be aware of the progress made in oceanography since its beginnings.

The earliest studies of the oceans were concerned principally with problems of navigation. Information concerning tides, currents, soundings, ice, and distances between ports was needed as ocean commerce increased. According to Posidonius, a depth of 1,000 fathoms had been measured in the Sea of Sardinia as early as the second century BC. About the middle of the 19th century, the Darwinian theories of evolution gave a great impetus to the collection of marine organisms, since it is believed by some that all terrestrial forms have evolved from oceanic ancestors. Later, the serious depletion of many fisheries called for investigation of the relation of the economically valuable organisms to the physical characteristics of their environment, especially in northwestern Europe and off Japan. Still later, the growing use of the oceans in warfare, particularly after the development of the submarine, required that much effort be expended in problems of detection and attack, resulting in the study of many previously neglected scientific aspects of the sea.

### Oceanographic Exploration

Exploration of the seas was primarily geographical until the 19th century, although the accumulated observations of seafarers, as recorded in the early charts and sailing directions, often included data on tides, currents, and other oceanographic phenomena. The great voyages of discovery, particularly those beginning in 1768 with Captain Cook, and continued by such commanders as La Perouse, Bellingshausen, and Wilkes, included scientists in their complements. However, scientific work on the oceans at this period was severely limited by lack of suitable instruments for probing conditions below the surface. Meanwhile, Lieutenant Matthew Fontaine Maury, USN, working in the forerunner of the U. S. Naval Oceanographic Office in Washington, developed to a high degree of perfection the analysis of log-book observations. His first results, published in 1848, were of great importance to ship operations in the recommendation of favorable sailing routes, and they stimulated international cooperation in the fields of oceanography and marine meteorology.

In the rapid advances in technology after 1850, oceanographic instrumentation problems were not neglected, with the result that the British Navy in 1872-76 was able to send HMS CHALLENGER around the world on the first purely deep-sea oceanographic expedition ever attempted. Her bottom samples, as analyzed by Sir John Murray, laid the foundation of geological oceanography, and 77 of her sea water samples, analyzed by C. R. Dittmar, proved for the first time that various constituents of the salts in sea water are everywhere in virtually the same proportions.

Since that time, the coastal waters and fishing banks of many nations have been extensively studied, and numerous vessels of various nationalities have conducted work on the high seas. Notable among these have been the American ALBATROSS from 1882 to 1920; the Austrian POLD in the Mediterranean and Red Seas between 1890 and 1896; the Danish DAND, which during its voyages of 1920-22 discovered the breeding place of the European eels in the Sargasso Sea; the American CARNEGIE in 1927-29; the German METEOR in the Atlantic from 1928 to 1938; and the British DISCOVERY II in the antarctic between 1930 and 1939. Notable also were the drifts of the Norwegian vessels FRAM and MAUD in the arctic ice pack from 1893 to 1896 and 1918 to 1925, respectively; the attempt by Sir George Hubert Wilkins to operate under the ice in the British submarine NAUTILUS in 1931; and the Russian station set up at the North Pole in 1937, which made observations from the drifting pack ice.

At the same time, investigations pursued ashore under the leadership of Helland-Hansen in Norway and Ekman and the Bjerknes in Sweden provided the theoretical basis for the exploration of ocean currents. Martin Knudsen in Denmark worked out the precise details of the relationship between chlorinity, salinity, and density, thus enabling the theories to be verified by field observations.

During World War II, basic investigations were interrupted while work on purely military applications of oceanography was carried out. Deep-sea expeditions were renewed by the Swedish ALBATROSS after the war, followed by the Danish GALATHEA, the second British CHALLENGER (built in 1931) and DISCOVERY II in the antarctic, and vessels of the American Scripps Institution in the Pacific. Oceanographic work was carried out by Americans and Russians in the arctic. By 1961, a total of ten Russian and three United States drifting ice stations had been established. Two United States stations were also established aboard floating ice islands.

## Institutions

Among the leading oceanographic institutions in Europe are the Geophysical Institute of the University of Bergen in Norway; the Oceanographic Institute at Göteborg, Sweden; the National Institute of Oceanography in Great Britain; the German Hydrographic Institute in Hamburg; and the Museum of Oceanography at Monaco. The Marine Biological Station at Naples, Italy, has served as a model for others throughout the world.

In the Far East, the Hydrographic Division of the Maritime Safety Agency is perhaps the most prominent of a number of Japanese oceanographic activities. The Institute of Oceanology at Vladivostok is the foremost oceanographic establishment on the Asiatic mainland.

Canada maintains the Pacific Oceanographic Group at Nanaimo, B. C., and the Atlantic Oceanographic Group at St. Andrews, N. B. In the United States, the leading nongovernmental oceanographic institutions include the Scripps Institution of Oceanography of the University of California, La Jolla, Calif.; the Department of Oceanography of the University of Washington, Seattle, Wash.; Woods Hole Oceanographic Institution, Woods Hole, Mass.; the Marine Laboratory of the University of Miami, Coral Gables, Fla.; and the Department of Oceanography of Texas A. & M. College, College Station, Texas.

There exist also various international organizations in the field of oceanography, which coordinate and promote international cooperation. The International Council for the Exploration of the Sea was established with headquarters in Copenhagen to exchange data on fisheries problems in the waters of northwestern Europe. The Council has been notably successful, and similar organizations have been established in other areas.

## THE COAST GUARD AND OCEANOGRAPHY

Alexander Hamilton, in a 4 June 1791 letter to the captain of the revenue cutter BALTIMORE, stated:

> It has also occurred (sic) that the Cutters may be rendered and (sic) instrument of useful information concerning the coasts, inlets, Bays and Rivers of the United States. And it will be particularly acceptable if the Officers improve the opportunities they will have . . . . in making such observations and experiments in respect to these objects as may be useful in the business of navigation, communicating the result from time to time to the Treasury.

This directive from the Secretary of the Treasury of our fledgling republic initiated oceanographic and hydrographic data collection by the parent service of the modern Coast Guard, and these activities were conducted on an informal basis for more than 75 years.

In 1867, within three months after signing the Alaskan purchase treaty with Russia, the United States dispatched the revenue cutter LINCOLN to assess the natural resources of its newly acquired domain. The territory was sparsely inhabited, and the lands and waters were virtually unknown to the new owners. For several months, the LINCOLN plied Alaskan coastal waters while scientists aboard collected environmental data and samples. Speed and direction of tides and currents and temperatures of surface and subsurface seawater were measured and recorded. The cruise of the LINCOLN exemplifies early Coast Guard activities contributing to the still-expanding interest in oceanography.

For over 100 years, the Coast Guard has pursued a policy of supporting national oceanographic projects with its unique resources. This activity can be traced from the cruise of the cutter LINCOLN in 1867, through the Arctic expeditions of the cutters CORWIN and BEAR (figure 2), to the historic cruises of the cutter NORTHWIND in the first half of the 1960's, and to the 1970 cruise of the cutter SOUTHWIND.

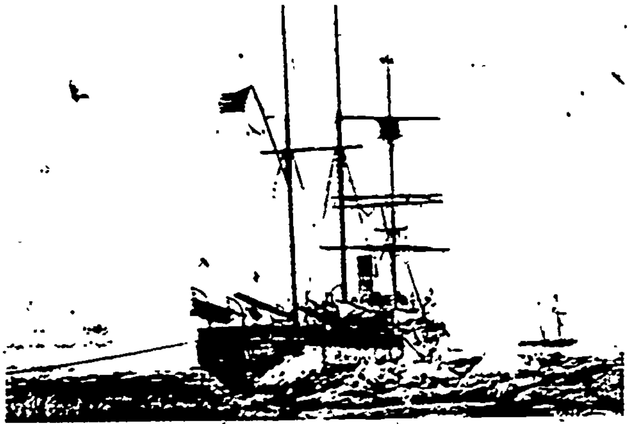

Figure 2.—USCG cutters BEAR and CORWIN in Alaskan ice jam, about 1890.

Since 1914 the Coast Guard has conducted the International Ice Patrol Service in the North Atlantic Ocean as required by 46 USC 738 and the International Conference on the Safety of Life at Sea. Some Coast Guard contributions to oceanography which were produced by Ice Patrol activity are:

1. Development of survey methods into a sophisticated routine to produce periodically dependable ocean-current charts.
2. Development of standard dynamic topographic charts of the Grand Banks of Newfoundland.
3. Introduction of the conductivity bridge for salinity determinations at sea.
4. Introduction of a portable shipboard computer for rapid data processing and production of dynamic topographic charts during the progress of a survey.

Although hampered by lack of legislative authority, the ocean-station program brought another opportunity in oceanography to the Coast Guard. However, the oceanographic work of the OSV's was limited to cooperative projects which were funded by other agencies. Their systematic time-series observations of the temperature structure and plankton distribution constitute the only long-term oceanographic collections at these mid-ocean stations.

Recognizing the capabilities of the Coast Guard and supporting Presidential emphasis on oceanography, the 87th Congress passed an Act which amended Title 14 of the United States Code to provide for expansion of Coast Guard activities to the conduct of "oceanographic research on the high seas and in waters subject to the jurisdiction of the United States." Signed into law on 5 October 1961, the Act added a new section to Title 14:

> 94. Oceanographic Research
>
> The Coast Guard shall conduct such oceanographic research, use such equipment or instruments, and collect and analyze such oceanographic data, in cooperation with other agencies of the Government, or not, as may be in the national interest.

The Coast Guard responded to the Congressional mandate by issuing a nine-year provisional long-range plan in oceanography on 5 March 1962. This plan suggested four basic divisions of Coast Guard oceanographic activity:

1. Ocean Station Project
2. Special Patrols Project
3. Coastal Oceanographic Project
4. Cooperative Facility Projects

The 1962 Plan recommended expansion of the Coast Guard Oceanographic Unit to plan Coast Guard activities, to provide scientific and technical direction, and to process and disseminate the collected data. By 1965 the Unit was located in facilities in Washington, D. C., and was manned by officer and enlisted personnel as well as scientific, technical, and administrative civilian personnel.

In August 1965, the Commandant outlined the Coast Guard program and its areas of responsibility:

1. Commandant — The Commandant directs the Coast Guard oceanographic program toward fulfillment of the Coast Guard's goal.
2. Coast Guard Oceanographic Unit — The Oceanographic Unit is responsible for development and cognizance of standard intra-service oceanographic programs, provision of scientific and technical support for these programs, and the conduct of oceanographic research in support of Coast Guard missions.
3. Area Commander — Authority for approving cooperative oceanographic projects involving the use of ships and aircraft under his operational control or requiring coordinated use of major search and rescue facilities of more than one district within the area boundaries resides with the area commander.
4. District Commander — Authority for approving cooperative projects involving the use of district facilities on a local basis resides with the district commander.
5. Unit Commander — Responsibility for proper conduct of the assigned oceanographic missions rests with the unit commander.
6. Supervision — The authority directing the performance of a cooperative oceanographic project is responsible for continued supervision of the project to its completion.
7. Referral — Requests to assist in cooperative projects which are of doubtful oceanographic validity or which apparently conflict with or duplicate established programs should be referred to the Commandant. Any other proposal may be referred to the Commandant for advice concerning the propriety of providing Coast Guard support.

In accordance with an interagency agreement for support of the National Oceanographic Data Center, the Coast Guard provides funds in addition to any data collected in cooperation with other agencies or institutions.

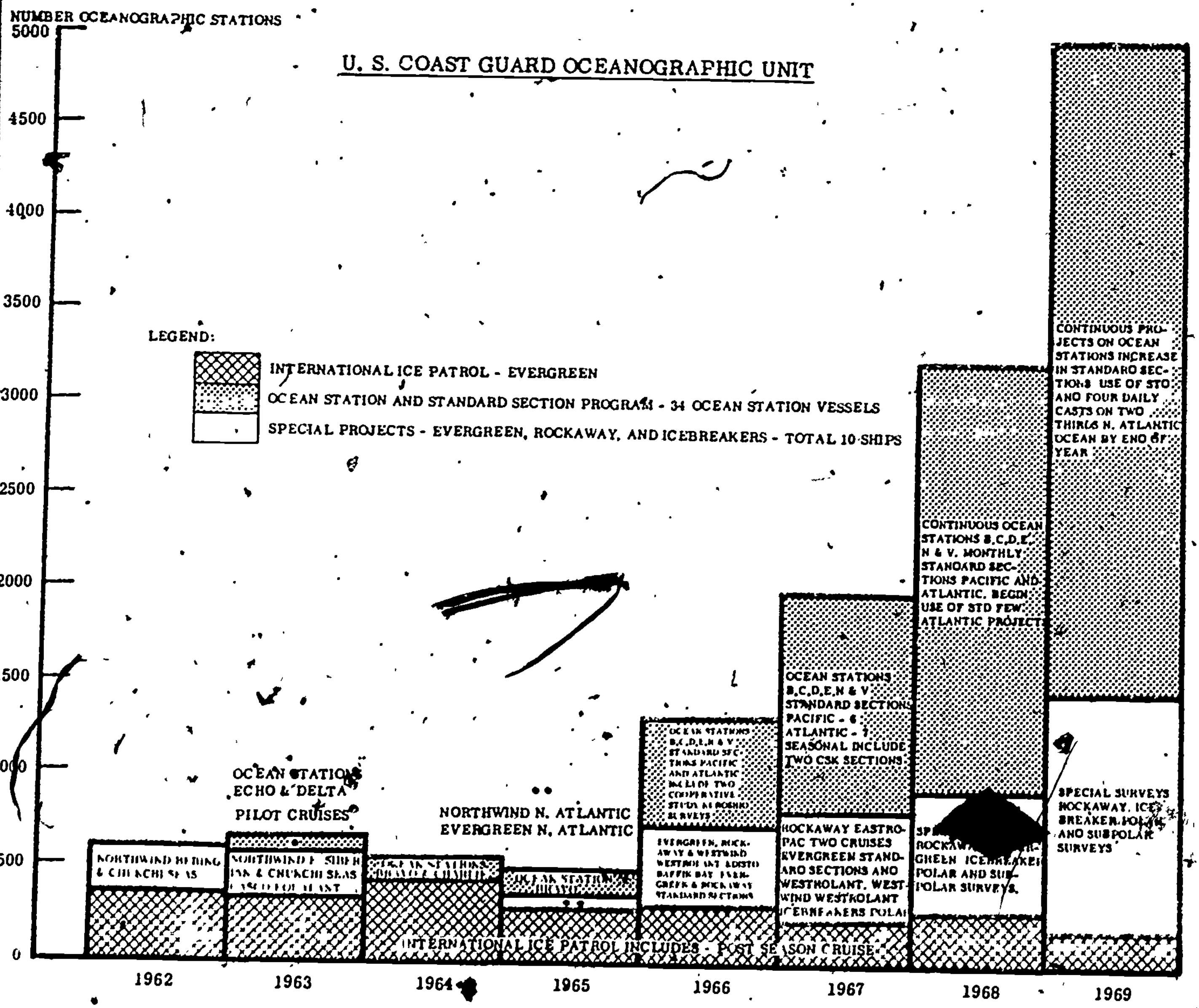


Figure 3. —Coast Guard Oceanographic Activity

Some of the ships and projects of the sixties were the CASCO on project EQUALANT; EVERGREEN and EASTWIND between Brazil and the Mid-Atlantic Ridge; EDISTO off the West Coast of Chile and off the East Coast of Argentina; NORTHWIND in the Arctic, GLACIER in the Weddell Sea; COURAGEOUS, LAUREL, and ROCKAWAY on project BOMEX; and the ACUSHNET in the Pacific.

As we look ahead in the seventies, there will be more projects, more ships, and more men. To start the seventies, we have an Academy program to train officers, a class "A" school at Governors Island to train enlisted personnel, three vessels designated WAGO's—the ROCKAWAY, EVERGREEN, and ACUSHNET—and the experience to do the varied tasks that we may be called upon to perform.

# MARINE GEOLOGY

## ORIGIN OF THE OCEANS

Although many leading geologists still disagree with the conclusion that the structure of the continents is fundamentally different from that of the oceans, there is a growing body of evidence in support of the theory that the rocks underlying the ocean floors are more dense than those underlying the continents. According to this theory, all of the earth's crust floats on a central liquid core, and the portions that make up the continents, being lighter, float with a higher freeboard. Thus, the thinner areas, composed of heavier rock, form natural basins where water has collected.

The origin of the water in the oceans is also controversial. Although some geologists have postulated that it fell in great torrents of rain as soon as the earth cooled sufficiently, another school holds that the atmosphere of the original hot earth was lost, and that the water gradually accumulated as it was given off in steam by volcanoes or worked to the surface in hot springs.

Most of the water on the earth's crust is now in the oceans—about 328,000,000 cubic statute miles, or about 85 percent of the total. The mean depth of the ocean is approximately 3,800 meters (figure 4), and the total area is 139,000,000 square statute miles.

## BASIC EARTH STRUCTURE

In this branch of oceanography, we shall deal with the container of the ocean. The basic structure of the earth will be our first consideration.

The earth is divided into three parts: the crust, mantle, and core. The crust, also called the lithosphere, is the outer, solid portion of the earth that is bounded by the atmosphere and the hydrosphere and by the mantle. The mantle, also called the asthenosphere, is the relatively plastic region between the crust and core of the earth. The core, also called the centrosphere, is the central zone of the earth. (See figure 5.)

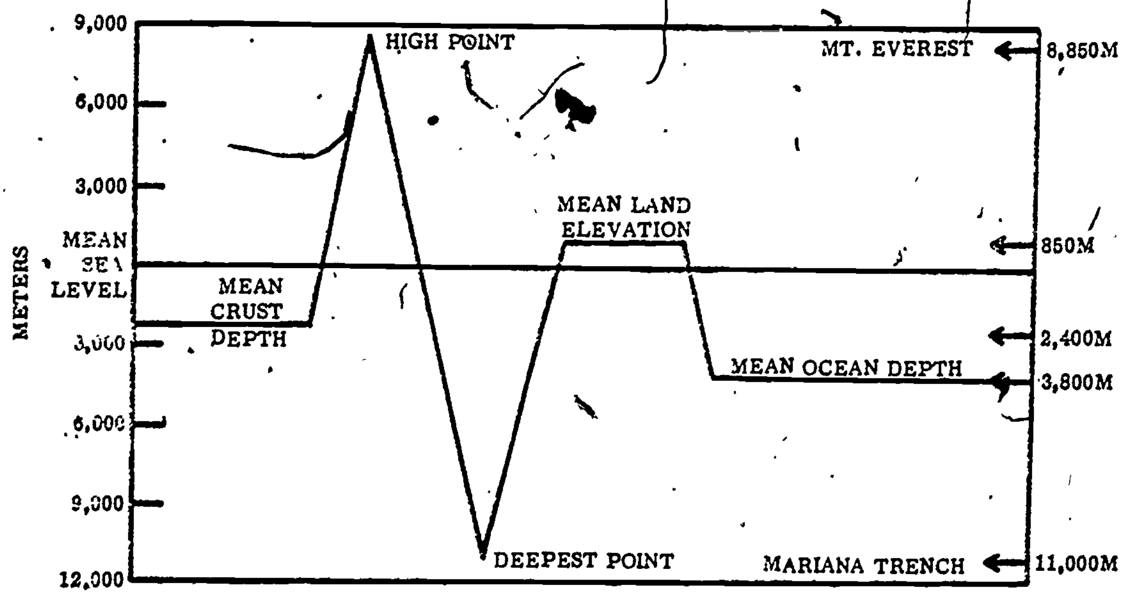


Figure 4.— A relationship of approximate height and depth of selected points to mean sea level.



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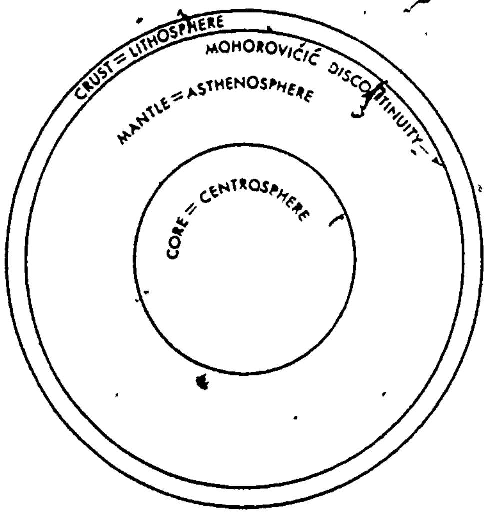



Figure 5.—Basic earth structure.

Scientific studies in seismology and gravity have produced many interesting theories concerning the three parts of the earth. One such theory suggests that the core of the earth is composed of an inner solid core of iron and nickel surrounded by a liquid of the same composition. The mantle contains the greatest amount of the earth's mass and is believed to be composed predominantly of oxygen, magnesium, and silicon. The composition of the crust is the division of which Marine Science Technicians should have the greatest knowledge and interest.

The crust of the earth is composed of two basic rock types. The rock of the lesser density, called SIAL, is a silicon-aluminum base material and floats on the more dense SIMA, an iron-magnesium composite. The sima layer appears to be a continuous layer over the mantle while the lighter sial is found only in the continental areas, being of lesser density and riding over the sima to form a greater thickness of the crust. (See figure 6.) This phenomenon would support the theory of the floating continents and the theory of continental drift.

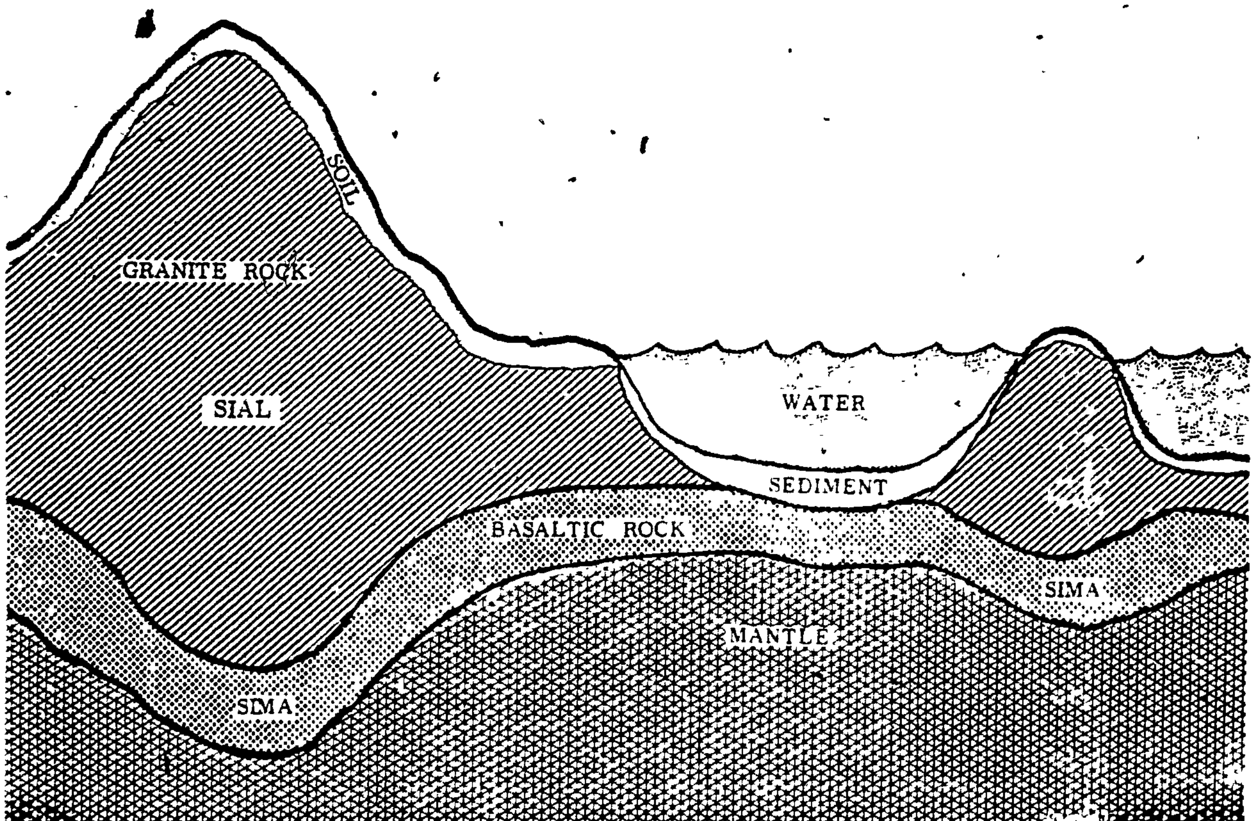



Figure 6.—General crustal features of the earth.

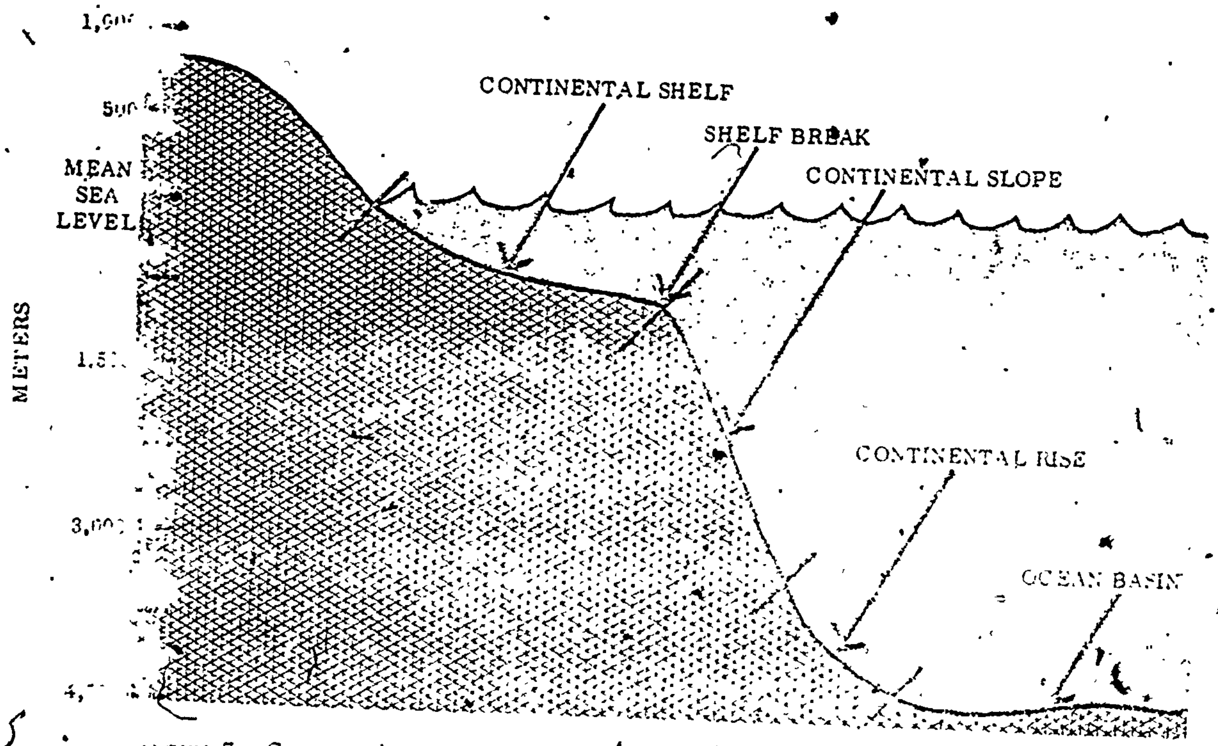



Figure 7.—General bottom features extending seaward from major land areas.

The MOHO, named after a Yugoslav seismologist, A. Mohorovicic, is a line of discontinuity between the crust and mantle and has been determined to exist at an average depth of 35 km under continents but only 6 km beneath the ocean floor. Even though Project MOHOLE was terminated by Congress in 1966, plans are in existence to drill through the earth's crust to increase knowledge of the outer portion of the earth.

## OCEAN'S CONTAINER

Now that the basic earth structure has been outlined, our next consideration is the container or that portion of the crust that is covered by sea water. The container is generally divided into three major provinces: (1) the continental shelf, (2) the continental slope and rise, and (3) the ocean basin.

### Continental Shelf

In general the continental shelf slopes gently seaward to depths usually from 60 to 100 fathoms and terminates at a break, called the continental shelf break, in the slope where the gentle slope abruptly becomes much steeper. This break may range from a sharp edge to a rounded shoulder where the gradient ranges from less than 1:1,000 miles to a gradient greater than 1:40 miles.

Continental shelves vary greatly in width and slope. Continental shelves off glaciated coasts and areas which are predominantly low and flat may be very wide, whereas off mountainous coasts, the shelf may be virtually absent. Worldwide, the shelf width averages about 30 miles, with a range from near zero to over 800 miles.

Although the average slope of the shelf is gentle, within the shelf boundaries terraces, ridges, hills, depressions, and steep-walled canyons may occur. Where these features provide extremes in relief, the area is called a continental borderland. One of the well-known examples of a borderland is the area off the southern California coast. Instead of the usual gently sloping area of minor relief typical of shelf areas, this area is an extensive region of peaks and valleys more or less parallel to the topographic trends of the

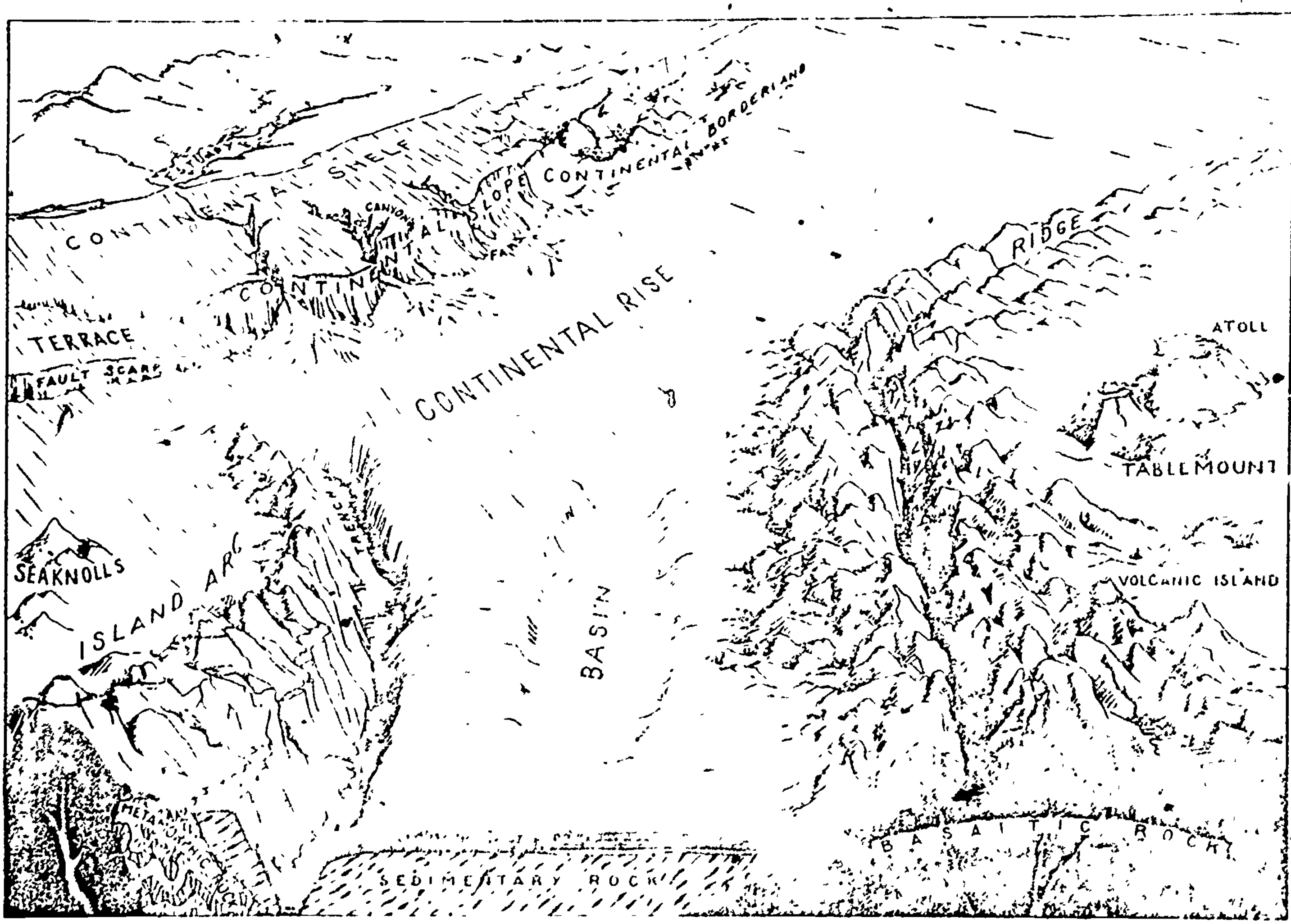



Figure 6. — Features of the Ocean...

adjacent land. Some of these peaks extend above sea level to form islands, and some of the valleys reach depths exceeding 5,000 feet. All of these features occur within an area that normally would be designated a continental shelf.

Continental Slope

Beyond the break at the seaward edge of the shelf is the continental slope, which inclines downward toward the ocean depths, giving way to a less steeply sloping zone known as the continental rise before the deep sea floor is reached. Generally the continental slope off mountainous coasts has an incline of about 1:20 miles, but off coasts with wide, well-drained plains these slopes incline about 1:30. Extreme slopes, such as those off volcanic islands where the shelf usually is absent, may incline as much as 50°. As on the continental shelf, the slope can and usually does have minor relief superimposed. What is called gullying on land is a feature that probably is typical of most of the slope areas of the world, particularly on the upper parts of the slopes. Common features of the slope are extraordinarily large gullies, known as submarine canyons. Most canyon heads are at or near the break in the shelf, but a few extend across part of the shelf. The Hudson Canyon off New York is a classic example of a submarine canyon.

Ocean Basin

Continental slopes grade smoothly to the incline of the continental rise, and this in turn grades almost imperceptibly to the floor of the ocean basin. This transition takes place at great depth, usually 500 fathoms or greater.

The deep sea floor is believed by many to be a flat featureless plain. Actually it does have, at most, a very gentle average incline of no more than 1:90 miles. However, this is true only over considerable distances. The relief superimposed on this average incline may be at least as rugged as the larger topographic features found on land. For example, seamounts rising from the ocean floor are widespread in the Pacific, and great mountain chains or ridges and deep trenches or furrows are common in all oceans. (See figure 8.) The larger ridges of the bottom often are oriented parallel to the coasts of the continents so that the oceans are divided into elongated basins. Transverse ridges in turn tend to subdivide these basins into smaller basins. These bottom features are found in the Atlantic, Arctic, and Indian oceans and in the western Pacific Ocean. The following are some of the major longitudinal ridges in the world:

1. The Mid-Atlantic Ridge divides the Atlantic Ocean into the western and eastern basins. This most conspicuous of longitudinal ridges extends from Iceland south across the Equator to about 55°S. The ridge rises from depths of about 2,500 fathoms, is continuous at depths of less than 1,500 fathoms over the greater part of its length, and in several places rises above sea level to form islands such as the Azores, St. Peter and St. Paul Rocks, Ascension, and Tristan da Cunha.

2. The Indian Ridge extends from India to Antarctica and is wider but does not rise as close to the surface as the Mid-Atlantic Ridge.

3. In the Pacific Ocean the ridges are less conspicuous, though the West Pacific Ridge, which is composed of several shorter ridges, can be traced from Japan to Antarctica. Another ridge extends south and west of Central America.

4. In the Arctic Ocean the Lomonosov Ridge extends from northern Greenland to the shelf off the New Siberian Islands and separates this ocean into two basins.

Trenches are of much more limited extent than the great ridges, but within these relatively small areas the deepest points in the ocean are found. Depths in some of the deepest trenches are in excess of 34,000 feet, with the deepest sounding (36,173 feet reported by the VITYAZ, March 1959) recorded in the Marianas Trench. Conversely the highest mountain on land, Mount Everest, has a height of approximately 8,850 meters. (See figure 4.)

Probably many of the sea bottom features have existed essentially unchanged since their formation, since little or no erosion takes place at the depths in which they are found. These same features on land soon would tend to be smoothed and leveled by the action of wind and water. Most of the bottom features subject to active erosion are those near enough to the surface to be affected by wave action or strong currents, which tend to level irregular surfaces. The topography

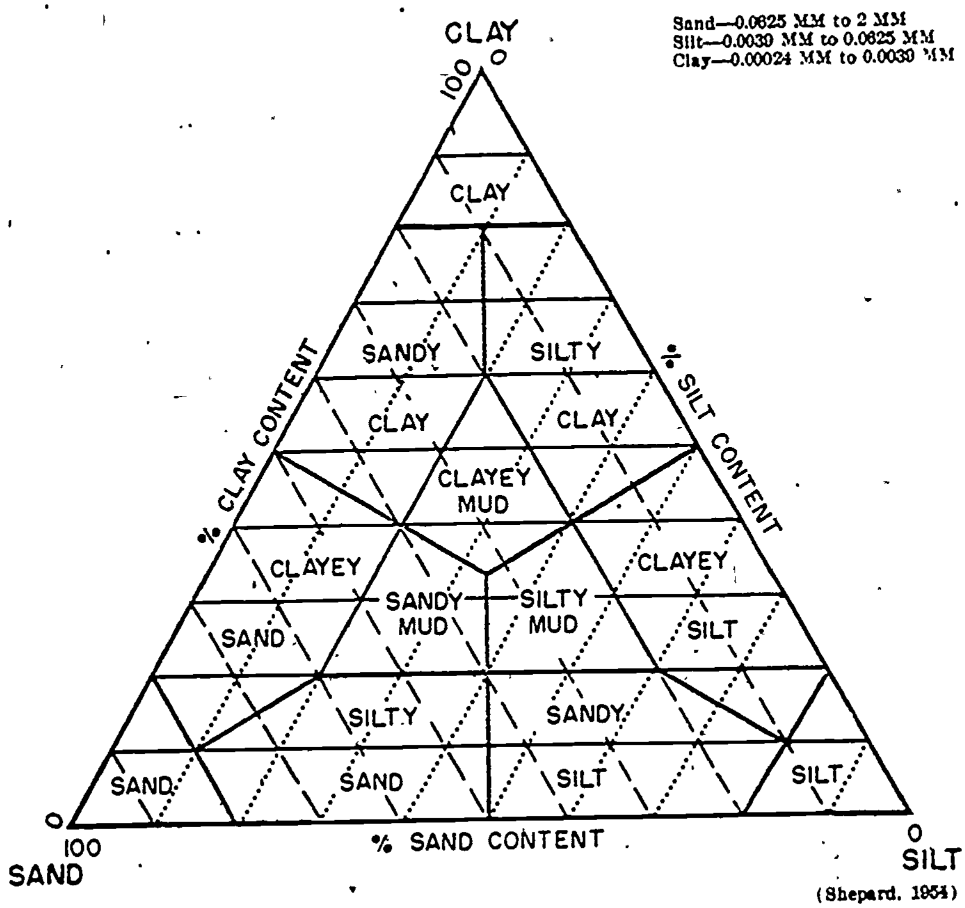



Figure 9.—Nomenclature of Sediment Types.

of the bottom is modified primarily by sedimentation. Sedimentary debris accumulating slowly on the bottom masks minor irregularities by filling depressions. Underwater photography has shown that areas of current flow are relatively free of sedimentary debris while areas of no motion show an undisturbed bottom covered by sediment with the mounds and burrows of bottom dwellers.

Composition of Ocean Floor

The ocean floor is composed of material deposited there through the years. The materials range in size from the finest clays and colloidal particles to bedrock, most of the material ranging from clay to sand particles in size. (See figure 9.) The type of bottom that will be present in an area is dependent on factors such as the geologic history of the area and the present environmental conditions.

Bottom composition may include bedrock, living or dead coral, calcareous algae, or detrital material. The last term refers to particles that have a comparatively short geologic history since separation from their parent rock, coral, or algal masses. This material, whether solid or in solution, has been transported from the parent bodies distances ranging from a few hundred feet to many miles. The transporting medium is usually water, although minor amounts of detrital material have been transported by the atmosphere before being dropped into the sea. As long as the water masses move at sufficient velocity, certain sizes of particles remain in suspension and can be transported from one place to another. However, when the velocity drops below a critical value, some of the larger particles in suspension are deposited while the finer material remains in suspension. If the velocity continues to decrease,

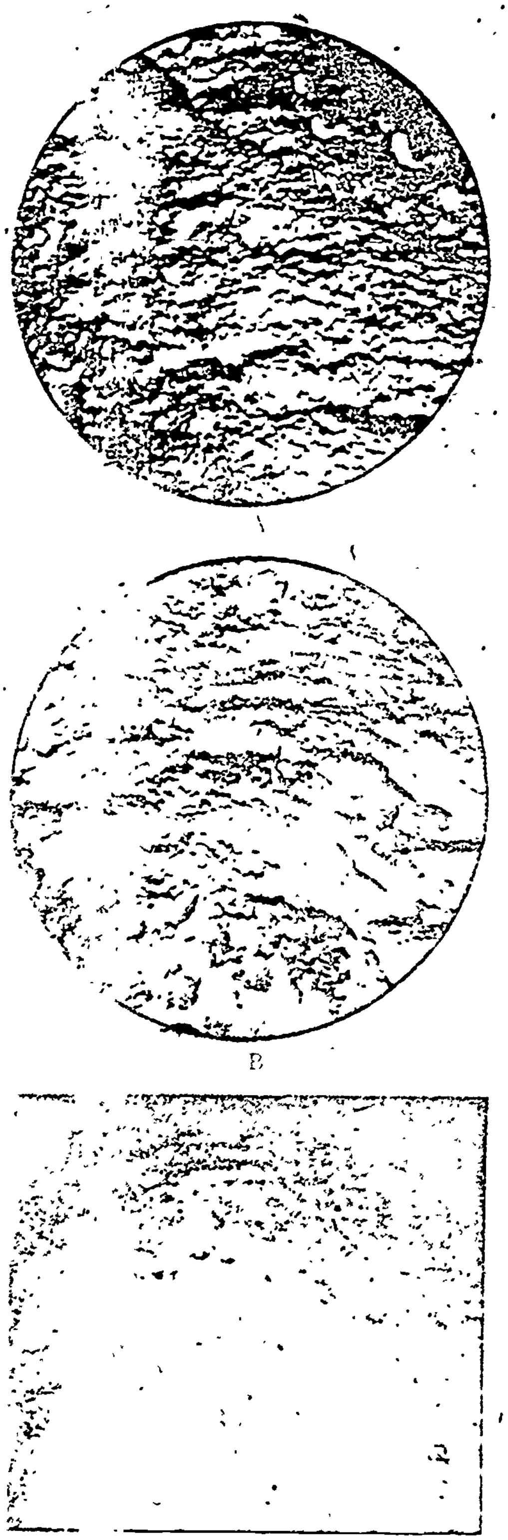



Figure 1: ... rom photographs at depths from ... to 5,500 meters.

only the smallest particles remain in suspension. Thus, the size of the material being transported and deposited depends on velocity and associated turbulence of the water.

Marine sediments are subdivided into two major groups: pelagic and terrigenous. Pelagic deposits are those found in deep water far from shore and may be predominantly either organic or inorganic in origin. These deposits are characterized by the absence of terrestrial mineral grains larger than colloidal. The most common constituents are clay minerals and the remains of planktonic unicellular organisms. The three most abundant pelagic sediments are: the calcareous oozes (48 percent, mostly globigerina ooze), red clay (38 percent), and siliceous oozes (14 percent, mostly diatom ooze). (See table 1.)

Terrigenous deposits are found near shore and in most semienclosed seas, gulfs, and bays; they generally contain some material of land origin. (See figure 11.)

Pelagic deposits containing more than 30 percent organic material are known as oozes. Usually these sediments are white or very light colored. A popular misconception is that the oozes are very fine grained; often they are in the coarse to fine sand range. Oozes can be subdivided into two general types, calcareous or siliceous, depending on the composition of their organic constituents. These two types can be further subdivided according to the characteristic organism present, so that within the calcareous category there are globigerina, pteropod, and coccolith oozes, and within the siliceous category there are diatom and radiolarian oozes. (See table 1.)

Pelagic inorganic deposits, known as red clay, contain less than 30 percent organic material. Although called red clay since the first samples collected were brick red, these deposits also occur in other colors; in fact most of them are brown or buff colored. Regardless of color, these deposits are composed predominantly of material of clay size or smaller.

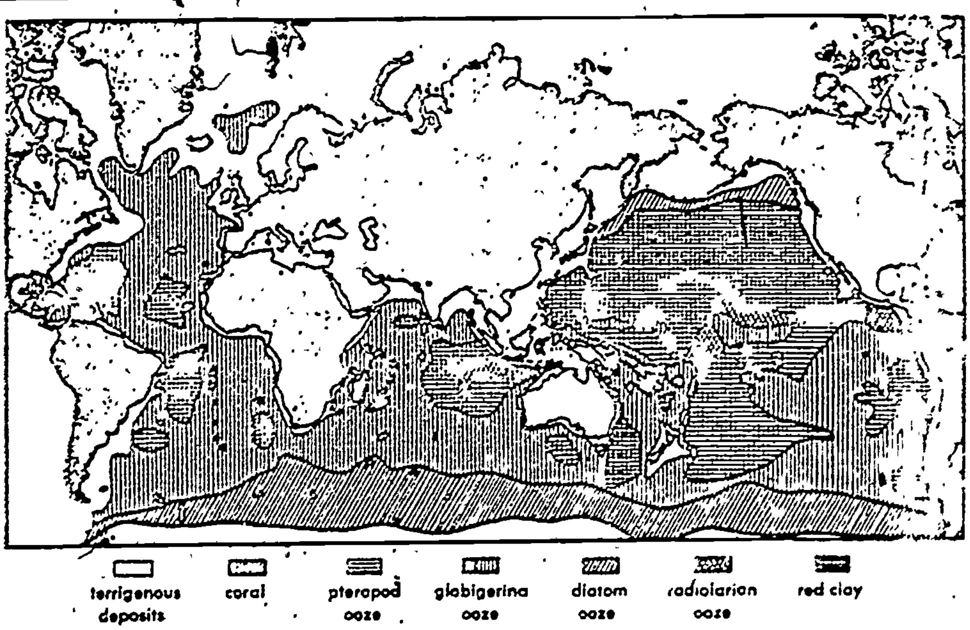
Terrigenous deposits cover a wide range of depths and a great variation in color, texture, and composition. The classification of these sediments is not as straightforward as that of the pelagic sediments. A number of systems have been suggested, but the character of terrigenous deposits depends so much upon local conditions

Table 1.— Areas Covered by Pelagic Sediments.

| | Atlantic Ocean | | Pacific Ocean | | Indian Ocean | | al | |
|---|---|---|---|---|---|---|---|---|
| | Area * | % | Area * | % | Area * | % | Ar[illegible] | % |
| Calcareous oozes: | | | | | | | | |
| Globigerina..... | 40.1 | | 51.9 | | 34.4 | | | |
| Pteropod........ | 1.5 | | | | | | | |
| Total......... | 41.6 | 67.5 | 51.9 | 36.2 | 34.4 | 54.3 | 127. | 47.7 |
| Siliceous oozes: | | | | | | | | |
| Diatom.......... | 4.1 | | 14.4 | | 12.6 | | | |
| Radiolarian | | | 6.6 | | 0.3 | | | |
| Total......... | 4.1 | 6.7 | 21.0 | 14.7 | 12.9 | 20.4 | 33. | 14.2 |
| Red clay........ | 15.9 | 25.3 | 70.3 | 49.1 | 16.0 | 25.3 | 10[illegible] | 38.1 |
| *(Millions Km²) | 61.6 | 100.0 | 143.2 | 100.0 | 63.3 | 100.0 | 268 | 100.0 |

(Sverdrup, Johnson . . . ming, 1942)

*Data on Oceans Related to Geography*




(Heezen, 1. 4)

Figure 11.— Distribution of the Major Types of Deep-Sea Sediments (See Table 1.)

that no one system has a very wide application. Compared to pelagic deposits, terrigenous deposits cover a small percentage of the sea floor. Since they show great changes in characteristics within relatively short distances seaward, the occurrence of the transitional types makes definition difficult. Therefore, a system of merely describing the mass properties of the bottom materials must suffice. Descriptive terms which depict the color, texture, and composition of materials are used; such terms include "green diatomaceous silty clay" or "gray calcareous sand."

The thickness of the sediment cover over the ocean bottom has been determined at a number of locations by seismic exploration. Off the east coast of the United States, the thickness has been estimated as about 17,00[illegible] feet on the continental shelf and about 30,000 feet on the continental slope and adjacent ocean floor. Off the United States along the outer edge of the continental shelf in the Gulf of Mexico, sediments are about 20,000 feet thick. Off the southern coast of California the thickness varies from 10,000 feet in the basins to practically no sediments over the ridges where rock is exposed. This last example is fairly typical of most regions exhibiting radical topographic differences; that is, the amount of sedimentary cover is at a minimum over elevations (nonexistent in some locations) and at a maximum over depressions. In general, the average thickness of sediments in the Atlantic has been estimated to be about 2,000 feet and in the Pacific about 1,000 feet. The value for the Atlantic probably is higher because of the greater number of large rivers carrying sediment into this ocean.

Bottom sediments can be closely associated with the transmission of underwater sound, particularly in regard to the bottom reflection (bounce) mode of transmission. The most serious limitation of this type of transmission is the loss of sound energy into the bottom. This energy loss mainly depends on bottom composition, frequency of sound transmitted, and angle of incidence of the sound ray at the sea bottom. The different types of bottom sediments are known to have varying effects on sound ranging, and several factors have been suggested as the principal causes of these variation.

Also associated with our consideration of the ocean bottom are such topics as mining and petroleum. We have purposely forgone a discussion of such topics in order to emphasize those areas of marine geology with which a Marine Science Technician is more involved.

# PHYSICAL OCEANOGRAPHY

Until recent years, physical oceanography was probably one of the least understood subjects of science. In general, the results of physical oceanography found the greatest application in the solution of fisheries' problems. Therefore, physical oceanography was considered more of a secondary study in the field of marine biology, and most of the early investigations made by scientific specialists were of the classic or general approach. Specialized investigation in other related fields of oceanography has evolved with the aggregation, or coming together, of highly trained researchers, each a specialist in his own field. Because of the existence of several similarities between oceanic and atmospheric problems, many meteorologists have been inducted into and successfully adapted to the field of physical oceanography.

Many advances in physical oceanography have been made in the last few years as a result of the development of improved observation programs and high speed computer systems which digest vast amounts of information (climatological, observational, etc.) previously impossible except through long and laborious physical computations. This accumulated data has provided the basis for many studies that are now available.

Much greater improvement in future instrumentation will be necessary before the study of physical oceanography can parallel the pace of present-day meteorology. Original instrumentation, instrumentation in numbers, and the feasible means of utilizing this instrumentation are needed before researchers will be capable of attaining the desired degree of worldwide synoptic observation.

## THE THREE-LAYERED OCEAN

A convenient method of visualizing the sea is to divide it into three different layers: (1) the mixed layer, (2) the main thermocline, and (3) the deep layer. We will now consider the boundaries, ranges, and variations of these layers.

The mixed layer is a region of fairly constant warm temperatures which, in middle latitudes, exist from the surface to an average depth of about 450 meters. In this layer the mixing of water is caused by action of surface storms, wind friction, wave action, etc. Below the mixed layers, no matter how violent the storm, no mixing will occur.

The main thermocline is the central layer of the ocean in which there is a rapid decrease of water temperature with depth.

The deep layer is the bottom layer of water which, in middle latitudes, exists below 1,200 meters. The deep layer is characterized by fairly constant cold temperatures, generally less than 4° C.

## PHYSICAL PROPERTIES OF SEA WATER

Some of the most common physical properties of sea water are temperature, pressure, salinity, density, water color, transparency, ice, and sound velocity. Less commonly known or determined properties are specific heat, osmotic pressure, eddy viscosity, electrical conductivity, compressibility, radioactivity, and surface tension. Development of instrumentation for use in securing measurements of the most common of these parameters has been fairly rapid in recent years. The least common parameters are usually determined by complex mathematical calculation and formulation from one or a combination of the common parameters.

Two variables—temperature and pressure—determine the physical properties of pure water. Here, however, we are interested in sea water and its properties. Besides temperature and pressure, salinity is also a variable to be considered.

The state of motion and the presence of small suspended particles are also important attributes of sea water. For one thing, sea water absorbs radiation differently than pure water, since the suspended matter causes increased scattering of

A. —Mean Annual Sea Surface Temperature (°C) for 10° Zones

| | Northern Hemisphere | | | | Southern Hemisphere | | | |
|---|---|---|---|---|---|---|---|---|
| Latitude | Atlantic | Indian | Pacific | Mean for all oceans | Atlantic | Indian | Pacific | Mean for all oceans |
| 0-10° | 26.6 | 27.9 | 27.2 | 27.3 | 25.2 | 27.4 | 26.0 | 26.4 |
| 10-20° | 25.8 | 27.2 | 26.4 | 26.5 | 23.1 | 25.9 | 25.9 | 25.1 |
| 20-30° | 24.1 | 26.1 | 23.4 | 23.7 | 21.1 | 22.5 | 21.5 | 21.7 |
| 30-40° | 20.4 | - | 18.6 | 18.4 | 16.8 | 17.0 | 17.0 | 17.0 |
| 40-50° | 13.4 | - | 10.0 | 11.0 | 8.6 | 8.7 | 11.2 | 9.8 |
| 50-60° | 8.7 | - | 5.7 | 6.1 | 1.8 | 1.6 | 5.0 | 3.0 |
| 60-70° | 5.6 | - | - | 3.1 | -1.3 | -1.5 | -1.3 | -1.4 |
| 70-80° | - | - | - | -1.0 | -1.7 | -1.7 | -1.7 | -1.7 |
| 80-90° | - | - | - | -1.7 | - | - | - | - |
| | 0-90° | | | | 0-80° | | | |
| | 20.1 | 27.5 | 22.2 | 19.2 | 14.1 | 15.2 | 16.8 | 16.0 |

(Defant, 1961)

B. —Annual Surface Temperature (°C) Variations in Northern Hemisphere

| Latitude | Equator | 10° | 20° | 30° | 40° | 50° |
|---|---|---|---|---|---|---|
| Oceans | 2.3 | 2.4 | 3.6 | 5.9 | 7.5 | 5.6 |
| Continents | 1.3 | 3.3 | 7.2 | 10.2 | 14.0 | 24.4 |

(Defant, 1961)

Table 2. —Mean Temperature Data

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the radiation, bringing about an increased absorption in layers of similar thickness. The motion of the water causes a change in the processes of chemical diffusion, heat conduction, and transfer of momentum from one layer to another.

It can readily be seen, therefore, that some physical properties of sea water are dependent upon pressure, temperature, and salinity; while on the other hand, other properties are affected by the suspension of minute matter and motion characteristics. The latter variables cannot be accurately measured; whereas pressure, temperature, and salinity can be determined with great accuracy.

Temperature

The temperature of the sea water, primarily in the upper portions of the mixed layer, has a marked effect upon the atmospheric and climatic conditions over the surface of the earth. In all latitudes, the ice-free portions of oceans receive a surplus of radiation and, therefore, at all latitudes, heat is given off to the atmosphere. Since the sea retains a portion of this heat, the sea surface temperature is normally higher than the air temperature. This has been borne out by observations. However, this is true only when the average conditions are considered, as this difference is dependent upon the locality, the season of the year, the character of the atmospheric circulation, and the character of the ocean currents.

The temperature of the ocean ranges from about -2°C to 30°C. Ocean water that is nearly surrounded by land may have higher temperatures, but the open sea, where the water is free to move about, hardly ever has temperatures higher than 30°C, because ocean currents distribute the heat and tend to equalize the temperature. The temperature of deep and bottom water is always low, varying between 4°C and -1°C.

The annual variation of sea surface temperatures in any region depends upon the variation of incoming radiation, the character of the ocean currents, and the character of the atmospheric circulation. Although the annual variation of surface temperature varies from one locality to another a few features stand out. First, the annual range of surface temperature is much greater over the northern hemispheric ocean than over that of the Southern Hemisphere. Second, in the southern hemispheric ocean, the annual range is definitely related to the range of incoming radiation, but the northern hemispheric ocean does not have the same relation. It appears that in the northern ocean the great range of temperature is associated with the character of the prevailing winds, particularly the cold winds blowing from continent to ocean. Near the Equator, a semiannual variation exists, corresponding to the semiannual period of incoming radiation.

The diurnal variation of sea surface temperature in open ocean is found to be slight; on the average, from 0.2°C to 0.3°C. The greatest variation takes place in the Tropics, with lesser variation at higher latitudes. The range of diurnal variation depends upon cloudiness and wind velocity.

For subsurface layers, the annual variation of temperature depends upon several additional factors, namely, the variation of the amount of heat that is directly absorbed at different depths, the effect of heat conduction, the variation in currents related to lateral displacement, and the effect of vertical motion. Diurnally, the variation of sea temperature in the subsurface layers is largely unknown. The diurnal variation is so slight that knowledge of the small variation is essential only to the study of the diurnal exchange of heat between the atmosphere and the ocean.

The basic vertical thermal structure of the ocean in its simplest form was briefly described under the "three-layered ocean" concept. There is generally little temperature change with depth through the mixed layer, a sharp temperature decrease through the thermocline layer, and a return to a gradual decrease in temperature through the deep water layer. (See figure 12.)

We can best understand the basic latitudinal vertical temperaure distribution by considering the vertical temperature distribution at high, middle, and low latitudes in winter. At high latitudes the vertical temperature structure is essentially isothermal. In mid latitudes, the structure is essentially the same as that described above for the basic vertical structure. In low latitudes, the mixed layer extends to about 300 feet, with the main thermocline lying between 300 and 2,100 feet. (See figure 13.) In this layer a temperature drop of about 8°C greater than in mid latitudes occurs due to the higher surface temperature at these latitudes. The deep water layer lies below 2,100 feet.

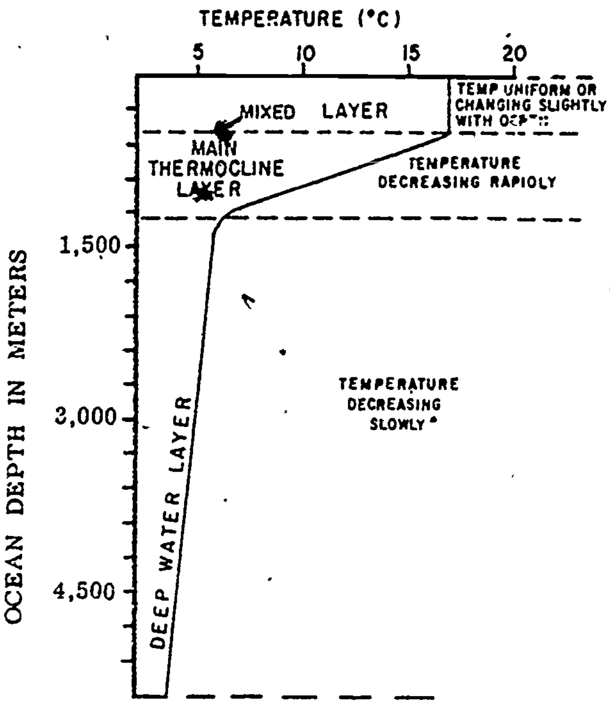


Figure 12. —Typical thermal structure of the oceans (winter conditions in midlatitudes).

At high latitudes there is no marked seasonal water temperature change. In midlatitudes, due to the gradual warming of the surface layer, a seasonal thermocline develops at a depth below which the warming has no effect. This warming takes place in the upper few hundred feet of the surface layer. It results in a seasonal thermocline becoming superimposed on the main thermocline with the total thermocline existing over a broader range of depth. Such a seasonal thermocline makes an appearance in spring and disappears by late autumn. (See figure 14.) In low latitudes a small seasonal temperature change makes it difficult to distinguish between a seasonal thermocline and the permanent thermocline.

Salinity

Salinity is formally defined as "the total amount of dissolved solids in sea water in parts per thousand by weight when all the carbonate has been converted to oxide, the bromide and iodide to chloride, and all organic matter is completely oxidized." The symbol used to express salinity is o/oo, which indicates the grams of dissolved material per kilogram of sea water

Salinity of sea water is based on the quantity of dissolved salts contained in a given amount of sea water after certain chemical changes have taken place. Direct determination of these values by recommended procedure is rarely carried out at the present time, because the method is too difficult and slow. Sea water composition adheres to the Law of Constant Proportions; i. e., the total amount of the major constituents in any two samples is always present in the same relative proportions. The constituents of sea water have been divided into major and minor groupings with 10 major constituents and between 32 and 49 minor constituents, depending upon the reference used. (See table 3.)

Since chloride ions constitute more than half of the total amount of chemicals in sea water,

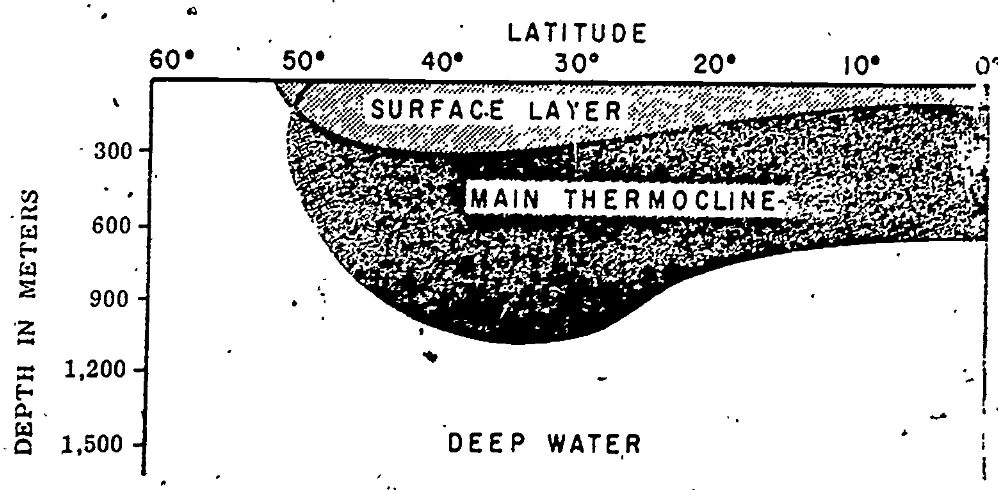


Figure 13. —North-south distribution of a simple three-layered ocean (North Atlantic in winter).

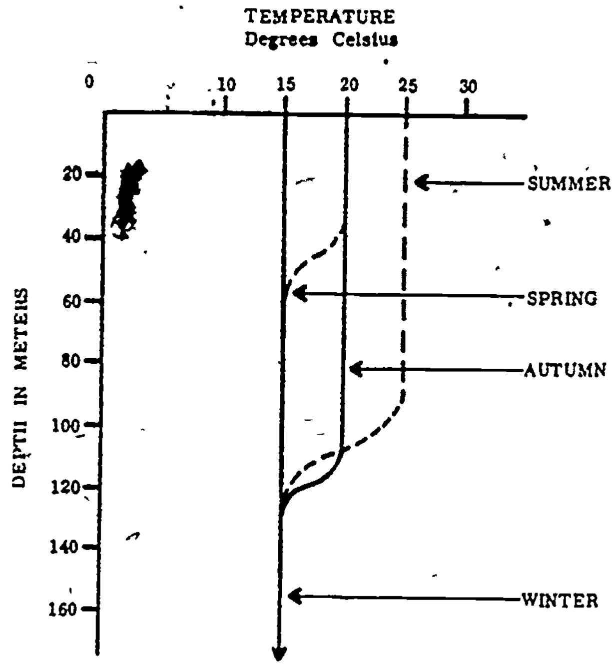


Figure 14.—Upper level thermal structure of seasonal thermocline in middle latitudes.

Table 3.— Sea Water Constituents.

| | |
|---|---|
| **A. Major constituents** | |
| Chlorine | 18.980 g/kg (%) |
| Sodium | 10.561 |
| Magnesium | 1.272 |
| Sulfur | 0 884 |
| Calcium | 0.40 |
| Potassium | 0.380 |
| Bromine | 0.065 |
| Carbon | 0.028 |
| Strontium | 0.013 |
| Boron | 0.005 |
| **B. Minor constituents** | |
| Silicon | $4\times10^{-8}$ to $2\times10^{-6}$ |
| Fluorine | $1.4\times10^{-6}$ |
| Nitrogen | $7\times10^{-7}$ to $6\times10^{-9}$ |
| Aluminum | $5\times10^{-7}$ |
| Rubidium | $2\times10^{-7}$ |
| Lithium | $1\times10^{-7}$ |
| Phosphorus | $1\times10^{-7}$ to $1\times10^{-9}$ |
| Barium | $5\times10^{-8}$ |
| Iodine | $5\times10^{-8}$ |
| Arsenic | $2\times10^{-8}$ to $2\times10^{-9}$ |
| Manganese | $1\times10^{-9}$ to $1\times10^{-8}$ |
| Copper | $1\times10^{-8}$ |
| Zinc | $5\times10^{-9}$ |
| Lead | $4\times10^{-9}$ |
| Selenium | $4\times10^{-9}$ |
| Cesium | $2\times10^{-9}$ |
| Uranium | $1.5\times10^{-9}$ |
| Molybdenum | $5\times10^{-10}$ |
| Thorium | $5\times10^{-10}$ |
| Cerium | $4\times10^{-10}$ |
| Silver | $3\times10^{-10}$ |
| Vanadium | $3\times10^{-10}$ |
| Lanthanum | $3\times10^{-10}$ |
| Yttrium | $3\times10^{-10}$ |
| Nickel | $1\times10^{-10}$ |
| Scandium | $4\times10^{-11}$ |
| Mercury | $3\times10^{-11}$ |
| Gold | $6\times10^{-12}$ |
| Radium | $3\times10^{-16}$ to $2\times10^{-17}$ |
| Cadmium | Trace |
| Cobalt | Trace |
| Tin | Trace |

salinity values can be empirically related to chlorinity once the latter has been established by chemical means. In 1964, the IAPO (International Association of Physical Oceanography) adopted the following equation for determining salinity from chlorinity: Salinity = 1.80655 x chlorinity.

Ocean water generally has a salinity between 33 o/oo and 37 o/oo, with an average salinity of 35 o/oo for the world ocean. In open oceanic areas, surface salinity is decreased by precipitation, increased by evaporation, and changed by vertical mixing and inflow of adjacent water. In nearshore regions, salinity is generally reduced by river discharge and runoff from land. In regions where ice occurs, salinity generally increases during periods of ice formation and decreases during periods of ice melt.

Surface salinity varies with latitude in a similar manner in all oceans. Maximum salinities occur between 20° and 23° north and south latitudes, whereas minimum salinities occur near the Equator and toward the higher latitudes. (See figure 15.) The controlling factor in average surface salinity distribution is the difference between evaporation and precipitation (E-P); the effect of ocean currents is of minor importance. Exceptions to this general statement do occur and local variations should be expected, especially near the mouths of such rivers as the Amazon, Rio de la Plata, and Mississippi, and in the Atlantic coastal waters of the United States, Labrador, Spain, and Scandinavia. Probably the best known region of strong horizontal salinity gradients is the region of the Grand Banks where the warm, saline Gulf Stream waters mix with the waters of the colder, less saline Labrador Current. Here, water with a salinity as low as 32 o/oo may possibly override or lie adjacent to water of salinity greater than 36 o/oo. A similar situation prevails in the Pacific Ocean in the region northeast of Japan where the Kuroshio and the Oyashio mix.

Positive (increasing with depth) salinity gradients tend to develop in latitudes higher than 40° north and south, where precipitation generally

2/

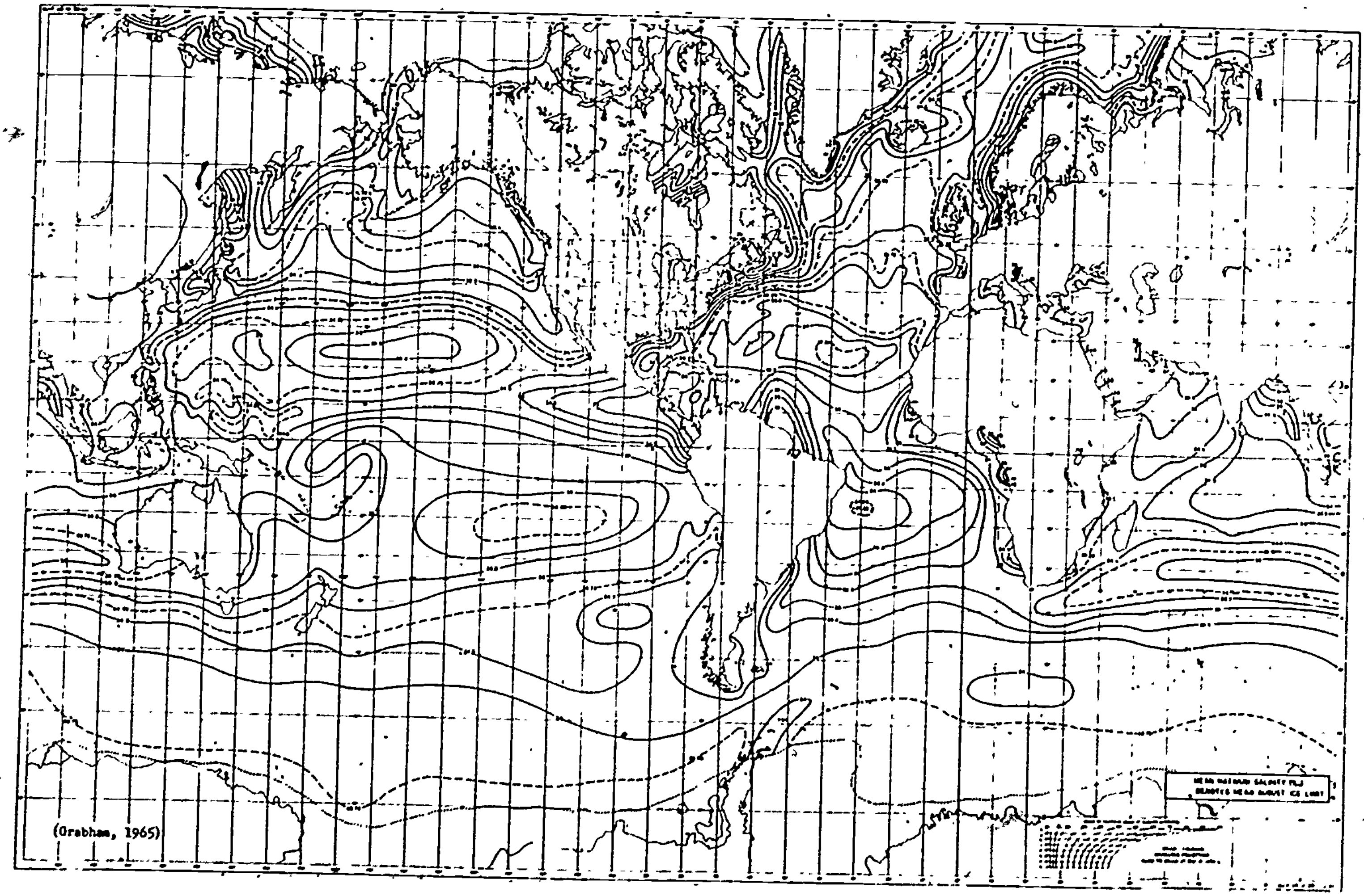


Figure 15. —Mean Annual Maximum Salinity

exceeds evaporation. In summer, these positive salinity gradients usually are accompanied by strong negative temperature gradients. Vertical stability of the water column, especially in coastal regions, results; and these strong, shallow salinity (and temperature) gradients persist throughout the summer.

Pressure

Pressure beneath the ocean surface is measured in terms of decibars. A decibar is one-tenth of a bar. As you already know, a bar is 1 million dynes per square centimeter. The pressure exerted by 1 meter of sea water very nearly equals 1 decibar.

The cause of the great pressure near the bottom of the sea is the weight of the fluid above. The weight per unit volume of sea, in turn, varies with the temperature and salinity. In a column of water of constant depth, pressure increases as the temperature of the sea decreases or the salinity increases, or both.

Since pressure in the ocean is essentially a function of depth, the numerical value of pressure in decibars approximates the ocean depth in meters. Therefore, the range in pressure is from zero at the surface to over 10,000 decibars in the deepest part of the ocean.

Density

Density is mass per unit volume. In oceanography the centimeter-gram-second system is used, in which density is expressed as grams per cubic centimeter. The ratio of the density of a substance to that of a standard substance under stated conditions is called specific gravity. By definition, the density of distilled water at 4°C or 39.2°F is one gram per milliliter (approximately one gram per cubic centimeter). Therefore, if this is used as the standard, as it is in oceanographic work, density and specific gravity are virtually identical numerically.

The density of sea water depends upon salinity, temperature, and pressure. (See figure 16.)



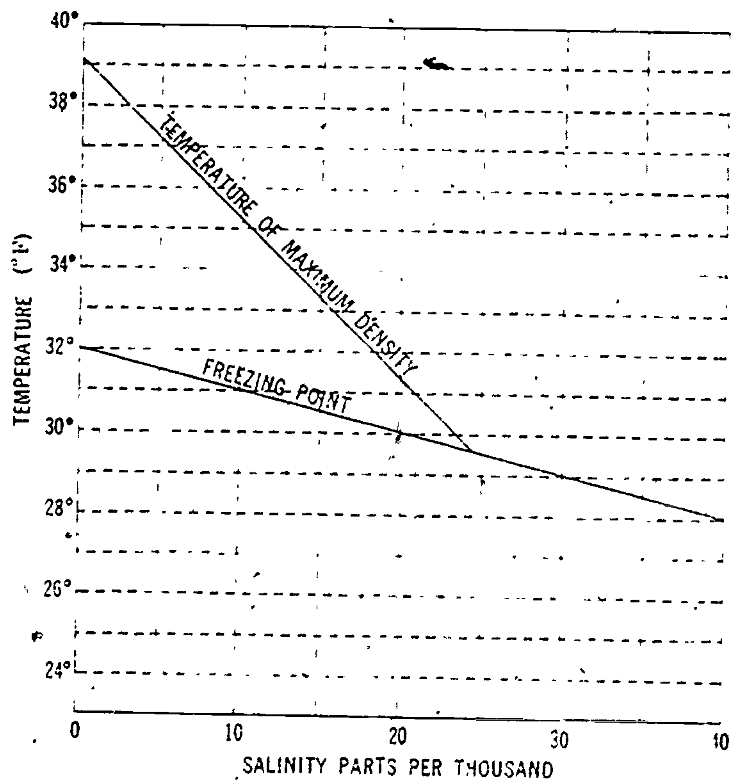


Figure 15. Relationship between temperature of maximum density and freezing point for water of varying salinity.

At constant temperature and pressure, density varies with salinity or, because of the relationship between this and chlorinity, with the chlorinity. A temperature of 32°F and atmospheric pressure are considered standard for density determination. The effects of thermal expansion and compressibility are used to determine the density at other temperatures and pressures. The density at a particular pressure affects the buoyancy of various objects, notably submarines. The density is also important in relation to ocean currents.

The greatest changes in density of sea water occur at the surface, where the water is subject to influences not present at depth. Here density is decreased by precipitation, run-off from land, melting of ice, or heating. When the surface water becomes less dense, it tends to float on top of the more dense water below. There is little tendency for the water to mix; therefore, the condition is one of stability. The density of surface water is increased by evaporation, formation of sea ice, and cooling. If the surface water becomes more dense than that below, it sinks to the level at which other water has the same density. Here it tends to spread out to form a layer, or to increase the thickness of the layer below it. The less dense water rises to make room for it, and the surface water moves in to replace that which has descended. Thus, a convective circulation is established. The circulation continues until the density becomes uniform from the surface to the depth at which a greater density occurs. If the surface water becomes sufficiently dense, it sinks all the way to the bottom. If this occurs in an area where horizontal flow is unobstructed, the water which has descended spreads to other regions, creating a dense bottom layer. Since the greatest increase in density occurs in polar regions, where the air is cold and great quantities of ice form, the cold dense polar water sinks to the bottom and then spreads to lower latitudes. This process has continued for a sufficiently long period of time that the entire ocean floor is covered with this dense polar water, thus explaining the layer of cold water at great depths in the ocean.

As we will see, in some respects, the oceanographic processes are similar to those occurring in the atmosphere. The convective circulation in the ocean is somewhat similar to that in the atmosphere. Water masses having nearly uniform characteristics are analogous to air masses.

Compressibility

Sea water is nearly incompressible, its coefficient of compressibility being only 0.000046 per bar under standard conditions. This value changes slightly with changes of temperature or salinity. The effect of compression is to force the molecules of the substance closer together, causing it to become more dense. Even though the compressibility is low, the total effect is considerable because of the amount of water involved. If compressibility of sea water were zero, sea level would be about 90 feet higher than it now is.

Viscosity

Viscosity is resistance to flow. Sea water is slightly more viscous than fresh water. Its viscosity increases with greater salinity, but the effect is not nearly as marked as that occurring with decreasing temperature. The rate is not uniform, becoming greater as the temperature decreases. Because of the effect of temperature upon viscosity, an incompressible object might sink at a faster rate in warm surface water than in colder water below. However, for most objects, this effect may be more than offset by the compressibility of the object.

Because of the turbulent motion within the sea the actual relationships existing in the ocean are considerably more complicated than indicated by the simple explanation given above. The disturbing effect is called eddy viscosity.

Specific Heat

Specific heat is the amount of heat required to raise the temperature of a unit mass of a substance a stated amount. In oceanographic work, specific heat is stated in centimeter-gram-second units, as the number of calories needed to raise one gram of the substance 1°C. Specific heat at constant pressure is usually the quantity desired when liquids are involved, but occasionally the specific heat at constant volume is required. The ratio of these two quantities has a direct relationship to the speed of sound in sea water.

The specific heat of sea water decreases slightly as salinity increases. However, it is much greater than that of land. This accounts, in part, for the greater temperature range of land and the atmosphere above it, resulting in

| SUBSTANCE | SPECIFIC HEAT |
|---|---|
| SOLIDS | |
| Asbestos | 0.200 |
| Bronze | 0.104 |
| Clay | 0.190 |
| Glass | 0.160 |
| Ice | 0.500 |
| Sand | 0.190 |
| Stone | 0.200 |
| LIQUIDS | |
| Alcohol | 0.650 |
| Ammonia | 1.012 |
| Mercury | 0.030 |
| Petroleum | 0.504 |
| Sea water | 0.940 |
| Fresh water | 1.000 |

Table 4.—Representative list of the Specific Heat of various substances.

monsoons and the familiar land and sea breezes of tropical and temperate regions.

Thermal Expansion

The rate of expansion with increased temperature is greater in sea water than in fresh water. Thus, at temperature 15°C or 59°F and atmospheric pressure, the coefficient of thermal expansion is 0.000151 per degree Celsius for fresh water and 0.000214 per degree Celsius for water of 35 parts per thousand salinity. The coefficient of thermal expansion increases not only with greater salinity, but also with increased temperature and pressure. At 35 parts per thousand, the coefficient of surface water increases from 0.000051 per degree Celsius at 0°C to 0.000334 per degree Celsius at 30°C. At a constant temperature of 0°C and a salinity of 34.85 parts per thousand, the coefficient increases to 0.000276 per degree Celsius at a pressure of 10,000 decibars (at a depth of approximately 10,000 meters).

Thermal Conductivity

In water, as in other substances, one method of heat transfer is by conduction. Fresh water is a poor conductor of heat, having a coefficient of thermal conductivity of 0.00139 calories per second per centimeter per degree Celsius. For sea water it is slightly less but increases with greater temperature or pressure.

However, if turbulence is present, which it nearly always is to some extent in the ocean, the processes of heat transfer are altered. The effect of turbulence is to increase greatly the rate of heat transfer. The "eddy" coefficient used in place of the still-water coefficient is so many times larger, and so dependent upon the degree of turbulence that the effects of temperature and pressure are not important.

Electrical Conductivity

Water without impurities is a very poor conductor of electricity. However, when salt is in solution in water, the salt molecules are ionized and therefore are carriers of electricity. Hence, the electrical conductivity of sea water is directly proportional to the number of salt molecules in the water. For any given salinity, the conductivity increases with an increase in temperature.

Radioactivity

Although the amount of radioactive material in sea water is very small, this material is present in marine sediments to a greater extent than in the rocks of the earth's crust. This is probably due to precipitation of radium or other radioactive material from the water. The radioactivity of the top layers of sediment is less than that of deeper layers. This may be due to absorption of radioactive material in the soft tissues of marine organisms.

Refractive Index

The refractive index of sea water increases as salinity becomes greater, or as temperature decreases. Since it varies with frequency of the radiant energy, the "D line" of sodium is usually used as the standard for comparison.

Surface Tension

Surface tension is usually expressed in dynes per centimeter or ergs per square centimeter. The surface tension of water in dynes per square centimeter (pressure) is approximately equal to $75.64 - 0.144T + 0.0399Cl$, where T is temperature in degrees Celsius and Cl is the chlorinity of the water in parts per thousand. As indicated by the last term, the surface tension increases with chlorinity and is therefore a little more for sea water than for fresh water. However, the presence of impurities causes it to be somewhat less than indicated by the formula.

Transparency

"Transparency" may be defined by any of the following terms: (1) the percent of surface light present at a specified depth, (2) the percent of absorption of light per unit length of path, (3) transmission of light as a percentage of transmission through distilled water, (4) hydrological range, and (5) Secchi disc value.

The degree of transparency is a result of the combined effects of scattering and absorption of light by the water surface, suspended particles of mud, clay, sand, dissolved matter, and plankton, as well as water molecules themselves. Scattering is the redirection of light by suspended particles, generally smaller in size than most plankton. When a train of light waves encounters particles (including molecules) whose dimensions are comparable to the wavelength of the light transmitted, scattering occurs. Minute particles scatter blue light most effectively, whereas larger particles (size of chalk dust or larger) scatter all wavelengths equally well. Absorption is the process of reduction of light through light conversion into other forms of energy, namely, heat. This is accomplished by suspended particles and/or

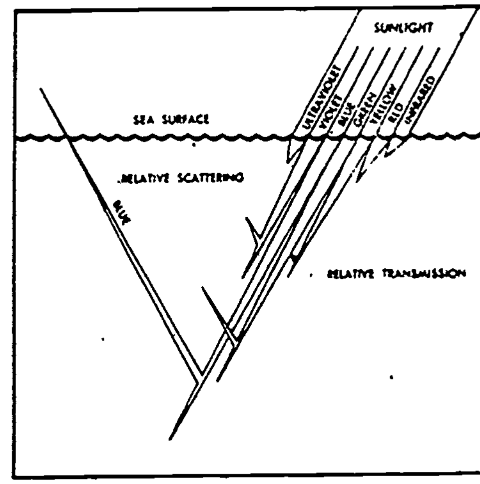


Figure 17.— Relative transmission and scattering of various colors by water.

water molecules. About 50 percent of the total radiant energy is absorbed in about the first 2-inch layer of the sea surface.

In distilled water, scattering is related to the molecular structure of the water. However, light absorption in normal (35 o/oo salinity) sea water does not differ in any important respect from that in distilled water and, as far as true absorption is concerned, sea water is identical with distilled

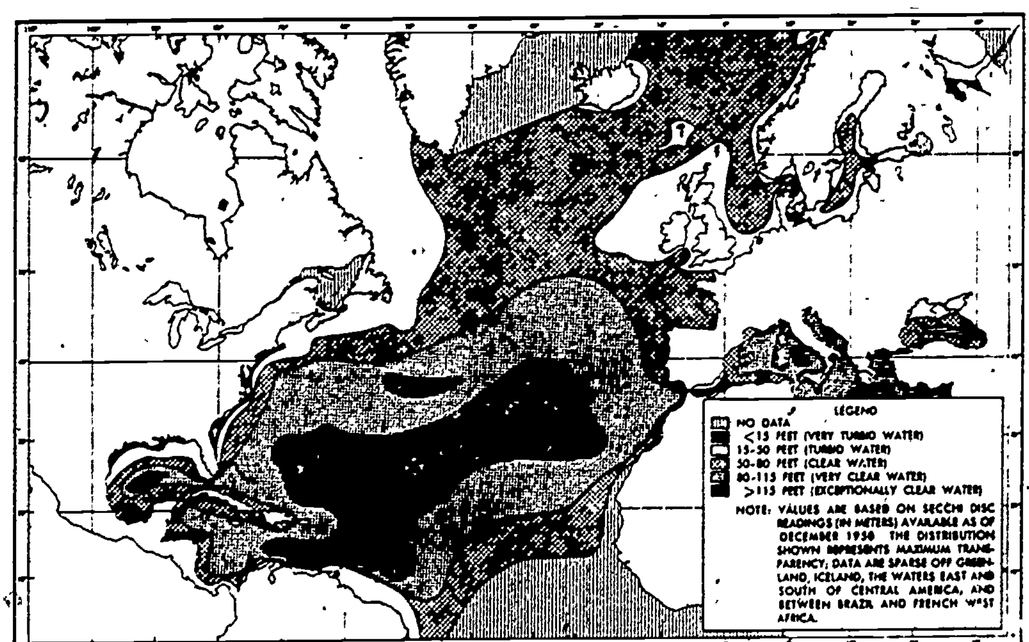


Figure 18.— Transparency chart of the North Atlantic Ocean.

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water. In clear oceanic water, absorption predominates, but in turbid nearshore waters, scattering is the dominating factor although absorption still is important.

Water Color

Deep (clear) ocean water is very transparent to the blue portion of the light spectrum; deep water is less transparent to green, yellow, and violet. The transmission of red, infrared, and ultraviolet light is practically nil in the sea. In the more turbid coastal, bay, and estuarine waters, green and yellow light penetrate to greater depths than does the blue light. (See figure 17.)

The various wavelengths of light are scattered differently by oceanic water. The scattering of blue light by water molecules and minute suspended particles results in the apparent blueness of the deep ocean water. However, the change in water color from blue to green and yellow in coastal areas cannot be attributed solely to scattering; part is ascribed to the inherent colors of suspended particles or dissolved solids and gases. Plankton often imparts a greenish, yellowish, or brownish red color to the water.

Ice

Ice covers about 3 percent of the world's water surfaces. The two main types of ice found in the seas and oceans are sea ice, which accounts for 95 percent of the total coverage, and glacier ice. Sea ice results from the direct freezing of sea water. It may be subdivided into ice of one year's growth or less (young ice and first-year ice) and ice of more than one year's growth (old ice or second-year ice and multi-year ice). A further breakdown distinguishes between freely floating ice (drift ice) and ice that is attached to the shore (shorefast ice). Glacier ice initially is composed of large accumulations of compacted snow that reach the sea as coastal glaciers and ice shelves. The fronts of these glaciers break off and release large numbers of icebergs and growlers, which then float away.

Sea Ice

Young ice and first-year ice - This ice forms in one year or less. Young ice ranges in thickness from 10 to 30 centimeters, whereas first-year ice is at least 30 centimeters thick. Since ice does not usually form during summer, the period of ice formation generally begins with the onset of freezing weather in autumn.

The freezing of a body of water is governed primarily by the temperature, salinity, and depth. However, the formation of ice may be retarded by winds, currents, and tides. Pure water freezes at 0°C, but the freezing point of sea water decreases approximately 0.28°C per a 5 o/oo increase in salinity. Thus, at 35 o/oo, water will begin to freeze at -1.9°C. (See figure 16.) Shallow bodies of low salinity water (less than 24.7 o/oo) freeze more rapidly than deeper basins because a lesser volume must be cooled. As a result, the first ice of autumn usually appears in the mouths of rivers that empty over a shallow continental shelf, such as that of northern Siberia.

During the increasingly longer and colder nights of autumn, winter fast ice forms along the shorelines as a semipermanent feature and widens by spreading into more exposed waters. When islands are close together, as in the East Siberian Sea, winter fast ice blankets the sea surface and bridges the waters between all land areas. Winter drift ice usually forms in the numerous openings within the polar pack, in the open water of the surrounding seas, or along the edge of fast ice that is broken by the action of wind, tide, and current.

Second-year ice or multi-year ice - This ice is the perennial sea ice found primarily in the arctic and antarctic polar pack. Ice of all ages, including a small portion of first-year ice, is amalgamated in the polar pack, which is a vast mass of converging, crushing, and dividing floes of various sizes, shapes, and thicknesses that drift around the Arctic Basin and Antarctica. Most of this polar drift ice has attained a state of equilibrium in which annual freezing compensates for an equivalent amount of summer melting. Polar fast ice is confined to northern Greenland, northern Ellesmere Island, and local bays in Antarctica.

The average distribution and variability of sea ice is such that a minimum is generally attained during the month of September while a maximum is generally attained during the month of March. In both cases, reference is to the Northern Hemisphere, with the conditions in the Southern Hemisphere being nearly opposite — minimum during March and maximum during September.

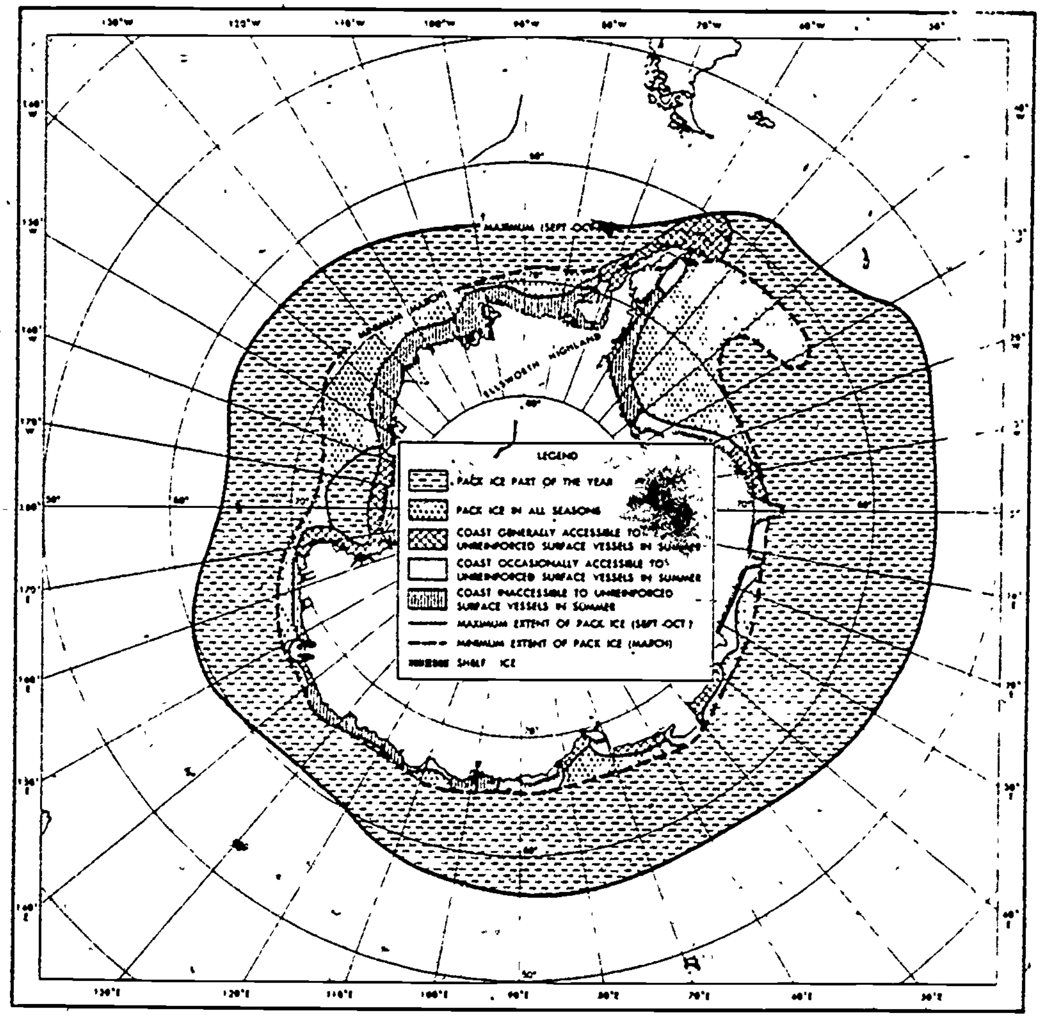


Figure 19.— Accessibility of Antarctic coasts.

The thickness of ice is related to the heat deficit, defined as the daily accumulation of degrees below freezing (degree days) since the onset of frost. This relationship presents the approximate number of degree days required for sea ice to attain certain thicknesses at various sustained mean temperatures. Sea ice may grow as much as 10 to 15 centimeters in the first 24 hours. However, because the ice acts as its own insulator, the rate of growth decreases as the ice thickens. For the same reason, snow also retards the development of sea ice.

Flat first-year ice rarely exceeds 2.5 meters in thickness; however, the ice may grow considerably thicker as a result of splashing, spraying, and flooding. The thickness of smooth multi-year ice usually reaches a state of equilibrium after several years in the polar pack. Multi-year ice normally fluctuates between thicknesses of 3 meters in late summer and 4.5 meters in spring. The arctic polar pack averages a thickness of 3.5 meters; the antarctic pack, somewhat less.

The drift of sea ice is primarily dependent on the wind. Within the normal range of wind speeds, the ice generally is deflected about 30° to the right of the wind between 60° and 90° latitude in the Northern Hemisphere. The deflection is to the left in the Southern Hemisphere.

Although winds, currents, tides, and swell may break up ice, the warm temperatures of spring and summer are the most destructive. When the factors combine, breakup is rapid.

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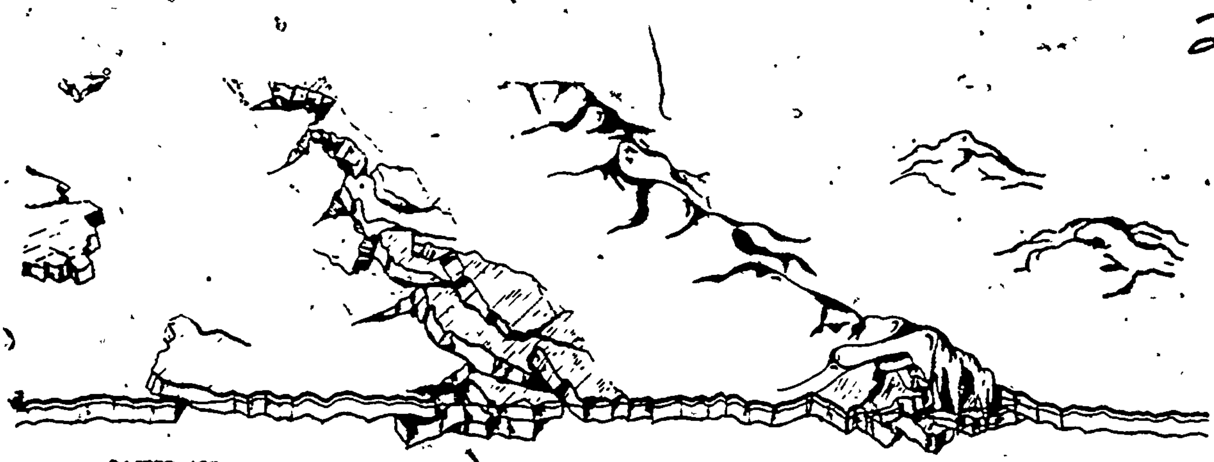


Figure 20.— Various types of ice topography caused by pressure.

River ice usually begins to disintegrate soon after the mean air temperature exceeds 0°C. Estuaries become ice free when inland water, warmed by strong continental heating, flows into the colder sea. The breakup along other portions of a coastline usually is initiated by warm offshore winds.

In the early stages of disintegration, cracks begin to crisscross the ice surface; then, as water seeps into these fissures and permeates the inner ice structure, the entire mass of ice becomes considerably weakened. As the fragments separate and decrease in size, melting is accelerated. Surface melting produces deep puddles that may be as wide as 500 feet. Owing to local differences of wind, tide, current, and coastal configuration, ice may persist from only a few days to 3 months after the initial breakup. If the summer is short, freezing may begin before the old ice has disappeared.

When drift ice is slowed in its forward motion by such obstacles as a shore, a narrow strait, an ice field, or convergent winds, the ice concentration will first increase to 10 tenths. Then, as the pressure increases, the ice buckles and forms large mounds, hummocks, and rows of undulations or ridges. Slabs of ice resembling huge pieces of a jigsaw puzzle may slide over one another in a process known as rafting. Hummocking, ridging, and rafting are manifestations of pressure ice. (See figure 20.) Intense sounds that resemble moans, screeches, bangs, and thunder emphasize the tremendous impact of converging ice. These noises can be heard over many miles, especially on calm winter nights.

Pressure ice may attain heights in excess of 10 meters, although such dimensions usually result from grounding in shallow coastal waters. For example, the ice may rise to 20 meters in the narrow and shallow passages of the Canadian Archipelago. Intense hummocking occurs throughout the arctic pack. (See figure 21.) In the Antarctic, where the ice is less confined, hummocks generally are smaller than in the Arctic.

Figure 21.—Fast Ice.

Whenever the process that leads to pressure ice is reversed (divergent wind, offshore circulation, and a widening strait), the ice field loosens and exposes numerous openings of all shapes and sizes. (See figure 22.) At low temperatures, when the opening freezes over, the opening is sometimes referred to as a skylight. Openings may be large (polynyas), narrow (leads), or incomplete (cracks). The frequency of openings varies widely with location and season. Openings are most numerous in summer and near ice boundaries with a seaward wind; they are rare in regions of intense hummocking.

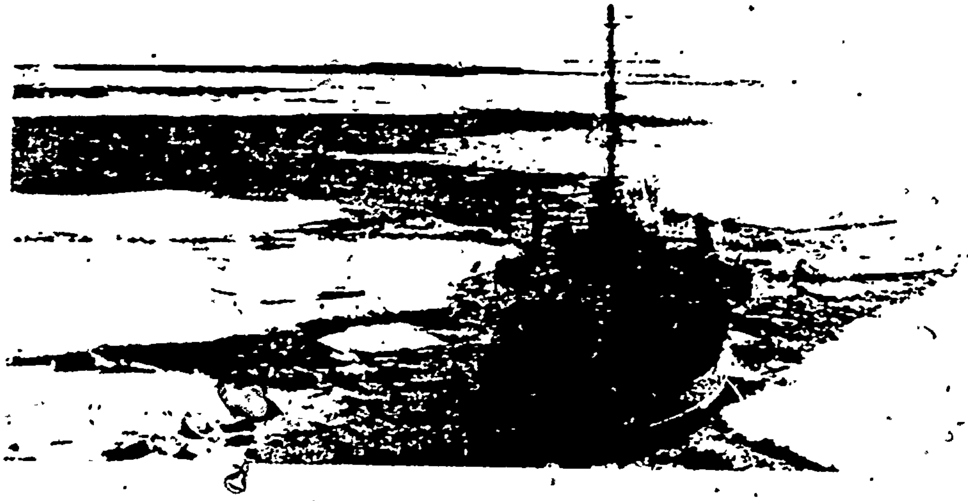

Figure 22.—Fracture and polynyas in sea ice.

Any strip of open of ice-free coastal water is called a coastal lead. This lead may be caused by offshore winds, inflow of warm river water, or rapid warming of shallow basins in spring. Strong offshore winds are more effective in creating coastal leads than prolonged light winds. During the cold months, coastal leads rapidly ice over when the wind abates. Onshore winds generally seal all coastal leads with large amounts of drift ice that sometimes fuse to the remaining fast ice and give it a rough outer boundary.

Land Ice

Ice of land origin, glacier ice, is composed initially of large accumulations of compacted snow that have reached the sea as coastal glaciers and ice shelves. Icebergs of various sizes and shapes break off (calve) from the fronts of these glaciers and drift away with the sea currents. Since 86 percent of the world's glaciers occur in Antarctica, most icebergs originate around that continent. Numerous coastal glaciers, some protruding seaward as much as 85 miles, pour large amounts of ice into the surrounding ocean.

Greenland, where most of the remainder of the world's glaciers are located, constitutes the main source of icebergs in the Northern Hemisphere (about 90 percent). Although many icebergs are calved along the east coast of Greenland, the principal source region is along the west coast, where nearly 70 percent of Greenland's icebergs originate near 68° north latitude in the vicinity of Disko Bugt. The icebergs generally do not drift very far from their source; consequently, most of them are confined to the Baffin Bay, Davis Strait, and Labrador Sea areas. As many as 95 percent of all of Greenland's icebergs become trapped in bays and shallow water before reaching 46°N; a relatively small number reach farther south.

Figure 23.— Aerial view of pack ice.

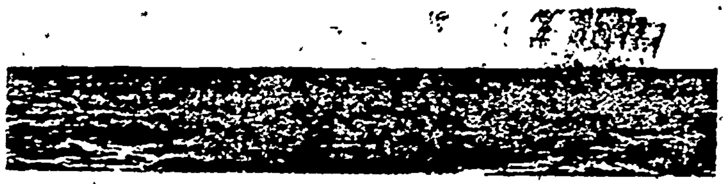

Figure 24.—A tabular iceberg.

In the Arctic Ocean, icebergs are relatively rare and are generally confined to the immediate vicinity of the glacier-bearing islands. On rare occasions, icebergs from Severnaya Zemlya have appeared along the eastern shore of Paluostrov Taymyr Peninsula. Because of the restricted extent of the island glaciers, bergs calved in the Arctic are small. Svalbard icebergs, for example, never exceed a height of 20 meters. Small icebergs are also calved in the passages of South Alaska but melt before entering the Bering Sea and northeast Pacific Ocean.

Nearly half of the icebergs in the Southern Hemisphere are tabular, a result of the extensive areas of shelf ice that surround Antarctica. (See figure 24.) Conversely, most Northern Hemisphere icebergs are irregularly shaped. (See figure 25.) However, the tabular ice islands of the Arctic originate in the ice shelf of northern Ellesmere Island and northern Greenland.

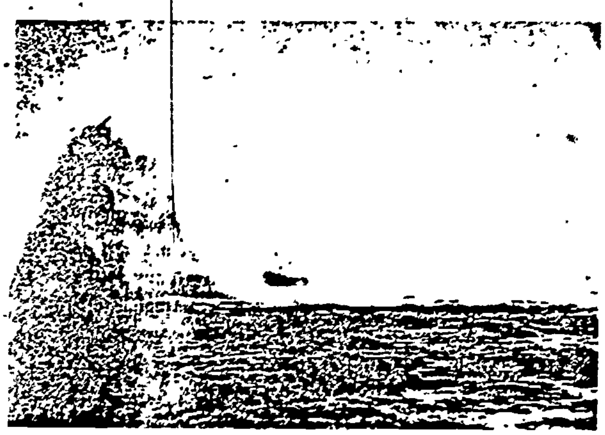

Figure 25 — USCG Achushnet (WAGO 167) on International Ice Patrol, 1950.

Icebergs originating in Greenland average 70 meters in height and 280 to 450 meters in length when first formed. The largest ones may exceed 120 meters in height and several miles in length. However, as they drift away from their region of origin, they decrease in size under the effects of melting and erosion. The height frequency of icebergs observed in Baffin Bay and Davis Strait during the period between 1946 and 1955 showed that 30 percent of the bergs observed were between 15 and 30 meters in height while only 1.4 percent were 120 meters or more in height. (See table 5.)

| HEIGHT IN METERS | PERCENTAGE |
|---|---|
| 15 to 30 | 29.6 |
| 31 to 60 | 50.7 |
| 61 to 90 | 15.5 |
| 91 to 120 | 2.8 |
| 120 or greater | 1.4 |

Table 5.— The height frequency of icebergs observed in Baffin Bay and Davis Strait during the years 1946 to 1955.

South of Newfoundland, the highest berg ever observed was 80 meters and the longest was 520 meters. Ice islands, though relatively low in height, have a total thickness of as much as 75 meters and may be as long as 20 miles. Icebergs originating in other parts of the Northern Hemisphere are rarely as high as 20 meters.

The tabular icebergs of the Southern Hemisphere, which average a height of 30 to 40 meters, sometimes reach a height of 100 meters, but their horizontal dimensions may greatly surpass those of the Northern Hemisphere. For example, one iceberg observed near Scott Island in 1956 measured 60 by 208 miles. The irregular and dome-shaped icebergs af Antarctica may exceed 450 meters in height.

The visible height of icebergs is dependent upon the shape of the berg and the density difference between sea water and ice. Sea water with a temperature of -1°C and 35 o/oo will produce a water density condition that will allow nearly 90 percent of the ice mass to remain submerged. The type of berg will determine the height of the ice mass that is visible. In the case of the tabular berg, the depth below the surface is about seven times the height above the water line. In the case of the pinnacle or irregularly shaped berg, the depth averages about five times that portion that is above the water line.

Ice islands are a rare form of floating ice which originally broke away from the shelf ice of northern Ellesmere Island and Greenland. These massive slabs of ice, which may be as thick as 75 meters and as extensive as 300 square miles, may drift for many years in the arctic pack, often completing several loops around the Arctic Basin before finally breaking up or escaping through the many passages of the Western Hemisphere.

Because of their deep draft, ice islands respond primarily to subsurface currents. As a result, they usually move more slowly than the surrounding sea ice, at an average speed of slightly more than 1 nautical mile per day.

Underwater Sound Velocity

The direction that a sound wave will travel in the ocean is largely dependent upon the speed of the individual sound wave or ray within the beam. The speed of sound in sea water depends on the temperature and composition of the water. In general these quantities vary both horizontally and vertically, but only temperature is of any great significance. Changes in velocity with depth (even slight ones due to warming of the surface water on a bright, calm day) deflect the sound beam from the desired straight path and may cause it to overshoot or undershoot an object.

The velocity of sound is directly proportional to the temperature of the medium (See figure 26.) The velocity of sound in air is 331.5 meters per second at 0°C and increases 0.6 meters per second for each degree Celsius increase in temperature. In sea water of 35 o/oo at 0°C, the velocity of sound is 1449.1 meters per second or 4.4 times the speed of sound in air. The increase in velocity per temperature change is greater at lower temperature. The velocity will increase by 41.1 m/sec if the temperature of the sea water is increased to 10°C and 72.8 m/sec if the temperature of the sea water is increased to 20°C.

The pressure and salinity affect the velocity of sound, but to a lesser degree than the temperature effect. As the depth or pressure increases so

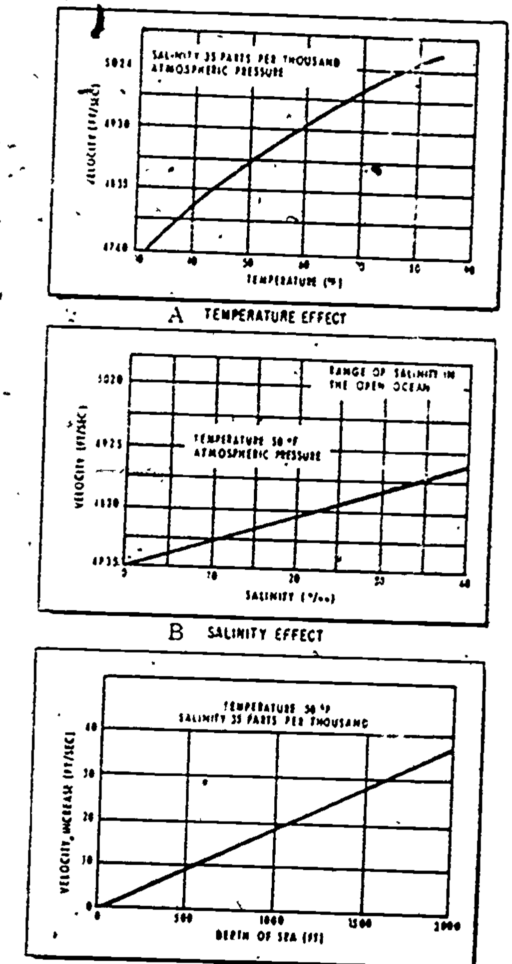


Figure 26.—Effect of temperature, salinity, and pressure on the speed of sound in sea water.

does the sound velocity. An increase in salinity will also increase the sound velocity.

In echo ranging work, in which only the upper few hundred feet of water are involved, temperature is generally the most important factor causing variations in sound velocity. Salinity is relatively uniform in the open ocean and therefore is of minor importance in determining sound velocity. Furthermore, in layers where vertical salinity gradients exist, there is nearly always a vertical temperature gradient. (See figure 27.)

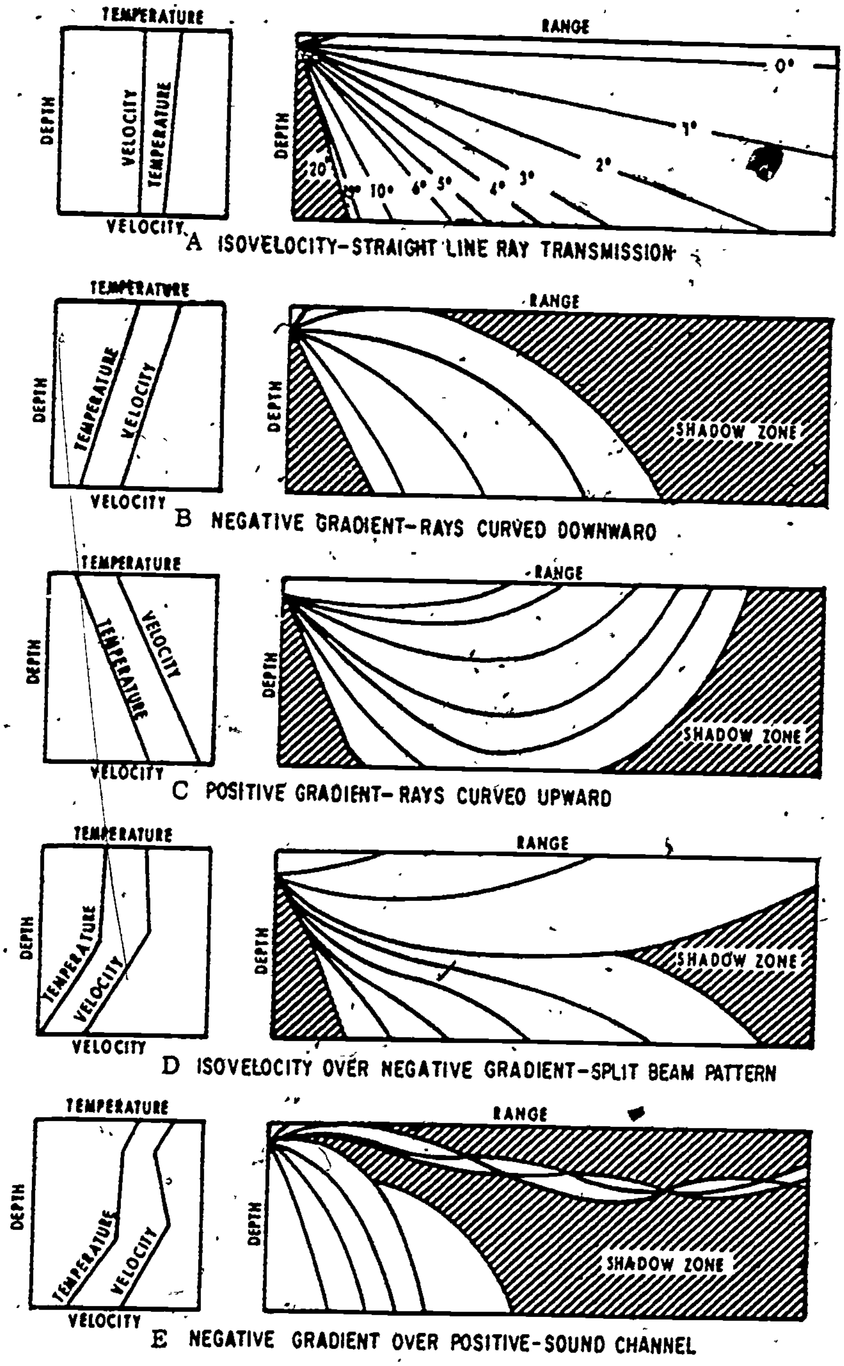


Figure 27.— Representative sound patterns based on temperature gradient.

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In sound transmission the vertical velocity gradient is more important than the velocity itself, since it is the change in velocity with depth that determines how much refraction will take place. (See figure 27.) The velocity gradient is readily determined from the gradients of salinity and temperature. The salinity gradient is defined as the rate of change of salinity with depth, in parts per thousand per meter. The temperature gradient is the rate of change of temperature with depth, in degrees Celsius per meter. These gradients are therefore called positive if the quantity in question increases with depth; negative if it decreases. In the majority of cases, temperature gradients in the sea are zero or negative. Moreover, except in certain localized areas, temperature gradients control the sound velocity gradients.

With a zero gradient in temperature (mixed layer), echo ranges are long because the sound rays are very nearly straight, having only a slight upward curvature due to the pressure effect. On the other hand, with a strong negative gradient near the surface, echo ranges will be short because the sound beam is refracted sharply downward. In the ocean it is common to find a mixed layer overlying a negative temperature gradient. In such cases the echo range on an object in the mixed layer will be long, but the part of the sound beam that enters the negative gradient will be refracted downward, resulting in reduction of range.

There are two phenomena which may cause reduction of range by refraction. With a strong negative temperature gradient from the surface downward, each ray of the sound beam curves down in a great arc, and beyond the horizontal limits of the beam is a so-called shadow zone into which no sound penetrates other than by scattering. An echo ranging vessel will not be able to detect an object in the shadow zone, but as soon as the latter comes within the direct beam, the echoes will come in loud and clear.

With slighter negative temperature gradients and generally with any gradient underlying a mixed layer, the shadow zone is not very clearly defined.

An object in the negative gradient beneath a mixed layer may be within the direct beam but still be undetectable because the echoes are too weak to be heard against the background of reverberation and ship's noise. This is known as the "layer effect."

Among the many factors affecting the transmission of sound under water, the following are considered to be particularly important: (1) reflection (2) refraction (3) reverberation, and (4) attenuation.

Reflection — Sound energy striking some solid surface may be reflected as a mirror reflects light with little loss of intensity, may be scattered in many directions, or may be lost by absorption into the medium.

The surface of the sea is rarely smooth; therefore, sound energy striking it is seldom relfected specularly (mirror reflection). Instead, only minute elements of the sea surface reflect sound as a mirror; however, because the orientation of each of these "mirrors" is changing continuously, the sound energy is reflected in many directions. Aside from the need for an accurate description of the sea surface, prediction of the reflective characteristics of the sea surface necessarily includes frequency of sound source and angle of incidence. (See figure 28.)

Because of the acoustic property differences between air and water, almost all sound energy is reflected at the air-sea interface. The fact that 99 percent of the sound energy in echo ranging is confined to the sea is important, because longer ranges than are predicted by ray diagrams are obtained and some portion of the sound energy is reflected back to the source as reverberation.

The ocean bottom also may reflect sound; however, the amount of sound energy reflected from the bottom depends upon the type of bottom material. A smooth sand bottom reflects sound very effectively. In contrast, a soft mud bottom is an especially poor reflector.

A smooth rock bottom is perhaps the best reflector because the amount of energy absorbed is small. Unfortunately, in many areas rock bottoms are irregular and consequently reflect sound in many directions. Much of this energy is scattered back to the sound source, causing intense reverberation which effectively masks any possible return signal. Nevertheless, if bottom properties are conductive to reflection and if refraction is favorable, long ranges are possible.

Obviously bottom reflection is most effective over reasonably flat bottoms. When echo ranging

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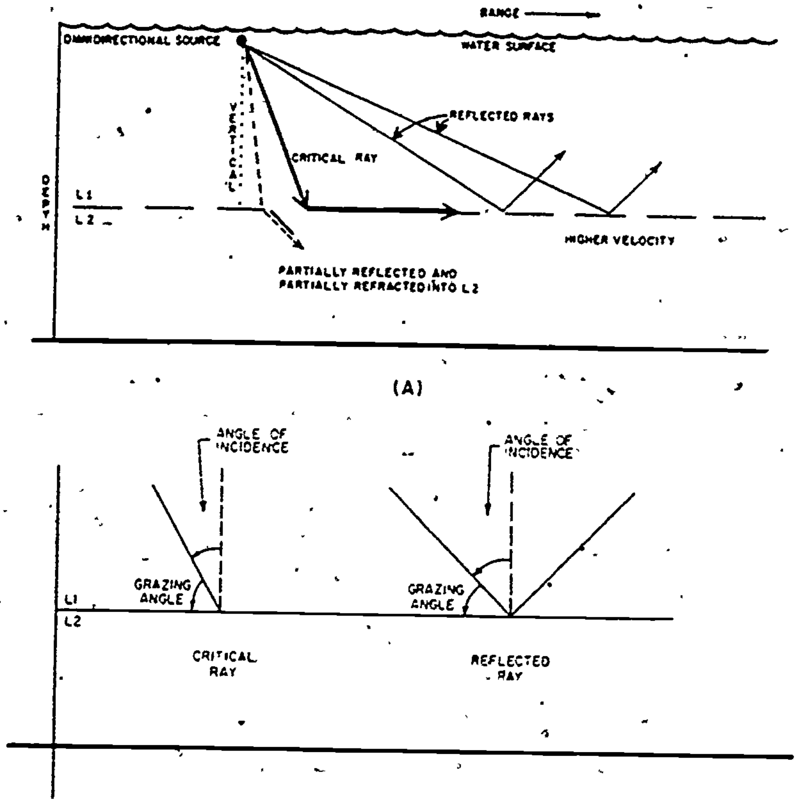
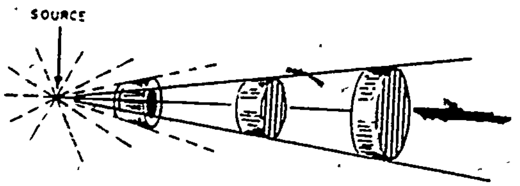
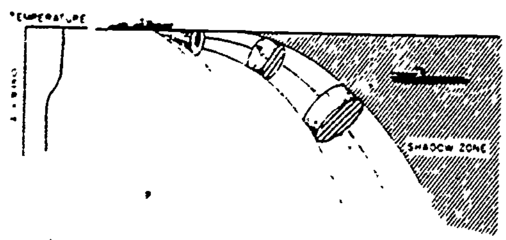



Figure 28.—Sound ray reflective characteristics. (A) Sound ray passing from a layer of one velocity to a second layer of a higher velocity; (B) diagrammatic depiction of sound ray transmission depicting an angle of incidence and a grazing angle.




A.—Diagrammatic drawing of outgoing ping showing shape of beam pattern and divergence of sound rays.




B.— Diagrammatic drawing of outgoing ping showing effect of refraction.

Figure 29.— Some characteristics of sound during travel.

occurs over hummocky or steeply sloping bottoms, ranges are adversely affected. For example, a submarine might hover behind a rise on the bottom where little if any sound energy could reach it.

Refraction — Variations in the temperature and salinity of sea water can profoundly affect sound transmission because they produce variation in the speed of sound as it travels from one point to another. This, in turn, causes refraction of sound waves. This phenomenon led to the development of the bathythermograph (BT) and accompanying prediction methods as instruments of naval warfare. (See figure 29.)

Sound waves travel in straight lines only in a medium in which the speed is everywhere constant.

(See figure 27.) In sea water the speed of sound generally varies with depth. Suppose, for example, the speed increases with depth. In that case every ray of the sound beam will be curved toward the surface. The more rapid the change of speed with depth, the more strongly the rays will be curved. This bending of the sound rays is refraction.

Reverberation — When a sound pulse is emitted in the ocean, the echo from an object may be masked by interfering or unwanted sounds. This background of interference is caused by reverberation and background noise. Reverberation is distinguished from background noise in that reverberation results directly from the emitted sound pulse.

If the surface and bottom of the ocean were absolutely smooth and no suspended matter (including fish) were in the water, there would be no reverberation. However, irregularities in the ocean surface, bottom, and water are capable of scattering the sound pulse and echoes. That portion of the scattered sound which returns to the transducer is called reverberation. The intensity with which reverberation occurs is directly proportional to the source intensity and ping length. Thus, increased sound output results in increased reverberation; a long ping length causes more reverberation than a short one.

Attenuation — Sound energy propagated through a volume of sea water undergoes some loss of energy because of attenuation, that is, absorption and scattering. In the passage of sound through water, some of the energy is converted into heat; this is call absorption. Scattering loss results from reflectors in the water that may vary in size from minute air bubbles to a whale.

Absorption results due to the fact that as a sound wave passes through the sea it is accompanied by successive compressions and expansions of the medium, which produce some frictional heat loss from the sound wave as well as heat loss produced by the dissociation of dissolved salts in sea water.

Although scattering is a component in the attenuation of sound, its contribution is not as important as that of absorption. When sound rays in deep ocean areas strike reflectors such as bubbles, fish, and suspended matter, the rays are deflected and small amounts of sound energy are scattered in many directions. The part of the scattered ray returned to the receiver is known as reverberation: the part not returned is lost energy.

Sea ice effectively scatters sound beams, especially when the underwater profile of the ice is uneven, as in hummocky ice fields and with ice containing numerous air bubbles. In ice fields the low frequencies (subsonic) appear to be transmitted most effectively, owing to the higher rate of absorption of the higher frequencies, particularly ultrasonic frequencies.

Ambient sea noise is the general continuous spectrum of noise which is found naturally in the sea. (See figure 30.) Since ambient sea noise comes from all directions, the noise effect relative to an object may be decreased by improving the ability to direct the sound beam and listening device.

A sound channel is produced under conditions of temperature, salinity, and depth in such a manner that a minimum velocity for sound is trapped between areas above and below with higher sound velocities. These differences in velocity cause a sound wave to be refracted from above and below in such a manner that the sound waves will travel for great distances at velocity minimums for that layer of water. (See figure 31.)

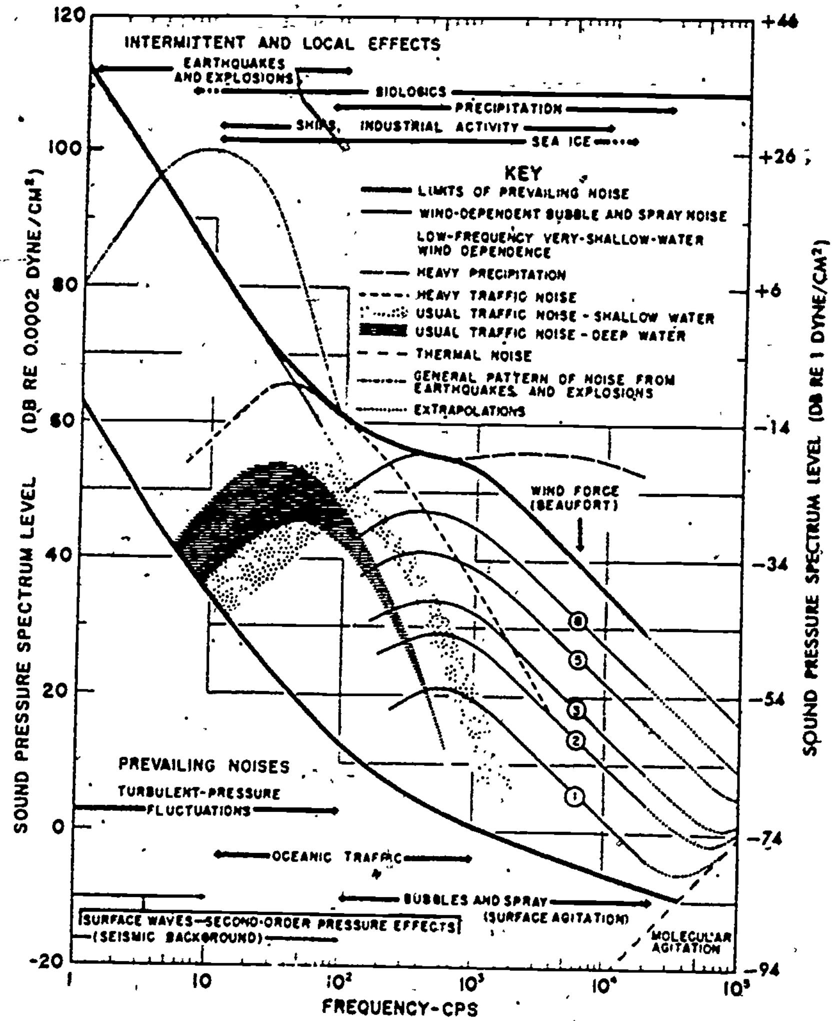



Figure 30.— A summary of ambient noise sources.

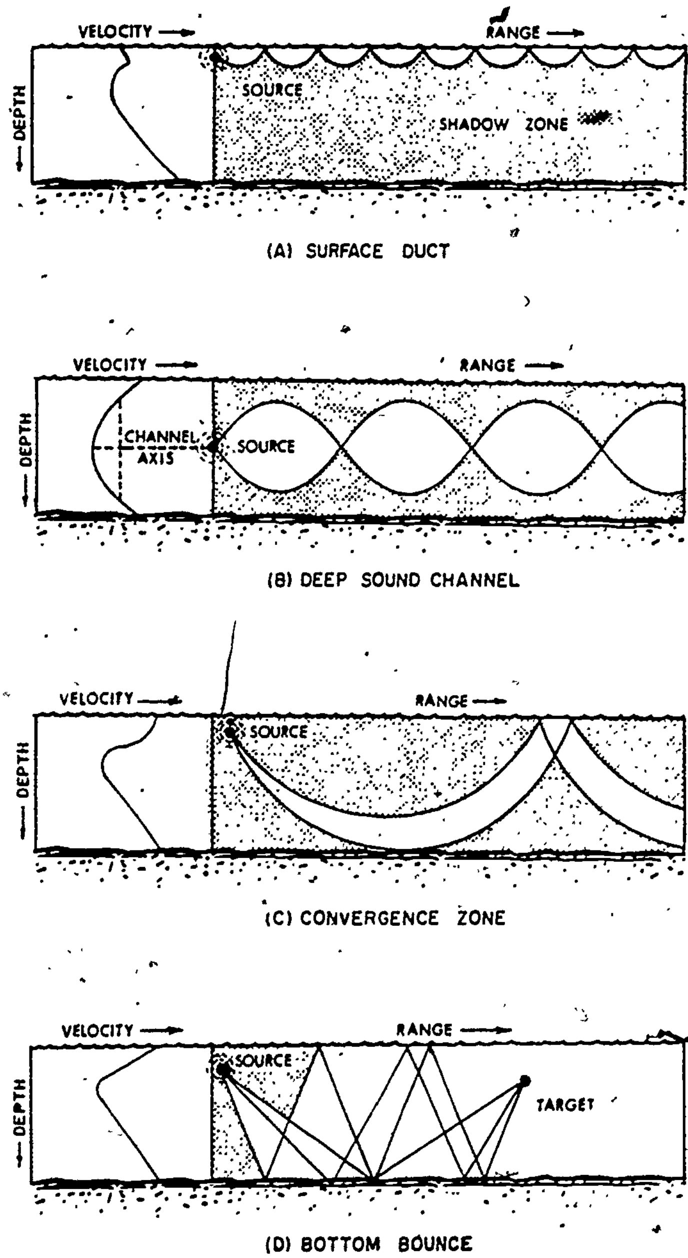



Figure 31.—Sound transmission paths. (A) Surface duct; (B) deep sound channel; (C) convergence zone; (D) bottom bounce.

# MARINE BIOLOGY

Sea water has all of the chemical elements needed to sustain plant and animal life. Because of this and the fact that the oceans contain about 300 times as much space for the existence of life as is available on land and in fresh water, organic material is present in vast quantities.

The infinite forms of marine organisms are classified and grouped in a number of ways. The universally recognized system is a classification according to structural, functional, and reproductive relationships and degree of individuality. The following is an example of the principal subdivisions by which a common marine animal, the edible mussel, is classified:

Kingdom — Animal

Phylum — Mollusca (snails, bivalves, chitons, squids, and octopuses)

Class — Pelecypoda (clams, oysters, mussels, and their relatives)

Order — Prinodesmacca (the more primitive Pelecypoda)

Family — Mytilidae (the mussels)

Genus — Mytilus (a mussel)

Species — edulis (edible)

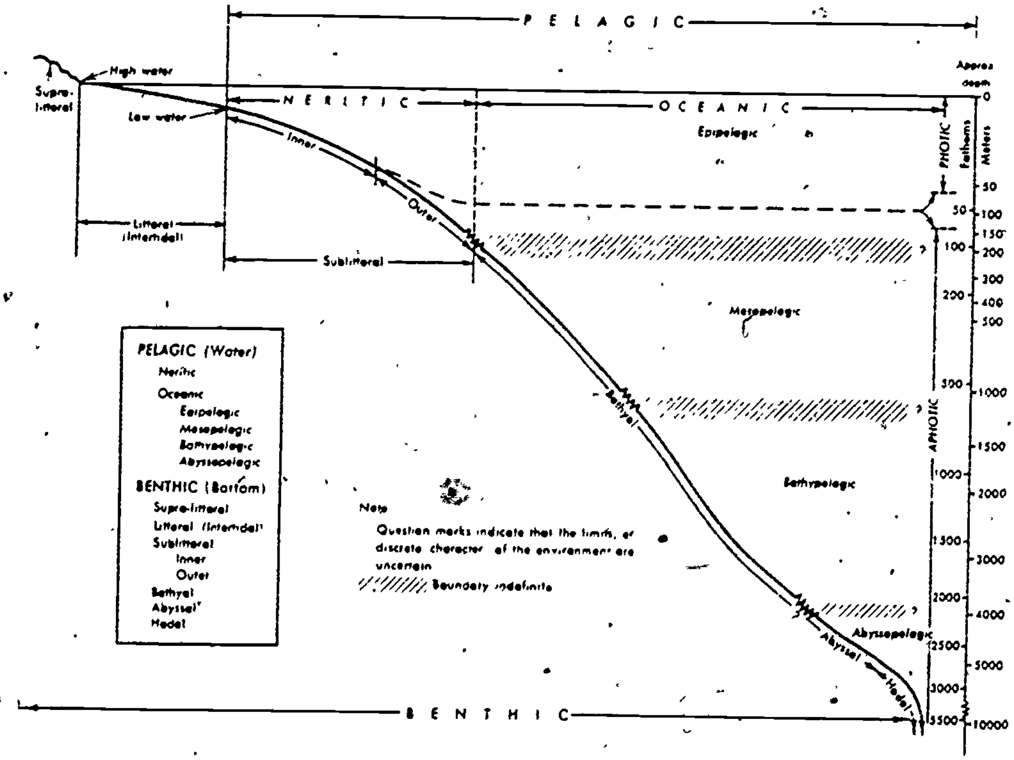
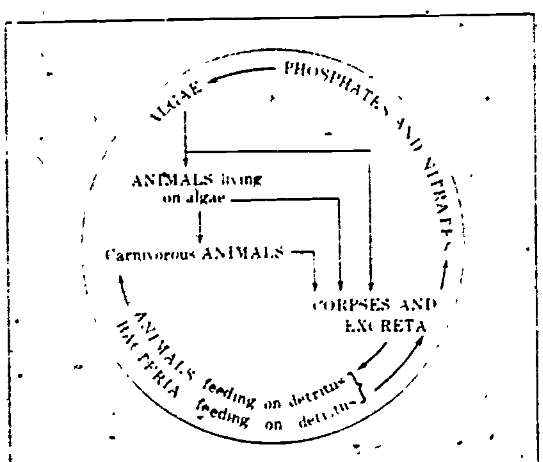



Figure 32.— Classification of Marine Environments.

Other systems group organisms by other sets of characteristics. One, commonly used, divides all marine life into three categories based upon habits of locomotion, mode of life, and environmental distribution, as follows: (1) Nekton — the swimming animals living in the pelagic (oceanic) environment, (2) Benthos - the attached, creeping, and burrowing organisms living at the bottom of the sea, and (3) Plankton — all of the floating or drifting life in the pelagic environment. Plankton may be divided into: (a) the phytoplankton, consisting of microscopic floating plants, and (b) zooplankton, consisting of feebly-swimming or floating animals. Most plankton vary in size from microscopic units to those a small fraction of an inch in length.

Most organic material in the sea is in the form of plankton that does not have sufficient strength to choose its environment and is at the mercy of the prevailing ocean currents. Either directly or indirectly, nearly all marine life depends upon these organisms. By means of photosynthesis, a process using sunlight, phytoplankton change chemical nutrients (silicates, nitrates, and phosphates) in the sea into primary food which is used by the zooplankton and, to some extent, by larger animals. However, most of the larger animals feed upon the zooplankton. The chemical nutrients are replaced by the excretion of animals and bacterial action in the decomposition of dead plants and animals. Thus, a food cycle is continually going on from chemical nutrient to phytoplankton to zooplankton to nekton and benthos to chemical nutrients. (See figure 33.)




SEA LIFE CIRCUIT

Figure 33.— An example of the Oceanic life cycle.

The growth of phytoplankton requires both sunlight and a supply of chemical nutrients. Sunlight in sufficient strength to permit photosynthesis penetrates to a maximum depth of about 100 meters or less. This upper layer in which the process occurs is called the euphotic zone. Within this zone, photosynthesis is limited primarily by the supply of chemical nutrients. Under favorable conditions, phytoplankton may increase by as much as 300 percent in a single day.

The abundance of marine life is directly related to the supply of phytoplankton. In shallow water, the chemical nutrients on the bottom are stirred up by motion of the water, and carried into the euphotic zone. This is why an area such as the Grand Banks is a good fishing ground. In polar regions the chemical nutrients are relatively abundant, being brought to the surface by convective currents as the cold surface water sinks and is replaced by the warmer water from the bottom. In the tropics, on the other hand, the sea is relatively stable, and the chemical nutrients have a tendency to sink below the euphotic zone. Even though the clear, blue water has the deepest euphotic zone, photosynthesis proceeds at a slow rate. For this reason, blue is sometimes called the "desert color of the sea."

Ocean currents and marine life are so interrelated that currents can sometimes be traced by their supply of plankton. In general, the oceanic circulation helps sustain marine life by stirring up the chemical nutrients and carrying them, or the plankton formed from them, into regions which have an inadequate supply. However, the reverse effect can occur. A notable example occurs from time to time off the west coast of South America. At varying intervals averaging about 12 years, a well-developed stream of tropical water having a relatively small supply of chemical nutrients and plankton flows southward, close to the shore. This water replaces the colder water which is rich in chemical nutrients and plankton. The result is a wholesale destruction of fish which cannot obtain a sufficient supply of food. In some areas the dead fish are washed ashore in such quantities as to constitute a serious problem. With the destruction of so many fish, the supply of guano (manure of sea birds) also decreases because of the death of large numbers of the birds which depend upon the fish for their food supply. Since this phenomenon commonly occurs near Christmas, it is called "El Niño." A strong current such as the Gulf Stream annually carries many fish to their deaths by transporting them from their normally warm habitat to areas where they encounter water which is too cold for them to endure.

## FOULING AND DETERIORATION

Among the many important problems associated with marine biology, none has greater economic significance than the control of marine fouling and deterioration. As a Marine Science Technician, you are probably well acquainted with the costly effects of marine growth on ships' hulls and salt water intakes. (See figure 34.) An equally important problem is the damage of shore installations resulting from the penetration of wood, plastics, concrete, and other structurally important materials by several marine organisms. It has been conservatively estimated that the annual cost to the Navy alone for the protection and maintenance of ships, waterfront structures, and offshore equipment against biological deterioration and fouling is approximately $100,000,000. Far more importantly, however, uncontrolled fouling and deterioration by marine organisms can effectively reduce the combat readiness of naval ships and shore facilities.

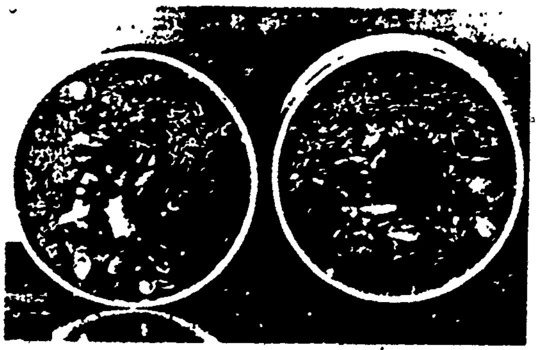


Figure 34.— A section of 6-inch pipe removed from a ship, indicating the results of marine-fouling growth.

The fouling of ships' hulls is, of course, an age-old problem. Man's historic efforts to discourage marine growth has resulted in the development of chemical agents, which today can protect hull surfaces for as long as 24 months. The problem is far from solved, however, because the development and use of submerged equipments vital to oceanic operations and technological progress constantly introduce new requirements for enduring antifouling agents.

The biological fouling of a sonar transducer can seriously impair the transducer's effectiveness by attenuating sound transmission. In certain areas of the world, critical fouling of unprotected surfaces can occur within a few months, rendering sonars unfit for research or ASW operations. Some success in developing reliable protective coatings for sonar domes has been realized, but the problem is complicated by the requirement that the agent used must not alter the equipment's acoustic properties.

The growing use of underwater optical instruments presents further complications. Complete fouling of an underwater television lens can be accomplished in an incredibly short period of time. Obviously, the lens cannot be painted with antifouling paint, as in the case of a ship's hull. The development of durable but transparent protective coatings is a necessary preliminary to the planned installation of submerged optical equipment such as television monitoring stations.

Moreover, the proposed construction of large, stationary structures in relatively deep ocean waters for various military and commercial projects creates additional fouling problems. Already, the underwater structures used in the recovery of offshore petroleum are approaching deeper waters. Because of the size and permanency of proposed structures, frequent maintenance will be impractical, if not impossible. Therefore, antifouling agents of enduring effectiveness must be developed. However, little field data is available at the present time to warrant the assumption that deep-ocean fouling will not differ from that occurring in shallow coastal waters. For this reason, far more data must be obtained about the ecology of fouling organisms in the deep sea before reliable fouling deterrents can be developed.

Deterioration of submerged installations by marine organisms is another serious threat to present and proposed marine operations. Extensive destruction is caused by species of Limmoria, or gribbles. (See figure 35.) These animals are related to the shrimp and lobster and are worldwide in distribution. They are normally found attacking the surface of submerged piling and other wooden structures in shallow water, but materials other than wood, such as the gutta-percha insulation of submarine cables in depths up to 110 meters, have been penetrated by gribbles. Other crustaceans burrow into, and consequently weaken, stone seawalls. (See figure 36.)

Figure 35.—Wood gribbles bore into a piling.

Figure 36.—Rock-boring bivalves, worms and sponges attack hard limestone

Certain mollusks, such as the well-known teredo, or "shipworm," which are relatives of the clam and oyster, attack submerged wooden structures in harbors, or burrow into rocks and coral. Mollusks are also responsible for destructive attacks on gutta-percha insulation of cables at depths ranging from a few feet to 2,200 meters, causing physical damage and short circuits. Others have been found to penetrate solid lead sheathing of submarine power cables. Even concrete is not immune to destructive attacks by these creatures.

Marine bacteria play a surprisingly important role in the deterioration and fouling of materials and equipment in sea water and marine sediments. These micro-organisms accomplish their destruction in a number of ways. By forming over antifouling agents, to which they are apparently immune, they provide a foothold for barnacles and other fouling animals. Cellulose-decomposing bacteria cause millions of dollars worth of damage to net cordage, seines, and lines used by commercial fisherman. Also present in the sea are cellulose-consuming fungi which infest natural fibers and woods. Rubber products such as hoses or gaskets, generally regarded as ~~being~~ impregnable, have been found to be decomposed by the action of marine bacteria. Sulfate-reducing bacteria have been associated with the accelerated corrosion of submerged metals. Here again, the problem of protecting deeply submerged materials from the ravages of these organisms is complicated by the fact that some bacteria actually thrive in deeper water, reproducing only when subject to great pressures.

Even the color of materials used in underwater installations has an influence on the attacks by marine fish. Attracted by the white color of polyethylene insulation of marine cables, certain fish cause extensive damage by nibbling on the insulation. Biologists have suggested a less attractive insulation color in order to reduce such attacks.

To meet the requirements for solving the problems of deterioration and fouling, biologists must better understand the vital processes which govern the life cycles and behavior of the offending organisms. Adequate knowledge of such processes should lead to the discovery of an inherent weakness in each organism which is susceptible to external control.

BIOLUMINESCENCE

A biological phenomenon well known to mariners is the relatively common yet curious sight of luminescence in the sea. Although luminescence was first believed to be caused by the presence of phosphorus within the water, for almost two centuries it has been known to be biologically induced. In its most familiar form, luminescence is observed as a bluish-green fluorescent glow in waters disturbed by bow waves and wakes and by cresting waves. Luminescent displays occasionally attain more spectacular proportions, however, forming parallel bars, or "wheel spokes," of pulsating light extending from horizon to horizon. Sometimes the wheel spokes appear to rotate like a giant pinwheel.

A simplified version of the occurrence is that tiny plants and animals, some even microscopic, exist in the near-surface regions of the sea in countless numbers and react to various stimuli by emitting light. The light emitting properties of many of these organisms permit them to alternate, or flash, their light in a manner similar to the common firefly. In most

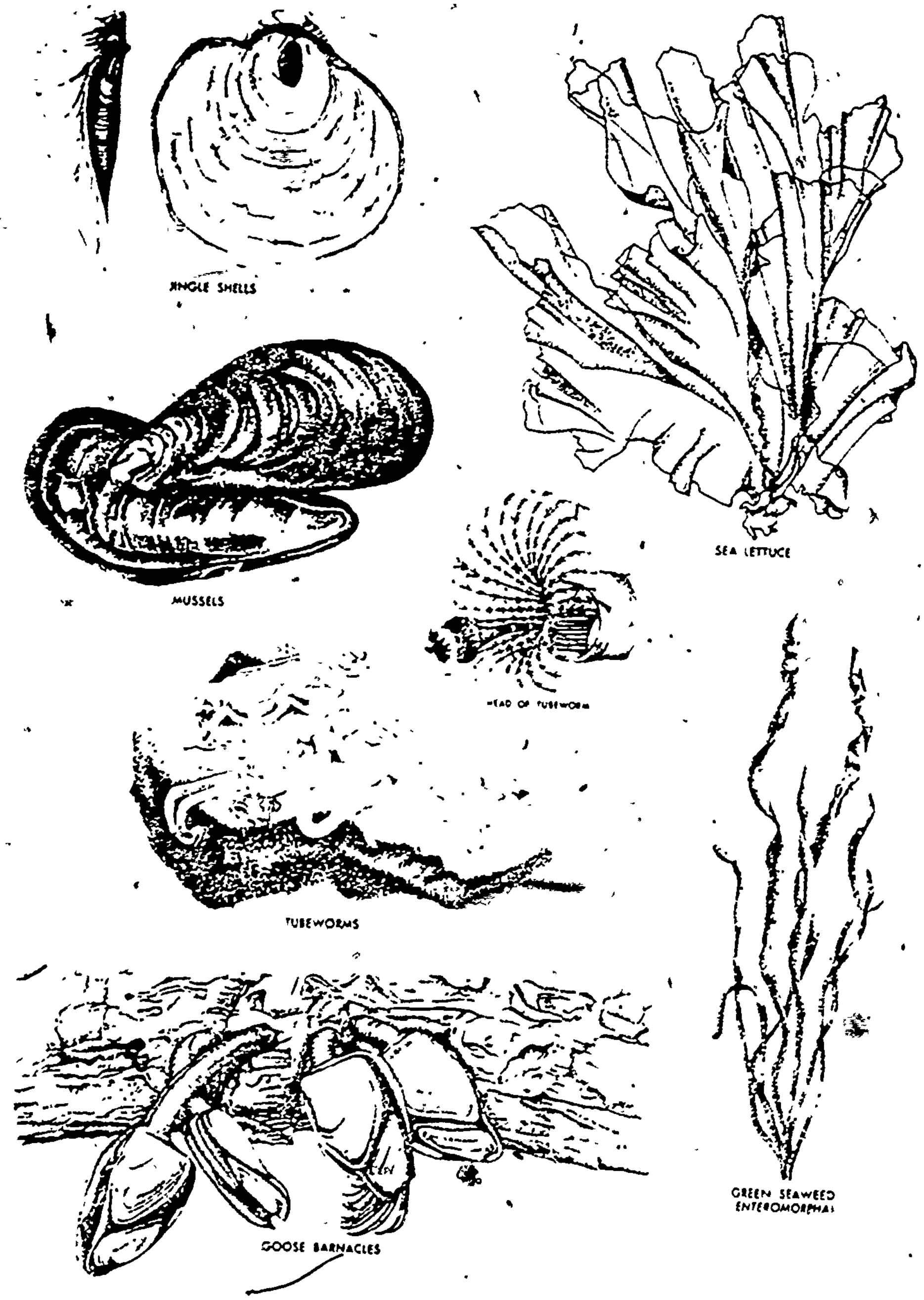



Figure 37.—Typical examples of some of the more common fouling organisms.

cases, the rhythm of flashing depends upon the kind of stimulation introduced. Some of the lowly dinoflagellata, a group of single-celled organisms strangely cast on the borderline between plants and animals, are known to possess a luminescent characteristic. Since they abound in the upper portions of the oceans, dinoflagellata are among the better known organisms responsible for the luminescence observed by seafarers.

Because they often exist in huge concentrations, luminescent organisms are capable of producing an amazing amount of light. In certain geographic regions, agitation of the sea by the passage of a vessel at night produces enough illumination on deck to enable one to read. When the stimulation is passed through the organisms in waves, their rhythmic reaction may give the impression of a symmetrical swirling movement of light, thus creating the pinwheel illusion. The parallel bar effect occasionally observed is accounted for by the movement of the sea, which even under calm conditions, circulates vertically in such a way as to concentrate the organisms in horizontal streaks.

While surface displays are the most frequently observed, bioluminescence is not confined to the upper regions of the sea. Light-producing organisms have been found to exist at every depth. In the blackness of the abyssal depths, where sunlight never penetrates, the light produced by certain animals provides almost constant illumination, to the mutual benefit of themselves and others not so equipped. The fact that the latter creatures have well-developed eyes and are obviously dependent upon alien sources of light, is evidence of the close interrelation of these deep dwelling species. To fully understand the significance of luminescence in the ecology of marine life is a constantly expanding project for oceanographers.

To the casual observer, luminosity of sea water is but a harmless manifestation of natural wonder. In the conduct of naval operations, however, the phenomenon is viewed with a jaundiced eye. Observed from the air, or from the bridge of a large vessel, the luminous wake of a ship travelling at even moderate speeds can be detected for some distance, clearly revealing the position and, roughly, the direction and speed of the ship. During World War II amphibious landings and other naval movements were, on several occasions, compromised by the presence of bioluminescence. Consequently, another goal of the oceanographer is to eventually establish a pattern of reoccurrence in order to forecast the periods of luminescence in areas of projected naval operation.

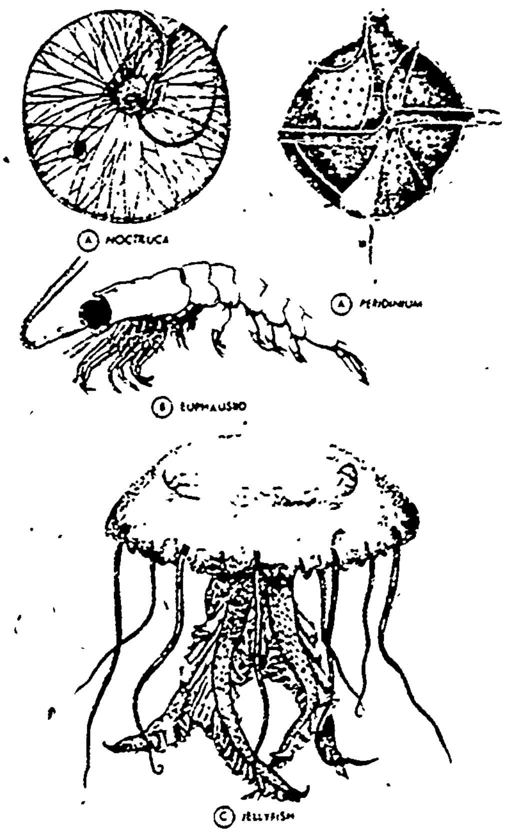



Figure 38.—Representative bioluminescent organisms.

## THE DEEP SCATTERING LAYERS

Another biological phenomenon which has gained increasing importance to both mariners and oceanographers during the last two decades is the sea's "deep scattering layers (D.S.L.s)." Briefly, these are the horizontal sound reflecting bands that exist at various depths over broad reaches of the world's ocean. Mariners today are probably quite familiar with the physical aspects of the D.S.L.s, which often produce "false bottoms" on the recording traces of echo-sounding devices. (See figure 39.) Indeed, it has been widely conjectured that misinterpreted "echograms" may have led to the charting of nonexistent shoals. Today, determination of the exact composition, behavior, and distribution of the layers is a continuing oceanographic project, for much more information is needed regarding their possible influence on sonar systems.

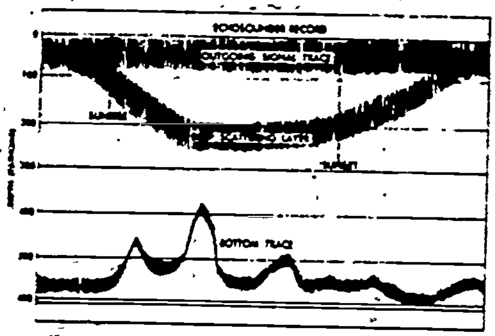



Figure 39.—Representation of the deep scattering layers (D.S.L.s).

Discovered by accident during World War II, the "layers" have a relatively brief but interesting history. A group of physicists experimenting with sonic submarine detection gear consistently, and annoyingly, recorded echoes from a uniform layer some distance above the sea's floor. During daylight hours an exceptionally well-defined layer was frequently observed at 300 to 350 meters. At night it disappeared. The feature could only be attributed to a suspended stratum of some sound reflecting, or scattering, agent and thus derived the name "deep scattering layer." The name was pluralized after subsequent experiments revealed the existence of multiple layers.

Soon after this initial discovery, a causative solution was sought in some physical property of the sea capable of producing the sonic reflection. To this end, attempts were made to correlate the phenomenon with density discontinuities, or abrupt temperature differences, in the sea. However, workers were unable to suggest any physical effect that would account for the layers' characteristic of ascending to the surface at sunset and descending to depth at sunrise.

Due to both the lack of any physical effect and the diurnal vertical migrations of certain marine animals, biologists postulate that the scattering layers are of biological origin. This theory has endured the test of time and is universally accepted today.

On the basis of this correlation and later field experiments, it was concluded that huge aggregations of tiny planktonic animals were reflecting some of the sonic impulses, or "pings," from sound apparatus. The animals, it was suggested, rose to the surface at nightfall to feed upon the abundant phytoplankton. At daybreak they would again seek the darkness of depth, either through the fear of predatation or their natural sensitivity to light. Further investigations have shown that during the day the layers remain at depths roughly between 210 and 730 meters. At night they rise almost to the surface and diffuse, or they may merge into a broad band as much as 150 meters thick. Most places in the deep ocean usually have three layers, the deepest at an average of 575 meters. Sometimes, sounding traces show very diffuse layers that stay at the same depth day and night.

From physical evidence as a result of sampling and bathyscaph observations, many researchers are of the opinion that shrimp-like crustaceans called euphausiids and sergestids are the reflecting agents in the layers. (See figure 38.) Others, however, argue that crustaceans rarely occur in sufficient densities to produce reflection layers. In rebuttal, the latter researchers suggest that fish and similar animals with swim bladders, or gas filled bubbles, are the causative agents. Quantities of myctophid, or lantern fish, 2- to 3-inch predators which feed upon crustaceans, have been collected in net tows to reinforce this contention. At least one observer has concluded that concentrations of tiny jelly fish equipped with gas-filled floats are a source of the scattering layers.

The complexity of the problem is indicated by the apparent likelihood that several agents are involved, for a single layer often "splinters" during vertical migration into as many as four separate elements. These elements never cross one another, each seeking a precise depth as though adjusted to a particular level of twilight. Because of this stratification, exact identification of each element is dependent upon the sampling devices' selectivity, which at present leaves much to be desired.

The inevitable development of improved sampling techniques and echo-sounding apparatus will, undoubtedly, resolve the problems of the deep scattering layers. But apart from the acoustical problems the layers present, biologists view the phenomenon as a valuable ecological tool for understanding the mass distribution of life within the sea.

NATURAL SEA NOISES

Marine animals contribute another source of acoustic interference. Contrary to the belief that the sea was a silent environment, many aquatic animals are now known to produce noises of widely varying nature. At times, concentrations of animal sound-emitters can set up a veritable clangor beneath the sea, and because of the diverse properties of air and water, little of it ever reaches the casual listener above the surface. Over hydrophones, however, these "fishy" noises can be plainly heard and recorded. While the sea's inhabitants are apparently well adjusted to this condition (having no other choice), such noises can have serious effects on naval operations.

The military implications of natural sea noises were not fully realized until World War II, when their intensity and worldwide distribution were recognized as limiting factors in antisubmarine operations. Early researchers found that hydrophone reception was decidedly hampered by the ambient noise level produced by animal sound-emitters. Some of the sounds are characteristic of surface and underwater craft. At least one organism, or group, produces a sound like an unrhythmic hammering on steel to the understandable dismay of a hydrophone operator.

Mindful of the obvious operational and psychological stress that the noises placed on ship's crews, the Navy initiated a program to record and identify them. The object of the program was to train operators of acoustic gear to discriminate between biological sounds and mechanical sounds and to possibly redesign equipment to filter out undesirable sounds.

The problem of identification is complicated by the fact that, over hydrophones, the sounds made by an individual animal may differ from the effect produced by a group. Thus, the croaker often makes a drumming sound, but the noise produced by a dense shoal of croakers has been described as resembling that of a pneumatic drill tearing up pavement. In some instances their chorus becomes so voluminous that it drowns out completely any ship or propeller noise. The snapping shrimp, an inedible variety smaller than a man's little finger, produces a sharp "snap" with its lobster-like claw, but the over-all noise created by a large number of such animals is a continuous crackling noise similar to radio static. (See figure 40.)

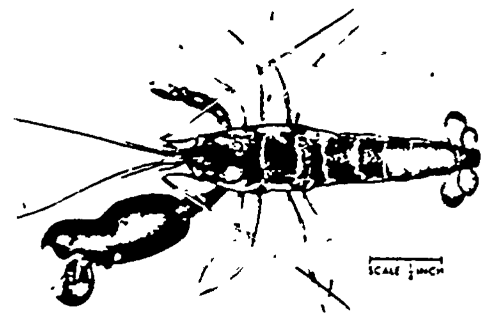


Figure 40.—Snapping shrimp.

In the effort to catalog marine-animal noises, workers found it necessary to correlate the sounds recorded with more familiar terrestrial ones. Today, it is known that porpoises and whales whistle, click, bark, and moan; barnacles slurp; black mussels crackle; toadfish croak, growl, and whistle; weakfish, silver perch, and spot perch produce a rapid, raspy croak; the Atlantic croaker, true to its name, makes a similar, almost drumming sound at a slower rate; the northern puffer or swellfish squeaks and coughs, among other noises; the striped barnfish coughs; and the striped sea robin makes a sound like fingernails being scraped over a drum. On the other hand, many fish have been found to be practically mute, such as the flounder and mullet.

The manner in which the organisms produce their sounds is fairly well known. Crustacea sounds are normally of the percussion variety, such as the claw-snapping of shrimp. The noises made by free-swimming fish are usually the product of their swim-bladder. This organ varies in form with the species of fish, and the type of sound emitted is a particular function of its size, shape, and the manner in which it is vibrated. Fish also produce rasping, scraping, grinding, or whining noises either by grinding their teeth or by rubbing their fins together.

The exact function of marine animal noises is still uncertain. They appear in some instances to be associated with breeding and spawning; in others, to be defensive and protective. It seems likely that sounds produced by at least some fish are used by them for spatial orientation in a manner similar to sonar. It has also been determined that some of the sounds made serve no useful purpose at all and in some cases even reveal the originator's presence to a lurking predator.

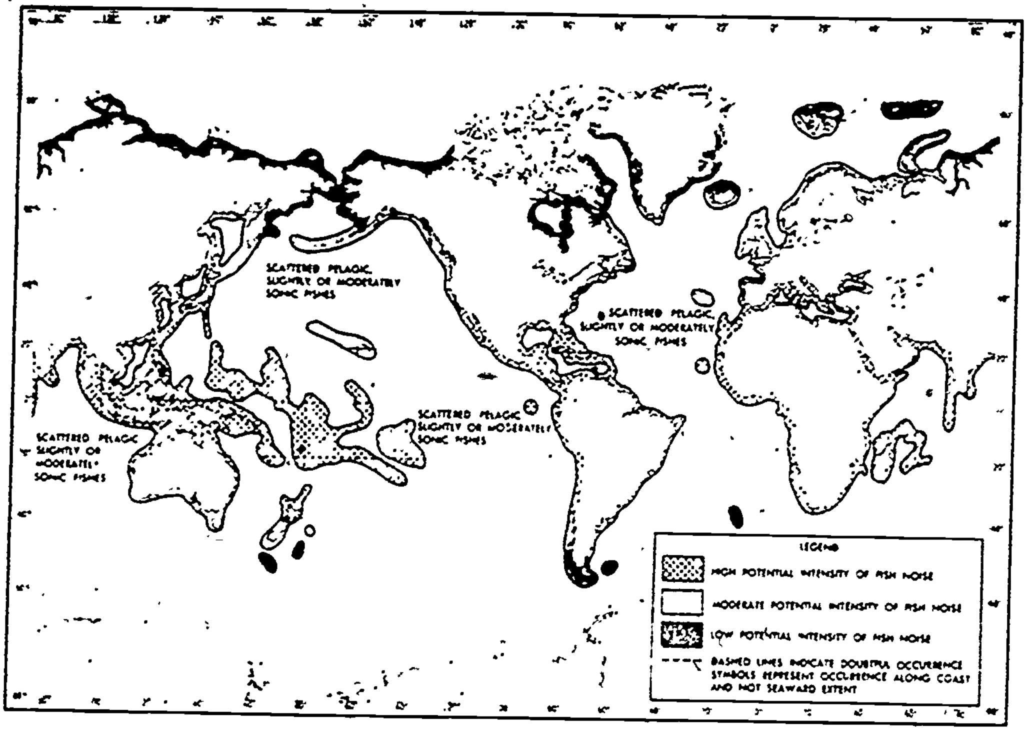



Figure 41. —Estimated distribution of fish noise based on the presence and abundance of sonic species and their sonic abilities.

Marine biologists are particularly interested in determining the exact biological significance of sounds and look upon the non-military use of hydrophones as a valuable oceanographic instrument. It is evident that if certain sounds are peculiar to certain animal groups, underwater listening could be used to plot the distribution of such animals. Moreover, by classifying the creature's various sounds, such as those made while spawning and feeding and those believed to be "emotional," biologists hope to broaden their understanding of the behavioral traits of marine animals.

## CORAL REEFS

Probably no branch of oceanography involves as many of the earth's sciences as the study of the origin and development of coral reefs. Primarily an active biological process, the building of a reef embraces geological, chemical, and physical processes, the extent of which varies with the location and type of formation under construction. While considerable work has been done in this field over the years, there remain wide gaps in knowledge which impede progress, particularly in the physiology and ecology of reef organisms.

Following World War II, a war fought in coral seas of which little was known, a marked intensification of coral reef investigation took place which has resulted in the acquisition of valuable biological data. The importance of continued research lies not only in the fact that the constantly growing reefs pose a serious threat to present and future marine operations, but improved harbor maintenance and the stabilization of many important islands may depend upon a better knowledge of coral formation. The studies are also important in expanding our knowledge of the general ecology of the sea, for as a reef develops, other organisms become adapted to the environment, thriving and contributing to a relatively "closed system" of existence.

The most important builder of a coral reef is a polyp, a creature very low on the scale of evolution. These animals cement themselves to an underwater platform and proceed to secrete an

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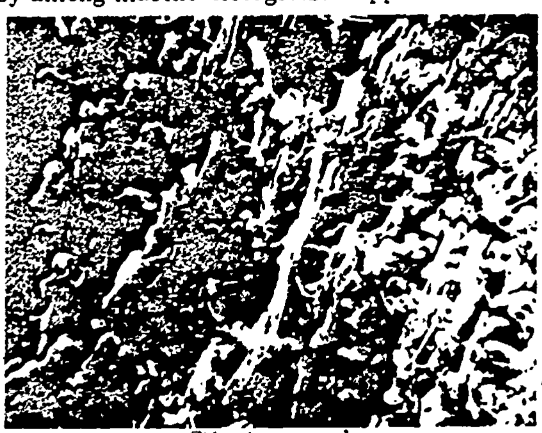
external layer, or skeleton, of calcium carbonate which, due to the shape of the young polyp, produces a stony limestone cup. As each polyp matures, it grows in size and complexity of structure, branching and multiplying to eventually form large masses of dense rock. At certain times of the year, the polyps reproduce their kind by releasing larva, which are carried by the currents to other sites, where, if suitable conditions of temperature and depth exist, a new reef is formed. It has been estimated that billions of tons of rock are thus created each year.

Corals are specialized carnivores, subsisting on tiny planktonic animals which they capture with their paralyzing tentacles. Typical reef-building corals characteristically contain within their tissues numerous algae cells which they are incapable of expelling. This symbiotic relationship between animal and plants contributes mutually to each other's well being, the exact significance of which is the subject of considerable controversy among marine biologists. It appears evident that the relationship is beneficial, at least to the host polyp, for the most vigorous coral growth occurs within the lighted depths, from 20 to 30 fathoms, apparently due to the fact that the contained algae, like all plants, require light for survival.

Coral growth is also dependent on other factors which include favorable temperature, salinity, and nutrient value of the surrounding water mass.

A secondary but integral part of reef construction are the various calcareous algae which grow upon the reef. In the course of time, these stony plants have a mortise-like effect upon the environment that binds the reef mass together, contributing to its over-all strength.

Coral reefs are constantly subject to various forces that can damage or weaken them. Erosion from the constant battering of the sea can eventually cause massive breakage, and the deposition of sediments on living coral beds results

A

Stinging coral

C

A bed of both calcareous and stony coral

B

Elkhorn coral

D

Common sea coral

Figure 42.— Representative coral forms.

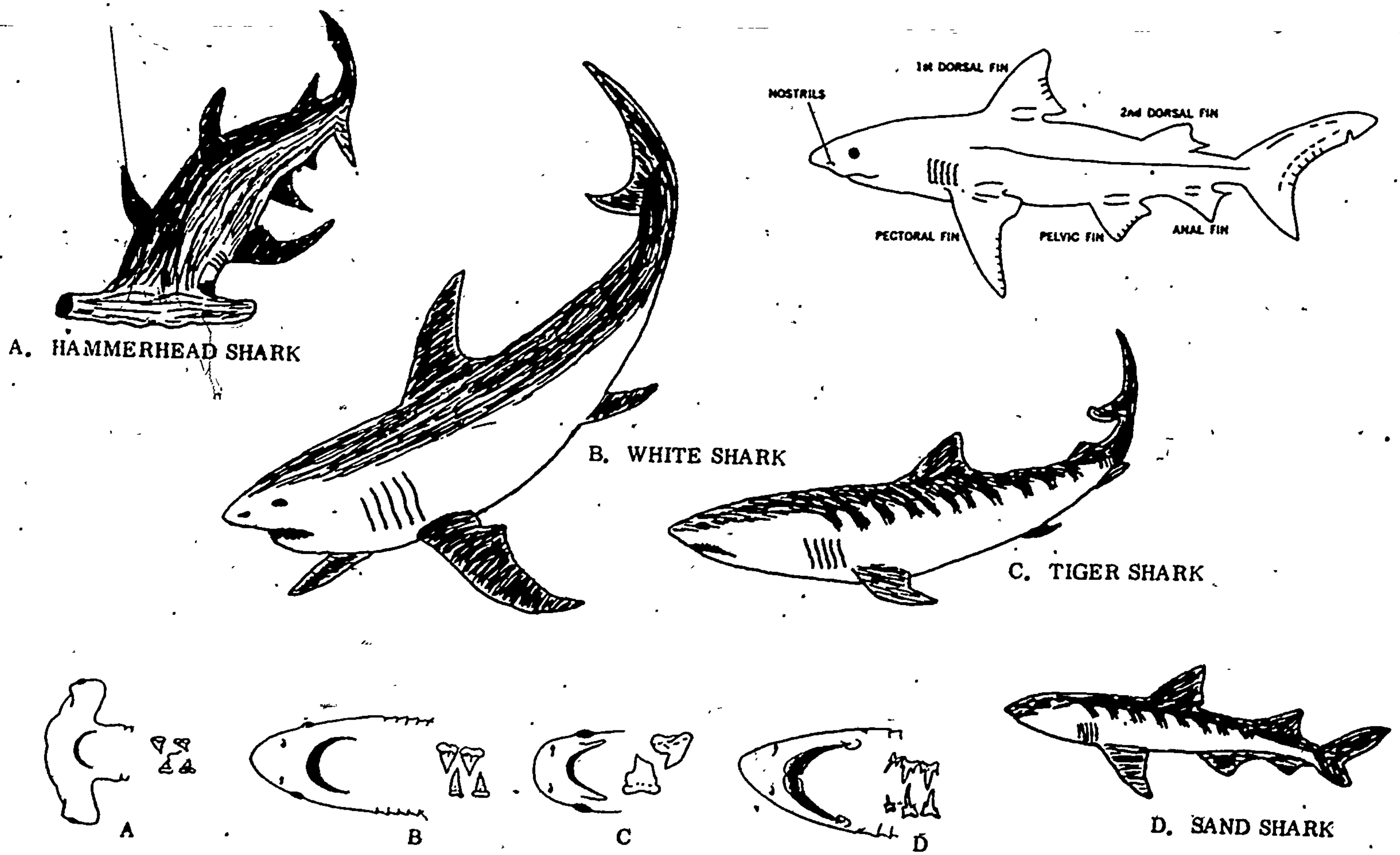



Figure 43. —Some Members of the Shark Family and their Different Visual Characteristics

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in eventual death of the beds. A number of snails, worms, and barnacles bore deeply into the very foundation of coral colonies. Naturally, a greater knowledge of the effects of these forces is essential to present and future coral reef studies.

## HARMFUL AND USEFUL ASPECTS OF MARINE LIFE

Probably the most important problem that man associates with survival at sea is the danger of attacks by obnoxious animals. Whether this or other factors are the primary detriment to survival is debatable. The fact remains that sea life poses a serious threat to naval operations involving swimmers and divers. Furthermore, as the rapid advances in underwater equipment and techniques extend the depth and range of such operations, there is a greater need for effective deterrents against the threat.

The number of species of marine animals capable of harming man has been estimated at more than 3,000, and these are separable into three categories: poisonous, venomous, and carnivorous. The last category is undoubtedly the most familiar, for it includes the biters such as the fearsome shark. For a man in the water, the fear of sharks is well founded, for out of approximately 250 species that inhabit the seas, more than 50 are known to be dangerous. Furthermore, sharks are to be found in all oceans from 45° north to 45° south latitude.

Because of the many attacks attributed to them, no other marine animal has been more extensively observed than the shark. Over the years, chemical repellent agents have been developed and used in survival circumstances. Their effectiveness has been less than complete, for incidents have been recorded in which sharks have demonstrated unpredictably savage conduct in apparent disregard of the repellents released.

Attacks by other marine carnivores such as the barracuda and the moray eel present a physical, as well as psychological hazard to many types of underwater operations. Venomous animals, such as the stonefishes, sea snakes, and numerous invertebrates, and a variety of stinging organisms represent a constant menace to the survivor at sea or the unwary swimmer or scuba diver. The development of truly effective defenses against all of these forms will require far more ecological and behavioral information than is now available.

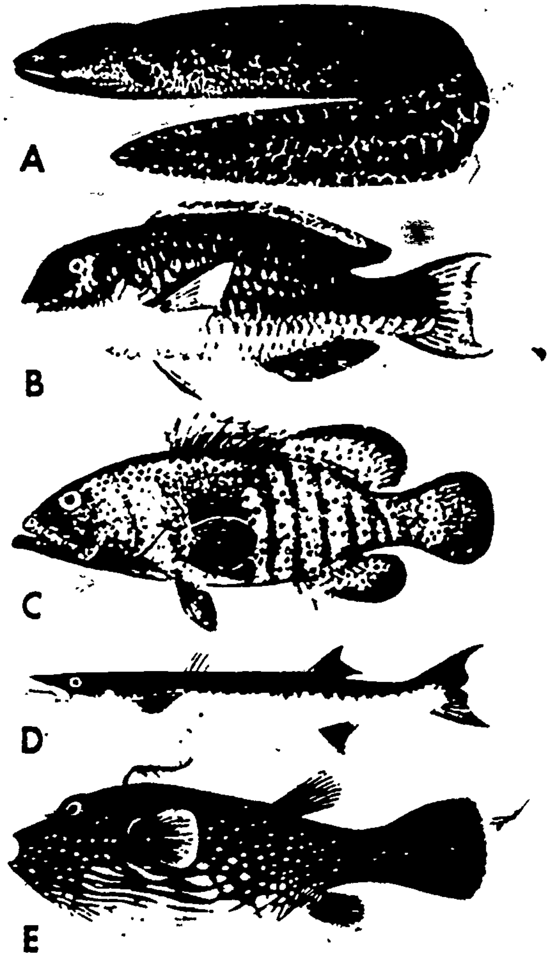


Figure 44.— Some obnoxious fishes: A. Moray eel. B. Parrot fish. C. Sea bass, or grouper. D. Barracuda. E. Puffer.

On the brighter side, however, there are good indications that marine life itself can provide the answers to these and many other problems. It has been observed that certain marine animals and plants produce substances which either kill, repel, or confuse other forms. By isolating and examining these substances, biologists hope to discover more effective repellents or deterrents for use against obnoxious animals.

Studies of the pharmacological properties of marine plants and animals may open the door on a new family of drugs. The defensive poisons exuded by many sea organisms are believed to be the source of potent new drugs for possible use in the war against cancer as well as other human diseases. For example, anti-cancer drugs are being sought in the tissues of shark brains.

Studies of the amazing swimming characteristics of certain marine animals, such as the dolphin and seal, may provide information useful in the design and construction of new hulls for surface ships and submarines. Research on the swimming techniques of marine animals indicates that many possess highly efficient propulsion mechanisms, completely silent and accomplished without detectable turbulence. This phenomenon is of considerable interest to the Navy in the development of future submersibles.

Biologists have determined that many kinds of marine animals have the ability to detect and identify targets at great distances and then swim toward them with unerring accuracy. Closely related to this phenomenon is the ability of shoals of fish to perceive and respond quickly to some sort of self-induced signal. These signals suggest a highly effective system of underwater communications. Research in this field is expected to evolve new concepts of target detection and identification, long-range submerged navigation, and underwater communications.

Many other unique capabilities of marine organisms are being studied in an effort to create new, and improve existing, man-made devices. Biologists are investigating how marine animals such as whales, porpoises, seals, and numerous fishes can sound rapidly to great depths without developing the bends and other diseases contracted by humans under similar conditions. The remarkable process by which some marine animals can replace lost or damaged parts of their bodies may hold secrets of cell formation useful to medical sciences. The anti-bacterial activity of marine algae may aid in the development of new antibiotics. The possibility of emulating natural processes of air purification by constructing analogues based on the photosynthesis of algae is being investigated as a means of improving submarine habitability. These are but a few of the potentially great discoveries at hand, and, in every instance, success will depend upon the systematic acquisition of fundamental biological data.

## THE CHALLENGE OF MARINE BIOLOGY

The foregoing has been a brief look at some of the problems and a few of the paths open or being opened to solve the problems faced. There can be no serious doubt that these problems can be solved at the present level of our technology. The results of applied research today will be merely the basic knowledge of tomorrow, as whole new concepts and goals will undoubtedly come into focus. This, however, is a healthy progression and one which will provide the necessary motivation for continued effort.

The modern challenge to marine biologists is to understand, explain, and predict the intricate interrelationships of life in the sea. It is, of course, impossible to foretell the extent that this knowledge will affect the future of mankind. That it will be profound appears evident in the many imaginative programs being undertaken. The ultimate goals are far reaching and constantly being extended as the sciences adjust, almost daily, to an increasing awareness of the ocean's great potential. Today, it seems reasonable to envision spectacular achievements in inner space that will parallel those of outer space.

To this end the National Oceanographic Program will be greatly aided by the formation of the National Oceanic and Atmospheric Administration that was formally organized in late 1970. The formation of NOAA will reduce duplication of effort as well as give the concerted effort needed to systematically investigate the ocean and atmosphere.

# WATER MOTIONS

## WAVES AND SURF

Ocean surface waves are advancing crests and troughs of water propagated by the force of the wind. Waves usually are defined and measured by their height, period, and length. Height is the vertical distance between crest and trough, period is the time between passage of successive crests or troughs at a reference point, and length is the horizontal distance between successive crests. Deepwater wavelength and period are related by a simple equation: wavelength = 5.12 x period$^2$ . Also, individual wave speed (knots) = 3.03 x period.

Although wave observations can be made by direct measurements, some uncertainty may exist as to what actually has been measured. Therefore, in order to obtain a clear idea as to the combinations of waves present on an apparently confused ocean surface, a knowledge of the growth of wind waves (sea) and the decay of swell is necessary.

### Growth of Wind Waves (Sea)

Under the influence of a newly formed wind, ripples develop into waves whose dimensions tend to increase with the wind velocity, duration, and fetch (the length of the area over which the wind is blowing). Waves also are subject to decaying influences, as discussed later. Further development in a steady wind results in variously dimensioned waves with progressively increasing heights and periods, until a steady state of sea is reached in which the sea is fully developed for the prevailing wind speed. That is, the relative proportions of waves of varying heights and periods remain the same as long as the wind does not change. These wind waves, generated locally by a continuing wind, are known as sea. Although this sea originated in a single wind system, it is a combination of many different waves which are angular and short crested, have various heights and directions, and give the appearance of a rapidly changing ocean surface.

Comparison of visual wave height observations and the more comprehensive mechanical wave height measurements shows that the former indicate only the higher waves. An observer's judgment of wave height is biased toward the higher waves, whereas a wave meter measures all of the waves. Fortunately, a simple relation exists between the two: A visual observation of wave height at a given time and place is about the same as the average of the highest 1/3 of all the waves at that time and place. This average is called the significant height.

With present observational techniques, the features of an individual sea wave are unpredictable. What can be forecast, however, is the statistically probable distribution of heights, periods, and directions of sea. The different distributions for the various sea states are illustrated in Table 6 for fully developed seas, where averages rather than distributions are given.

The wave frequency; speed, direction, and fetch of the wind; and the decay distance (the distance the waves proceeded from the generating area) are used to obtain a number (E) which is related to wave height. Values of wave height, length, and period are subsequently determined from E. Instructions for making such a statistical forecast are found in N.O. Pub. No. 603.

### Swell

Sea persists only in the fetch area and for the duration of the generating wind. If the wind dies down or if the waves leave the fetch area, the ocean surface waves become swell, which in time can be distinguished from sea by its appearance. Swell waves characteristically are rounded, their crests are longer and lower than those of sea waves, and they are more regular in height, period, and direction. A particular swell can be followed for some distance across the ocean's surface.

| Sea state | Sea description | Wind force (Beaufort) | Wind: Description | Wind: Range (knots) | Wind velocity (knots) | Wave height (feet): Average | Wave height (feet): Significant | Wave height (feet): Average 1/10 highest | Significant range of periods (seconds) | T max (period of maximum energy of spectrum) | T̄ (average period) | L̄ (average wave length) | Minimum fetch (nautical miles) | Minimum duration (hours) | E value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sea like a mirror | 0 | Calm | <1 | 0** | 0 | 0 | 0 | — | — | — | — | — | — | — |
| 0 | Ripples with the appearance of scales are formed, but without foam crests | 1 | Light airs | 1-3 | 2 | 0.05 | 0.08 | 0.10 | to 1.2 | 0.7 | 0.5 | 10 in | 5 | 18 min | 0.00 |
| 1 | Small wavelets. Still short but more pronounced. Crests have a glassy appearance but do not break | 2 | Light breeze | 4-6 | 5 | 0.18 | 0.29 | 0.37 | 0.4-2.8 | 2.0 | 1.4 | 6.7 ft | 8 | 39 min | 0.02 |
| | Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses | 3 | Gentle breeze | 7-10 | 8.5 | 0.6 | 1.0 | 1.2 | 0.8-5.0 | 3.4 | 2.4 | 20 | 9.8 | 1.7 hrs | 0.09 |
| | | | | | 10 | 0.88 | 1.4 | 1.8 | 1.0-6.0 | 4.0 | 2.9 | 27 | 10 | 2.4 | 0.22 |
| 2 | Small waves, becoming larger. Fairly frequent white horses | 4 | Moderate breeze | 11-16 | 12 | 1.4 | 2.2 | 2.8 | 1.0-7.0 | 4.8 | 3.4 | 40 | 18 | 3.8 | 0.25 |
| | | | | | 13.5 | 1.8 | 2.9 | 3.7 | 1.4-7.6 | 5.4 | 3.9 | 52 | 24 | 4.8 | 0.65 |
| | | | | | 14 | 2.0 | 3.3 | 4.2 | 1.5-7.8 | 5.6 | 4.0 | 59 | 28 | 5.2 | 1.20 |
| 3 | | | | | 16 | 2.9 | 4.6 | 5.8 | 2.0-8.8 | 6.5 | 4.6 | 71 | 40 | 6.6 | 1.40 |
| 4 | Moderate waves, taking a more pronounced long form. Many white horses are formed (chance of some spray) | 5 | Fresh breeze | 17-21 | 18 | 3.8 | 6.1 | 7.8 | 2.5-10.0 | 7.2 | 5.1 | 90 | 55 | 8.3 | 2.70 |
| | | | | | 19 | 4.3 | 6.9 | 8.7 | 2.8-10.6 | 7.7 | 5.4 | 99 | 65 | 9.2 | 4.70 |
| | | | | | 20 | 5.0 | 8.0 | 10 | 3.0-11.1 | 8.1 | 5.7 | 111 | 75 | 10 | 6.30 |
| 5 | Large waves begin to form. The white foam crests are more extensive everywhere (probably some spray) | 6 | Strong breeze | 22-27 | 22 | 6.4 | 10 | 13 | 3.4-12.2 | 8.9 | 6.3 | 134 | 100 | 12 | 7.70 |
| | | | | | 24 | 7.9 | 12 | 16 | 3.7-13.5 | 9.7 | 6.8 | 160 | 130 | 14 | 12.30 |
| | | | | | 24.5 | 8.2 | 13 | 17 | 3.8-13.6 | 9.9 | 7.0 | 164 | 140 | 15 | 19.20 |
| 6 | | | | | 26 | 9.6 | 15 | 20 | 4.0-14.5 | 10.5 | 7.4 | 188 | 180 | 17 | 21.30 |
| | Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind (spindrift begins to be seen) | 7 | Moderate gale | 28-33 | 28 | 11 | 18 | 23 | 4.5-15.5 | 11.3 | 7.9 | 212 | 230 | 20 | 28.70 |
| | | | | | 30 | 14 | 22 | 28 | 4.7-16.7 | 12.1 | 8.6 | 250 | 280 | 23 | 41.60 |
| | | | | | 30.5 | 14 | 23 | 29 | 4.8-17.0 | 12.4 | 8.7 | 258 | 290 | 24 | 58.70 |
| | | | | | 32 | 16 | 26 | 33 | 5.0-17.5 | 12.9 | 9.1 | 285 | 340 | 27 | 61.90 |
| 7 | Moderately high waves of greater length. Edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray affects visibility | 8 | Fresh gale | 34-40 | 34 | 19 | 30 | 38 | 5.5-18.5 | 13.6 | 9.7 | 322 | 420 | 30 | 81.10 |
| | | | | | 36 | 21 | 33 | 44 | 5.8-19.7 | 14.5 | 10.3 | 363 | 500 | 34 | 111.00 |
| | | | | | 37 | 23 | 37 | 46.7 | 6-20.5 | 14.9 | 10.5 | 376 | 550 | 37 | 148.00 |
| | | | | | 38 | 25 | 40 | 50 | 6.2-20.8 | 15.4 | 10.7 | 392 | 600 | 38 | 168.00 |
| | | | | | 40 | 28 | 45 | 58 | 6.5-21.7 | 16.1 | 11.4 | 444 | 710 | 42 | 195.00 |
| 8 | High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected | 9 | Strong gale | 41-47 | 42 | 31 | 50 | 64 | 7-23 | 17.0 | 12.0 | 492 | 830 | 47 | 253.00 |
| | | | | | 44 | 36 | 58 | 73 | 7-24.2 | 17.7 | 12.5 | 534 | 960 | 52 | 316.00 |
| | | | | | 46 | 40 | 64 | 81 | 7-25 | 18.6 | 13.1 | 590 | 1110 | 57 | 399.00 |
| | Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected | 10 | Whole gale* | 48-55 | 48 | 44 | 71 | 90 | 7.5-26 | 19.4 | 13.8 | 650 | 1250 | 63 | 498.00 |
| | | | | | 50 | 49 | 78 | 99 | 7.5-27 | 20.2 | 14.3 | 700 | 1420 | 69 | 616.00 |
| | | | | | 51.5 | 52 | 83 | 106 | 8-28.2 | 20.8 | 14.7 | 736 | 1560 | 73 | 733.00 |
| | | | | | 52 | 54 | 87 | 110 | 8-28.5 | 21.0 | 14.8 | 750 | 1610 | 75 | 870.00 |
| | | | | | 54 | 59 | 95 | 121 | 8-29.5 | 21.8 | 15.4 | 810 | 1800 | 81 | 919.00 |
| 9 | Exceptionally high waves (small and medium-sized ships might for a long time be lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected | 11 | Storm* | 56-63 | 56 | 64 | 103 | 130 | 8.5-31 | 22.6 | 16.3 | 910 | 2100 | 88 | 1110.00 |
| | | | | | 59.5 | 73 | 116 | 148 | 10-32 | 24.0 | 17.0 | 985 | 2500 | 101 | 1531.00 |
| | Air filled with foam and spray. Sea completely white with driving spray. Visibility very seriously affected | 12 | Hurricane* | 64-71 | >64 | >80*† | >128*† | >164*† | 10-(35) | (26) | (18) | — | — | — | — |

* For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen.

** A heavy box around this value means that the values tabulated are at the center of the Beaufort range.

*† For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

(Pierson, Neumann, James and Marks)

Table 6. —Wind and Sea Relationship

Another important difference between sea and swell is the uniformity or nonuniformity of periods, heights, and directions. Sea wave periods are variable, whereas swell wave periods are fairly uniform. Under the influence of a generating wind, sea waves are from various directions. A group having a given direction tends to travel together, but as these waves leave the area of generation they separate from the sea waves having other directions; this is known as angular spreading. This group of separated sea waves now is known as unidirectional swell. If a subgroup of swell waves having a given period is chosen from the unidirectional group and if then the subgroup travels a few hundred miles, another phenomenon, known as dispersion, becomes evident. The waves having shorter periods (traveling slower) will have dropped behind the subgroup, and the longer period waves will have sped ahead of the subgroup. Thus, any swell sufficiently removed from its origin is comparatively uniform in both period and direction.

Forecasts of the distribution of swell characteristics are made in terms of the separation (filtering) by angular spreading and dispersion.

Wave Decay.—As a swell wave progresses, in the absence of a sustaining wind, its height decreases with a consequent reduction in wave steepness (height to length ratio). This alteration of wave form, that is, the tendency of waves to level off to a smooth ocean surface, is known as wave decay. One reason for wave decay is a loss of energy from the wave that is brought about by: (1) internal friction (eddy viscosity), (2) resistance encountered as waves tend to overtake the wind, (3) restraint by crosswinds, (4) action of currents in the path of waves, and (5) the effects of seaweed, ice, shoals, islands, or continents in the path of waves.

In a group of waves which were generated together in a storm area, height decay occurs partly because of the decay of individual waves and partly because of angular spreading and dispersion. In the latter phenomenon, waves are separated from each other through angular spreading (differences in direction) or through dispersion (differences in period or wavelength). In each process, wave heights which formerly reinforced each other in height no longer do so, and the effect is that the observed wave heights are less than before angular spreading and dispersion took place, although the heights of the individual waves are essentially the same.

Another aspect of wave decay, the change of wavelength, comes about as a result of dispersion; that is, long waves travel ahead of short waves because of the difference in speed. Thus, the assortment of wavelengths near a generating storm contains comparatively few long-length waves as compared to the assortment away from the storm.

Surf

Waves, which originated in a distant storm often travel as long low swell which, although scarcely noticeable until they near the shore, eventually become surf. As these waves pass among outlying islands, they are deflected and scattered; they are further bent around points and into bays, tending to orient their crests parallel to the shoreline. Hence, there is often considerable local variation in surf characteristics.

Sea and swell involve not only action at the surface but also motion of water particles at depth. As a wave passes through an area, the surface water particles in the area move up, forward, down, and backward, describing circles in planes parallel to the direction of wave travel. Subsurface water particles do likewise, describing circular orbits whose diameters diminish with increasing depth. As the wave enters shallow water, the particles orbit beneath the surface, and the orbits become ellipses which flatten with depth. Finally, at the bottom the particles no longer have vertical motion. In deep water, below the greatest depth of wave influence, there is no motion due to wave action, whereas in shallow water, particles oscillate to and fro along the bottom parallel to the direction of wave travel.

As the wave enters water of depth less than one-half the wavelength, it is said to feel bottom. As its wavelength decreases, steepness increases and height may change. When the steepest surface of the wave inclines more than 60° from the horizontal, the wave becomes unstable and plunges forward.

When breakers and surf are forcasted, a number of factors must be considered, as variations in these factors greatly influence local surf conditions. Some of these factors are: the height, period, length, and direction of the incoming wave train; the winds near shore; bottom and beach topography; angle of breakers with shoreline;

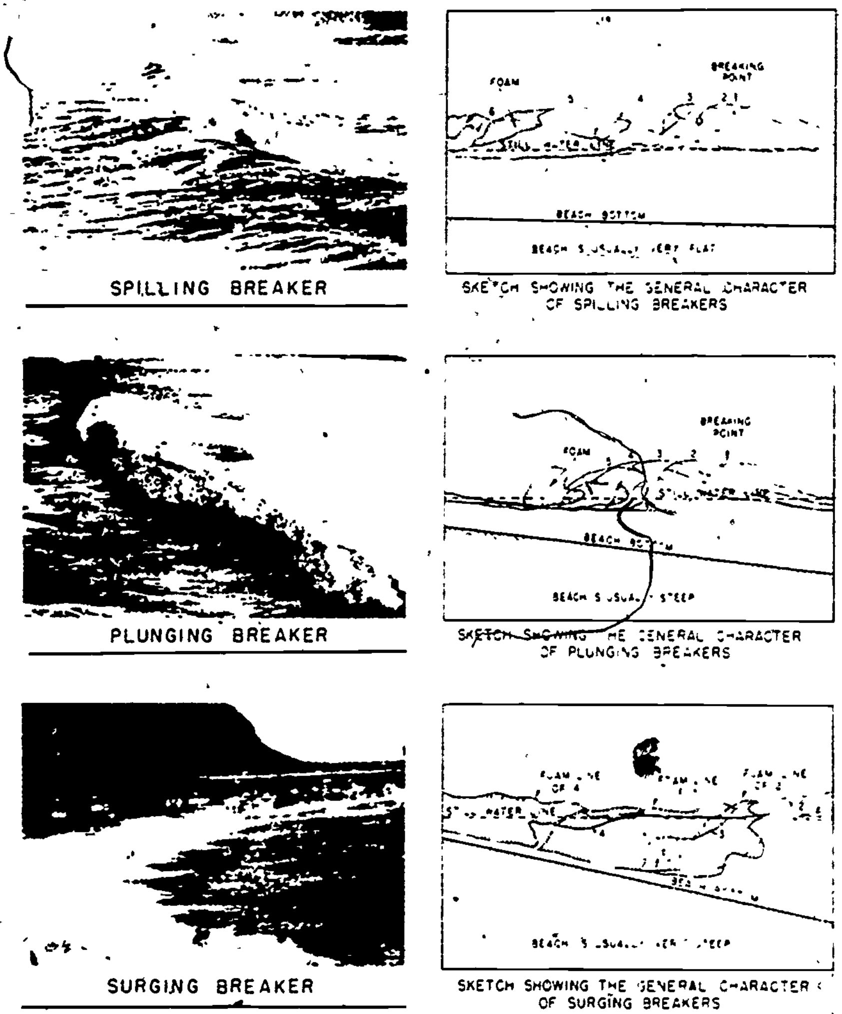


Figure 45.—The three types of breakers.

distance of outermost breakers from the beach; and average depth of water at point of breaking.

Depiction of Sea and Swell

A knowledge of sea and swell conditions is basic in the planning of many naval operations. For example, the effectiveness of sonar equipment can be limited by wave conditions; rough seas produce high background noise, whereas relatively calm seas may produce thermal stratifications that affects sonar ranges. The efficiency of air and radar search for submarines and snorkels also depends, to some extent, upon surface wave conditions.

Sea and swell usually are presented graphically in atlases and other oceanographic publications by means of roses, which picture the percent frequency of various sea snd swell height categories by direction. Also, bargraphs and isolines are used to give the percent frequency of occurrence of selected sea and swell height categories.

Data for sea and swell presentations usually are obtained from machine punch cards whose source material is wave observations from marine meteorological and oceanographic forms, deck logs, and special observation forms. Additionally, wave data may be computed directly

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from wind observations at sea. The data are generally combined into sea and swell roses for areas of various sizes, depending upon the relative uniformity of conditions within the area and the number of available observations. Examples of the frequency distribution of sea are shown in figure 46, and examples of the frequency distribution of swell are shown in figure 47. Note that swell penetrates some distance into ice covered areas, depending on its period and the concentration and thickness of the pack, whereas sea is largely attenuated by ice.

Sea and swell data usually are grouped by seasons, since in most areas of the world seasonal variations are greater than those of shorter periods. However, the presentations of the data are general and do not take into account temporary local effects such as the passing of storms, frontal systems, local atmospheric disturbances, and land and sea breezes which occur along coastlines.

Controls

Since, as has been stated, waves are produced by winds, the principal controlling factors in determining average wave patterns over an ocean area and the seasonal changes in a local area are the climatological features having a primary effect on wind, namely, surface barometric pressure distribution and storms. Figure 48 is a typical synoptic wave chart for the North Atlantic, with the atmospheric pressure pattern superimposed, showing how waves are related to winds over a major ocean area. The wave heights have been reported by ships or have been determined from wind velocities and duration, fetch, and decay distance. The relationship of the major wave trains to the synoptic weather pattern is obvious, as is the association of the higher waves with the strong winds of low pressure systems.

Although ocean waves are generated as a direct result of wind action, other factors affect their magnitude and direction. The following are examples:

Currents.— When waves enter an area of strong opposing currents, the wave form steepens even to the point of breaking. Conversely, when waves move with a component of the current, they increase in length and decrease in height.

Bottom Topography. —. Water is defined as shallow if the water depth is less than one-half of the distance between wave heights on the surface (wavelength). Changes in depth within this shallow water zone result in velocity changes of various segments of a wave. This process, called wave refraction, is similar to the bending of light rays when they pass through various substances. Wave velocity decreases as water depth decreases, and unless the direction of propagation is perpendicular to the bottom contours, the portion of a wave entering shallow water moves more slowly than the portion of the same wave in deeper water. The portions of shallow water waves passing over depressions on the bottom move faster than the portions on either side; hence, wave-crests stretch and heights decrease. Observations of variations in wave heights in shallow water may indicate the approximate position of underwater ridges and depressions. Islands lying in the path of waves cause refraction around their sides. Leeward of an island, the waves may meet and pass through each other, producing a confused cross sea.

Local Winds.— All sea areas near the shores of continents and large islands are influenced by land and sea breezes. Modification of the existing wind field by onshore winds during the afternoon and by offshore winds during morning causes corresponding increases or decreases in sea heights. Also, gravity winds, which are formed when dense cold air accumulates on continental highlands and flows rapidly down the slope and out over the sea, produce high waves for short distances from shore.

CURRENTS

A general knowledge of currents is essential for an understanding of both the interaction of the sea and air and the oceanic circulation in general. Oceanic circulation plays a major rôle in the distribution of many environmental factors.

Although the directions and speeds of the principal surface currents are fairly well known, knowledge of subsurface currents is seriously limited. Recent important developments in current measuring devices and new current investigating techniques have led to some significant discoveries in subsurface circulation. For example, a southward flow has been found to great depths beneath the powerful north-setting Gulf Stream,



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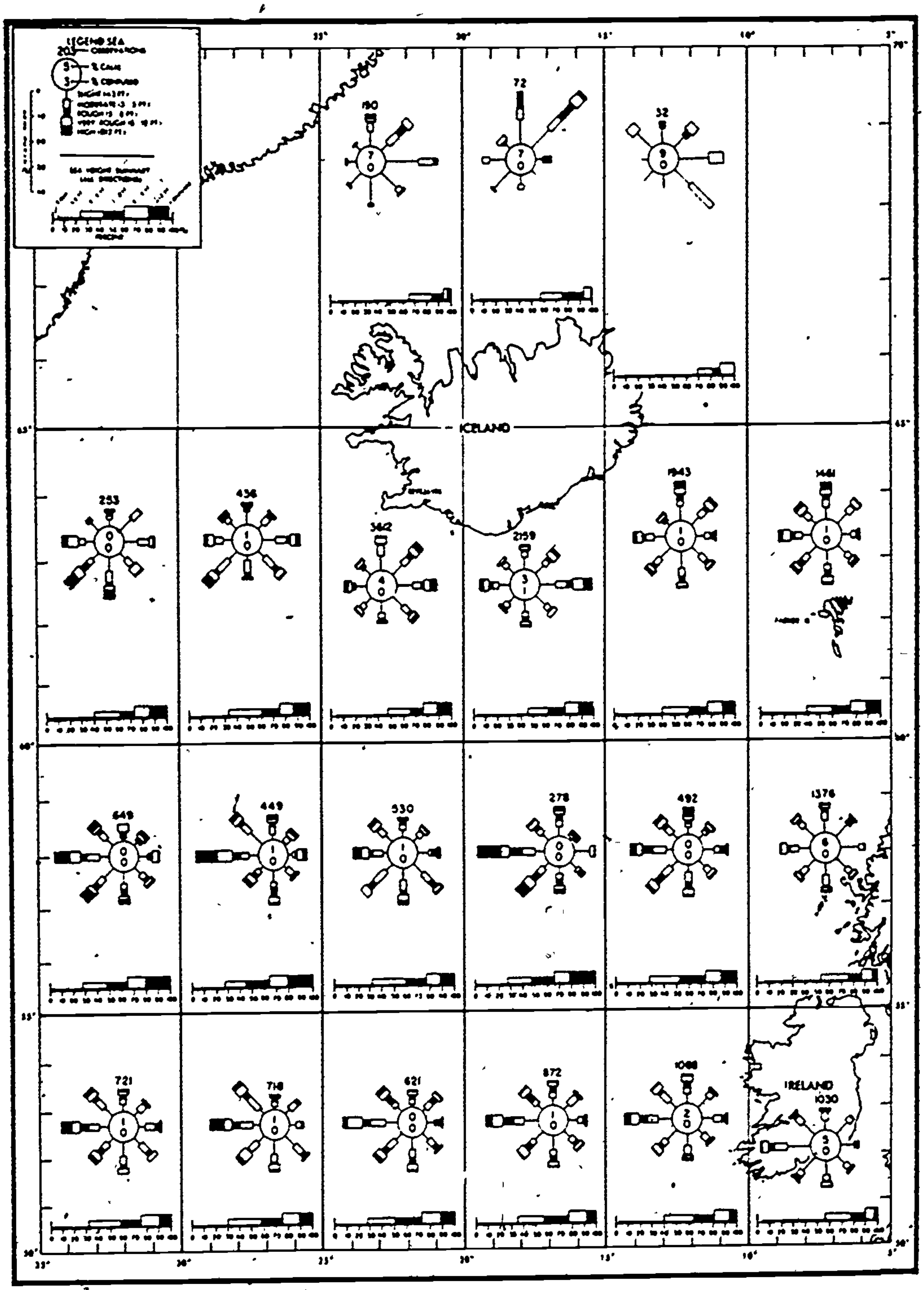


Figure 46.— State of sea.

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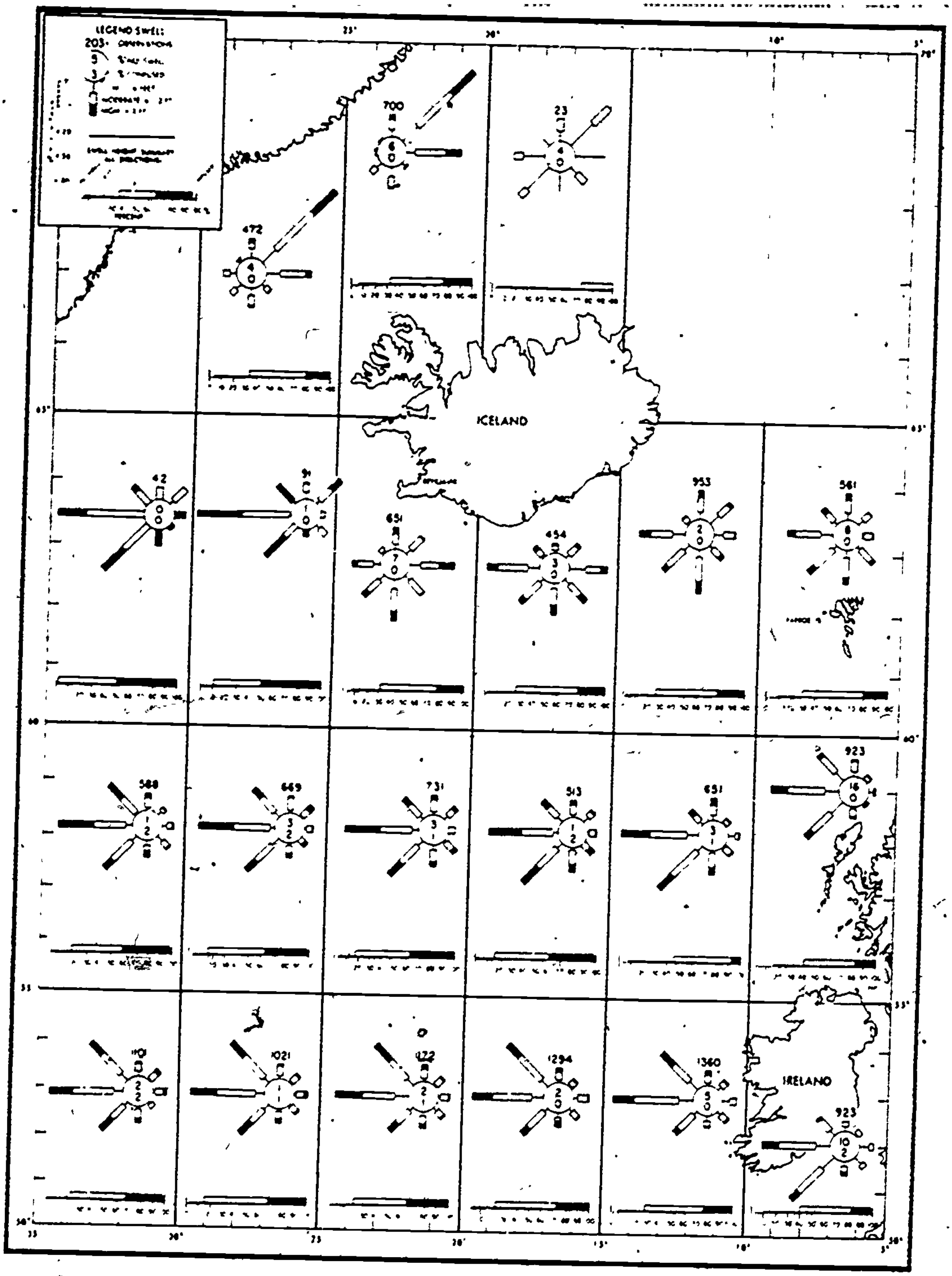


Figure 47.— Swell.

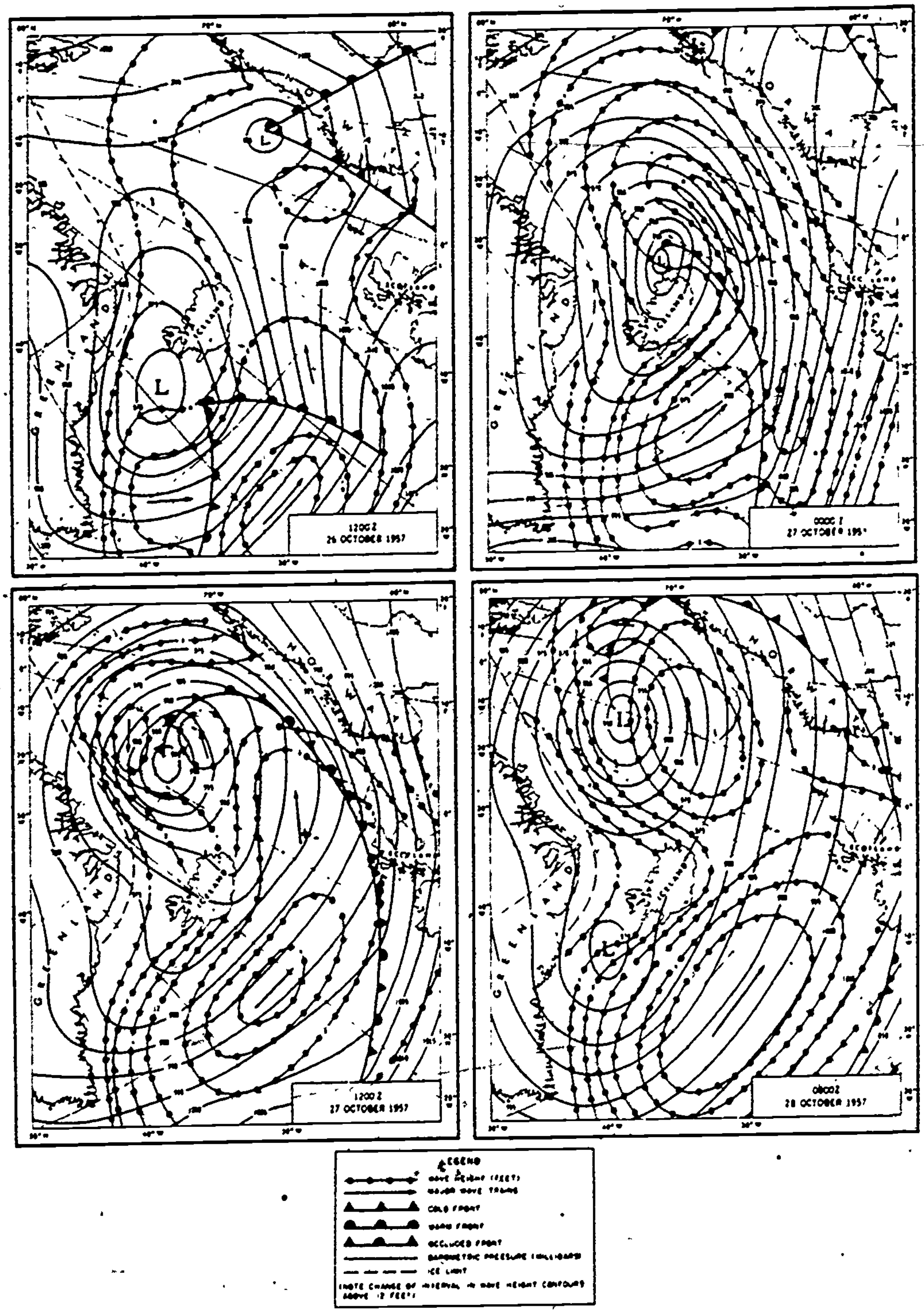


Figure 48.— Synoptic wave chart, 26-28 October 1957.

and an unexplained jet of eastward-flowing subsurface water (the Cromwell Current) with speeds to 3 knots has been discovered setting counter to the west-setting North Equatorial Current in the Pacific Ocean. However, direct subsurface current measurements in the ocean are not nearly abundant enough to establish a pattern of subsurface circulation. Our knowledge of subsurface circulation is based primarily on a method of water density computations from the distribution of temperature and salinity, factors much easier to measure and for which much more abundant data are available. Current charts that are constructed from these computations are generalized, but knowledge of subsurface currents would be even more scanty if based entirely on direct observations.

Currents in the sea generally are produced by wind, tide, differences in density between water masses, sea level differences, or runoff from the land. They may be roughly classified as tidal or nontidal currents. Nontidal currents, those not caused by tidal movement, include the permanent currents in the general circulatory systems of the ocean; geopotential currents, which are those associated with density differences in water masses; and temporary currents, such as wind-driven currents, which arise from meteorological conditions. Tidal currents are the horizontal expression of tide forces and usually are significant only in shallow water, where they often become the strong or dominant flow. Although tidal currents will be considered in greater detail at the end of this section, it is important to note here that currents are usually a combination of tidal and nontidal currents. One type of current, the hydraulic current, can be classified as either tidal, nontidal, or a combination. Hydraulic currents are caused by differences in sea level between two bodies of water and usually occur in straits separating such bodies of water.

Wind-driven currents, of course, are those motivated by the force of the wind exerting stress on the sea surface. This stress causes the surface water to move, and this movement is transmitted to the underlying water to a depth which is dependent mainly on the strength and persistence of the wind. Most ocean currents are the result of winds that tend to blow in a given direction over considerable amounts of time. Likewise, local currents, those peculiar to an area in which they are found, will arise when the wind blows in one direction for some time. In many cases, the strength of wind may be used as a rule of thumb for determining the speed of a local current; the speed is figured as 2% of the wind's force. Hence, if a wind blows for 3 or 4 days in a given direction at about 20 knots, it may be expected that a local current of nearly 0.4 knot is being experienced.

The speed of a current is known as its drift. Drift is normally measured in nautical miles per hour. The term "velocity" is often used as the equivalent of "speed" in reference to current, although strictly "velocity" implies direction as well as speed. Set, the direction in which the current acts or proceeds, is measured according to compass points or degrees. Observations of currents are made directly be mechanical devices that record speed and direction, or indirectly by water density computations, drift bottles, or visually (slicks and water color differences).

Ocean Currents

The system of currents in the oceans of the world keeps the water continually circulating. The midwinter positions of these major ocean currents (general circulation) are shown in figure 49. These positions shift only slightly with the seasons, except in the northern part of the Indian Ocean and along the China coast where the monsoons cause the currents to flow in opposite directions in winter and summer. Currents appear on most charts as well-behaved continuous streams defined by clear boundaries and with gradually changing directions. These representations usually are smoothed patterns derived from averages of many observations and do not represent synoptic or instantaneous situations. Figure 50 is an example, based on actual observations of the meandering of the Gulf Stream, that can be expected within short periods of time. Unfortunately, prediction of such meanders cannot be made at present. Thus, surface and subsurface charts must represent resultant or prevailing currents derived statistically and based on many observations.

Ocean currents usually are strongest near the surface and sometimes attain considerable speed, such as 5 knots or more reached by the Florida Current. In the middle latitudes, however, the strongest surface currents rarely reach speeds above 2 knots. At depth, currents generally are slow (less than 0.5 knot), but recent investigations have disclosed the existence of high velocity streams, such as the Cromwell Current in the

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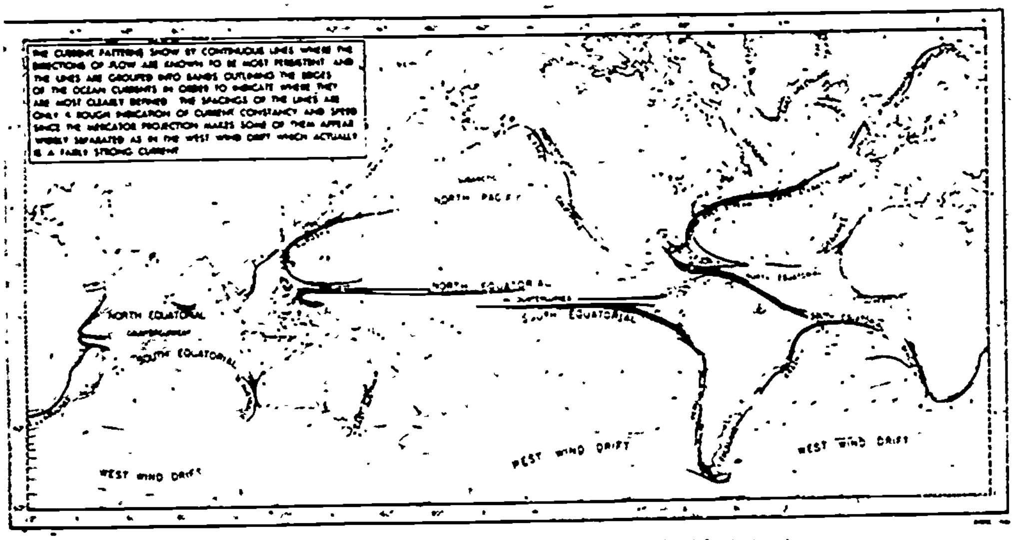


Figure 49.— Major ocean currents (midwinter).

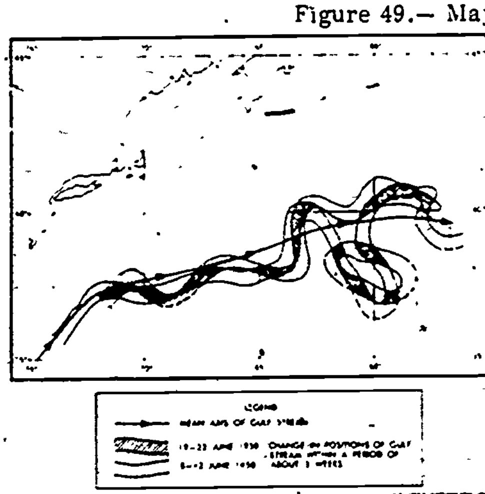

Figure 50.—Example of Gulf Stream meanderings.

Pacific Ocean. At very great depths, in trenches for example, it was believed that currents were imperceptible, but now some evidence indicates a measurable flow.

Winds are the primary generating force responsible for the general current patterns shown in figure 49. Figure 51 shows the wind systems of the world whose characteristics are similar in many respects to the currents shown in figure 49. A wind-driven current does not flow in exactly the same direction as the wind, but is deflected by the earth's rotation. This deflecting force (Coriolis force), greater at higher latitudes and more effective in deep water, is to the right of the wind direction in the Northern

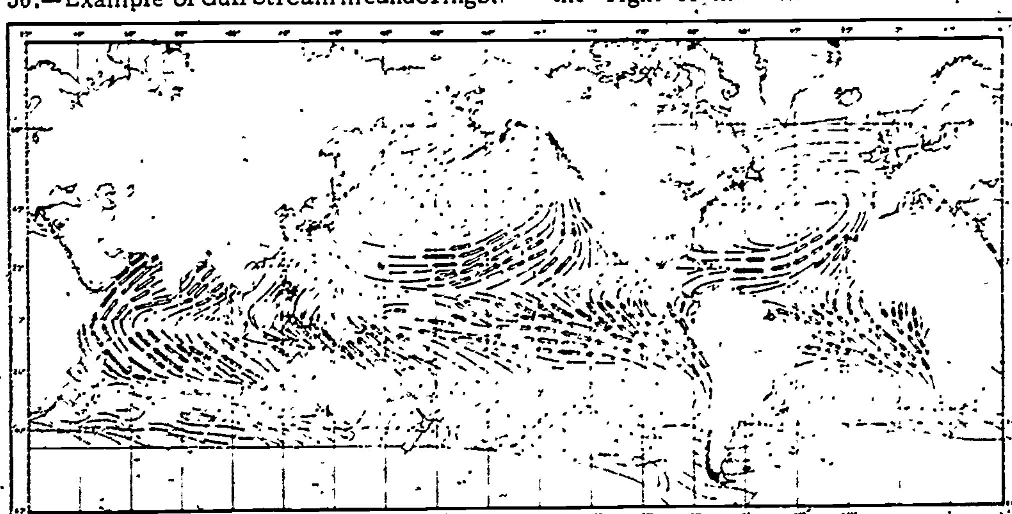

Figure 51.—World chart showing the prevailing winds in February.

Hemisphere and to the left in the Southern Hemisphere. At latitudes between 10°N and 10°S, the current usually sets down wind. In general, the angular difference in direction between the wind and the surface current varies from about 10° in shallow coastal areas to as much as 45° in some areas of the open ocean. The angle increases with depth of current, and at certain depths the current may flow in the opposite direction to that at the surface. Some major wind-driven currents are the West Wind Drift in the Antarctic, the North and South Equatorial Currents that lie in the trade wind belts of the ocean, and the seasonal monsoon currents in the western Pacific.

Ocean currents have a definite structure which often is obscured near the surface by effects of winds and other factors. Large density gradients may develop in the vicinity of strong ocean currents. Within the prevailing current systems centered at mid-latitudes, the surfaces of equal density slope downward toward the right of the observer facing downcurrent in the Northern Hemisphere and downward toward his left in the Southern Hemisphere. In some areas, where currents carrying water of different densities converge, confused currents usually exist. Examples of such areas are the convergence of the warm Gulf Stream and the cold Labrador Current in the western Atlantic and the warm Kuroshio and the cold Oyashio in the western Pacific.

In deep water, currents are related to the thermocline (layer of rapid temperature decrease with depth), and three general situations may be recognized: (1) Above the thermocline the subsurface currents have about the same speed and direction as surface currents, (2) current speed frequently decreases sharply at the thermocline, and (3) below the thermocline current speeds gradually decrease with depth, and their direction may differ appreciably from that above the thermocline. The depths to which significant subsurface flow can be detected vary with each current or in different parts of the same current. Usually, water having characteristics of that on the surface extends deeper near the axis of major current systems. Though seasonal warming may develop a sharp shallow thermocline, the stronger current and resulting turbulence near the axis of a system produces a deeper homogeneous layer conducive to better detection ranges.

When adjacent currents of different physical characteristics set (flow) in opposite directions, such as the cold south-setting coastal current and the warm north-setting Gulf Stream along our east coast, warm water often forms a shallow wedge over the denser colder water. For example, figure 52 shows a latitudinal cross section of two currents flowing side by side. Since the distance in this figure from A to C represents 100 miles, the vertical scale is greatly exaggerated. In proceeding from A to C, the submarine travels through two areas of fairly deep surface layers near A and C. In each of these layers the thermoclines are deep, and sound conditions are relatively good. Away from the centers of these current systems, the surface layers shoal, and near B (the boundary between the two currents) the warm water overlies the cold water as a shallow wedge. Tongues of warm and cold water intertwine along this interface and usually cause poor sound conditions. Similarly, where the west-setting North and South Equatorial Currents border on the east-setting Equatorial Countercurrent, the thermocline is shallow and echo ranging conditions are poor.

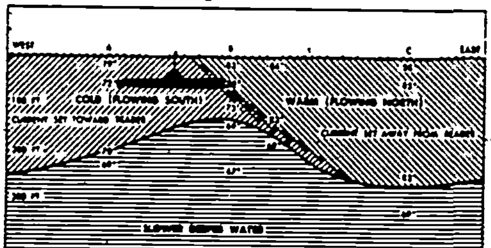

Figure 52.— Idealized cross section of an ocean current and countercurrent.

Eddies, which vary in size from a few miles to 75 miles or more in diameter, branch from major currents. Large eddies are common on both sides of the Gulf Stream from Cape Hatteras to the Grand Banks. How long such eddies persist and retain their characteristics near the surface is not well known, but large eddies near the Gulf Stream are known to persist longer than a month. The surface speeds of currents within these eddies, when first formed, may reach 2 knots. Smaller eddies have much less momentum and soon die down or lose their surface characteristics through wind stirring. Eddies are a potential source of poor and variable sound conditions.

Vertical Currents

In addition to currents that travel horizontally in the sea, there also are those that move vertically. In some areas this vertical movement is primarily responsible for the occurrence of strong thermal gradients. Most vertical circulation occurs in the upper 1,000 feet. Vertical circulation at great depths is represented by a general overturning of the water masses, rather than vertical transport by definite currents.

Sinking of Surface Water. —A highly variable phenomenon much influenced by local water movements and weather is the vertical downward movement (sinking) of heavier (denser) surface water. Sinking may occur in almost any part of the oceans, but ordinarily occurs at the convergence between two water masses of different characteristics, especially where there is considerable cooling or evaporation of surface water. Sinking may be significant to submarine operations in a convergence zone that is only a few yards wide and several miles long. Such a convergence area may have the choppy appearance of a tide rip and contain debris brought into it by the converging currents. Also, the downdraft sometimes is strong enough to sink debris of slight buoyancy, and the surface currents may be strong enough to hold a drifting vessel in the convergence despite crosswind. Unfortunately, very little information is available about the size and form of the downward currents, since most observations of their existence have been at the surface.

Upwelling.— Converse to the descending movement of surface waters is the ascending movement (upwelling). Upwelling may occur anywhere in the oceans, but most often it occurs in coastal regions where a strong wind blows the surface water seaward and allows the deeper colder water to rise in its place. Upwelling normally occurs along the west coasts of continents, being particularly strong off Peru, California, and the west coast of Africa. Offshore winds tend to produce upwelling, but wind paralleling the coast also may cause upwelling along the shore, as Coriolis force will deflect the flow of water considerably (figure 53). For example, a north or northwest wind along the coast of California causes upwelling, whereas a southerly wind does not. In the Southern Hemisphere southerly winds may cause upwelling, as off the coast of Peru.

Coastal and Tidal Currents

Coastal currents are caused mainly by river discharge, tide, and wind; however, in part they

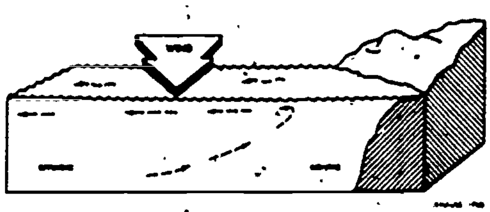

Figure 53.— Example of upwelling in Northern Hemisphere.

may also be produced by the circulation in the open ocean. Because of the tides or local topography, coastal currents often are irregular. Much theory regarding deepwater currents does not apply to water movement shoreward of the 100-fathom contour.

Tidal currents, a factor of little importance in general deepwater circulation, are of great influence in coastal waters. The tides furnish energy through tidal currents, which keep coastal waters relatively well stirred, often resulting in isovelocity sound conditions. However, close to shore and especially near the mouths of estuaries, fresh water outflow often is restricted to the surface and produces a distinct layer. A strong tidal current usually produces considerable turbulence. This turbulence may affect sound conditions, maneuverability of vessels, and factors of importance to ASW.

Having considered the relationship of coastal currents and tidal currents to one another and to ocean currents, let us now examine in greater depth the tidal phenomenon.

Tidal Phenomenon

The tidal phenomenon is composed of two closely related movements—tide and tidal current. "Tide" refers to the vertical rise and fall of water, and "tidal current," to the horizontal flow. The tide rises and falls; the tidal current floods and ebbs. The movements are intimately related, and both are caused by forces of the moon and the sun upon the earth.

Tides.— In general, a tide rises and falls twice daily. The tide rises until it reaches a maximum height, called high tide or high water, and then falls to a minimum level, called low tide or low water. The difference in height between consecutive high and low waters is called the range of the tide.

The rate of rise and fall of a tide is not uniform. From low water the tide rises slowly at first and increases until about half way to high water. Then the rate of rise decreases until high water is reached, at which time the rise ceases and for a brief period, called stand, no change in water level can be detected. A falling tide behaves in a similar manner.

A graphic representation of the rise and fall of the tide at New York during a 24-hour period is shown in figure 54. Notice that the tide curve has a general form of a sine curve.

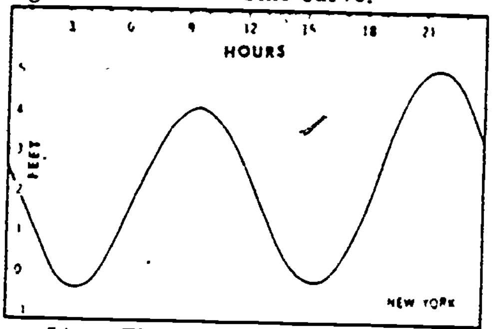


Figure 54.— The rise and fall of the tide at New York.

As we have already stated, tides result from differences in the gravitational attraction of various celestial bodies, principally the moon and the sun, upon the earth. The moon has the greatest tide-producing effect; the sun has somewhat less. The effect of other heavenly bodies is insignificant.

The gravity of the earth acts approximately toward the earth's center and tends to hold the earth in the shape of a sphere. However, the moon and sun provide disturbing, or tide-producing, forces.

Figure 55 represents the tides which would be produced by the moon alone if the earth were a non-rotating, perfect sphere with a uniform coating of water. The gravitational attraction of the moon would cause the waters to bulge out at two opposite points. These bulges, directly in line with the moon, would be the two points of maximum high tide. From there the water level would slope down to minimum low tide 90° from the points of high tide. If the earth were then rotated under the water, all places on its surface would be carried through alternate high and low tides.

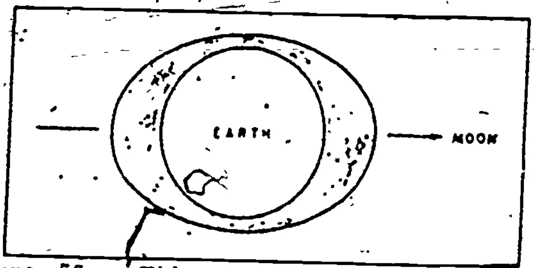


Figure 55. —Tides are caused by a bulging out of water in the direction of the moon and in the direction opposite the moon.

The gravitational pull of the moon or sun does not actually lift the water in the bulges from the earth. The fluidity of water permits the water to move in the direction of the attracting body and pile up at the point nearest the center of the attractive force, as well as at a point 180° from it. The piling up or accumulation of water causes the bulges.

Because of its comparative closeness to the earth, the moon has a greater tide-producing effect than the sun. Therefore, we will consider the moon and its effects in greater detail.

The tide-producing forces of the moon tend to create high tides on the sides of the earth nearest to and farthest from the moon, with a low tide belt between them. As the earth rotates on its axis, a point on earth passes through two high and two low tidal areas each day if the moon is over the equator (figure 56A). As the moon orbits around the earth, it occupies different positions relative to the equator. The angular distance of the moon, north or south, from the equator is called its declination. When the moon is north or south of the equator, the tidal force pattern is as shown in figure 56B, and a point on the equator passes through two unequal highs or only one high. Thus, due to the moon's declination, a particular place may have two high tides in a day, one of which is higher than the other, and two low tides, one of which is lower. The various tides during the day at a given place are termed higher high water, lower high water, higher low water and lower low water.

The tide-producing forces due to the sun are similar to those of the moon, and the tide experienced on earth is a resultant of the two. That part of the tide caused by the tide-producing forces of the moon is called lunar tide. That part caused by the sun's forces is solar tide.

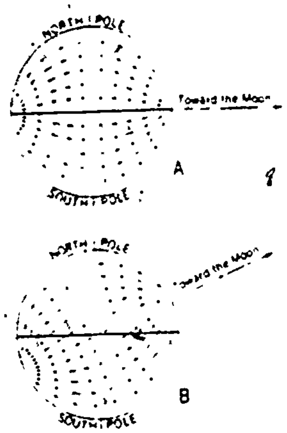


Figure 56.— Tide-producing forces. The arrows represent the magnitude and direction of the horizontal component of the tide-producing force on the earth's surface. (A) When the moon is in the plane of the equator, the forces are equal in magnitude at the two points on the same parallel or latitude and 180° apart in longitude. (B) When the moon is at north (or south) declination, the forces are unequal at such points and tend to cause an inequality in the two high waters and the two low waters of a day.

A body of water has a natural period of oscillation that is dependent upon its dimensions. The ocean is not a single oscillating body; instead, it is made up of a number of oscillating basins. When such basins are acted upon by the tide-producing forces, some respond more readily to daily or diurnal forces, others to semidiurnal forces, and others almost equally to both. Hence, tides at a place are classified as one of three types — semidiurnal, diurnal, or mixed — according to the characteristics of the tidal pattern occurring at the place.

In the semidiurnal type of tide, there are two high and two low waters each tidal day, with relatively small inequality in the high and low water heights. Tides on the Atlantic coast of the United States are representative of the semidiurnal type, which is illustrated in figure 57 by the curve for Boston Harbor.

In the diurnal type of tide, only a single high and single low water occur each tidal day. Tides of the diurnal type occur along the northern shore of the Gulf of Mexico, in the Java Sea, in the Gulf of Tonkin (off the Vietnam-China

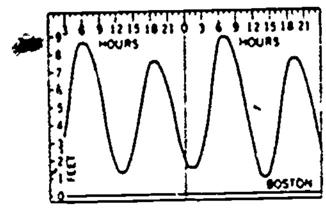


Figure 57.— Semidiurnal type of tide.

coast), and in a few other localities. The tide curve for Pakhoi, China, (figure 58) is an example of the diurnal type.

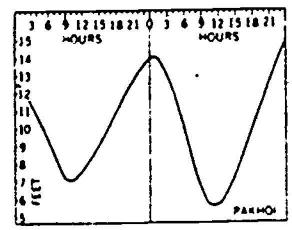


Figure 58.— Diurnal type of tide.

In the mixed type of tide, the diurnal and semidiurnal oscillations are both important factors, and the tide is characterized by a large inequality in the high water heights, low water heights, or in both. There are usually two high and two low waters each day, but occasionally the tide may become diurnal. Such tides are prevalent along the Pacific coast of the U. S. and in many other parts of the world. Examples of mixed types of tide are shown in figure 59.

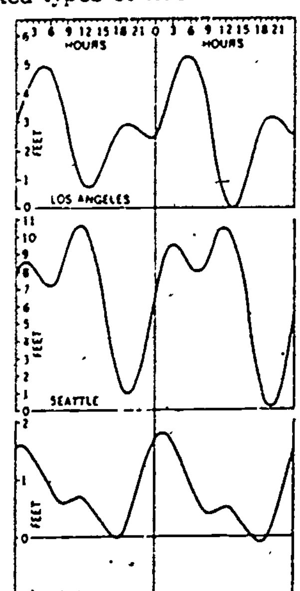


Figure 59.—Mixed types of tide.

At Los Angeles, it is typical that the inequalities in the high and low waters are about the same. At Seattle the greater inequalities are typically in the low waters, while at Honolulu the high waters have the greater inequalities.

A special feature of a mixed tide that is sometimes observed is the double low water (as at Hook of Holland) and the double high water (as at Southampton, England). At such places there is often a slight fall or rise in the middle of the high or low water period. The practical effect is to create a longer period of stand at high or low tide. Tide tables direct attention to these and other peculiarities where they occur.

The natural period of oscillation of a body of water may accentuate either the solar or the lunar tidal oscillations. Although, as a general rule, tides follow the moon, the relative importance of the solar effect varies in different areas. There are a few places, primarily in the South Pacific and the Indonesian areas, where the solar oscillation is the more important, and at those places the high and low waters occur at about the same time each day. At Port Adelaide, Australia, (figure 60) the solar and lunar semidiurnal oscillations are equal and nullify one another at neaps.

The attractive force of the sun is slightly less than half the amount caused by the moon. This is because of the moon's relative size and short distance from the earth as compared to the sun. Therefore, lunar tides are more pronounced than those caused by the sun.

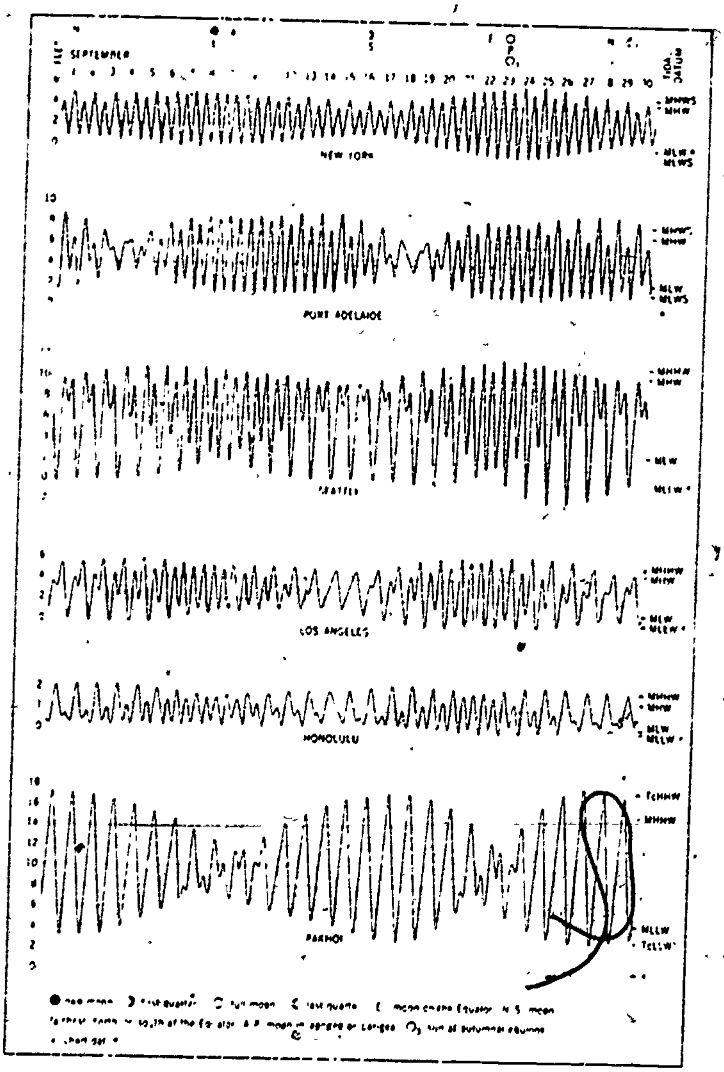


Figure 60.— Tidal variations at various places during a month.

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When the moon and sun are in line with the earth (at both new and full moon), the two effects act together or reinforce each other. High tides are then at a maximum, and low tides a minimum. Tides caused by the joint action of the sun and moon are called spring tides. The name has no connection with the seasons of the year.

The sun and moon are at quadrature when they are 90° from one another as measured from the earth (at both first and last quarter). At quadrature, the two tidal effects tend to counteract each other. High tides are not as high nor are low tides as low. These tides are called neap tides. Spring tides have the greatest range; neap tides, the least range.

A tide at a particular place exhibits many variations during the month (figure 60). The range of the tide varies in accordance with the intensity of the tide-producing force, though there may be a lag of a day or two between a particular astronomic cause and the tidal effect.

As the moon orbits around the earth, its distance from the earth varies. At perigee, the moon is at the point in its orbit nearest the earth. At apogee, the moon is farthest from the earth. The moon's distance from the earth affects the strength of the tide-producing forces and, consequently, the range of the tide.

When the moon is closest to the earth— at perigee— the semidiurnal range is increased and perigean tides occur. When the moon is farthest from the earth — at apogee— the smaller, apogean tides occur. When the sun and moon are in line and are pulling together, as at new and full moon, spring tides occur. When the moon and sun oppose each other, as at quadrature, the smaller, neap tides occur. At certain times, these phenomena coincide, reinforcing each other to produce the great, perigean spring tides and the small apogean neap tides. These are variations in the semidiurnal portion of the tide.

When the moon is at its maximum semimonthly declination (either north or south), the range of the tide is at a maximum. The tides that occur during this period are called tropic tides. When the moon crosses the equator, the diurnal range is at a minimum. These smaller-range tides are called equatorial tides.

When the range of tide is increased, as in spring tides, the high waters rise higher, and the low waters fall lower. The greater the range of a tide, the more depth at high tide and the less depth at low tide. For example, there is more depth at neap low water than at spring low water. With tropic tides, there is usually more depth at one low water during the day than at the other.

While it is desirable to know the meanings of these terms, the best way of determining the height of the tide at any given place and time is to examine the tide predictions for the place as given in the tide table. Figure 61 illustrates variations in the ranges and heights of tides in a locality where the water level always exceeds the charted depth.

Tide Cycles: Tide predictions can also be based on a knowledge of tide cycles. The basic tide cycle extends from any phase of a tide to the next recurrence of the same phase. During a lunar day (averaging 24 hours and 50 minutes) each of the two semidiurnal cycles is completed in about 12 hours and 25 minutes. Another cycle, which is caused by the phases of the moon, lasts about two weeks—the approximate time that the moon requires to change from new to full or from full to new. The tide cycle involving the moon's distance from the earth requires approximately a lunar month (a synodical month of about 29 1/2 days). The sun's declination and distance cycles are a half year and a year in length, respectively. An important lunar cycle, called the nodal period, is 18.6 years (usually expressed in round figures as 19 years). For a tide value, particularly a range, to be considered a true mean, it must either be based upon observations extended over the nodal period of time or be adjusted to take account of variations known to occur during the period.

Since the lunar tide-producing force has the greater effect in producing tides at most places, the tides "follow the moon." If the earth were not rotating, high water on the open sea would occur at about the time of meridian passage (upper and lower) of the moon. Because of the rotation of the earth, high water lags behind meridian passage. The tidal day, which is also the lunar day, is the time between consecutive transits of the moon, or 24 hours and 50 minutes on the average. Where the tide is largely semidiurnal in type, the lunitidal interval—the interval between the moon's meridian transit and a particular phase of tide— is fairly constant throughout the month, varying somewhat with the tide cycles.

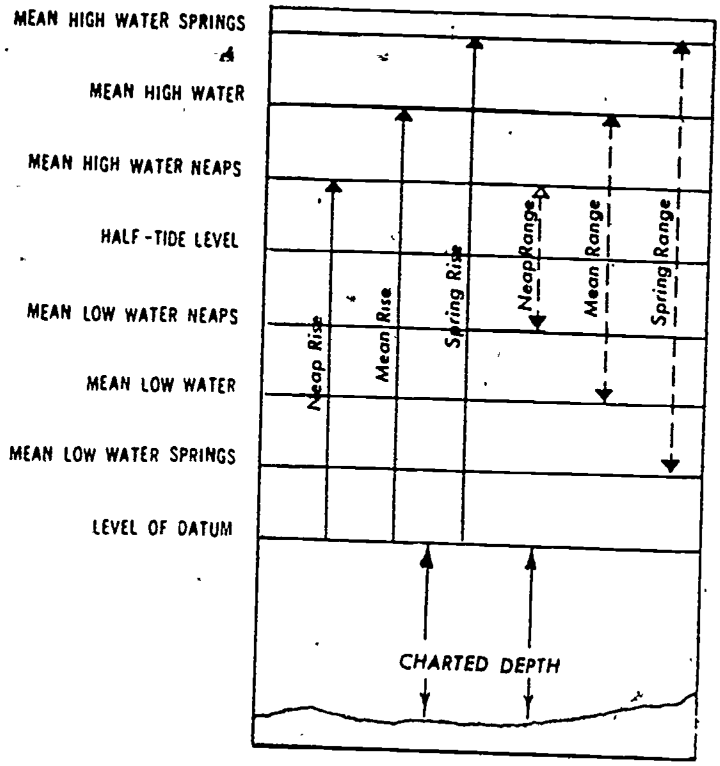


Figure 61.— Variations in the ranges and heights of tide in a locality where the water level always exceeds the charted depth.

In the ocean, the tide may be of the nature of a progressive wave with the crest moving forward, a stationary or standing wave which oscillates in a seesaw fashion, or a combination of the two. Consequently, caution should be used in inferring the time of tide at a particular place from tidal data for nearby places. In a river or estuary, for example, because the tide enters from the sea and is usually sent upstream as a progressive wave, the tide occurs progressively later at various places upstream.

The nature of a tide at any given place can also be affected by land-mass interference. Land masses interfere with the action that would normally be carried out if the earth were without these barriers. This is especially true of harbor basins with narrow, restricted entrances where the water is kept from flooding the basin as rapidly as the water level of the ocean rises. Similarly, the water is prevented from ebbing as quickly as the ocean level falls.

Tidal Datums: Determination of the height and depth of tides is based on an arbitrary point of reference known as a tidal datum. There are a number of such levels of reference that are important to the mariner. The relation of the tide each day during a month to these datums is shown, for certain places, in figure 60.

The most important level of reference to the mariner is the datum of soundings on charts. Since the tide rises and falls continually while soundings are being taken during a hydrographic survey, the tide should be observed during the survey so that soundings taken at all stages of the tide can be reduced to a common datum. Soundings on charts show depths below a selected low water datum (occasionally mean sea level), and tide predictions in tide tables show heights above the same level. The depth of water available at any time is obtained by adding the height of the tide at the time in question to the charted depth, or by subtracting the predicted height if it is negative.

By international agreement, the level used as chart datum should be just low enough so that low waters do not go far below it. At most places, however, the level used is one determined from a mean of a number of low waters (usually over a 19-year period); therefore, some low waters can be expected to fall below it. The following are some of the tidal datums in general use.

The highest low water datum in considerable use is mean low water (MLW), which is the average height of all low waters at a place. About half of the low waters fall below it. Mean low water spring (MLWS), usually shortened to low water springs, is the average level of the low waters that occur at the times of spring tides. Mean lower low water (MLLW) is the average height of the lower low waters at a place. Tropic lower low water (TcLLW) is the average height of the lower low waters (or of the single daily low waters if the tide becomes diurnal) that occurs when the moon is near maximum declination and the diurnal effect is most pronounced. This datum is not in common use as a tidal reference. Indian spring low water (ISLW), sometimes called indian tide plane or harmonic tide plane, is a low datum that includes the spring effect of the semidiurnal portion of the tide and the tropic effect of the diurnal portion. It is about the level of lower low water of mixed tides at the time that the moon's maximum declination coincides with the time of new or full moon. Mean lower low water springs is the average level of the lower of the two low waters on the days of spring tides. Some still lower datums used on charts are determined from tide observations, and some are determined arbitrarily and are later referred to the tide. Most of these datums fall close to one of two datums—lowest normal low water and lowest low water. Lowest normal low water is a datum that approximates the average height of monthly lowest low waters, discarding any tides disturbed by storms. Lowest low water is an extremely low datum. It conforms generally to the lowest tide observed, or even somewhat lower. Once a tidal datum is established, it is generally retained for an indefinite period, even though it might differ slightly from a better determination from later observations. When this occurs, the established datum may be called low water datum, lower low water datum, etc.

In some areas where there is little or no tide, such as the Baltic Sea, mean sea level (MSL) is used as chart datum. This is the average height of the surface of the sea for all stages of the tide over a 19-year period. This may differ slightly from half-tide level, which is the level midway between mean high water and mean low water.

Inconsistencies of terminology are found among charts of different countries and between charts issued at different times. For example, the spring effect as defined here is a feature of only the semidiurnal tide, yet it is sometimes used synonymously with tropic effect to refer to times of increased range of a diurnal tide. Such inconsistencies are being reduced through increased international cooperation.

Large-scale charts usually specify the datum of soundings and may contain a tide note giving mean heights of the tide at one or more places on the chart. These heights are intended merely as a rough guide to the change in depth to be expected under the specified conditions. They should not be used for the prediction of heights on any particular day. Such predictions should be obtained from Tide Tables.

Heights of land features are usually referred on nautical charts to a high water datum. The one used on charts of the United States, its territories, and possessions, and widely used elsewhere, is mean high water (MHW), which is the average height of all high waters over a 19-year period. Any other high water datum in use on charts is likely to be higher than this. Other high water datums are mean high water springs (MHWS), which is the average level of the high waters that occur at the time of spring tides; mean higher high water (MHHW), which is the average height of the higher high waters of each day; and tropic higher high water (TcHHW), which is the average height of the higher high waters (or the single daily high waters if the tide becomes diurnal) that occur when the moon is near maximum declination and the diurnal effect is most pronounced. A reference merely to "high water" leaves some doubt as to the specific level referred to, for the height of high water varies from day to day. Where the range is large, the variation during a two-week period may be considerable.

Tide Predictions: The tide at different places responds differently to the tide-producing forces. Thus, the nature of the tide at any place can be determined most accurately by actual observation. The predictions in Tide Tables and the tidal data on nautical charts are based on such observations.

Tides are usually observed by means of a continuously-recording gage. A year of observation is the minimum length desirable for determining various factors used in prediction. A longer period of time is necessary for determining mean sea level or long-time changes in the relative elevations of land and sea. For these, as well as other special uses, observations have been made at important locations over periods of 20, 30 and even 50 years.

Observations for a month or less will establish the type of tide. Such observations can be used for comparison with tides of a similar type to determine differences and variations.

Most published tide predictions are made on the tide predicting machine. In its calculations, the machine takes into account all of the various tide-producing forces and factors, including phase of the moon, and distance and declination of the sun and moon.

Tide Tables: Tide Tables are published annually by the National Oceanic and Atmospheric Administration. They are published in four volumes, which cover the areas of Europe and West Africa; East Coast of North and South America, including Greenland; West Coast of North and South America, including Hawaii; and the Central and Western Pacific Ocean and Indian Ocean.

Table 1 gives the daily tide predictions, list of reference stations, explanation of the table, typical tide curves for certain United States ports, and daily predictions for reference stations. In order to extract the time of tide for any port in the vicinity of a reference station, it is first necessary to locate the nearest reference point and then if a ratio or difference is indicated, apply it to the tabular value of time or height of tide of the reference station according to the information desired.

Table 2 lists Tidal Differences and Constants, explanation of the table, and lists Secondary or Subordinate stations in geographical order according to latitude and longitude and includes such information as will be applicable to the predictions of a stated reference station, enabling mariners to obtain tidal information for the vicinity of the subordinate station. The Differences Column of the table gives times of advance or retard of the time of the tide near the reference station. Differences are marked either plus or minus and must be added to or subtracted from the times shown in Table 1, according to the sign listed in Table 2. The mean range and spring range of tide are also listed and are shown in feet and tenths of feet.

Table 3 provides information for use in finding the approximate height of the tide at any time between high water and low water.

Table 4 is a sunrise-sunset table at five-day intervals for various latitudes from 76°N to 60°S (40°S in one volume).

Table 5 provides an adjustment to convert the local mean time of Table 4 to zone or standard time.

Table 6 (two volumes only) gives the zone time of moonrise and moonset for each day of the year at certain selected places.

Table 7 gives certain astronomical data. In the two volumes not having moonrise-moonset tables, this is Table 6.

Tidal Currents.—As you have already learned, the rise and fall of tides cause currents called tidal currents. When the horizontal movement is toward the land, the current is known as a flood current, and inversely when it is away from the land, it is called an ebb current. The period of time when there is no motion of the water, such as when the tide is near high and again when it is near low water, is called slack water. The maximum speed of a current between consecutive slack waters is referred to as the strength of flood or the strength of ebb. Although the term "strength" is often used to refer to speed, it is used more often to refer to the greatest speed between consecutive slack waters.

Tidal currents are most pronounced in the entrances to large tidal basins that have restricted openings to the sea. This fact often accounts for steerage problems experienced by vessels.

Tide rips caused by swift tidal currents flowing over an irregular bottom often set up rips and eddies that are generally deceptive in appearance and will sometimes change a ship's course as much as 30 degrees. One characteristic appearance of a tide rip is in the coloring of the water. The line caused may not always be straight, but can usually be seen if watched for. Another characteristic is the small wavelets caused by the wind. The water outside the current will often have many small wavelets, whereas the swift running current may be barren of wavelets, and again a quite visible line may be detected, giving the helmsman a clue to what may be forthcoming as the ship passes from one side of the line to the other.

In rivers or straits, where the direction of flow is more or less restricted to certain channels, the tidal current is reversing; that is, it flows alternately in approximately opposite directions, with slack water at each reversal of the current. During the flow in each direction, the speed varies from zero at the time of slack water to a maximum at the strength of flood or the strength of ebb, which occurs about midway between the slacks. Reversing currents can be indicated graphically, as in figure 62, by arrows that represent the speed of the current at each hour. The flood is usually depicted above the slack water line and the ebb below it. The tidal curve formed by the ends of the arrows has the same characteristic sine form as the tide curve. (In illustrations for certain purposes, as in figures 65 and 68, it is convenient to omit the arrows and show only the curve.)

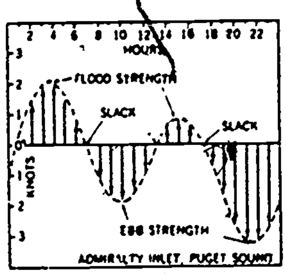


Figure 62.— Reversing tidal current.

A slight departure from the sine form is exhibited by the reversing current in a strait, such as East River, New York, that connects two tidal bodies of water. The tides at the two ends of a strait are seldom in phase or equal in range. This current, called hydraulic current, is generated largely by the continuously changing difference in height of water at the two ends. The speed of a hydraulic current varies directly in relation to the height of the water at the two ends. The speed reaches a maximum more quickly and remains at strength for a longer period than shown in figure 62, and the period of weak current near the time of slack is considerably shortened.

Besides being found in narrow bights or along coasts, tidal currents are also found on the high seas. These, however, are not as frequent as the tidal currents near shore.

Offshore, where the direction of flow is not restricted by any barriers, the tidal current is rotary; that is, it flows continuously, with the direction changing through all points of the compass during the tidal period. The tendency for the rotation in direction has its origin in the deflecting force of the earth's rotation, and unless modified by local conditions, the change is clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The speed usually varies throughout the tidal cycle, passing through two maximums in approximately opposite directions and two minimums about halfway between the maximum in time and direction. Rotary currents can be depicted, as in figure 63, by a series of arrows representing the direction and speed of the current at each hour. This depiction is sometimes called a current rose. Because of the elliptical pattern formed by the ends of the arrows, it is also referred to as a current ellipse.

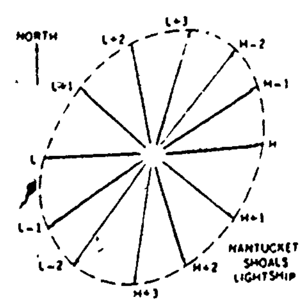


Figure 63.—Rotary tidal current. Times are hours before and after high and low tide at Nantucket Shoals Lightship. The bearing and length of each arrow represents the hourly direction and speed of the current.

Tidal currents are classified as semidiurnal, diurnal, or mixed, corresponding to a considerable degree to the type of tide at the place, but often with a stronger semidiurnal tendency.

The tidal currents in tidal estuaries along the Atlantic coast of the United States are examples of the semidiurnal type of reversing current. At Mobile Bay entrance, they are almost purely diurnal. At most places, however, the type is mixed a greater or lesser degree. At the Tampa and Galveston entrances, there is only one flood and one ebb each day when the moon is near its maximum declination, and two floods and two ebbs each day when the moon is near the equator. Along the Pacific coast of the United States, there are generally two floods and two ebbs every day, but one of the floods or ebbs has a greater speed and longer duration than the other, the inequality varying with the declination of the moon. The inequalities in the current often differ considerably from place to place even within limited areas, such as adjacent passages in Puget Sound and various passages between the Aleutian Islands. Figure 64 shows several types of reversing current. Figure 65 shows how the flood disappears as the diurnal inequality increases at one station.

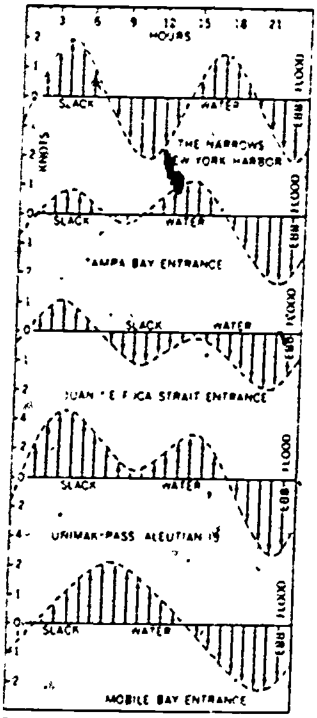


Figure 64.—Several types of reversing currents. The pattern changes gradually from day to day, particularly for mixed types, which pass through cycles somewhat similar to those shown for tides in figure 59.

In a purely semidiurnal type of current unaffected by nontidal flow, the flood and ebb each last about six hours and 13 minutes. But if there is either diurnal inequality or nontidal flow, the durations of flood and ebb may be quite unequal.

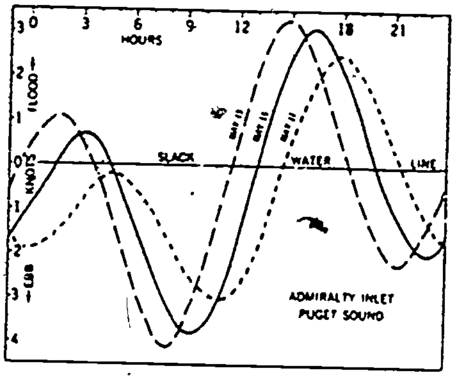


Figure 65.—Changes in a current of the mixed type. Note that each day as the inequality increases, the morning slacks draw together in time until on the 17th the morning flood disappears. On that day the current ebbs throughout the morning.

Offshore rotary currents that are purely semidiurnal repeat the elliptical pattern (figure 63) each tidal cycle of 12 hours and 25 minutes. If there is considerable diurnal inequality, the plotted hourly current arrows describe a set of two ellipses of different sizes during a period of 24 hours and 50 minutes, as shown in figure 66, and the greater the diurnal inequality, the greater the difference between the sizes of the two ellipses. In a completely diurnal rotary current, the smaller ellipse disappears and only one ellipse is produced in 24 hours and 50 minutes.

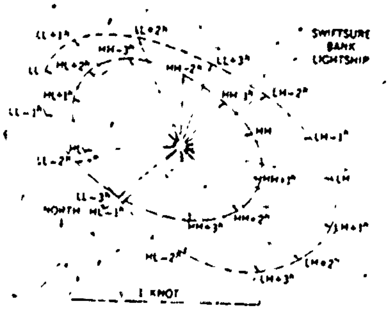


Figure 66.—Rotary tidal current with diurnal inequality. Times are in hours referred to tides (higher high, lower low, lower high, and higher low) at Swiftsure Bank Lightship.

Tidal currents have periods and cycles similar to those of the tides, and are subject to similar variations, but flood and ebb of the current do not necessarily occur at the same times as the rise and fall of the tide.

The speed at strength increases and decreases with the variation in range of tide during two-week, monthly, and annual cycles. The strong currents, spring and perigean, occur near the times of new and full moon and near the times of the moon's perigee, respectively, or at times of spring and perigean tides, respectively. The weaker currents, the neap and apogean, occur at the times of neap and apogean tides, respectively.

As with tides, a mean value represents an average obtained from a 19-year series. Since a series of current observations is usually limited to a day or two and seldom covers more than a month or two, it is necessary to adjust the observed values, usually by comparison with tides at a nearby place, to obtain such a mean.

As you have already learned, a current existing at any time is seldom purely tidal; it usually includes a nontidal current that is due to drainage, oceanic circulation, wind, or another cause. The method in which tidal and nontidal currents combine is best explained graphically, as in figures 67 and 68. The pattern of the tidal current remains unchanged, but the curve is shifted from the point or line from which the currents are measured in the direction of the nontidal current and by an amount equal to it. It is sometimes more convenient graphically merely to move the line or point of origin in the opposite direction.

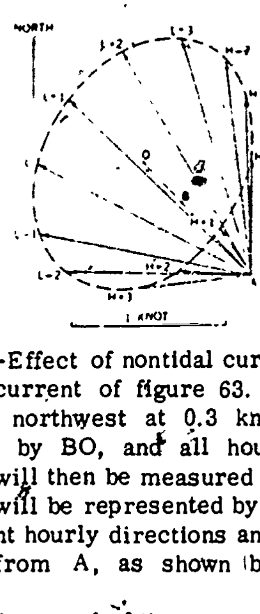


Figure 67.—Effect of nontidal current on the rotary tidal current of figure 63. If the nontidal current is northwest at 0.3 knot, it may be represented by BO, and all hourly directions and speeds will then be measured from B. If it is 1.0 knot, it will be represented by AO and the actual resultant hourly directions and speeds will be measured from A, as shown by the arrows.

Thus, the speed of the current flowing in the direction of the nontidal current is increased by an amount equal to the magnitude of the nontidal current, and the speed of the current flowing

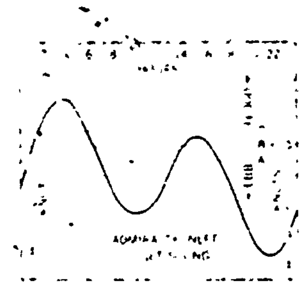

Figure 68.—Effect of nontidal current on the reversing tidal current of figure 61. If the nontidal current is 0.5 knot in the ebb direction, the ebb is increased by moving the slack water line from position A up 0.5 knot to position B. Speeds will then be measured from this broken line as shown by the scale on the right, and times of slack are changed. If the nontidal current is 1.0 knot in the ebb direction, as shown by line C, the speeds are as shown on the left and the current will not reverse to a flood in the afternoon; it will merely slacken at about 1500.

in the opposite direction is decreased by an equal amount. In figure 67 a nontidal current is represented both in direction and speed by the vector AO. Since this is greater than the speed of the tidal current in the opposite direction, point A is outside the ellipse. The direction and speed of the combined tidal and nontidal currents at any time is represented by a vector from A to that point on the curve representing the given time, and can be scaled from the graph. The strongest and weakest currents may no longer be in the directions of the maximum and minimum of the tidal current.

In a reversing current (figure 68), the effect is to advance the time of one slack and to retard the following one. If the speed of the nontidal current exceeds that of the reversing tidal current, the resultant current flows continuously in one direction without coming to a slack. In this case, the speed varies from a maximum to a minimum and back to a maximum in each tidal cycle.

In figure 68 the horizontal line A represents slack water if only tidal currents are present. Line B represents the effect of a 0.5-knot nontidal ebb, and line C, the effect of a 1.0-knot nontidal ebb. With the conditions shown at C, there is only one flood each tidal day. If the nontidal ebb were to increase to approximately two knots, there would be no flood, two maximum ebbs, and two minimum ebbs occurring during a tidal day.

As we have already suggested, at many places where current and tide are both semidiurnal, there is a definite relation between times of current and times of high and low water in the locality. Current atlases and notes on nautical charts often make use of this relationship by presenting for particular locations the direction and speed of the current at each succeeding hour after high and low water at a place for which tide predictions are available.

In localities where there is considerable diurnal inequality in tide or current, or where the type of current differs from the type of tide, the relationship is not constant, and it may be hazardous to try to predict the times of current from times of tide. Note the current curve for Unimak Pass in the Aleutians in figure 64. It shows the current as predicted in the Tidal Current Tables. Predictions of high and low waters in the Tide Tables might have led one to expect the current to change from flood to ebb in late morning, whereas actually the current continued to run flood with some strength at that time.

Since the relationship between times of tidal current and tide is not everywhere the same and may be variable at the same place, one should exercise extreme caution in using general rules. The belief that slacks occur at local high and low tides and that the maximum flood and ebb occur when the tide is rising or falling most rapidly may be approximately true at the seaward entrance to, and in the upper reaches of, an inland tidal waterway. But generally this is not true in other parts of inland waterways. When an inland waterway is extensive or its entrance constricted, the slacks in some parts of the waterway often occur midway between the times of high and low tide. Usually in such waterways the relationship changes from place to place as one progresses upstream, slack water getting progressively later with respect to the local tide until at the head of tidewater (the inland limit of water affected by a tide) the slacks occur at the times of high and low tide.

The variation in the speed of the tidal current from place to place is not necessarily consistent with the range of tide. It may be the reverse. For example, currents are weak in the Gulf of Maine where the tides are large, and strong near Nantucket Island and in Nantucket Sound where the tides are small.

At any one place, however, the speed of the current at strength of flood and ebb varies during the month in about the same proportion as the range of tide, and one can use this relationship to determine the relative strength of currents on any day.

In inland tidal waterways, the time of tidal current varies across the channel from shore to shore. On the average, the current turns earlier near shore than in midstream; where the speed is greater. Differences of half an hour to an hour are not uncommon, but the difference varies and the relationship may be nullified by the effect of nontidal flow.

The speed of the current also varies across the channel, usually being greater in midstream or midchannel than near shore, but in a winding river or channel the strongest currents occur near the concave shore. Near the opposite (convex) shore, the currents are weak or may eddy.

In tidal rivers the subsurface current acting on the lower portion of the hull may differ considerably from the surface current. An appreciable subsurface current may be present when the surface movement appears to be practically slack, and the subsurface current may even be flowing with appreciable speed in the opposite direction to the surface current.

In a tidal estuary, particularly in the lower reaches where there is a considerable difference in density from top to bottom, flood usually begins earlier near the bottom than at the surface. The difference may be an hour or two or as little as a few minutes, depending upon the estuary, the location in the estuary, and freshet conditions. Even when the fresh water runoff becomes so great as to prevent the surface current from flooding, it may still flood below the surface. The difference in time of ebb from surface to bottom is normally small but subject to variation with time and location.

The ebb speed at strength usually decreases gradually from top to bottom, but the speed of flood at strength often is stronger at subsurface depths than at the surface.

Observations: Observations of a tidal current are made by means of either a current meter or a current pole and log line. In the past, most successful meters required a vessel and observers in continual attendance, as is necessary with the pole and line. Because of the difficulty and expense of such observations, they usually covered only a period of a day or two at a place. Observations of a month were the exception, and longer series were obtained only where ship and observers were available because of other duties, such as at lightships, where observations have been continued over a number of years.

Newer meters which have been or are being developed are suspended from a buoy and record either in the buoy or send speed and direction impulses by radio to a base station on ship or land. With them, the period of observation has been increased so that in some surveys of United States harbors, the minimum period of observation is four days, with observations at several stations being continued over a period of 15 to 29 days.

Tidal Current Tables and Charts: Predictions of tidal currents must be based on specific information for the locality in question. Such information is contained in various forms in many navigational publications.

Tidal Current Tables, issued annually, list daily predictions of the times and strengths of flood and ebb currents and the times of intervening slacks. Due to lack of observational data, coverage is considerably more limited than for the tides. The Tidal Current Tables do include supplemental data by which tidal current predictions can be determined for many places in addition to those for which daily predictions are given. The predictions are made by the tide-predicting machine, using current harmonic constants that are obtained by analyzing current observations in the same manner as for tides.

Tidal Current Tables are somewhat similar to Tide Tables, but the coverage is less extensive, being given in two volumes—one for the Pacific and one for the Atlantic. The volume for the Pacific contains four tables; the volume for the Atlantic, five tables. Of the following descriptions of each of the Tidal Current Tables, those for Tables 1 through 4 apply to both the Atlantic and the Pacific and the description of Table 5 applies only to the Atlantic.

Table 1 contains a complete list of predicted times of maximum currents and slack and the velocity of the maximum currents, for a number of reference stations.

Table 2 gives differences, ratios, and other information related to a relatively large number of subordinate stations.

Table 3 provides information for use in finding the speed of the current at any time between tabulated entries in Tables 1 and 2.

Table 4 gives the number of minutes the current does not exceed stated amounts, for various maximum speeds.

Table 5 (Atlantic Coast of North America only) gives information on rotary tidal currents.

It must be noted that the content of these tables is not limited to only the data mentioned above. Each table contains additional, useful information related to currents.

Sets of tidal current charts, each containing 12 charts, are published by the National Oceanic and Atmospheric Administration of the Department of Commerce. These charts are printed in color and show, by use of arrows and numbers, the direction and velocity of the tidal currents for each hour of the tidal cycle. The charts, good for any year, present a comprehensive view of the tidal current movement in the respective waterways as a whole, and also supply a means for readily ascertaining the direction and velocity of the current at various localities throughout the area covered, at any time.

These charts are available for the following locations: San Francisco Bay, Narragansett Bay to Nantucket Sound, Long Island Sound, Block Island Sound, New York Harbor and Boston Harbor, Delaware Bay and River, Tampa Bay, and Puget Sound—northern and southern parts.

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# THE ATMOSPHERE

A correspondence course pamphlet consisting of excerpts from:

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U.S. COAST GUARD INSTITUTE
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WARNING

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# FUNDAMENTALS OF METEOROLOGY

An understanding of meteorology necessitates an understanding of some mathematics and physics. However, it is often difficult to separate the physical aspects of meteorology into pure physics. Therefore, some physical aspects of meteorology are treated as part of meteorological explanations. In other cases the pure physics is self-evident.

The treatment of meteorology in this course progresses from the overall governing fundamentals of meteorology in this section to a thorough description of meteorological elements in Section 2. Sections 3 through 5 consider the meat of the study of meteorology: atmospheric circulation; fronts; air masses; and weather phenomena, such as thunderstorms, tornadoes, and hurricanes.

## HISTORY OF METEOROLOGY

Perhaps one of the best ways for a Marine Science Technician to launch into a study of a major science such as meteorology is to review a little of its history. Learning how meteorological concepts evolved through the centuries allows you to gain appreciation of the problems which meteorologists faced in the past.

Combining the observed facts with the known laws of physics and chemistry, weather experts have developed the science referred to as METEOROLOGY. Meteorology is defined as the science, or branch of physics, treating of the atmosphere and its phenomena, especially of its variations of heat, pressure, moisture, and winds. Previously you may have heard "meteorology" referred to as "aerology," but with the technical advances in the science of weather, the all-encompassing word "meteorology" is now officially used.

Though meteorology is young in development, it is old in history and dates back to the pre-Christian era. In writing the history of meteorology, it is difficult to give complete coverage because of its close relationship to other sciences, such as mathematics, physics, and astronomy.

At the beginning man undoubtedly took notice only of spectacular weather phenomena. As he progressed intellectually, he ascribed weather phenomena to the manifestations of the gods. In pre-Biblical times, weather proverbs were formulated and passed on from generation to generation. It is known that wind vanes were in use in Greece around 100 B.C. As early as 400 B.C., ancient Greek scholars wrote treatises on meteorology and related subjects. Two of these were Hippocrates and Aristotle. Hippocrates wrote his first book showing the influences of weather on the medical well-being of man. Aristotle collected material on meteorology and put it into his Meteorologica, recognized until recent times as an authoritative treatise on weather. Also during this period, rainfall measurements were made in India, where the amount of rainfall was of particular interest in agriculture.

Theophrastus, a student of Aristotle, compiled the Book of Signs, which consisted of numerous signs for rain, winds, storms, and fair weather. Virgil, the Roman, made a similar compilation in his Georgics. Erasmus Darwin, the grandfather of Charles Darwin, put into verse form similar signs for weather. Much of the folklore and proverbs concerning weather have thus been preserved through the ages. Many of these rules or signs were remarkably reliable; some of them were pure superstition. All of them point to man's concern about the weather and his attempts to study it and foretell it.

Very little progress was made in meteorology as a science during the Dark Ages. Meteorology awaited progress in mathematics and physics for theoretical advances and progress in technology for advances in instrumentation. Without instruments to measure the atmospheric elements, meteorology was lifeless.

The Renaissance marked the beginning of rapid development in meteorology. This development in meteorology occurred in conjunction with the developments in physics and mathematics. At the time there were few meteorologists—as such. Instead, there were mostly philosphers, mathematicians, or physicists who made discoveries and inventions with meteorological application. Francis Bacon introduced the scientific method to the study of meteorology. Galileo invented the air thermometer. Torricelli invented the barometer and discovered the true nature of atmospheric pressure. Hooke constructed an anemometer and other instruments of meteorological significance. Edmund Halley made surveys of heating on the earth and correlated them to the general circulation. Boyle and Dalton experimented with gases and formulated their famous laws.

Following this period, steady improvement in instruments was achieved. By the middle of the eighteenth to the middle of the nineteenth century the theoretical foundations of the atmospheric processes were laid. It was during this period that the first organized network of meteorological stations was set up. This brought about the first attempts at constructing synoptic charts. The French astronomer Le Verrier established the usefulness of synoptic charts when he was commissioned by Napoleon III to trace the history of a destructive storm that had caused serious damage to the French fleet in the Black Sea.

The most important achievements in modern weather forecasting have been made since 1918, when V. Bjerknes, a Norwegian meteorologist, and his associates developed the polar front and wave theory of cyclones. These developments led to the air-mass and frontal methods of weather forecasting which have become a basic tool in present-day forecasting. The use of radio equipment for upper air sounding has provided useful information for 3-dimensional analysis of the atmosphere. A very fruitful period in the history of meteorology was between World War I and World War II. Some of the important discoveries and developments were as follows:

1. Polar front.

2. Wave theory of cyclones.

3. Air-mass and frontal methods of forecasting by V. Bjerknes.

4. Theories on convection, condensation, and precipitation processes.

5. Improved techniques of surface and upper air observations.

6. Reporting networks established and expanded.

7. Accuracy in 24- to 36-hour forecasts improved.

8. Experiments in long-range forecasting.

During and since World War II many of the developments have been in the field of electronic means for obtaining meteorological data. Some of the equipment includes the following:

1. Transmissometer Set, AN/GMQ-10.
2. Cloud Height Set, AN/GMQ-13.
3. Aerograph Sets, AN/AMQ-17 and -18.
4. Rawin Set, AN/GMD-1A, and GMD-2.
5. Radar Sets, AN/FPS-41, -68 and -81.
6. Weather satellites.—The TIROS program has proven highly successful for satellite weather data collection during the past few years. The need for a continuous daily full-earth coverage is provided by TOS (TIROS Operational Satellite).

The major postwar advance in theoretical and practical meteorology is the application of electronic computers in numerical weather forecasting. In addition, thorough studies are being made of thunderstorms and tropical cyclones (hurricanes and typhoons) and have already resulted in better methods of forecasting these phenomena. Improved methods for forecasting tornado conditions have also been developed. Theories concerned with the development of wave cyclones have been refined as a result of the availability and utilization of upper air data.

The foregoing treatment of the history of meteorology was necessarily brief. However, it should have been sufficient to show that great strides have been and are still being made in meteorological science. These advances are treated in detail in later chapters.

## EARTH-SUN RELATIONSHIP

The earth is a part of the solar system. Although the system has many components, we are primarily interested in only the earth and the sun. In this section, we will consider the effect the sun has upon the earth.

### SUN

The sun may be regarded as the only source of heat energy that is supplied to the earth's surface and the atmosphere. The cause of all weather and motions in the atmosphere may, therefore, be found in the energy radiated from the sun.

The sun, with a surface temperature of about 6,000° C. (10,300° F.), radiates electromagnetic energy in all directions. The earth intercepts about one two-billionths of this energy. Most of the electromagnetic energy radiated by the sun is in the form of light waves. Only a tiny fraction is in the form of heat waves. Even so, better than 99.9 percent of the earth's heat is derived from the sun. Radiant energy is the prime contribution by the sun.

### EARTH

Of the nine planets of our solar system, the earth is third in distance from the sun. Its maximum distance from the sun is 94 million miles in summer and its minimum distance from the sun is 91 million miles in winter. It has an atmosphere more than 600 miles thick.

### MOTIONS OF THE EARTH

The earth is subject to four motions: rotation of the earth about its axis, revolution of the earth around the sun, precessional motion, and solar motion. Only two of these motions are of any importance to meteorology: the earth's rotation about its axis and its revolution around the sun.

The earth rotates on its axis once in 24 hours, and one-half of the earth's surface is therefore facing the sun at all times. The side facing the sun is experiencing daylight and the side facing away from the sun is experiencing darkness, which account for our day and night. Rotation about its axis takes place in an eastward direction. Thus, the sun rises in the east and sets in the west, as illustrated in figure 1.

The second motion of the earth is its revolution around the sun. The revolution around the sun and the tilt of the earth on its axis are responsible for our seasons. The earth makes one complete revolution around the sun in approximately 365 1/4 days. The earth's axis is at an angle of 23 1/2° to its plane of rotation. The earth points in a nearly fixed direction in space toward the North Star (Polaris) at all times. This tilt of the earth has major consequences, as you will see by examining figure 2.

When the earth is to the left of the sun as shown for June in figure 2, the Northern Hemisphere is inclined 23 1/2° TOWARD the sun. This inclination results in more of the sun's rays reaching the Northern Hemisphere than the Southern Hemisphere. On or about June 22, the sun shines OVER the North Pole down the other side to latitude 66 1/2° N. (the ARCTIC CIRCLE), and the most perpendicular rays of the sun are received at 23 1/2° N. lat. ( the TROPIC OF CANCER). The Southern Hemisphere is tilted AWAY from the sun at this time, and the sun's rays reach only to 66 1/2° S. lat. (the ANTARCTIC CIRCLE) and do not go beyond this latitude. The area between the Antarctic Circle and the South Pole is in darkness; the area between the Arctic Circle and the North Pole is receiving the sun's rays for 24 hours each day. Note carefully the shaded and unshaded area of the earth in figure 2 for all four positions.

At the equinoxes in March and September, the tilt of the earth's axis is neither toward nor away from the sun. For this reason, the earth receives equal numbers of the sun's rays in both the Northern Hemisphere and the Southern Hemisphere and the sun's rays shine most perpendicularly at the Equator.

In December, the situation is exactly reversed from that in June. The Southern Hemisphere now receives more of the sun's rays. The most perpendicular rays of the sun are received at 23 1/2° S. lat. (the TROPIC OF CAPRICORN). The south polar area is completely in sunshine, and the north polar area is completely in darkness.

Since the revolution of the earth around the sun is a gradual process, the changes in the area receiving the sun's rays are gradual, and the changes in seasons are also gradual. However, it is customary and convenient to

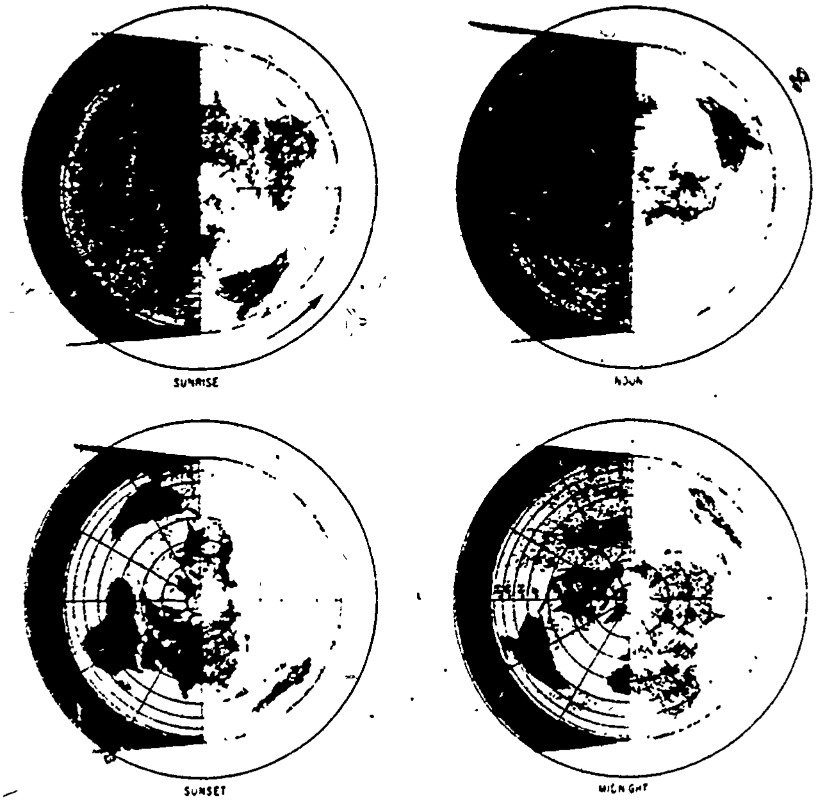


Figure 1.— Rotation of the earth about its axis (during equinoxes).

mark these changes by specific dates and to identify them by specific names. These dates are as follows:

1. March 21.— The VERNAL EQUINOX, when the earth's axis is perpendicular to the sun's rays. Spring begins in the Northern Hemisphere and fall begins in the Southern Hemisphere.

2. June 21.— The SUMMER SOLSTICE, when the earth's axis is inclined 23 1/2° toward the sun and the sun has reached its northernmost zenith at the Tropic of Cancer. Summer officially commences in the Northern Hemisphere and winter begins in the Southern Hemisphere.

3. September 22.— The AUTUMNAL EQUINOX, when the earth's axis is again perpendicular to the sun's rays. This date marks the beginning of fall in the Northern Hemisphere and spring in the Southern Hemisphere. It is also the date, along with March 21, when the sun reaches its highest position (zenith) directly over the Equator.

4. December 22.— The WINTER SOLSTICE, when the sun has reached its southernmost zenith position at the Tropic of Capricorn. It marks the beginning of winter in the Northern Hemisphere and the beginning of summer in the Southern Hemisphere.

In some years the actual dates of the solstices and the equinoxes vary by a day from the dates given here because the period of revolution is 365 1/4 days and the calendar year is 365 days, except for leap year when it is 366 days.

Because of its 23 1/2° tilt and its revolution around the sun, the earth is thus marked by five natural light (or heat) zones according to the zone's relative position to the sun's rays. Since the sun is ALWAYS at its zenith between the Tropic of Cancer and the Tropic of Capricorn, this is the hottest zone. It is called the Equatorial Zone, the Torrid Zone, the Tropical Zone, or simply the Tropics.

The zones between the Tropic of Cancer and the Arctic Circle and between the Tropic

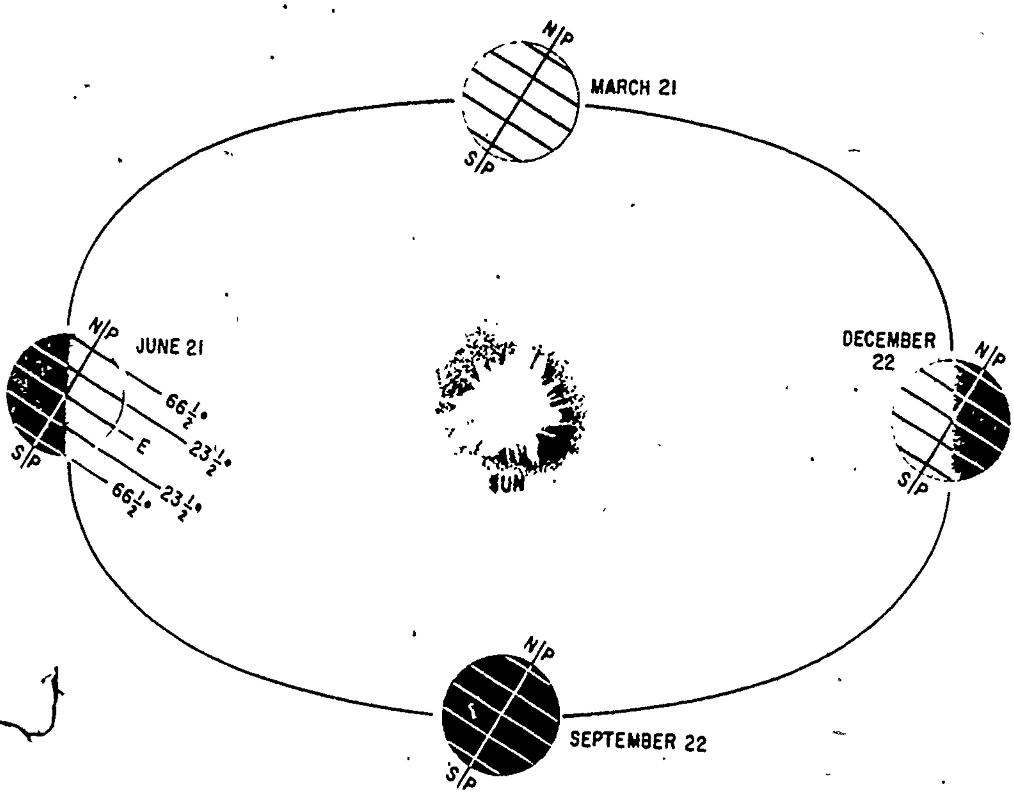


Figure 2.— Revolution of the earth around the sun.

of Capricorn and the Antarctic Circle are the Temperate Zones. These zones receive sunshine all year, but less of it in their respective winter and more of it in their respective summer.

The zones between the Arctic Circle and the North Pole and between the Antarctic Circle and the South Pole receive the sun's rays only for parts of the year. (Directly at the poles there are 6 months of darkness and 6 months of sunshine.) This, naturally, makes them the coldest zones. They are therefore known as the Frigid or Polar Zones.

SOLAR RADIATION.

Previously you have studied the motions of the earth in relationship to the sun and particularly in relation to the sun's rays. Now you will explore what the sun's rays are and what effect they have on the weather.

All substances radiate electromagnetic energy. This type of energy radiated is primarily dependent on the temperature of the substance. The higher the temperature, the greater the radiation intensity and variety of wavelengths.

Solar radiation is defined as the total electromagnetic energy emitted by the sun. The sun's 6000° C. surface emits gamma rays, X-rays, ultraviolet, visible light, infrared, heat, and electric waves. Even though the sun radiates in all wavelengths, about half of the radiation is visible light with most of the remainder being infrared.

The earth receives the sun's SHORT WAVE radiation, converts it to LONG WAVE radiation, and reradiates it out to space. This process is known as MOLECULAR STIMULATION. A measure of molecular activity is temperature. Therefore, a substance which is undergoing molecular stimulation is having its temperature raised.

The rate of solar radiation received just outside the earth's atmosphere has been found to be nearly constant (2 to 3 percent variation) and to have an approximate average value of 1.94 gram calories per minute per square centimeter. This value is known as the SOLAR CONSTANT.

For work in meteorology, the measurement of solar radiation at the fringe of the earth's atmosphere was found to be impractical. What was needed was a measure of the sun's radiation actually received at the earth's surface. Such a measurement was found and is referred to as INSOLATION. Insolation is the rate at which solar radiation is received by a unit horizontal surface at any point on or above the surface of the earth. Henceforth in this training course, insolation is used when speaking about incoming solar radiation.

## HEAT TRANSFER

Heat is a form of energy. Heat is also an index of molecular activity. We measure the quantity of heat in calories and the degree of heat as temperature. Look at it this way. Imagine two pots of water on a stove, each at the same temperature, but one pot having twice the amount of water as the other. Since both pots of water are at the same temperature, the molecules of water are moving at the same speed. However, since one pot has more water (and more molecules in motion), more heat (calories) was required to bring the water to the same temperature as that in the other pot.

As stated previously, molecular stimulation produces heat and that molecular stimulation is due to RADIATION. Radiation is not the only means of stimulating molecules. The other method of stimulating molecules is CONDUCTION, which is the stimulation of molecules occurring between two substances when one substance stimulates another. Therefore, we can say that we are dealing with HEAT TRANSFER.

Heat transfer is very important in meteorology. All weather as we know it comes about because a heat transfer has taken place, sometimes alone, and sometimes in conjunction with other processes. Let us briefly investigate the three methods of heat transfer.

### Radiation

Radiation refers to the process by which electromagnetic energy is propagated through space. Radiation occurs at the speed of light, that is, at about 186,300 miles per second. Radiation travels in straight lines and does not need a material medium through which to pass. It is the most important single means of heat transfer for the earth as a whole. All of the heat the earth receives is by radiation.

### Conduction

Conduction is the transfer of heat through molecules which are in contact with one another. Most solids are good conductors of heat. The atmosphere (and gases in general) are poor conductors of heat. Conduction of heat in the atmosphere takes place in the first few inches of air above the ground. In general, it is insignificant as a method of heat transfer in meteorology.

### Convection

Convection is the method of heat transfer in a fluid resulting in transport and mixing of the properties of that fluid. Visualize a pot of boiling water. The water at the bottom of the pot is heated by conduction. It becomes less dense and rises. Cooler and denser water from the sides and the top of the pot rushes in and replaces the rising water. In time, the water is thoroughly mixed. As long as heat is applied to the pot, the water continues to transfer heat by convection. The transfer of heat by convection in this case applies only to what is happening to the water in the pot.

Convection occurs regularly in the atmosphere; the air "boils" so to speak, and the results of this boiling are mass motions in the atmosphere; for example, the big bulging cumulus clouds we see in the sky.

### Advection

Advection is really a form of convection, but in meteorology it means the transfer of heat or other properties along the HORIZONTAL. Convection is the term reserved for the VERTICAL transport of heat. Henceforth in this training course, the words "convection" and "advection" are used to mean the vertical and horizontal transfer of atmospheric properties, respectively.

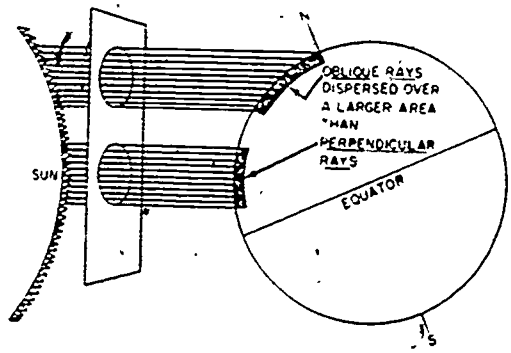


Figure 3.— Differential Insolation.

## EFFECTS OF THE EARTH

Having gained the necessary background, you are now ready to study the disposition of insolation, the insolation balance, and the heat balance in the earth's atmosphere.

### DISPOSITION OF INSOLATION

The earth is not uniformly warm. This means that there must be differences in insolation over the surface of the earth. This portion of the section explains how the differences in insolation are accounted for.

#### Dispersion

In the portion of this section entitled "MOTIONS OF THE EARTH," you learned that the earth's axis is inclined at an angle of 23 1/2°. This inclination of the earth's axis causes the sun's rays to be received on the surface of the earth at varying angles, depending on the position of the earth. When the sun's rays are not perpendicular to the surface of the earth, they become DISPERSED over a greater area, as can be seen in figure 3. Therefore, if the same number of rays has to cover a larger area, they cannot produce as much heat when they are dispersed, and the temperature in the area where the sun's rays are dispersed must be lower. Dispersion of insolation in the atmosphere takes place daily all over the earth due to the rotation of the earth, as can be seen from examining figure 1. Dispersion of insolation also takes place with the seasons in all latitudes of the earth, but especially in the latitudes in the polar areas, as illustrated in figure 2.

#### Absorption

Insolation is absorbed by a substance and is converted to heat, as has already been explained. Some substances absorb all radiant energy which reaches them; some absorb none; and some absorb only that in specific wavelengths. The latter is the case with some of the constituents of the atmosphere. The earth's surface absorbs an average of 51 percent of the isolation.

#### Reflection

Reflection is the process whereby a surface turns back a portion of the incident radiation into the medium through which the radiation came.

Some insolation is reflected by a substance. This means that the electromagnetic waves simply bounce back to space without stimulating molecules. The earth reflects an average of 36 percent of the insolation. The percent of reflectivity of all wavelengths of a surface is known as its ALBEDO. The earth's average albedo is from 36 to 43 percent. In calculating the albedo of the earth, the assumption is made that the average cloudiness over the earth is 52 percent.

All surfaces do not have the same degree of reflectivity; consequently they do not have the same albedo. Some examples are as follows:

1. Upper surfaces of clouds.— From 40 to 80 percent, with an average of about 55 percent.

2. Snow surfaces.— Over 80 percent for cold, fresh snow; as low as 50 percent for old, dirty snow.

3. Land surfaces.— From 5 percent for dark forests to 30 percent for dry land.

4. Water surfaces.— From 2 percent when the sun is directly overhead to 100 percent when the sun is very low on the horizon. This increase is not linear; after the sun is more than 25° above the horizon, the albedo is less than 10 percent so that, in general, the albedo of water is quite low.

When the earth as a whole is considered, cloud surfaces are most important in determining the earth's albedo.

Scattering

Insolation is also scattered before it reaches the earth's surface. When insolation is scattered in the sky, it causes us to see a blue sky.

Greenhouse Effect

The atmosphere itself absorbs some of the insolation, but on a selective basis. The shorter wavelengths of insolation pass through the atmosphere to the earth, but earth radiation (longer wavelength infrared radiation) is "trapped" by the atmosphere. Some of this trapped radiation is reradiated to the earth. This causes a higher earth temperature than would occur from direct insolation alone. This is the greenhouse effect. It gets its name because the process is the same as that taking place in a greenhouse: Most of the short-wave solar radiation passes through the glass roof and is absorbed by objects inside. These objects reradiate at their temperatures, which are relatively low compared to the sun's temperature; consequently they emit infrared radiation, which is absorbed by the glass. The glass, in turn, radiates energy back into the greenhouse, as well as outward, so that the temperature inside the greenhouse remains warmer than that outside.

Inversions

Inversions describe the atmospheric conditions when the temperature increases with altitude, rather than decreases as is usual. Inversions result from the selective absorption of the earth's radiation by the water vapor in the air and also from the sinking or subsidence of air, which results in its compression and, therefore, heating. Either effect alone may cause an inversion; combined, the inversion would be stronger.

Inversions are a frequent occurrence, especially at night, in the Tropics, and in the polar regions. For night conditions all over the world, for the polar regions, and for the tropical regions, it may be said that inversions in the lower levels are the rule rather than the exception.

RADIATION BALANCE IN THE ATMOSPHERE

The sun radiates insolation to the earth, the earth radiates energy back to space, and the atmosphere radiates energy also. As is shown in figure 4, a balance is maintained between incoming and outgoing radiation. Now let us consider the various radiation processes in maintaining this balance.

Insolation

The insolation that enters the earth's atmosphere is almost entirely short-wave radiation. About 36 percent is reflected back into space by the surface of the earth, cloud cover, and atmospheric particles; 13 percent is absorbed directly by water vapor and air; and 51 percent is absorbed by the earth. These figures are representative of average conditions.

Terrestrial (Earth) Radiation

Radiation emitted by the earth is almost entirely long-wave radiation. Most of the terrestrial radiation is absorbed by the water vapor in the atmosphere, with a small amount (about 8 percent) being radiated directly to outer space. Some is carried aloft by convection and turbulence, and the condensation-precipitation-evaporation cycle (hydrological cycle) carries the remainder into the atmosphere.

Atmospheric Radiation

The atmosphere reradiates to outer space most of the terrestrial radiation (about 43%) and insolation (about 13%) that it has absorbed. Some of this radiation is emitted downward and is known as COUNTERRADIATION. This radiation is of great importance in the greenhouse effect.

Diffuse Sky Radiation

About 25 percent of the incoming solar radiation is scattered by the atmosphere. About two-thirds of this scattered radiation reaches the earth as diffuse sky radiation. Diffuse sky radiation may account for almost 100 percent of the radiation received by polar stations during winter.

Summary

The foregoing discussion accounts for the TOTAL radiation. Some of the radiation makes several trips, being absorbed, reflected, or reradiated by the earth or the atmosphere. Insolation comes into the atmosphere, and all of it

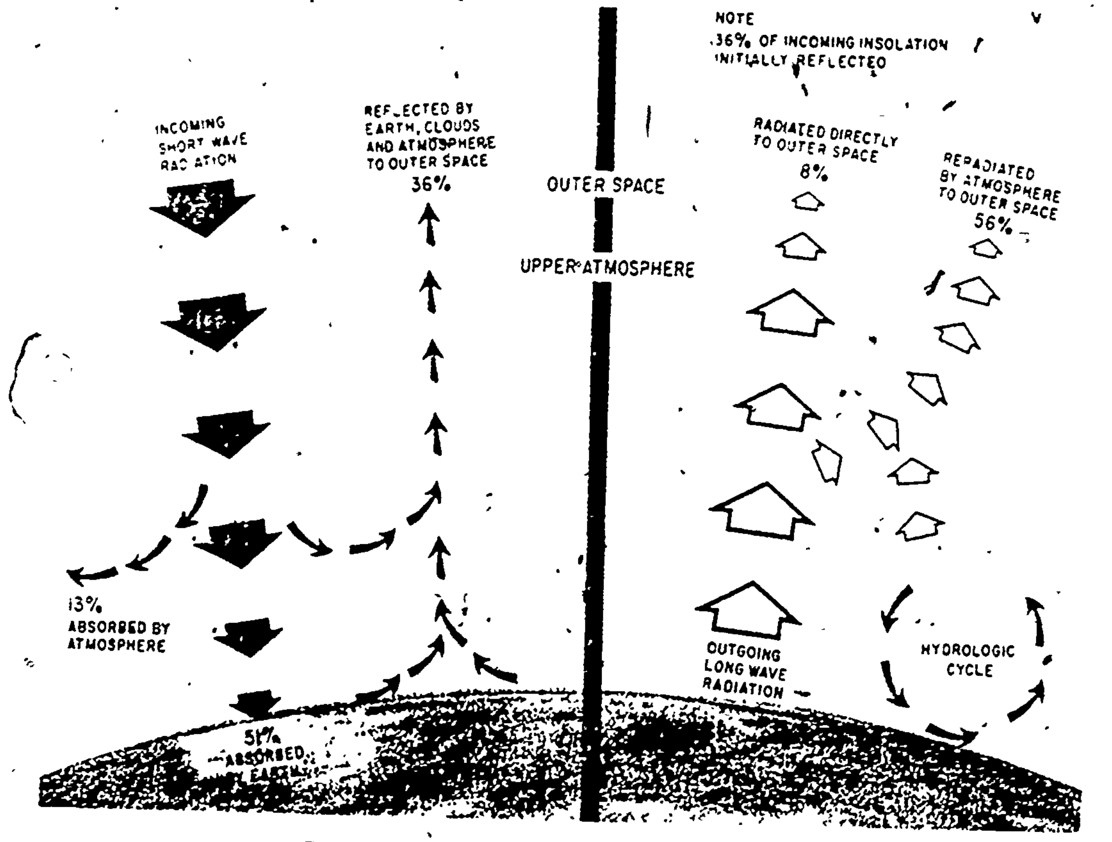


Figure 4.— Radiation balance in the atmosphere.

is reradiated. How many trips it makes while in our atmosphere does not matter. The direct absorption of radiation by the earth and atmosphere and the reradiations into space balance.

## HEAT BALANCE IN THE ATMOSPHERE

You have seen how the balance of incoming and outgoing radiation in the atmosphere is maintained. Due to the differential insolation (uneven heating) that the earth receives, a balance of heat must be maintained on earth.

It has been shown that the earth absorbs more insolation than the atmosphere above it, and because the intensity of reradiation decreases through each ascending layer, temperature normally decreases with height to the tropopause.

In the Tropics, heat is being supplied to the atmosphere constantly. The temperature of the air is thus higher than in areas poleward. Because of the expansion of warm air, this column of air is much taller than over the poles. At the poles the earth receives little insolation and the column of air is much shorter and heavier. This differential in insolation sets up a circulation that transports warm air from the Tropics poleward aloft and cold air from the poles equatorward on the surface (figure 5). Modifications to this general circulation are discussed in detail in Section 3.

## ATMOSPHERIC COMPOSITION

The earth's atmosphere is divided into layers or zones according to various distinguishing features as illustrated in figure 6. These divisions are for reference of thermal structure or other significant features and are not intended to imply that these layers or zones are independent domains. The earth is surrounded by one atmosphere, not by a number of subatmospheres.

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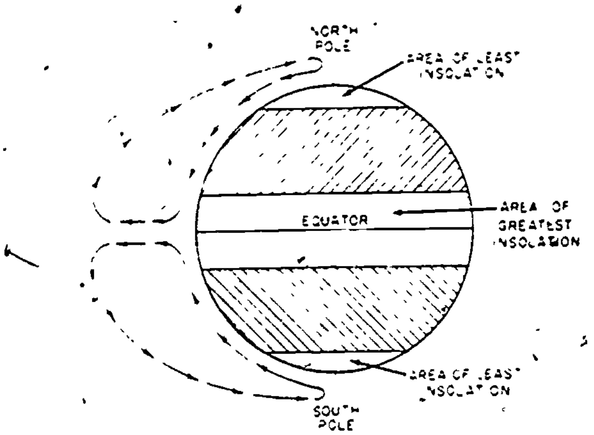


Figure 5.— Beginning of a circulation.

The temperatures shown are generally based on the latest "U.S. Extension to the ICAO Standard Atmosphere" and are representative of mid-latitude conditions. The extension to 500 miles shown in the insert is speculative.

These layers and zones are discussed under two separate classifications. One is the METEOROLOGICAL classification, which defines zones according to their significance for the weather; and the other is the ELECTRICAL classification, which defines zones according to electrical characteristics of gases of the atmosphere.

Meteorological Classification

In the meteorological classification (commencing with the earth's surface and proceeding upward) are encountered the troposphere, tropopause, stratosphere, stratopause, mesophere, mesopause, thermosphere, and the exosphere. These classifications are based on temperature characteristics.

TROPOSPHERE.— The troposphere is the layer of air enveloping the earth immediately above the earth's surface. It is approximately 5 1/2 miles (29,000 ft or 9 km) thick over the poles, about 7 1/2 miles (40,000 ft or 12.5 km) thick in the mid-latitudes, and about 11 1/2 miles (61,000 ft or 19 km) thick over the Equator. The figures for thickness are average figures; they change somewhat from day to day and from season to season. The troposphere is thicker in summer than in winter and is thicker during the day than during the night. The thickness of the troposphere is important in forecasting the weather. All weather as we know it occurs in the troposphere.

Table 1.— Gaseous composition of the dry atmosphere.

| Gas | Percent |
|---|---|
| Nitrogen ($N_2$) | 78.09 |
| Oxygen ($O_2$) | 20.95 |
| Argon | 0.93 |
| Carbon Dioxide | 0.03 |
| Other Gases* | less than 0.01 |

*Other gases include traces of neon, helium, hydrogen, krypton, and xenon

The troposphere is composed of a mixture of several different gases. By volume, the composition of dry air in the troposphere is as follows: 78 percent nitrogen, 21 percent oxygen, nearly 1 percent argon, and about 0.03 percent carbon dioxide. In addition, it contains minute traces of other gases, such as helium, hydrogen, neon, krypton, and others. (See table 1.)

The air in the troposphere also contains a variable amount of water vapor. The maximum amount of water vapor that the air can hold depends on the temperature of the air and the pressure; that is, the higher the temperature, the more water vapor it can hold at a given pressure. However, the amount of water vapor the air can hold is never more than about 4 percent by volume.

The air also contains variable amounts of impurities, such as dust, salt particles, soot, and chemicals. These impurities in the air are important because of their effect on visibility and especially because of the part they play in the condensation of water vapor. If the air were absolutely pure, there would be little condensation; these minute particles act as nuclei for condensation of water vapor. Nuclei which have an affinity for water vapor are called HYGROSCOPIC NUCLEI.

The temperature in the troposphere usually decreases with height, but there may be inversions for relatively thin layers at any level.

TROPOPAUSE.— The tropopause is a transition layer between the troposphere and the stratosphere. It is not uniformly thick, and it is not continuous from the Equator to the poles.

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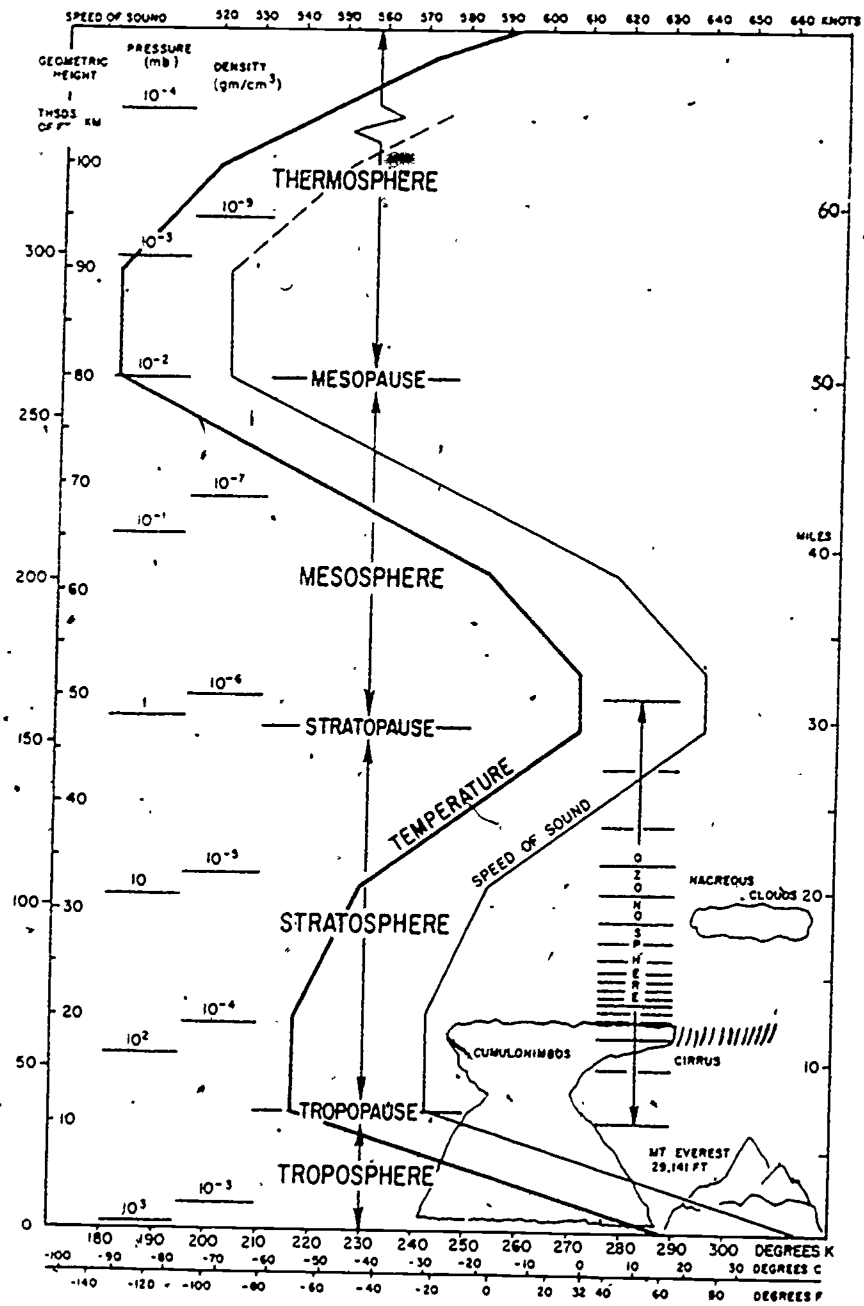


Figure 6.— Upper atmosphere.



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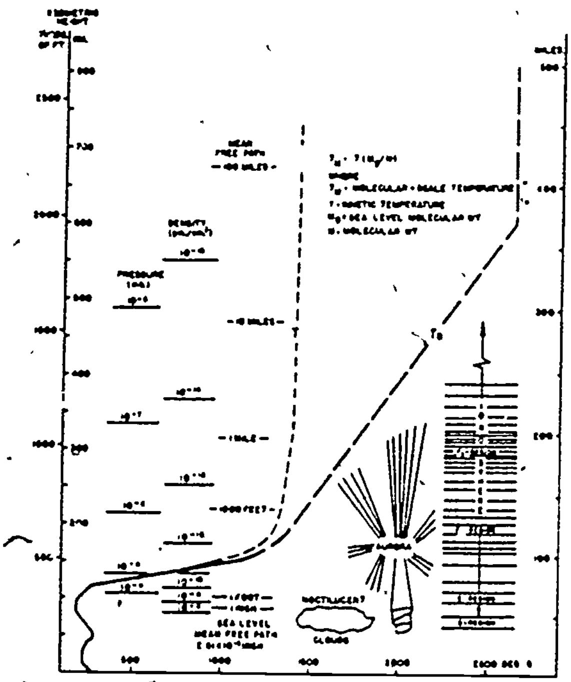

Figure 6.— Upper atmosphere—Continued.

In each hemisphere the existence of three distinct tropopauses is generally agreed upon—one in the subtropical latitudes, one in middle latitudes, and one in subpolar latitudes. These may overlap or may be folded.

The tropopause is characterized by an isothermal lapse rate; that is, it is marked by little or no increase or decrease of temperature with increasing altitude. The composition of gases is about the same as that for the troposphere. However, water vapor is found only in very minute quantities at the tropopause and above it.

STRATOSPHERE.— The stratosphere directly overlies the tropopause and extends to about 30 miles (160,000 ft). Temperature varies little with height in the stratosphere through the first 30,000 feet; however, in the upper portion the temperature increases approximately linearly to values nearly equal to surface temperatures. This increase in temperature through this zone is attributed to the presence of ozone which absorbs most of the incoming ultraviolet radiation.

STRATOPAUSE.— The stratopause is the top of the stratosphere. It is the zone marking another reversal of temperature with increasing altitude.

MESOPHERE.— The mesophere is a layer approximately 20 miles (100,000 ft) thick which directly overlies the stratopause. The temperature decreases with height from about 0° C. at the stratopause to about -93° C. at the mesopause.

MESOPAUSE.— The mesopause is the thin boundary zone between the mesophere and the thermosphere. It is marked by a reversal of temperature; i.e., temperature again increases with altitude.

THERMOSPHERE.— The thermosphere, a second region in which the temperature increases with height, extends from the mesopause to outer space.

EXOSPHERE.— The very outer limit of the earth's atmosphere is regarded as the exosphere. It is the zone in which gas atoms are so widely spaced that they rarely collide with one another and have individual orbits around the earth. It is believed not to be of meteorological significance.

Electrical Classification

The description of the electrical classification is necessarily brief because you do not need much detail on this classification. The primary emphasis is on the effects on communications and radar. The electrical classification outlines three zones—the troposphere, the ozonosphere, and the ionosphere.

TROPOSPHERE.— In the troposphere, the primary emphasis is on the formation of inversions of temperature; that is, the increase of temperature with gain in altitude. Certain types of inversions cause significant bending or refraction of radio and radar waves. Under certain circumstances the range of communication and radar is thereby increased, and under other circumstances the range is shortened. Therefore, the formation of inversions is important to communicators and radar operators. Meteorologists are called upon to forecast the formation of inversions.

OZONOSPHERE.— This layer is nearly coincident with the stratosphere. As was discussed

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earlier in this section, the ozone found in this zone is responsible for the increase in temperature with height in the stratophere. Therefore, the ozonosphere is the primary source of heat in the rarefied upper atmosphere.

IONOSPHERE.— The ionosphere extends from about 40 miles (200,000 ft) to an indefinite height. Ionization of air molecules through this zone provides conditions that are favorable for radio propagation. This zone is subdivided into the D, E, and F regions. The F regions are considered the most important for increasing communication capabilities.

# METEOROLOGICAL ELEMENTS

The next step in the study of meteorology is to learn the properties of meteorological elements. These elements are the weather or they make the weather. Any element which plays a part in defining the state of the atmosphere is properly a meteorological element. However, in this discussion, interest lies mostly with those elements which affect the atmosphere from the aspect of naval operations; that is, interest lies in the elements which make the weather good or bad for naval operations—subsurface, surface, air, and space.

Most weather, as it is known and as it has a bearing on naval operations, occurs in the troposphere. The meteorological elements that bring about this weather are air temperature, atmospheric pressure, humidity, hydrometeors (cloud, fogs, precipitation), lithometeors, luminous meteors, igneous meteors, and winds. These elements receive most of the coverage in this section.

Above the tropopause, little or no weather as such occurs, because water vapor is present only in very small quantities. Since precipitation, fogs, and clouds are composed of condensed water vapor, we can deduce that the presence of water vapor in the air is the most important factor controlling the type and intensity of weather.

## PRESSURE

Although extremely light, air has weight and is highly elastic and compressible. Because of its weight and density, the atmosphere exerts a certain pressure. By definition, atmospheric pressure is a force per unit area. Under standard conditions, the atmosphere exerts a pressure of 14.7 pounds per square inch upon the surface of the earth at sea level. This is equivalent to 1,013.2 mb. The millibar is the unit of pressure commonly used in meteorology.

Molecules present in the atmosphere exert pressure in all directions at the same time; this makes it possible to measure atmospheric pressure by several different means.

## TEMPERATURE

One of the most important properties of the atmosphere is its ability to absorb and lose heat. The heating and cooling of the atmosphere exert a tremendous influence on the processes that determine the weather. Consequently, temperature is one of your principal concerns. It is necessary to know the meaning of temperature, the scales and instruments used in its measurement, and the important temperature values. Procedures for observing temperature are given in another pamphlet.

Temperature may be regarded as a measure of molecular motion determined from an absolute zero point at which all molecular motion stops. Temperature may be defined as the degree of hotness or coldness, or it may be considered as a measure of heat intensity. This being the case, we may conveniently measure temperature in several different ways.

One way of measuring temperature is by means of a liquid thermometer. Observe the changes in volume of certain sensitive substances, such as alcohol or mercury, which expand greatly with an increase in molecular activity (temperature increase) and contract greatly when the molecular activity slows down (temperature decreases).

Another way to measure temperature is to place substances, usually metals, next to one another and note the difference in their expansion or contraction. Each substance has an expansion coefficient which is based on the amount it expands per degree of temperature increase. One metal alone can be used to measure temperature; but since the expansion is usually small, it is very difficult to get an easy and an accurate measurement. Two metals welded together make the measurement easier, because the strip with the lesser expansion coefficient bends the one with the greater, and the curve of bending is easily magnified, thus affording an easy and accurate measure of temperature. Welded strips of two dissimilar metals are called bimetallic strips.

Another method of measuring temperature is by a color comparison of the same substance at different temperatures. You know that iron is blue-gray when cold, becomes orange when heated, then red, and finally turns almost white when it is completely melted and about to vaporize. For ordinary meteorological purposes, this method is unimportant.

There are other methods, such as measuring the electrical resistance of a substance (resistance changes with temperature; therefore, you can find temperature by finding the resistance), spectral analysis, measurements of the speed of sound, and measurement of electromagnetic radiation. Some of these methods are indirect and have little direct application in meteorology at the present time.

Temperature measurements used most extensively are those dealing with a confined substance (alcohol or mercury), differences in linear expansion (bimetallic strip), and changes in electrical resistance (radiosondes).

Long ago it was recognized that uniformity in the measurement of temperature was essential. It would be foolhardy to rely on such subjective judgments of temperature as "cool," "cooler," and "coolest"; therefore, arbitrary scales were devised. Some of them are described in this section. They are the Fahrenheit, Celsius, and absolute (Kelvin) scales. These are the scales in use by most meteorological services of all the countries in the world.

FAHRENHEIT SCALE

The Fahrenheit scale was invented by Gabriel Daniel Fahrenheit about 1710. He was the first to use mercury in a thermometer. The Fahrenheit scale has 180 divisions or degrees between the freezing point (32° F.) and boiling point (212° F.) of water.

CELSIUS SCALE

The Celsius scale was devised by Anders Celsius during the 18th century. This scale has reference points with respect to water of 0° C. for freezing and 100° C. for boiling.

The terms "centigrade scale" and "degrees centigrade" have been used for many years; however, the accepted terminology is "Celsius scale" and "degrees Celsius."

ABSOLUTE SCALE

Another scale in wide use by scientists in many fields is the absolute scale or Kelvin scale (also called the thermodynamic temperature scale). It was developed by Lord Kelvin of England. On this scale the freezing point of water is 273° A. (or K), and the boiling point of water is 373° A. (or K). The absolute zero value is considered to be a point at which, theoretically, no molecular activity exists. This places the absolute zero at a minus 273° on the Celsius scale, since the degree divisions are equal in size on both scales. The absolute zero value on the Fahrenheit scale falls at minus 459.6° F.

SCALE CONVERSIONS

Since all three scales are used in meteorology, it is often necessary to change the temperature value of one scale to that of another scale. Only a few methods for such conversion are described in this section.

It is helpful to note that there are 100 divisions between the freezing and boiling points of water on the Celsius scale, whereas there are 180 divisions between the same references on the Fahrenheit scale. Therefore, one degree on the Celsius scale equals nine-fifths degree on the Fahrenheit scale. For converting Fahrenheit values to Celsius values, the formula is:

$$C = (F - 32°) \times \frac{5}{9}$$

For example, 50° F. is equivalent to 10° C. By applying the formula,

$$C = (50 - 32) \times \frac{5}{9} = 10 \text{ Celsius}$$

For converting Celsius values to Fahrenheit values, the formula is:

$$F = \frac{9}{5} \times C + 32$$

For example, 5° C. is equivalent to 41° F. By applying the formula,

$$F = \frac{9}{5} \times 5° + 32° = 41° F.$$

To change a Celsius reading to an absolute value, add the Celsius reading to 273° algebraically. For example, minus 35° C. is equivalent to 238 absolute, arrived at by adding minus 35 C. to 273°.

To change a Fahrenheit reading to an absolute value, first convert the Fahrenheit reading to its equivalent Celsius value, which is then added algebraically to 273°. Consequently, 50° F. is equivalent to 283° absolute, arrived at by converting 50° F. to 10° C. and then adding the Celsius value algebraically to 273°.

Another method of converting temperatures from one scale to another is the decimal method. This method uses the ratio 1° C. equals 1.8° F. To find Fahrenheit from Celsius, multiply the Celsius value by 1.8 and add 32. To find Celsius from Fahrenheit, substract 32 from the Fahrenheit and divide the remainder by 1.8. The following examples illustrate the method:

1. Given: 24° C.; Find: °F.
   24 x 1.8 = 43.2
   43.2 + 32 = 75.2 or 75° F.
2. Given: 96° F.; Find: °C.
   96 - 32 = 64
   64 ÷ 1.8 = 35.5 or 36° C.

You are often called upon to convert temperatures from one scale to another. Learn how to make these conversions and learn them well. They will make your work easier and more efficient.

## TEMPERATURE APPLICATIONS

Temperature is a comprehensive term and concept. For this reason it is reasonable to expect many variations in its expression and application. For instance, meteorologists use such terms as potential temperature, wet-bulb temperature, virtual temperature, maximum temperature, mean temperature, and many others. These terms have their special meanings, which are defined in the proper place where the concept first appears in this training course. When meteorologists simply say temperature, they mean the free air temperature. The free air temperature is the temperature of the air near the surface of the earth, measured so that air flows freely at the point of observation and where no influences other than the free air cause the thermometer to be affected. This means that the reading is not made in direct sunlight, or too close to buildings or other heat sources.

## HUMIDITY

As indicated earlier, weather conditions depend greatly upon the amount of water in the air. The water may be in any of three forms—gas, liquid, or solid. As a gas, it is called water vapor, which is invisible. Solid or liquid water is visible as precipitation or as clouds.

Humidity is a comprehensive concept; therefore, there are available many different definitions and many different manners of expressing humidity.

Most of the weather that interferes with the operation of aircraft is directly associated with water in some form. The water that is of primary interest at this point is that which exists in a gaseous state. In this section it is necessary to consider the characteristics of water vapor, the various manners in which humidity is expressed, and some of the instruments that are used in measuring humidity.

### WATER VAPOR CHARACTERISTICS

Water vapor is a universal constituent of the atmosphere. Any given volume of atmosphere at a given temperature can contain only a certain maximum quantity of water vapor. The maximum amount (by volume) of water vapor that the air can hold is about 4 percent. If more and more water vapor is injected into a given container of dry air kept at a constant temperature, a point is reached when the water vapor condenses, or becomes liquid, as fog within the container or as dew on its walls. As more and more water vapor is added, more of it condenses, but the total amount of vapor in the container remains unchanged, though the amount of liquid water in the form of fog or dew increases. The volume of air in the container is then said to be saturated with water vapor. The quantity of water vapor needed to saturate the container of air does not depend on the amount of air in the container; it takes approximately the same amount of water vapor to produce saturation whether the container is on the ground with air in it at a pressure of 1,000 millibars, or at 17,000 feet altitude with only 500 millibars of air pressure if the temperature is the same. In the second case, there is more water vapor per gram of air, though not more total water vapor in the given container.

Although the quantity of water vapor in a saturated volume of atmosphere is independent of the amount of air present, IT DOES DEPEND ON THE TEMPERATURE. The higher the temperature, the greater the tendency for liquid water to turn into vapor. At a higher temperature, therefore, more vapor must be injected into a given volume before the saturated state is reached and dew or fog forms. On the other hand, cooling a saturated volume of air forces some of the vapor to condense and the quantity of vapor in the volume to diminish.

## DEFINITIONS OF HUMIDITY

The actual amount of water vapor contained in the air is usually less than the saturation amount. The amount of water vapor in the air is expressed in several different manners. Some of the principal methods are described in the following portion of this section.

### Relative Humidity

Although the major portion of the atmosphere is not saturated, for weather analysis it is desirable to be able to say how near it is to being saturated. This relationship is expressed as relative humidity. The relative humidity of a volume of air is the ratio (in percent) between the water vapor actually present and the water vapor necessary for saturation at a given temperature.

Assume, for instance, that the temperature is 25° C. The amount of water vapor needed to saturate a cubic meter of air at this temperature is 23.05 grams. If observation indicates only 11.525 grams of vapor in a cubic meter, the sample volume is half saturated, or its relative humidity is 50 percent.

Relative humidity is also defined as the ratio (expressed in percent) of the observed vapor pressure to that required for saturation at the same temperature and pressure.

Relative humidity shows the degree of saturation, but it gives no clue to the actual amount of water vapor in the air. Thus, other expressions of humidity are useful.

### Absolute Humidity

The mass of water vapor present per unit volume of space, usually expressed in grams per cubic meter, is known as absolute humidity. It may be thought of as the density of the water vapor.

### Specific Humidity

Humidity may be expressed as the mass of water vapor contained in a unit mass of air (dry air plus the water vapor), or as the ratio of the density of the water vapor to the density of the air (MIXTURE OF DRY AIR AND WATER VAPOR). This is called the specific humidity and is expressed in grams per gram or in grams per kilogram. Since this value depends upon the measurement of mass, and mass does not change with temperature and pressure, the specific humidity of a parcel of air remains constant unless water vapor is added to or taken from the parcel. For this reason, air which is unsaturated may move from place to place or from level to level, and its specific humidity remains the same as long as no water vapor is added or removed. However, if the air is saturated and is cooled, some of the water vapor must condense; consequently, the specific humidity (which reflects only the water vapor) decreases. If saturated air is heated, its specific humidity remains unchanged unless water vapor is added to it, in which case the specific humidity increases. The maximum specific humidity which a parcel may have occurs at saturation and depends upon both the temperature and the pressure. Since warm air can hold more water vapor than cold air at constant pressure, the saturation specific humidity at high temperatures is greater than at low temperatures. Also, since moist air is less dense than dry air at constant temperature, a parcel of air has a greater specific humidity at saturation, if the pressure is low, than when the pressure is high.

### Mixing Ratio

The mixing ratio is defined as the ratio of the mass of water vapor to the mass of DRY AIR and is expressed in grams per gram or in grams per kilogram. It differs from specific humidity only in that it is related to the mass of dry air instead of to the total dry air plus water vapor. It is very nearly equal numerically to specific humidity, but it is always slightly greater. The mixing ratio has the same characteristic properties as the specific humidity, in that it is conservative for atmospheric processes involving a change in temperature but is nonconservative for changes involving a gain or loss of water vapor.

Previously you learned that air at any given temperature can hold only a certain amount of water vapor before it is saturated. The total amount of vapor which air holds at any given temperature, by weight relationship, is referred to as the saturation mixing ratio. It is useful to note that the following relationship exists between mixing ratio, saturation mixing ratio, and relative humidity: Relative humidity is equal to the mixing ratio divided by the saturation mixing ratio, multiplied by 100. If any two of the three components in this relationship are known, the third may be determined by simple mathematics.

### Dewpoint

The dewpoint is the temperature to which air must be cooled, at constant pressure and constant water vapor content, in order for saturation to occur. The dewpoint is a conservative and very useful element. When atmospheric pressure stays constant, the dewpoint reflects increases and decreases in moisture in the air and also shows at a glance, under the same conditions, how much cooling of the air might result in condensed moisture.

## HUMIDITY MEASUREMENTS

Humidity is measured by several different methods. The instruments and procedures used in humidity measurements are treated in the appropriate sections discussing instruments. It suffices to say here that cooling, vapor pressure differentials, expansion coefficients, and electrical resistance are the primary means used to determine the humidity of the air.

## WINDS

In general, a reference to wind means air in natural horizontal motion relative to the surface of the earth. Actually, wind has many components of direction. It may be upward or downward directed in a certain horizontal direction. The vertical components are difficult to measure. Thus we deal only with the horizontal component—the horizontal direction and speed. In meteorology, reference is generally made to the vertical component of the wind as turbulence, updrafts, or downdrafts.

The cause of windflow is the variation in pressure, which in turn results from a variation in temperature. The processes which cause a variation in pressure and temperature are described in section 1 of this training pamphlet, and the details of atmospheric circulation are covered in section 3.

At times confusion arises from the meaning of wind direction. Wind direction is always the direction FROM which the wind is blowing. Wind speed may be expressed in a number of manners, such as miles per hour, kilometers per hour, feet per second, meters per second, or in nautical miles per hour (knots). In meteorology, wind speed is often expressed in knots. Wind speed measurements are commonly made by the use of anemometers. There are several types of anemometers in use; the details of their operation are covered in appropriate sections on instruments.

## LUMINOUS METEORS

The luminous meteors are any one of a number of atmospheric phenomena which appear as luminous patterns in the sky. They constitute such phenomena as solar and lunar halos, solar and lunar coronas, rainbows, fogbows, and aurora borealis and aurora australis (northern and southern lights). Luminous meteors are not active elements; that is, they generally do not cause adverse weather. However, except for the auroras, they are related to clouds which do cause adverse weather. Thus, they help in describing the state of the atmosphere.

## HALOS

A halo is a luminous ring around the sun or moon. When it appears around the sun, it is a solar halo; when it forms around the moon, it is a lunar halo. It usually appears whitish, but it may show the spectral colors (red, orange, yellow, green, blue, indigo, and violet) with the red ring on the inside and the violet ring on the outside. The sky is darker inside the ring than outside. Halos are formed by REFRACTION of light as it passes through ice crystals. This means that halos are almost exclusively associated with cirriform clouds. Refraction of light means that the light passes through prisms; that is, ice crystals which act as prisms. Some reflection of light also takes place.

Halos appear in various sizes, but the most common size is the small 22-degree halo. The size of the halo can be determined visually with ease. Technically, the radius of the 22-degree halo subtends an arc of 22 degrees. This simply means that the radius of the halo is equal to a 22-degree angle as measured by an observer on earth. Halos of other sizes are formed in the same manner.

CORONAS

A corona is a luminous ring surrounding the sun (solar) or moon (lunar) and is formed by DIFFRACTION of light by water droplets. It may vary greatly in size, but is usually smaller than a halo. All the spectral colors may be visible, with red on the outside, but frequently the inner colors are not visible. Sometimes the spectral colors or portions of them are repeated several times and are somewhat irregularly distributed. This phenomenon is called iridescence.

NOTE

At this point it is good to review the definitions of reflection, refraction, and diffraction. Reflection occurs when light simply bounces off a substance. In reflection, the angle at which light arrives (angle of incidence) is equal to the angle at which it bounces off (angle of reflection). In refraction, the light enters the substance, is bent within the substance, and leaves at an angle different from that at which it entered. Prisms are good refractors; and because they are regular in shape, the angle of refraction can be calculated. Diffraction is similar to scattering. It occurs when the particles causing the diffraction are larger in diameter than the wavelength of the light, resulting in the dispersion of light. In the case of coronas, the diffractive agents are the water droplets of mid-clouds.

RAINBOWS

The rainbow is a circular arc seen opposite the sun, usually exhibiting all the primary colors, with red on the outside. It is caused by diffraction, refraction, and reflection of light within raindrops, often with a secondary bow outside the primary one. In this case the colors are reversed. The colors of a rainbow are red to blue and violet.

FOGBOWS

A fogbow is a whitish semicircular arc seen opposite the sun in fog. Its outer margin has a reddish tinge; its inner margin has a bluish tinge. The middle of the band is white. An additional bow, with the colors reversed, sometimes appears inside the first.

AURORAS

An aurora is a luminescence in the atmosphere. It is primarily an electrical phenomenon involving charged particles in the upper atmosphere in the higher latitudes in both hemispheres. It is closely associated with magnetic storms. An aurora may appear in such forms as arcs, rays, curtains, coronas, etc. In the Northern Hemisphere it is called aurora borealis; in the Southern Hemisphere it is known as aurora australis. Auroras are usually whitish, but they may have various colors. The lower edges of the arcs and curtains of the aurora are usually fairly well defined; the upper edges are usually ill-defined.

AIRGLOW

Airglow is similar in origin and nature to auroras; it, too, is an upper atmospheric electrical phenomenon. The main differences between airglow and aurora are that airglow is quasisteady ("quasi" means seemingly) in appearance, is much fainter than aurora, and appears in the middle and lower latitudes.

LITHOMETEORS

Along with hydrometeors, due consideration must be given to lithometeors, since they affect the state of the atmosphere. Lithometeors comprise a class of atmospheric phenomena among which dry haze and smoke are the most common examples. In contrast to a hydrometeor, which consists largely of water, a lithometeor is composed of solid dust or sand particles, or the ashy products of combustion.

HAZE

Haze is suspended dust or salt particles so small that they cannot be individually felt or seen by the unaided eye. They reduce visibility and lend a characteristic opalescent appearance to the air. Haze resembles a uniform veil over the landscape that subdues its colors. This veil has a bluish tinge when viewed against a dark background and a dirty yellow or orange tinge when viewed against a bright background.

Irregular differences in air temperature may cause a shimmering veil over the landscape. This is called optical haze.

SMOKE

Smoke is fine ash particles suspended in the atmosphere. When smoke is present, the disk of the sun at sunrise and sunset appears very red and during the daytime has a reddish tinge. Smoke at a distance, such as from forest fires, usually has a light grayish or bluish color and is evenly distributed in the upper air.

DUST

Dust is finely divided solid matter, uniformly distributed in the air. It imparts a tannish or grayish hue to distant objects. The sun's disk is pale and colorless or has a yellow tinge at all periods of the day.

SAND

Fine particles of sand picked up from the surface by the wind and blown about in clouds or sheets constitute a troublesome lithometeor in some regions.

IGNEOUS METEORS

Lightning is the only common igneous meteor of importance in meteorology. It is a visible electrical discharge occurring in the atmosphere. It occurs as a discharge within a cloud, from cloud to cloud, or between clouds and the ground. Distant lightning is any lightning that occurs so far from the observer that the resulting thunder cannot be heard. It may be observed as streaks or sheets.

HYDROMETEORS

Hydrometeors are composed primarily of water in either liquid or solid state. Hydrometeors comprise all forms of precipitation, such as rain, drizzle, snow, and hail, and such elements as clouds and fogs.

PRECIPITATION

Precipitation includes all forms of moisture that fall to the earth's surface, such as rain, snow, hail, drizzle, etc. Dew and frost are not forms of precipitation, although they are hydrometeors. They are treated in a separate section.

Precipitation is classified according to both its form (liquid, freezing, and solid) and size (and rate of fall). The size of precipitation drops determines their rate of fall to a large extent. Also, the size determines some of the different types of precipitation. Droplets with a diameter somewhat less than 0.2 mm constitute precipitation which usually evaporates before it reaches the ground—VIRGA. Droplets with a diameter of less than 0.02 inch (0.5 mm) constitute DRIZZLE, and the larger droplets constitute RAIN. Droplets with a diameter less than 0.1 mm do not fall and are not classified as precipitation. They are referred to as cloud droplets.

Rain

Precipitation which reaches the earth's surface as water droplets with a diameter of 0.02 inch (0.5 mm) or more is classified as rain. If the droplets freeze on contact with the ground or other objects, the precipitation is classified as freezing rain. Rain emanating from convective clouds is referred to as rain showers. Showers usually start and stop rather suddenly; they are quite intermittent in character; and the drops of which they are composed are usually larger and the impact (therefore the intensity) of the drops is greater than with other types of rain.

### Drizzle

Drizzle consists of very small and uniformly dispersed droplets that may appear to float while following air currents. Sometimes drizzle is referred to as mist. Unlike fog droplets, drizzle falls to the ground. However, the rate of fall is very slow. The slow rate of fall and the small size of the droplets distinguish drizzle from rain. When the droplets freeze on contact with the ground or other objects, they are called freezing drizzle. Drizzle always restricts visibility.

### Snow

Snow consists of white or translucent ice crystals. In their pure form the ice crystals are highly complex, hexagonally branched forms. However, most snow falls as parts of crystals, as individual crystals, or more commonly as clusters and combinations of these. Snow occurs in meteorological conditions similar to those in which rain occurs, except that with snow the initial temperatures must be at or below freezing. Snow falling from convective clouds is termed snow showers.

### Snow Pellets (Soft Hail)

Sometimes called soft hail, snow pellets are white, opaque, round (or occasionally conical) kernels of snowlike consistency, 1/16 to 1/4 inch in diameter. They are crisp and easily compressible. They may rebound or burst when striking hard surfaces. They occur almost exclusively in showers.

### Snow Grains

Sometimes called granular snow, snow grains take the form of minute, branched, starlike snowflakes, or of very fine simple crystals. They are the solid equivalent of drizzle with diameters generally less than 0.04 inch (1 mm).

### Sleet (Ice Pellets)

Sleet, sometimes called ice pellets, is composed of frozen raindrops or drizzle or largely melted and refrozen snowflakes that rebound when striking hard surfaces. Their fall may be continuous, intermittent, or showery.

### Hail

Ice balls or stones which range in diameter from that of a medium-size raindrop to an inch or more are referred to as hail. They may fall detached or frozen together into irregular, lumpy masses. They are composed either of clear ice or of alternating clear and opaque snowflake layers. Hail forms in cumulonimbus clouds and is associated with thundershower activity. Surface temperatures are usually above freezing when hail occurs. Determination of size is based on the diameter, in inches, of normally shaped hailstones.

### Precipitation Theory

Precipitation is an outgrowth of condensation. The condensation theory is discussed in this section under "Cloud Formation." The main concern at the present time is with the growth of condensed water droplets and their subsequent descent to the earth's surface.

Several theories have been formulated in regard to the growth of raindrops, and all of them have some validity. The theories which are most widely accepted today are treated here in combined form.

Raindrops grow in size primarily because water exists in all three phases in the atmosphere, and the air is supersaturated at times (especially with respect to ice) due to adiabatic expansion and radiational cooling. This means that ice crystals coexist with liquid water droplets in the same cloud. The difference in the vapor pressures between the water droplets and the ice crystals causes water droplets to evaporate and then to sublimate directly onto the ice crystals. Condensation alone does not cause droplets of water to grow in size. The turbulence in clouds permits this droplet growth process and aids it. After the droplets become larger, they start to descend and are tossed up again in turbulent updrafts within the cloud. The repetition of ascension and descension causes the ice crystals to grow larger (by water vapor sublimating onto the ice crystals) until finally they are heavy enough to fall out of the cloud as some form of precipitation. It is believed that most precipitation in the midlatitudes starts as ice crystals and that most liquid precipitation results from melting during descent through a stratum of warmer air. It is generally believed that most rain in the Tropics forms without going through the ice phase.

In addition to the above process of droplet growth, simple ACCRETION is important. The droplets colliding with other smaller ones simply hold the smaller ones, and the droplets thereby accumulate more layers. During the growing process, the droplets which form the outer layers are frozen onto the larger droplets. This process of accretion is thought to be especially effective in the growth of hail. There are, to be sure, other factors which explain in part the growth of precipitation, but the aforementioned processes are the primary ones.

## CLOUDS

A cloud is a visible mass of minute water droplets, or ice particles, suspended in the atmosphere. It differs from fog in that it does not reach to the surface of the earth. Clouds are a direct expression of the physical processes which are taking place in the atmosphere. An accurate description of both type and amount plays an important part in the analysis of the weather and in forecasting the changes which are taking place in the weather.

### Cloud Formation

To be able to thoroughly understand clouds, you must know the physical processes which form clouds.

Three conditions must be met before clouds can form as a result of condensation—presence of sufficient moisture, a cooling process, and hygroscopic or sublimation nuclei in the atmosphere. Moisture is supplied to the atmosphere by evaporation and is distributed horizontally and vertically by the winds and vertical currents. The first task is to consider the hygroscopic and sublimation nuclei.

Hygroscopic nuclei are particles of any nature on which condensation of atmospheric moisture occurs as a liquid. It can be said that hygroscopic nuclei have an affinity for water or that they readily absorb and retain water. The most effective hygroscopic nuclei are the products of combustion (sulfuric and nitric acids) and salt sprays. Some dust particles are also hygroscopic, but not effectively so. As has been stated, the presence of hygroscopic nuclei is a must. Water vapor does not readily condense without their presence. Air has been supersaturated in laboratories to over 400 percent before condensation began when there were no hygroscopic nuclei present. On the other hand, condensation has been induced with relative humidities of only 70 percent when there was an abundance of hygroscopic nuclei.

The condensation which results when all three mentioned conditions are fulfilled is in the form of clouds, fogs, or haze. Fogs are merely clouds on the surface of the earth. Fogs receive treatment in a separate portion of this section.

In our industrial cities in which byproducts of combustion are profuse, the distinction between smoke, fog, and haze is not easily discernible. A combination of smoke and fog gives rise to the existence of the so-called "smogs" which are characteristic of these industrial areas.

Little is known about the properties of sublimation nuclei, although it is believed that they are essential for sublimation to occur at all. It is assumed that sublimation nuclei are very small and very rare, possibly of a quartz or meteoric dust origin. All cirriform clouds are composed of ice crystals and are believed to be formed as a result of direct sublimation. Sublimation is the process whereby water vapor changes into ice without passing through the liquid stage.

In the atmosphere, water clouds, water and ice crystal clouds, and pure ice crystal clouds may exist at the same time.

Next under consideration is the cooling process which may induce condensation. There are several processes by which the air is cooled—convective cooling by expansion, mechanical cooling by expansion, and radiational cooling. Any of the three methods may be working in conjunction with another method, thus making it even more effective. The methods are as follows:

1. Convective cooling.— The ascent of a limited mass of air through the atmosphere due to surface heating is called thermal convection. If a sample of air is heated, it rises (being less dense than the surrounding air) and decreases in temperature at the day adiabatic lapse rate. (An adiabatic process is one in which no heat is

added to or taken away from the mass of air by exchange with its environment during the process.) The parcel of air continues to rise until the surrounding air has a temperature equal to, or higher than, the parcel of air. Then convection ceases. Cumuliform clouds are formed by this means with their bases at the altitude of saturation and their tops at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.

2. Mechanical cooling.— In this section, orographic and frontal processes for cloud formation are discussed as follows:

a. Orographic.— If air is comparatively moist and is lifted over mountains or hills, clouds may often be formed. The type of cloud depends upon the lapse rate (the rate of decrease in temperature with increase in height unless otherwise specified) of the surrounding air. If the lapse rate is weak (that is, a small rate of cooling with an increase in altitude), the clouds formed are of the stratiform type. If the lapse rate of the surrounding air is steep (that is, a large rate of cooling with increasing altitude), the clouds formed are of the cumuliform type.

b. Frontal.— In the discussion of clouds being formed by frontal slopes, we have two huge masses of air, each having its own characteristic properties. Due to the difference of density, the two air masses do not readily mix. Warm air is less dense than cold air. Therefore, the warm air moves up over the cold air. The cold air acts like an inclined plane, and the boundary between the two masses of air is called the frontal surface.

If warm air flows slowly up over a cold mass of air, the air is cooled adiabatically to its dewpoint and stratified clouds are formed. On the other hand, if cold air pushes under warm air, the warm is forced aloft rapidly, and upon condensation, cumuliform clouds result.

3. Radiational cooling.— At night the earth reradiates long-wave radiation, thereby cooling rapidly. The air in contact with the surface is not heated by the outgoing radiation but, instead, is cooled by contact with the cold surface. This contact cooling lowers the temperature of the air near the surface, causing a surface inversion. If the temperature of the air is cooled to its dewpoint, fog and/or low clouds form. Clouds formed in this manner dissipate during the day due to surface heating.

Cloud Classification

The international classification which has been adopted by most countries is a great help to pilots and meteorological personnel alike. The importance of an international classification of clouds cannot be overestimated, since it tends to make cloud observations standard throughout the world. As for the pilot, if he can properly interpret the meaning of clouds, he is usually able to avoid the types which are dangerous to aircraft.

Clouds have been divided into 3 stages, 10 genera, 14 species, and 9 varieties. This classification is based primarily on the process which produced the clouds. Although clouds are continually in a process of development and dissipation, they nevertheless have many distinctive features which make this classification possible.

ETAGES.— Observations have shown that clouds are generally encountered over a range of altitudes varying from sea level to about 60,000 feet in the Tropics, to about 45,000 feet in middle latitudes, and to about 25,000 feet in polar regions. By convention, the part of the atmosphere in which clouds are usually present has been vertically divided into three etages—high, middle, and low. Each etage is defined by the range of levels at which clouds of certain genera occur most frequently.

Cirrus, cirrocumulus, and cirrostratus are always found in the high etage. Altocumulus and altostratus are found in the middle etage, but altostratus may often extend into the high etage. Nimbostratus is invariably found in the middle etage, but may extend into the high, and especially the low etage. Cumulus, cumulonimbus, stratus, and stratocumulus are always associated with the low etage, but the tops of cumulus or cumulonimbus may extend into either or both of the two other etages.

The HIGH ETAGE extends from about 10,000 to 25,000 feet in polar regions, 16,500 to 45,000 feet in temperate regions, and 20,000 to 60,000 feet in tropical regions.

The MIDDLE ETAGE extends from about 6,500 to 13,000 feet in polar regions, 6,500 to 23,000 feet in temperate regions, and 6,500 to 25,000 feet in tropical regions.

The LOW ETAGE extends from near the earth's surface to 6,500 feet in all regions of the earth.

GENERA.— The genera of clouds are as follows:

1. Cirrus (Ci).— Thin featherlike clouds.

2. Cirrocumulus (Cc).— Thin cotton or flake-like clouds.

3. Cirrostratus (Cs).— Very thin, high sheet cloud.

4. Altocumulus (Ac).— Sheep-back-like clouds.

5. Altostratus (As).— Medium high, uniform sheet cloud.

6. Nimbostratus (Ns).— Low amorphous and rainy layer.

7. Stratocumulus (Sc).— Globular masses or rolls.

8. Stratus (St).— Low, uniform sheet cloud.

9. Cumulus (Cu).— Dense, dome-shaped puffy looking clouds.

10. Cumulonimbus (Cb).— Cauliflower towering clouds with cirrus veils on top.

SPECIES.— The following are the definitions of the various species of clouds. The cloud genera in which these species generally occur are also mentioned. In addition, the species are also enumerated under individual cloud descriptions.

1. Fibratus.— Detached clouds or a thin cloud veil, consisting of nearly straight or more or less irregularly curved filaments which do not terminate in hooks or tufts. The term applies mainly to cirrus.

2. Uncinus.— Cirrus often shaped like a comma, terminating at the top in a hook, or in a tuft which is not in the form of a rounded protuberance.

3. Spissatus.— Cirrus which is sufficiently thick to appear grayish when viewed towards the sun.

4. Castellanus.— Clouds which present, in at least some portion of their upper part, cumuliform protuberances in the form of turrets. The turrets, which are generally taller than they are wide, are connected to a common base. The term applies mainly to cirrocumulus, altocumulus, and stratocumulus, but especially altocumulus.

5. Floccus.— A species in which each cloud unit is a small tuft with a cumuliform appearance, the lower part of which is more or less ragged and sometimes accompanied by virga. The term applies mainly to cirrocumulus and altocumulus, but especially altocumulus.

6. Stratiformis.— Clouds which are spread out in an extensive horizontal sheet or layer. The term applies to altocumulus, stratocumulus, and occasionally to cirrocumulus.

7. Nebulosus.— A cloud like a nebulous veil or layer, showing no distinct details. This term applied mainly to cirrostratus and stratus.

8. Lenticularis.— Clouds having the shape of lenses or almonds, often v[illegible] elongated and having well-defined outlin[illegible]rm applies mainly to cirrocumulus, altocu[illegible], and stratocumulus.

9. Fractus.— Clouds in the form of irregular shreads, which have a clearly ragged appearance. The term applies only to stratus and cumulus.

10. Humilis.— Cumulus clouds of only a slight vertical extent; they generally appear flattened.

11. Mediocris.— Cumulus clouds of moderate vertical extent, the tops of which show fairly small protuberances.

12. Congestus.— Cumulus clouds which are markedly sprouting and are often of great vertical extent. Their bulging upper part frequently resembles cauliflower.

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13. Calvus.— Cumulonimbus in which at least some protuberances of the upper part are beginning to lose their cumuliform outlines but in which no cirriform parts can be distinguished.

14. Capillatus.— Cumulonimbus characterized by the presence, mostly in the upper portion, of distinct cirriform parts of clearly fibrous structure. Often appears in the form of an anvil, plume, or vast disorderly mass of hair.

VARIETIES.— Varieties of clouds are established mainly on the basis of the cloud's transparency or its arrangement in the sky. The varieties are nine in number; but since observations of clouds do not ordinarily involve the recording of the specific variety, they are not covered here. A detailed description of the several varieties can be found in the International Cloud Atlas. However, a knowledge of the varieties of a species of clouds aids you, the observer, greatly in identifying the cloud; and for this reason, we urge you to read the International Cloud Atlas.

SUPPLEMENTARY FEATURES.— Supplementary features and accessory clouds, like the varieties, aid in the clear identification of clouds. Supplementary features are incus, mamma, virga, praecipitatio, arcus, and tuba. They are defined and associated with the parent clouds in the next portion on Cloud Description.

The accessory clouds are those cloud forms which are distinct, but which are relatively minor in vertical or horizontal extent, and are definitely associated with the parent clouds. The accessory clouds are pileus, velum, and pannus. These terms are defined next.

Cloud Description

Clouds are named and described with Latin terms. Therefore, it is necessary for the Marine Science Technician to become familiar with the terms used in these descriptions. The meaning of the Latin words suggests the shape of the cloud. Later in this training course, these terms are again used when you observe, log, encode, and decode clouds during the process of an observation. The important Latin terms along with the associated cloud genera or species are as follows:

1. Arcus.— Arch, arcade, bow (Cb, Cu).
2. Alto.— Height, upper air.
3. Calvus.— Bald, stripped, bared (Cb).
4. Capillatus.— With hair (Cb).
5. Castellanus.— Castlelike (Cc, Ac, Sc).
6. Cirrus.— Lock or tuft of hair.
7. Congestus.— Congested, piled up (Cu, Cb).
8. Cumulus.— Pile, heap, accumulation.
9. Duplicatus.— Doubled or repeated (Ci, Cs, Ac, As, Sc).
10. Fibratus.— Fibrous (Ci).
11. Floccus.— Fluff or tuft (Cc, Ac).
12. Fractus.— Fracture, break (St, Cu).
13. Humilis.— Small, humble (Cu).
14. Incus.— Anvil (Cb).
15. Intortus.— Twist, entangle (Ci).
16. Lenticularis.— Lenticular, Lens shaped (Cc, Ac, Sc).
17. Mamma.— Breast or pouch (Ac, As, Sc, Cb).
18. Mediocris.— Medium (Cu).
19. Nebulosus.— Nebulous, misty, foggy (Cs, St).
20. Nimbo.— Rainy cloud.
21. Opacus.— Shady, thick, bushy (Ac, As, Sc, St).
22. Pannus.— Shreds. (Ragged shreds sometimes in layers, below or attached to As, Ns, Cu, Cb.)
23. Perlucidus.— To allow light to pass through (Ac, Sc).
24. Pileus.— Cap (Cu, Cb).
25. Praecipitatio.— To fall down (from a high place) (As, Ns, Sc, St, Cu, Cb).
26. Radiatus.— Being radiant, having rays (Ci, Ac, As, Sc, Cu).
27. Spissatus.— To thicken, to condense (Ci).
28. Stratus.— Spread or flatten out.
29. Translucidus.— Transparent (Ac, As, Sc, St).



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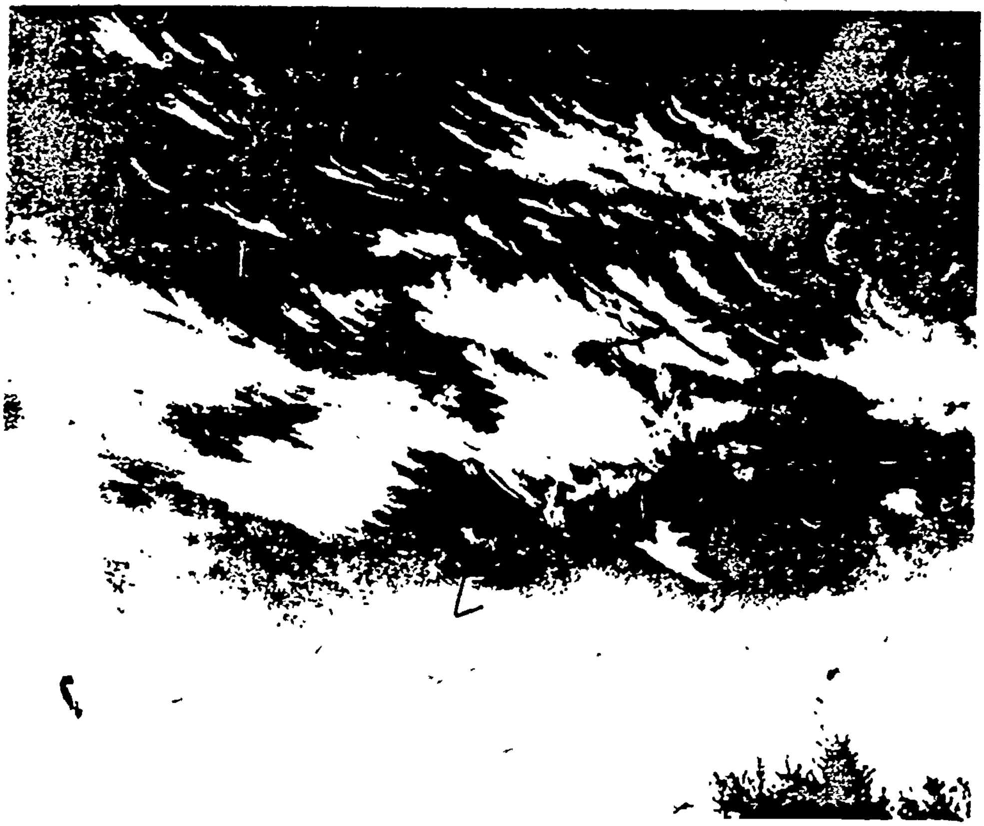

Figure 7.— Cirrus.

30. Tuba.— Tube, conduit, trumpet (Cb, Cu).

31. Uncinus.— Hook shaped (Ci).

32. Undulatus.— Waved, wavelike (Cc, Cs, Ac, As, Sc, St).

33. Virga.— Rod, stick, (Streaks of precipitation which evaporate before reaching the surface.) (Cc, Ac, As, Ns, Sc, Cu, Cb.)

34. Velum.— Veil. (Accessory cloud veil, close to or attached to upper portion of Cu or Cb.)

HIGH CLOUDS.— High clouds are described as follows:

1. Cirrus (Ci).— Cirrus (figure 7) are detached clouds of delicate and fibrous appearance, generally white (cirrus are the whitest clouds in the sky) in color, without shading. They appear in the most varied forms, such as isolated tufts, lines drawn across the sky, branching featherlike plumes, and curved lines ending in tufts.

Since cirrus are composed of ice crystals, their transparent character depends upon the degree of separation of the crystals.

Before sunrise and after sunset, cirrus may still be colored bright yellow or red. Being high altitude clouds, they light up before lower clouds and fade out much later.

Cirrus often indicate the direction in which a storm may lie.

Cirrus appear in the following species— cirrus fibratus, cirrus uncinus, cirrus spissatus, cirrus castellanus, and cirrus floccus. In addition, these species may have several varieties.

2. Cirrocumulus (Cc).— Cirrocumulus (figure 8), commonly called mackerel sky, look like

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Figure 8.— Cirrocumulus.

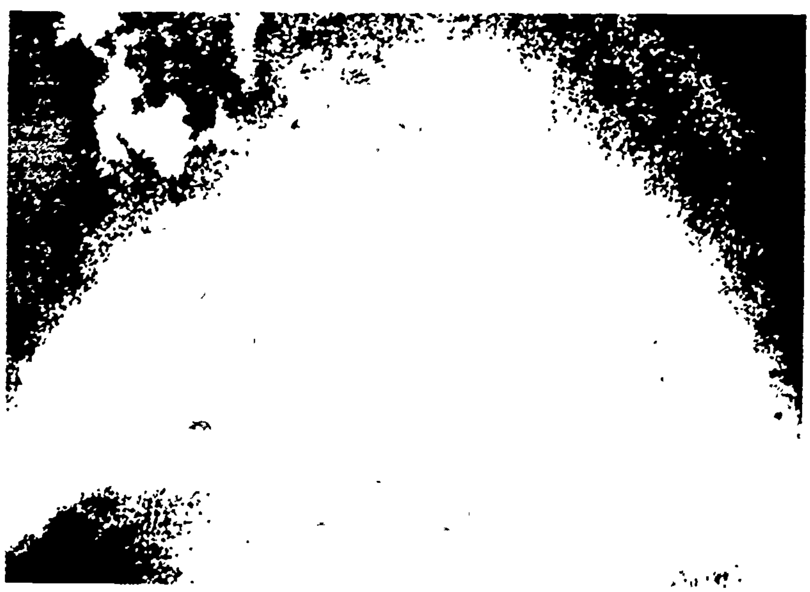

Figure 9.— Cirrostratus.

rippled sand or like cirrus containing globular masses of cotton usually without shadows. Cirrocumulus are an indication that a storm is probably approaching. The individual globules of cirrocumulus are rarely larger than 1 degree as measured by an observer on the surface of the earth at or near sea level.

Cirrocumulus may be observed in four species—cirrocumulus stratiformis, cirrocumulus lenticularis, cirrocumulus castellanus, and cirrocumulus floccus.

3. Cirrostratus (Cs).— Cirrostratus (figure 9) are a thin, whitish veil, which does not

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Figure 10.— Altocumulus advancing over the sky in parallel bands.

blur the outlines of the sun or the moon, but gives rise to halos. A milky veil of fog, thin stratus, and altostratus are distinguished from a veil of cirrostratus of similar appearance by the halo phenomenon, which the sun or moon nearly always produces in a layer of cirrostratus.

The appearance of cirrostratus is a good indication of rain. In the Tropics, however, cirrostratus quite often may be observed with no rain following.

Cirrostratus occur in two species—cirrostratus fibratus and cirrostratus nebulosus.

MIDDLE CLOUDS.— Middle clouds are described as follows:

1. Altocumulus (Ac).— Altocumulus (figure 10) are a layer (or patches) of clouds composed of flattened globular masses, the smallest elements of the regularly arranged layer being fairly small and thin, with or without shading. The balls or patches usually are arranged in groups, in lines, or in waves. This cloud form differs from cirrocumulus by generally having larger masses, by casting shadows, and by having no connection with cirrus forms. A corona or irisation is frequently observed on altocumulus.

Altocumulus are divided into four species—altocumulus stratiformis, altocumulus lenticularis, altocumulus castellanus, and altocumulus floccus. In addition, altocumulus may be observed in several more varieties.

2. Altostratus (As).— Altostratus (figure 11) look like thick cirrostratus; but without halo phenomena; altostratus are a fibrous veil or sheet, gray or bluish in color. Sometimes the sun or moon is completely obscured.

Light rain or heavy snow may fall from a cloud layer that is definitely altostratus.

Altostratus can sometimes be observed at two different levels in the sky and sometimes in conjunction with altocumulus, which may also exist at two different layers in the sky. Altostratus are not divided into any species, but several varieties of these clouds do appear.

LOW CLOUDS.— Low clouds are described as follows:

1. Nimbostratus (Ns).— Nimbostratus (figure 12) are a low, amorphous, and rainy layer of cloud. Of a dark gray color, they are usually nearly uniform and feebly illuminated, seemingly from within.

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Figure 11.— Altostratus.

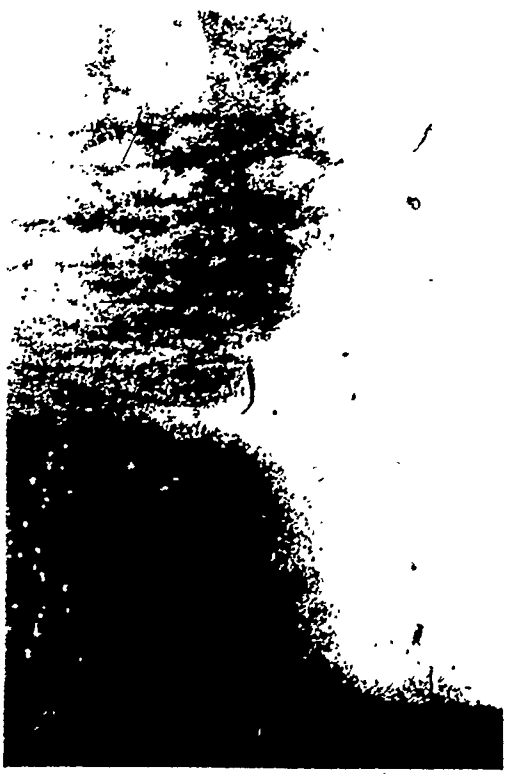

Figure 12.— Nimbostratus.

When precipitation occurs, it is in the form of continuous rain or snow. However, nimbostratus may occur without rain or snow reaching the ground. In cases in which the precipitation does not reach the ground, the base of the cloud is usually diffuse and looks wet.

In most cases, nimbostratus evolve from altostratus layers which grow thicker and whose bases become lower until they become a layer of nimbostratus.

Nimbostratus are not divided into any species or varieties.

2. Stratocumulus (Sc).— Stratocumulus (figure 13) are a layer (or patches) of clouds composed of globular masses or rolls. The smallest of the regularly arranged elements are fairly large. They are soft and gray, with darker spots.

Underneath stratocumulus waves or rolls, strong winds occur. Under the thick parts, strong up-currents rise. Above the cloud layer, the air is smooth, but it is turbulent below and within the layer.

Figure 13.— Stratocumulus.

Figure 14.— Stratus.

Stratocumulus appear in three species—stratocumulus stratiformis, stratocumulus lenticularis, and stratocumulus castellanus. Several varieties of stratocumulus are also observed.

3. Stratus (St).— Stratus (figure 14) are a low, uniform layer of clouds, resembling fog, but not resting on the ground. When a layer of stratus is broken up into irregular shreds, it is designated as fractostratus. Stratus nebulosus and stratus fractus are the two species of stratus. Three varieties of stratus also form in the sky.

A veil of stratus gives the sky a characteristically hazy appearance. Usually, drizzle is

Figure 15.— Cumulus (congestus).

Figure 16.— Cumulonimbus (capillatus).

the only precipitation associated with stratus. When there is no precipitation, the stratus cloud form appears drier than other similar forms, and it shows some contrasts and some lighter transparent parts.

4. Cumulus (Cu).— Cumulus (figure 15) are dense clouds with vertical development. Their upper surfaces are dome shaped and exhibit rounded protuberances, while their bases are nearly horizontal. Fractocumulus resemble ragged cumulus in which the different parts show constant change.

Strong updrafts exist under and within all cumulus formations. In fact, cumulus, like other forms of vertical development, are caused by updrafts.

Four species of cumulus form in the sky— cumulus humilis, cumulus mediocris, cumulus congestus, and cumulus fractus.

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5. Cumulonimbus (Cb).— Cumulonimbus (figure 16) are heavy masses of cloud, with great vertical development, whose cumuliform summits resemble mountains or towers. Their upper parts have a fibrous texture; often they spread out in the shape of an anvil.

Cumulonimbus are cumulus type clouds with great vertical development; tops may extend higher than 60,000 feet. The top is composed of ice crystals and often resembles an anvil. Cumulonimbus are the familiar thunderclouds, and their precipitation is of a violent, intermittent, showery character. Hail often falls from well-developed cumulonimbus.

Cumulonimbus appear in two species—cumulonimbus calvus and cumulonimbus capillatus. Cumulonimbus have no varieties, although they may show one or several supplementary features, such as mamma, pileus, virga, or tuba. The tuba is the tornado funnel.

The Marine Science Technician must learn to infallibly recognize the various cloud types as seen from the earth's surface.

In figure 17 there is a view of all types of clouds in a tier, each cloud type being shown at its average height.

Although one never sees all these types at any one time in nature, quite frequently two or three layers of clouds of different types may be observed simultaneously.

## FOG

Fog may be defined as a cloud on the earth's surface; that is, visible condensation in the atmosphere of sufficient density to interfere with marine and aerial navigation. Fog varies in depth from a few feet to many hundreds of feet. Its density is variable, resulting in visibilities from near zero to several miles.

Fog consists of visible water droplets or ice particles suspended in the atmosphere. It differs from other clouds in that it exists on the ground or on the surface of bodies of water, while other clouds may be thousands of feet aloft. It differs from rain or mist in that its water or ice particles are more minute and suspended, and do not fall earthward.

The forecasting of fog is frequently a difficult job. In addition to knowledge of the meteorological causes of fog formation, it is necessary to have a thorough knowledge of local geography and topography, for a slight air drainage may be enough to prevent fog formation, or a quick shift in the wind direction may cause fog to cover an airport.

The atmosphere may be considered as a mixture of water vapor in dry air. The amount of water vapor which the air can hold depends primarily upon the temperature: The higher the temperature, the more water vapor the air can contain. For any given amount of water vapor, the temperature can be reduced just so much without liquid water particles being condensed out. If the temperature drops below this point, some of the invisible water vapor must be condensed out in the form of visible water droplets, as the colder air can no longer retain it in solution.

The temperature to which air must be cooled, at a constant pressure and a constant water vapor content, in order for saturation to occur is the dewpoint. This is a variable, based upon the amount of water vapor present in the atmosphere. The more water vapor present, the higher the dewpoint. Thus, the dewpoint is really an index of the amount of water vapor present in the air at a given pressure.

The two manners in which the temperature and dewpoint may be made to coincide are as follows:

1. By raising the dewpoint until it equals the temperature.

2. By lowering the temperature to the dewpoint.

The first results from the addition of water vapor to the air by evaporation from water surfaces, wet ground, or rain falling through the air. The second results from the cooling of the air by contact with a cold surface underneath.

### Types of Fog

There are several classifications of fog—radiation fog, advection fog, upslope fog, and frontal fog.



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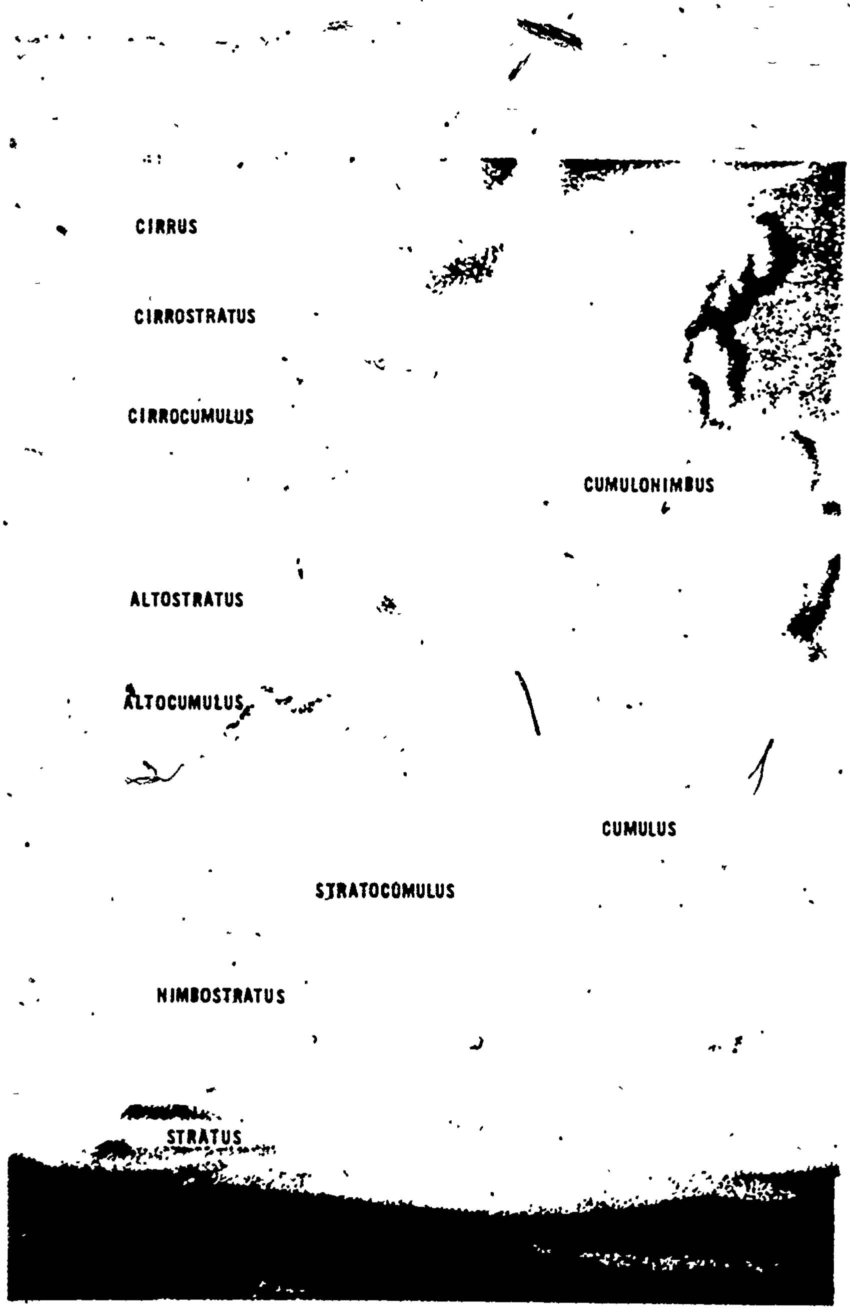


Figure 17.— Layer diagram of clouds at various levels.

RADIATION FOG.— Radiation fog, which generally occurs as ground fog, is caused by the radiational cooling of the earth's surface. It forms only at night and over a land surface. It never forms over a water surface. This type of fog usually covers a wide area.

After sunset, the earth receives no heat from the sun, but it continues to radiate heat. The surface begins to cool because of this heat loss. As the earth cools, the layer of air close to the earth is cooled by conduction (the transfer of heat from warmer to colder matter by contact). This causes the layer near the earth to be cooler than the air immediately above it, a condition called an inversion. If the air beneath the inversion layer is sufficiently moist and it cools to its dewpoint, fog forms. (See figure 18.) In case of a calm, this cooling by conduction affects only a very shallow layer (a few inches deep), because air is a poor conductor of heat. Wind of low speed (3 to 5 knots) causes slightly turbulent currents. This turbulence is enough to spread the fog through

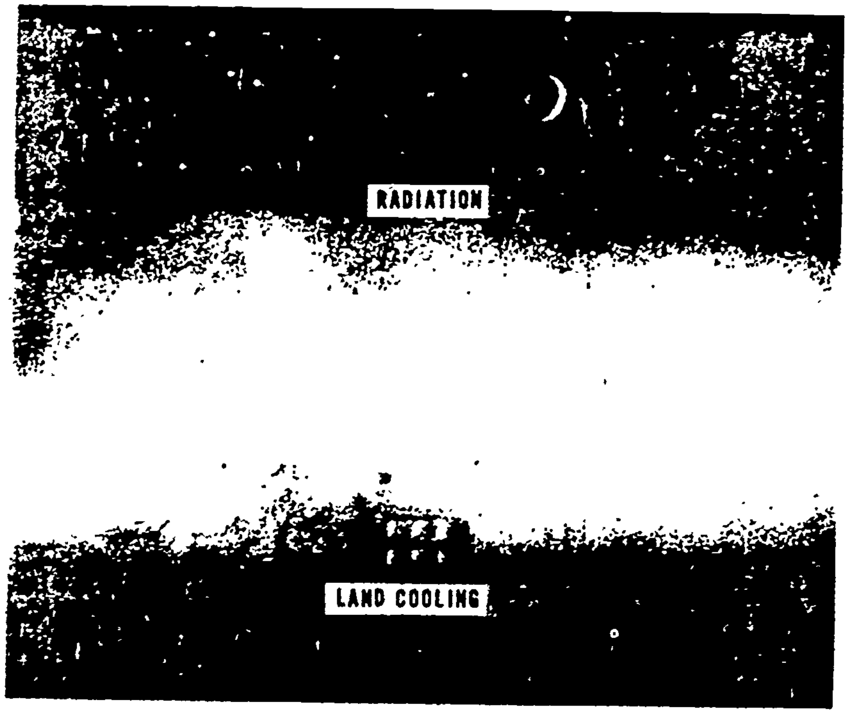


Figure 18.— Radiation fog.

succeedingly deeper layers. As the nocturnal cooling continues, the air temperature drops further, more moisture is condensed, and the fog becomes deeper and denser.

After the sun rises, the earth is heated. Radiation from the warming surface heats the lower air, causing evaporation of the lower part of the fog, thereby giving the appearance of lifting. Before noon, heat radiated from the warming surface of the earth destroys the inversion, and the fog evaporates into the warmed air.

Radiation fog is common in high-pressure areas where the wind speed is usually low (2 to 5 knots) and clear skies are frequent. This permits maximum radiational cooling.

ADVECTION FOG.— Advection fog is the name given to fog produced by air in motion or to fog formed in one place and transported to another. This type of fog is formed when warmer air is transported over colder land or water surfaces. Cooling from below takes place and gradually builds up a fog layer. The cooling rate depends on the wind speed and the difference between the air temperature and the temperature of the surface over which the air travels.

Advection fog can form only in regions where marked temperature contrasts exist within a short distance of each other, and only when the wind blows from the warm region toward the cold region. (See figure 19.) It is easy to locate areas of temperature contrast on the weather map. They are usually found along coastlines or between snow-covered and bare ground.

SEA FOG is always of the advection type and occurs when the wind brings moist, warm air over a colder ocean current. The greater the difference between the air temperature and the ocean temperature, the deeper and denser the fog. Sea fog may occur during either the day or the night. Some wind is necessary, not only to provide some vertical mixing, but actually also to move the air to the place where it is cooled. Most advection fogs are found at speeds between 4 and 13 knots. Sea fogs have been maintained with wind speed as high as 26 knots. They exist at such speeds because of the lesser frictional effect over a water surface. Winds

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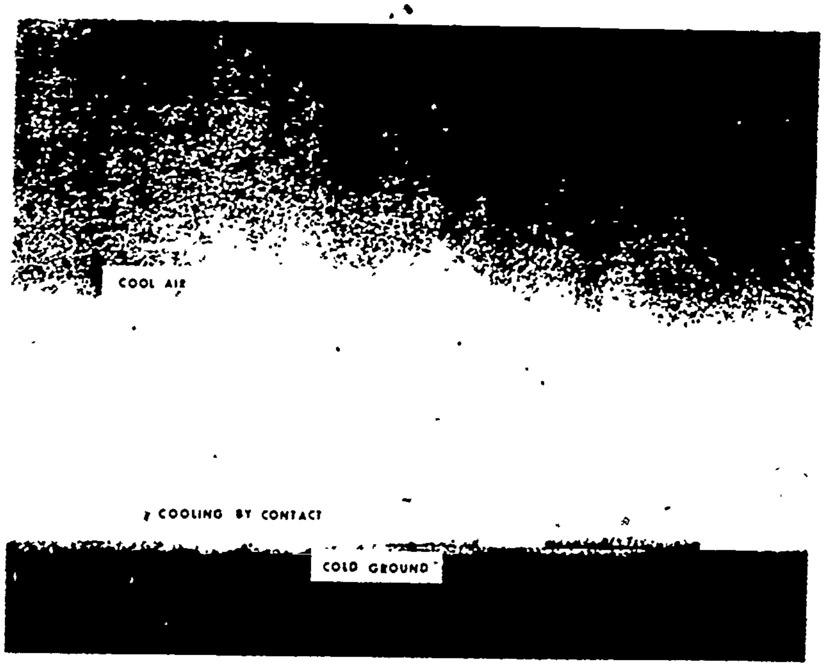


Figure 19.— Advection fog.

of equal speed produce less turbulence over water than over land.

Sea fogs, which tend to persist for long periods of time, are quite deep and dense. Since the temperature of the ocean surface changes very little during the day, it is not surprising to hear of sea fogs which have lasted for weeks. A good example of sea fog is that off the coast of Newfoundland.

LAND ADVECTION FOG is found near large bodies of water, that is, along seacoasts and large lakes. Onshore breezes bring maritime air over a land surface which has cooled by radiation at night. (See figure 20.) Also, fogs may form over the ocean and be blown over the land during either the day or the night. Another situation favorable to fog formation is one in which air flows from warm, bare ground to snow-covered ground nearby.

Land advection fog cannot exist with as high wind speed as the sea type because of the greater turbulence. If only a slight amount of cooling is necessary to cause condensation, even a cloud cover may permit the land surface to cool enough to cause fog. This type of fog dissipates over a land surface in much the same fashion as radiation fog; however, since it is usually deeper, it requires a longer time to disperse.

STEAM FOG, another type of advection fog, occurs within air masses; but, unlike other air-mass fogs, which are formed by the cooling of the air temperature to the dewpoint, steam fog is caused by saturation of the air through evaporation of water. It occurs when cold air moves over warm water. Evaporation from the surface of the warm water easily saturates the cold air, causing fog. It rises from the surface like smoke. It should be noted that the actual process, heating cold air over a warm surface, tends to produce instability. Denseness and persistence are favored by the presence of an inversion above the surface, which prevents the fog from rising very high.

This type of fog forms on clear nights over inland lakes and rivers in late fall before they are frozen. They are prevalent along the Mississippi River and Ohio River at that time of year.

ARCTIC SEA SMOKE (name given to steam fogs in the Arctic region) forms when cold air moves over a warmer water surface, which is most often found in breaks of the surface ice in this area.



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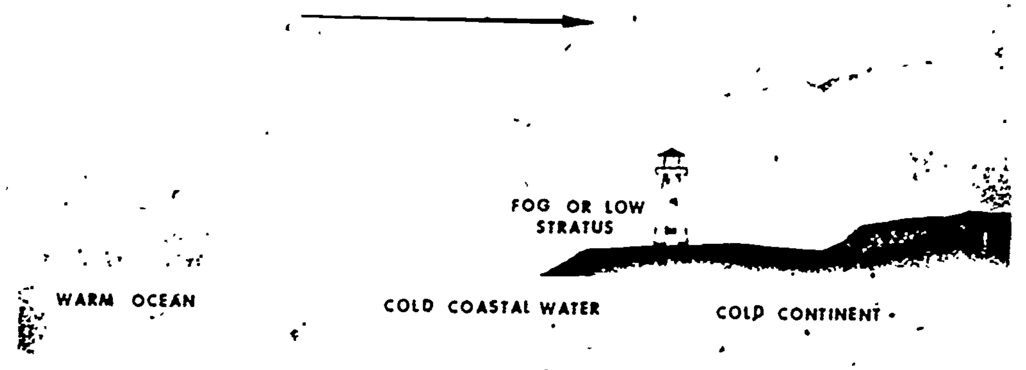


Figure 20.— Fog caused by an onshore wind and cold coastal water.

UPSLOPE FOGS.— There is a type of fog, called upslope fog, which is caused by adiabatic cooling of rising air (adiabatic cooling is the cooling of the air by expansion as it rises). Upslope fog is formed when moist, warm air is forced up a slope by the wind. The cooling of the air is almost entirely adiabatic, since there is very little conduction to the surface of the slope. The air must be stable before it starts its motion so that the lifting does not cause convection, or vertical currents, which would dissipate the fog.

Some wind speed is needed, of course, to cause the upslope motion. The fog is usually found where the air moves up a gradual slope. This type of fog is deep and requires considerable time to dissipate. The most common fog of this type is called CHEYENNE FOG and is caused by the westward flow of air from the Missouri Valley, which produces fog on the eastern slope of the Rockies.

FRONTAL FOGS.— Frontal fogs are another hazard which must be added to the list of weather troubles associated with fronts (a front is the line where two air masses meet). The actual fog occurs under the frontal surface in the cold air mass. It is due to the evaporation of falling rain. This additional water vapor gradually saturates the air. Precipitation falls from the lifted warm air through the cold air. Evaporation from the rain continues as long as the temperature of the raindrops is higher than the temperature of the air, even though the cold air is already saturated. Naturally, the upper regions become saturated first because the temperature and dewpoint are lower at the higher altitude. As the evaporation from the rain continues, a layer of clouds begins to build down from the frontal surface. Eventually, this cloud layer extends to the ground and becomes fog. During the day, there may be enough turbulence caused by solar heating to keep this cloud off the ground. However, after dark, because of dying convection currents and the nocturnal cooling of the air, the ceiling drops very suddenly. It is this sudden closing in after dark that makes this type of fog so dangerous.

Cold fronts usually move so rapidly and have such narrow bands of precipitation and high wind speeds that COLD-FRONT FOG is comparatively rare and short lived.

WARM-FRONT FOG, on the other hand, is common and dangerous. Since frontal systems are quite extensive, warm-front fog may cover a wide area. This type fog is also very deep, because it extends from the ground to the frontal surface. The clouds above the frontal surface also slow down the dissipating effect of solar heating. All those factors make the warm-front fog the worst possible type to encounter. (See figure 21.)

## DEW

Dew is a deposit of waterdrops on objects at or near the ground. It is produced by condensation

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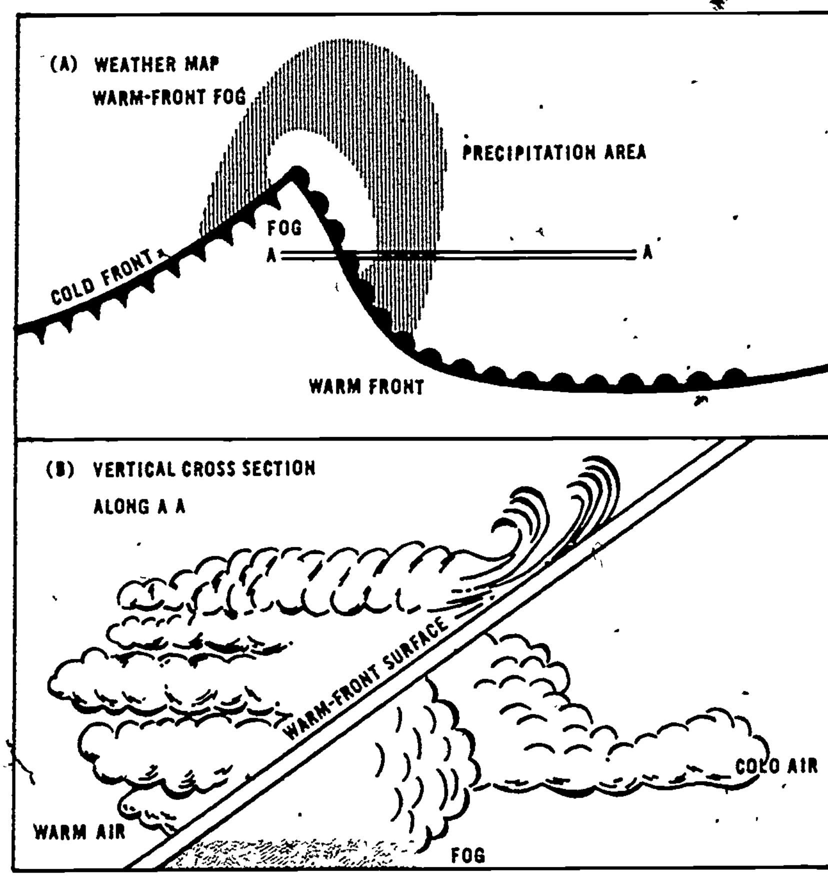


Figure 21.— Warm-front fog.

of water vapor from the surrounding clear air and occurs on relatively calm, clear nights.

FROST

Frost, or hoarfrost, is a deposit of ice having a crystalline appearance. It generally assumes the form of scales, needles, feathers, or fans. Hoarfrost is the solid equivalent of dew and should not be confused with white dew, which is dew frozen after it formed. Frost forms as such directly without going through the liquid stage.

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# CIRCULATION OF THE ATMOSPHERE

For an understanding of large-scale motions of the atmosphere, it is essential that the Marine Science Technician study the primary or general circulation of the atmosphere as a whole.

The sun's radiation is the energy that sets the atmosphere in motion, both horizontally and vertically. The vertical motion is caused by the rising and expanding of the air when it is warmed, or the descending and contracting of the air when it is cooled. The horizontal motion is caused by differences of atmospheric pressure; air moves from areas of high pressure toward areas of low pressure. Differences of temperature, the cause of the pressure differences, are due to the unequal absorption of the sun's radiation by the earth's surface. Due to the relative position of the earth with respect to the sun, much more radiation is absorbed near the Equator than at other areas, with the least radiation being absorbed at or near the poles. Consequently, the principal factor affecting the atmosphere is incoming solar radiation, and its distribution depends on the latitude and the season.

The differences in the type of surface; the differential heating; the unequal distribution of land and water; and the relative position of oceans to land, forests to mountains, lakes to surrounding land, and the like, cause different types of circulations of the air.

First, there is the general or primary circulation of the atmosphere as a whole. This explains the circulation of the atmosphere as a whole with little attention to details and minor differences from time to time or place to place.

Then, there are the secondary circulations. These explain the various adjustments the primary circulation makes to major differences in heating which result from the distribution of land and sea on a large, but not a global, scale.

Finally, there are the various tertiary (third order) circulations, which explain the adjustments of the primary and secondary circulations to strictly local differences in heating.

## GENERAL CIRCULATION

The general circulation theory attempts to explain the global circulation of the atmosphere with some minor exceptions. The general circulation theory is based on and evolved from physical laws and observed weather data. Since the earth heats unequally, the heat is carried away from the hot area to a cooler one as a result of the operation of physical laws. This global movement of air which restores a balance of heat on the earth is the general circulation. Since heat is the first cause, we will discuss the world temperature distribution first.

### WORLD TEMPERATURE GRADIENT

Temperature gradient is the rate of change of temperature with distance in any given direction at any point. World temperature gradient refers to the change in temperature that exists in the atmosphere from the Equator to the poles.

The change in temperature, or temperature differential, which causes atmospheric circulation can be compared to the temperature differences produced in a pan of water placed over a gas burner. As the water is heated, it expands and its density is lowered. This reduction in density causes the water to rise to the top of the pan. As it rises, it cools and proceeds to the edges of the pan. It cools further and sinks to the bottom, eventually working its way back to the center of the pan where it started. This process sets up a simple circulation pattern due to successive heating and cooling.

Ideally, the air within the troposphere may be compared to the water in the pan. The most direct rays of the sun hit the earth near the

Equator and cause a net gain of heat. The air at the Equator heats, rises, and flows in the upper atmosphere toward both poles. Upon reaching the poles, it cools and sinks back toward the earth, where it tends to flow along the surface of the earth back to the Equator. Simple circulation of the atmosphere would occur as described above if it were not for the following factors:

1. The earth rotates, resulting in an apparent force known as the Coriolis (or deflecting) effect and also resulting in constant change of the area being heated. The Coriolis effect is the more important result of the two.

2. The earth is covered by irregular land and water surfaces.

Regions under the direct rays of the sun receive more heat per unit time than those under oblique rays. The heat brought by the slanting rays of early morning may be compared with the heat that is caused by the slanting rays of winter. The heat which is due to the more direct rays of midday may be compared with the heat resulting from the more direct rays of summer.

The length of day, like the angle of the sun's rays, influences the temperature. The length of day varies with the latitude and the season. Near the Equator there are about 12 hours of daylight every day in the year, and the sun at noonday is always high in the sky (giving nearly direct rays). Consequently, equatorial regions have no pronounced seasonal temperature changes.

During the summer in the Northern Hemisphere, all places north of the Equator have more than 12 hours of daylight. During the winter the situation is reversed, latitudes north of the Equator having less than 12 hours of daylight.

Large seasonal variation in the length of the day and the seasonal difference in the angle at which the sun's rays reach the earth's surface cause seasonal temperature differences in middle and high latitudes.

The weak temperature gradient in the subtropical areas and the steeper gradient poleward can be seen in figure 22. Note also how much steeper the gradient is poleward in the winter season of each hemisphere than it is in the summer season (See figures 22 and 23.)

PRESSURE OVER THE GLOBE

Previously you learned that pressure decreases with an increase in temperature. This is the principal factor in the distribution of pressure over the world. In figures 24 and 25, note that a low-pressure area lies along the doldrums in the equatorial region. This is due to the higher temperatures maintained throughout the year in this region. At the poles, permanent high-pressure areas remain near the surface because of the low temperatures in this area throughout the entire year. The subtropical high-pressure-areas at 30° N. and S. lat. are caused mainly by the "piling up" of air in these regions. There are other areas which are dominated by relatively high or low pressures during certain seasons of the year.

ELEMENTS OF CIRCULATION

We have previously shown how temperature differences cause pressure differences. Pressure differences in turn cause air movement. Now let us go a step further and consider how the air movements work and how they evolve into the various circulations—general, secondary, and tertiary.

Static Earth

If the earth were a nonrotating sphere composed of a uniform surface, the atmospheric circulation would be relatively simple. The air at the Equator would be heated and become less dense, causing it to rise and expand. Due to less insolation at the poles, the air would be cooled and become denser, causing it to descend. Therefore, if the earth were static, the flow of air would be a simple circulation from the poles to the Equator at the surface, and from the Equator to the poles aloft.

Static Nonuniform Earth

On a static earth composed of nonuniform surface, the atmospheric circulation would be very similar to that of a static earth with a uniform surface, with the exception that some major eddies or currents would be set up within the primary cell. The major eddies thus formed

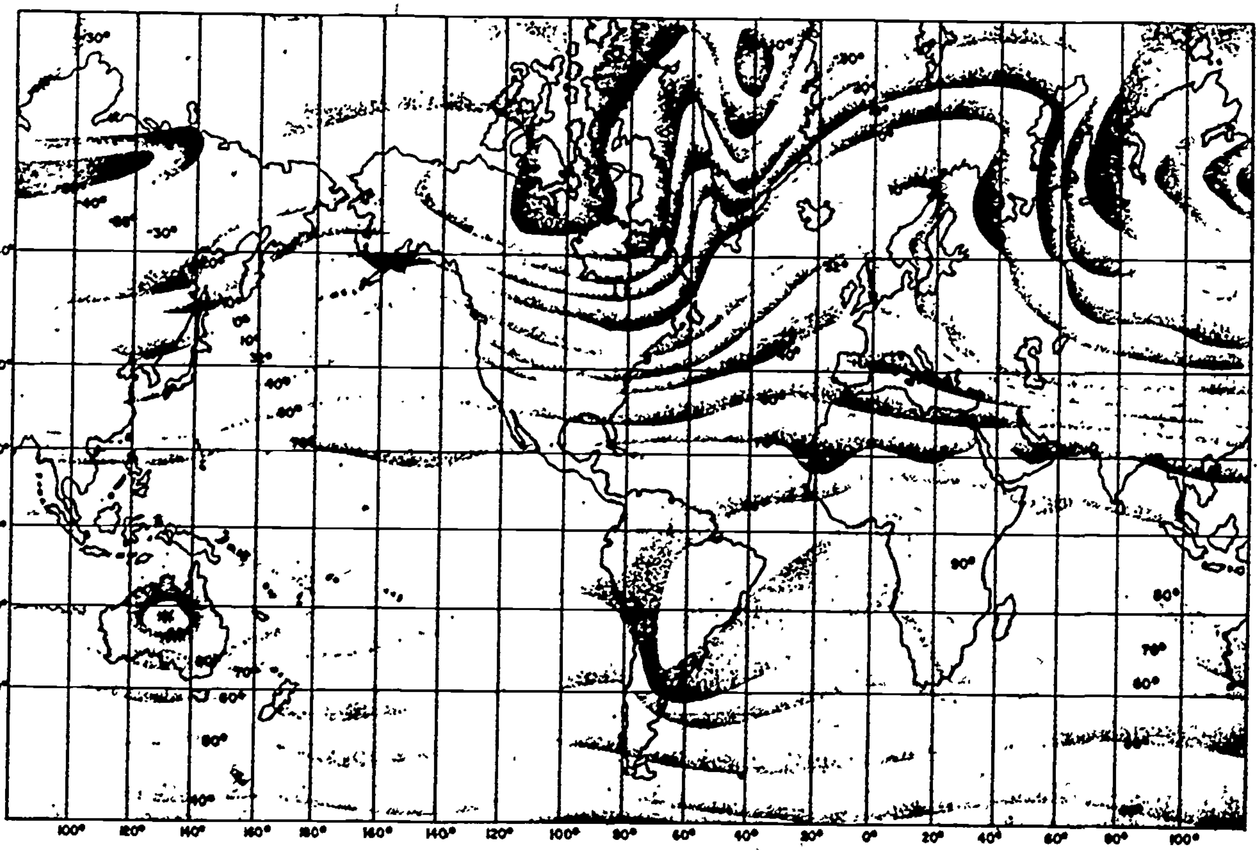


Figure 22. — Mean world temperatures for January.

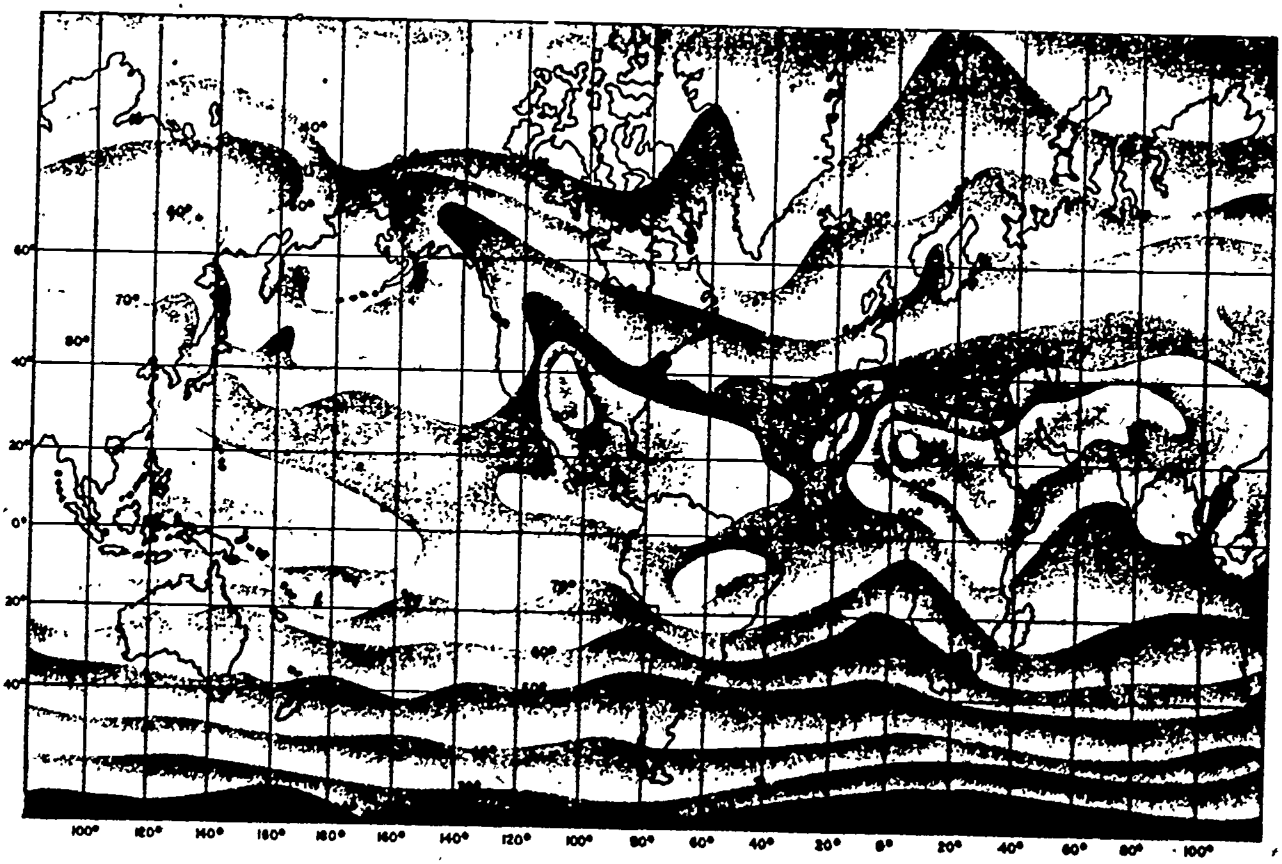


Figure 23. — Mean world temperatures for July.

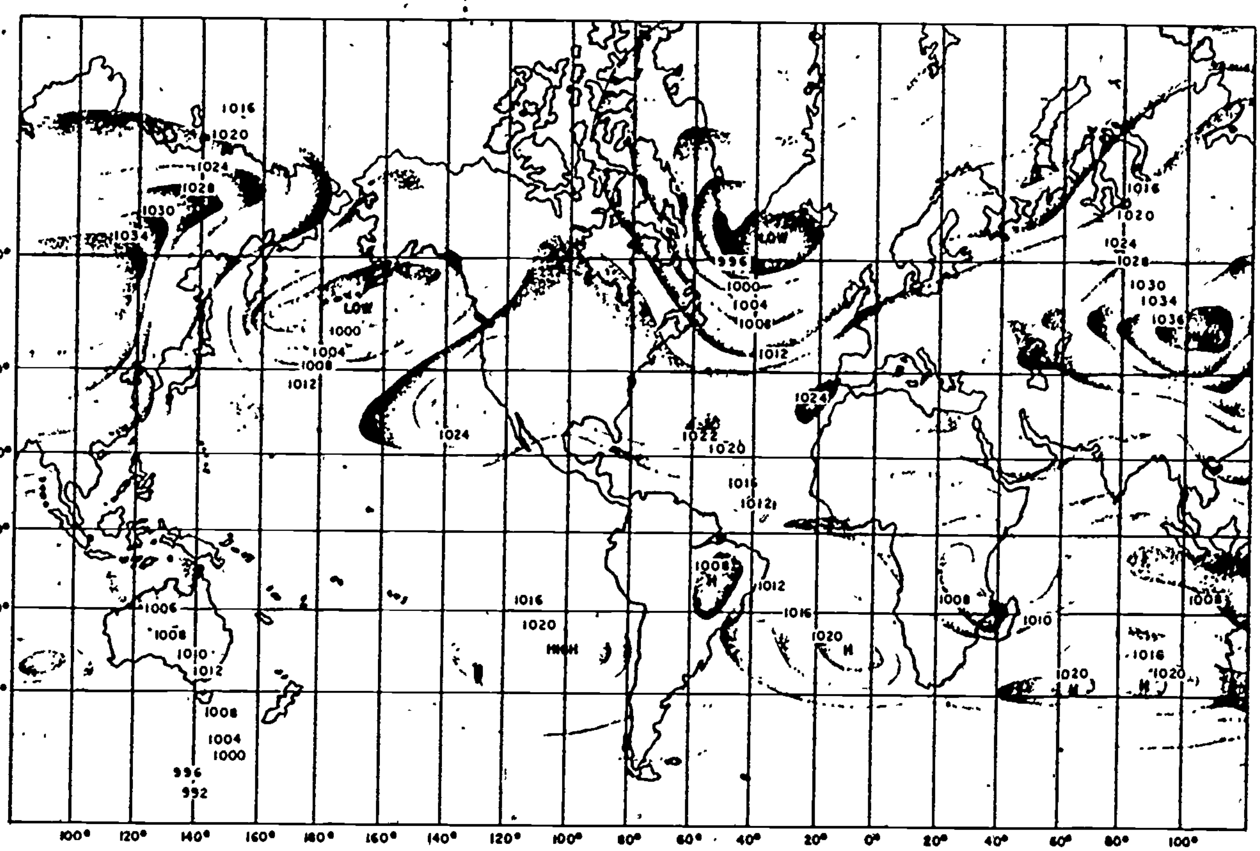

Figure 24. — Mean world pressure for January.

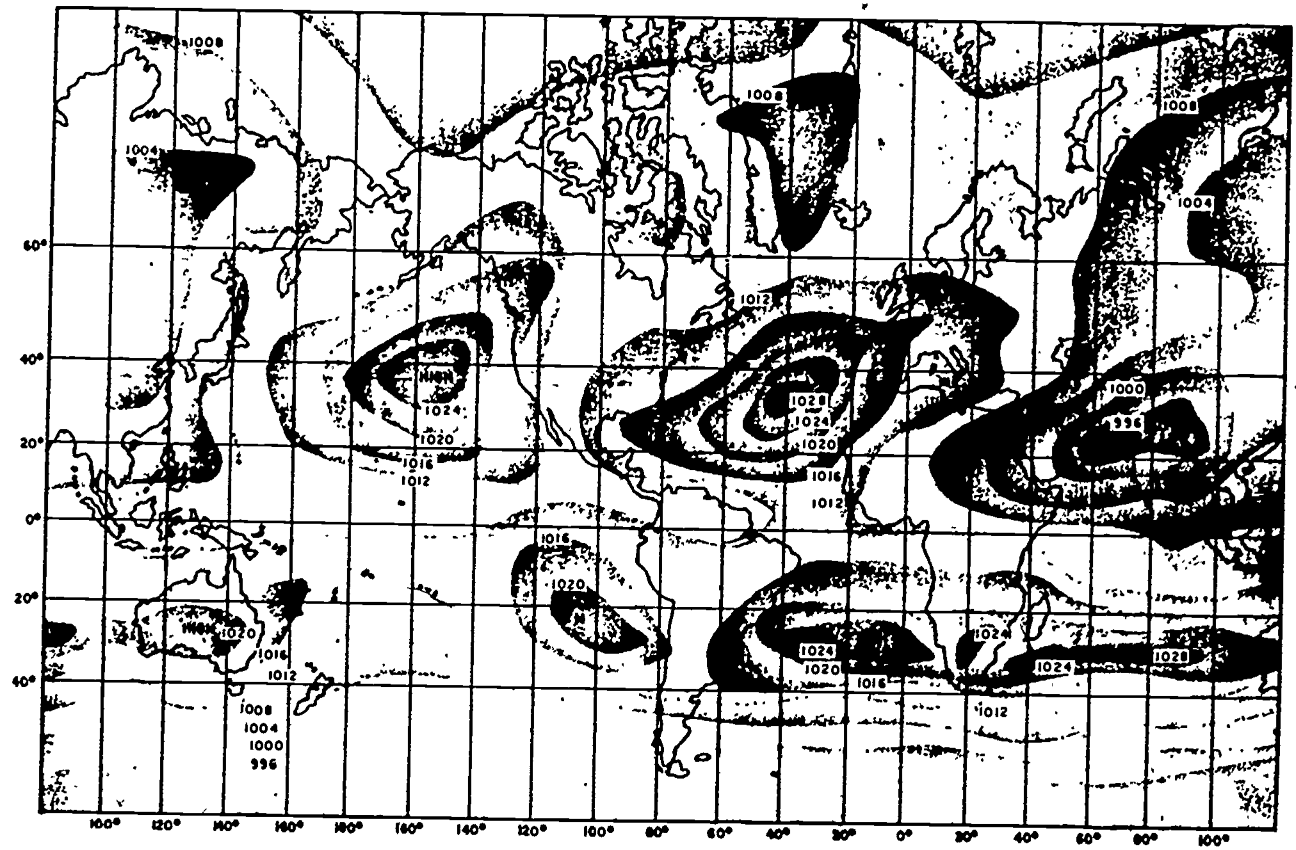


Figure 25. — Mean world pressure for July.

would be of a more or less permanent nature, changing only with the seasons. The differences in heating of the various surfaces would have a deflecting effect on the primary flow, and the circulation would become more complex.

Rotating Nonuniform Earth

The earth is neither static nor uniform; therefore, it is necessary to proceed one step further to explain the primary atmospheric circulation.

Due to the rotation of the earth, there is an apparent deflecting force on windflow called the Coriolis effect. (See figure 26.) This effect causes a deflection of the winds to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. The complex circulation resulting from the interplay of the Coriolis effect with the flow of air is known as the 3-cell theory. (See figure 27.)

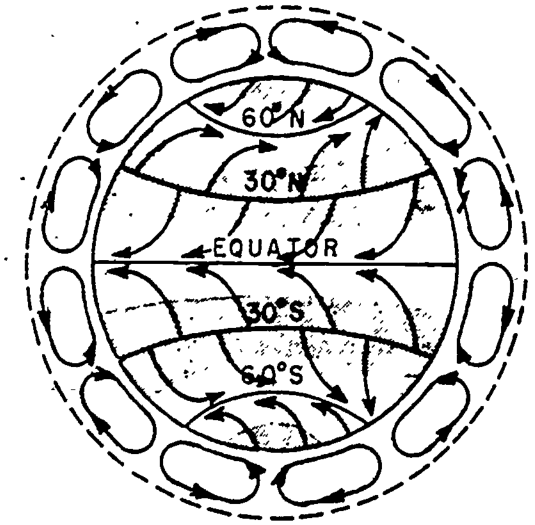


Figure 26.— Coriolis effect on windflow.

THE 3-CELL THEORY

The rotation of the earth exerts a tremendous influence on the circulation of the earth's atmosphere. The 3-cell theory of the circulation offers an explanation of the effect of the earth's rotation.

According to the 3-cell theory, the earth is divided into six circulation belts—three in the Northern Hemisphere and three in the Southern Hemisphere. The dividing lines are the Equator, 30° N. and S. lat., and 60° N. and S. lat. The three cells of general circulation of the Northern Hemisphere are similar to those of the Southern Hemisphere.

First, observe the tropical cell of the Northern Hemisphere which lies between the Equator and 30° N. lat. The air at the Equator heats and rises. When it reaches the extremity of the troposphere, it tends to flow toward the North Pole. By the time the air has reached 30° N. lat., the Coriolis effect has deflected it so much that it is moving eastward instead of northward. This results in a piling up of air near 30° N. lat. and a descending current of air toward the surface which forms a belt of high pressure. When the descending air reaches the surface, part of it flows poleward to become part of the midlatitude cell; the other part flows toward the Equator, is deflected by the Coriolis effect, and forms the northeast trades.

The midlatitude cell is located between 30° and 60° N. lat. The air which comprises this cell circulates poleward at the surface and equatorward aloft with rising currents at 60° (polar front) and descending currents at 30° (high-pressure belt). However, in general, the winds, both at the surface and aloft, blow from the west. This is easily explained for the surface wind by the Coriolis effect on the poleward moving surface air. The west wind aloft is not so easily explained. Most authorities agree that this wind is frictionally driven by the west winds in the two adjacent cells.

The polar cell lies between 60° N. lat. and the North Pole. The circulation in this cell begins with a flow of air at a high altitude toward the pole. This flow cools and descends at the North Pole and forms a high-pressure area in the polar regions. After reaching the surface of the earth, this air tends to flow equatorward and is deflected by the Coriolis effect so that it moves from the northeast. This air converges with the poleward flow from the midlatitude cell and is deflected upward with a portion circulating poleward again and the remainder equatorward. The outflow of air aloft between the polar and midlatitude cells causes a semipermanent low-pressure area at approximately 60° N. lat. and, due to the discontinuity in the temperature and density of these two cells, the polar front develops in this area.



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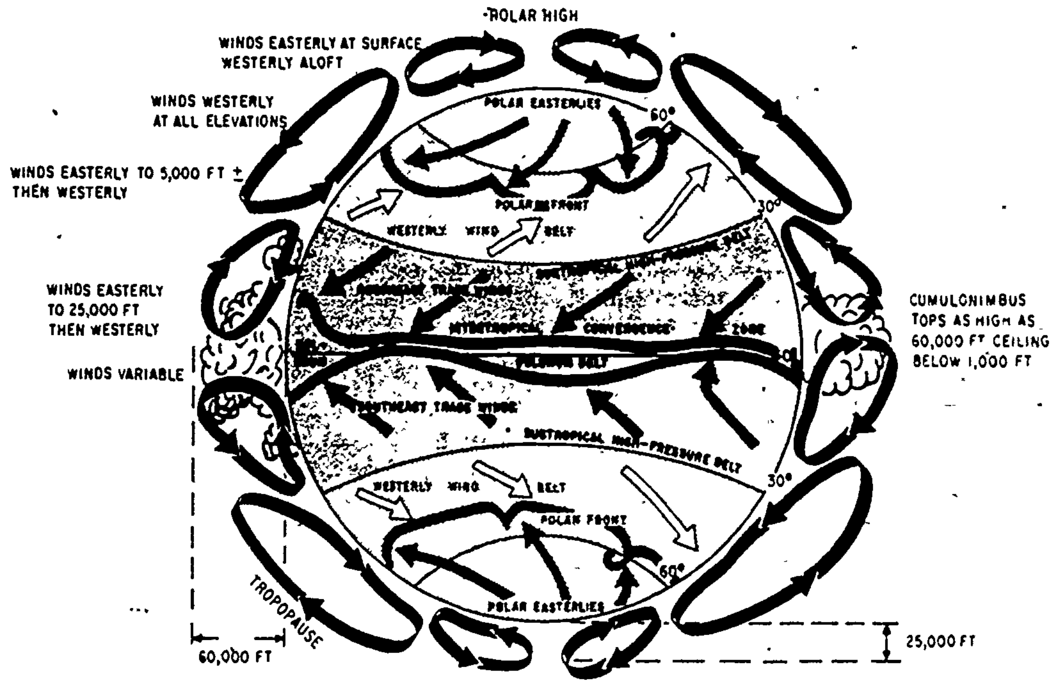


Figure 27.— Idealized pattern of the general circulation.

WORLD WINDS

In order to complete the picture of the general circulation of the atmosphere, observe the prevailing winds and the pressure belts of the world and examine some of the factors affecting windflow.

The equatorial belt of light and variable winds between the northeast trade winds of the Northern Hemisphere and the southeast trade winds of the Southern Hemisphere is called the doldrums of the intertropical convergence zone (ITCZ).

The doldrums vary in position and tend to move north and south of the Equator with the sun, though more of the area is generally located slightly to the north of the Equator. In the region of the doldrums the temperatures are high, and the wind is convergent (a net inflow of air into the area), which results in excessive precipitation.

On the poleward side of the doldrums the TRADE WINDS are found. Whenever the doldrums are absent in some part of the equatorial region, the trade winds of the Northern and Southern Hemisphere converge, causing heavy rain squalls. A noticeable feature of the trade wind belt is the regularity of these systems, especially over the oceans.

The wind blowing above and counter to the trade wind is the ANTITRADE. Formerly it was called the COUNTERTRADE.

In the subtropical high-pressure belts centered, in the mean, near 30° N. and 30° S. latitudes, winds are light and variable. These areas are referred to as the HORSE LATITUDES. Due to the descending air, fair weather is often characteristic of this region. The pressure decreases outward from this area, and the prevailing westerlies are on the poleward side, with the trade winds on the equatorial side.

The prevailing westerlies, which are on the poleward side of the trade winds, are persistent throughout the midlatitudes. In the Northern Hemisphere their direction at the surface is from the southwest and in the Southern Hemisphere from the northwest, due to the deflection caused by the Coriolis effect as the air moves poleward.

Poleward of the prevailing westerlies lies the belt of low pressure known as the polar front zone.

In the polar cells the surface winds are known as the polar easterlies. They move from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. They are very shallow due to the low temperatures and are overlain by the westerlies.

Geostrophic and Gradient Winds

The variation of pressure from one locality to another is the initial factor that produces movement of air, or wind. Assume that at three stations the pressure is lower at each successive point. This means that there is a horizontal pressure gradient—a decrease in pressure in this case—for each unit distance. With this situation, the air moves from the area of greater pressure to the area of lesser pressure.

On a weather map, the barometric pressure readings are entered from the reports of many stations. Some of the stations report the same pressure readings. One of the first steps toward analyzing a weather map is to draw lines connecting points of equal pressure. These lines are called isobars.

If the force of the pressure were the only factor acting on the wind, the wind would flow from high to low pressure, perpendicular to the isobars. Since experience shows the wind does not flow perpendicular to isobars, but at a slight angle across them and towards the lower pressure, it is evident that other factors are involved. These other factors are the Coriolis effect, caused by the rotation of the earth; frictional force, caused by the wind coming in contact with the surface over which it is passing; and centrifugal effect, due to the curvature of the isobars. If a unit of air moves under the influence of pressure force and the Coriolis effect (no friction force involved), the movement of air would be parallel to the isobars; this wind is termed either a gradient wind or a geostrophic wind.

Gradient wind is defined as a steady horizontal motion of the air blowing parallel to curved isobars. Geostrophic wind is defined as a steady horizontal motion of air along straight isobars. It can be stated that the geostrophic wind is a special case of gradient wind.

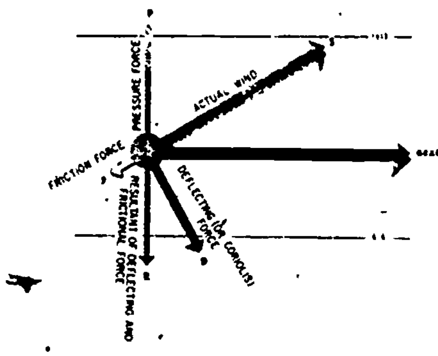


Figure 28.— Frictional force effect.

Suppose a unit of air (figure 28) moves with the speed and direction S. The deflecting force D is at right angles to the speed and direction S. The resultant force R is the resultant of the deflecting force D and the frictional force F which is directly opposite to the speed and direction S. To have a balanced motion, the pressure force P must be equal to the resultant force R and have a direction opposite R. Since the angle from S to R is greater than 90°, the angle from P to S is smaller than 90°. Since the pressure force is perpendicular to the isobars and the angle from P to S is less than 90°, the actual wind must flow to the left of the isobars. Since the frictional force decreases with altitude, the wind speed increases with increasing height.

The frictional layer is generally considered to be the layer of the atmosphere found approximately below 3,000 feet, where the friction is most noticeable.

Frictional Force

Friction tends to retard air movement. Friction depends on the nature of the surface over which the air is moving. It is least over water surfaces and greatest over mountainous terrain. The effect of surface friction extends from the surface to approximately 3,000 feet. It is usually safe to say that the wind above 3,000 feet is the same as the gradient or geostrophic wind in direction and speed. The reason the surface wind flows across the isobars instead of parallel to them is because of the frictional effect. The Coriolis effect and centrifugal effect depend upon the speed of the air particles making up the wind, but the pressure force depends upon the horizontal spacing of the isobars. Since the

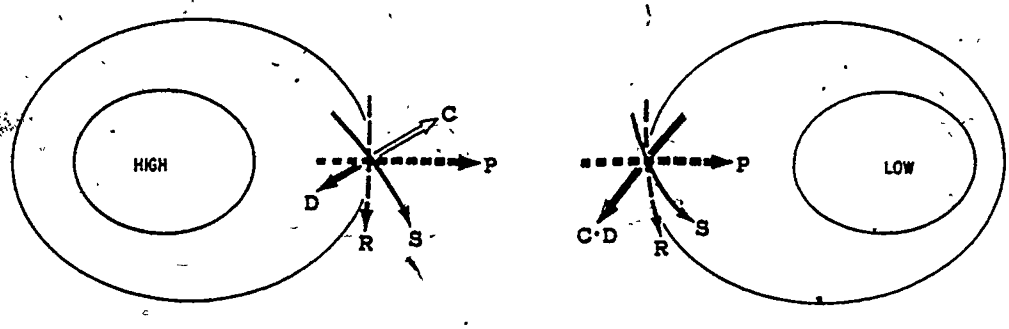


Figure 29.— Centrifugal effect on windflow.

frictional effect decreases the speed of the air particles, the forces that are in balance with the pressure gradient when aloft are weakened when introduced to the frictional layer over the earth. This means that the pressure force is the dominating force at the surface, and the surface wind direction is pulled somewhat toward the direction of the pressure force. (See figure 28.)

### Centrifugal Effect

Centrifugal effect is a factor when the isobars are curved. Its influence on the wind depends upon the speed of the wind and the radius of curvature of the isobars. (See figure 29.)

Above the frictional layer in a low-pressure area, the pressure gradient force equals the combined Coriolis and centrifugal effects. In a high-pressure area above the frictional layer, the pressure gradient and centrifugal effect balance the Coriolis effect.

### Cyclostrophic Wind

The Coriolis effect is at a minimum near the Equator; and as a result, the pressure gradient force is balanced primarily by the centrifugal effect. The wind that results when the pressure gradient force is balanced by the centrifugal effect is called the cyclostrophic wind. In the cyclostrophic wind, the pressure gradient force is inward directed and the centrifugal effect is outward directed. This is the balance of forces for a low-pressure system near the Equator. An example of cyclostrophic winds are the winds found in a hurricane.

### Convergence and Divergence

Convergence is the condition that exists when the distribution of winds within a given area is such that there is a net horizontal inflow of air into an area. The removal of the resulting excess is accomplished by an upward movement of air; consequently, areas of convergent winds are regions favorable to the occurrence of precipitation.

Divergence is the condition that exists when the distribution of winds within a given area is such that there is a net outward horizontal flow of air from the area. The resulting deficit is compensated by a downward movement of air from aloft; areas of divergent winds are regions unfavorable for the occurrence of precipitation. Since the wind flows from higher to lower pressure areas, it can be seen that convergence is associated with low-pressure areas and divergence with high-pressure areas. (See figure 30.)

## SECONDARY CIRCULATIONS

The general circulation is modified by the distribution of land and water over the surface of the earth, causing uneven heating and cooling of the earth's surface, and also the changes in heating which result from the change in seasons.

## CENTERS OF ACTION

The modifications of the general circulation result in permanent and semipermanent high-pressure and low-pressure cells known as

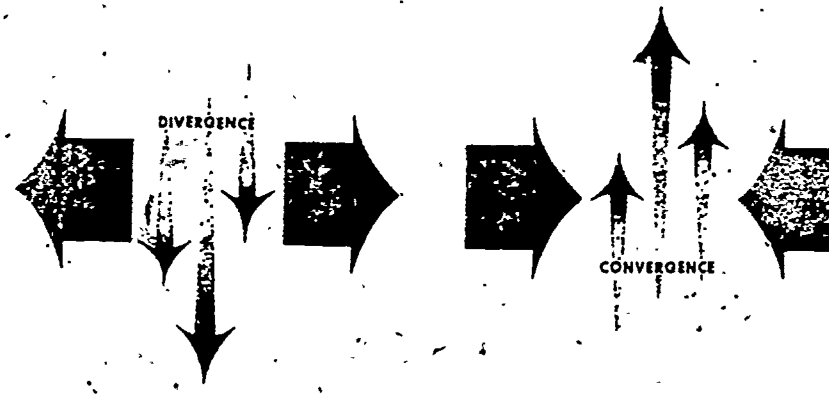


Figure 30.— Convergence and divergence.

centers of action. These centers have one or more closed isobars. The centers of action in the Northern Hemisphere are the semipermanent Aleutian low, the Icelandic low, the Pacific high, the Atlantic (or Azores) high, and the high-pressure areas that form over Siberia, northern Canada, and the United States during the winter months.

During the summer months, the subtropical highs (Pacific and Atlantic) are more pronounced than during the winter months. As the winter months approach, these higher pressure areas weaken and move toward the Equator.

The Aleutian and Icelandic lows become more pronounced during the winter months. Normally, the Aleutian low is centered in the Gulf of Alaska during the winter months. The Icelandic low is centered usually between Greenland and Iceland. Under certain conditions these lows split into two separate centers. The Aleutian low sometimes has one center in the Gulf of Alaska and another center off Kamchatka. The Icelandic low at times has one center located over Labrador and a second center in the form of a long trough extending southwestward from Spitsbergen to a point off Ireland. (A trough is defined as an elongated area of low pressure.)

In winter, oceanic areas are warmer than continental areas of the same latitude. The temperature range of continental areas is much greater than ocean areas over a given period of time. The principal reason for this difference in temperature range is that the upper layers of the ocean are subject to almost constant motion; therefore, heat losses or heat gains are distributed throughout large volumes of water. This mixing process sharply reduces the temperature contrast between day and night as well as between winter and summer. An additional consideration that helps explain the difference in temperature ranges over oceanic and continental areas is the difference between the specific heat of water and land. Since the specific heat of water is greater than land, water absorbs more heat than land for the same rise in temperature. Also, the heat from water is released more evenly than that from land.

You can then see that surfaces which are colder than surrounding surfaces generally have higher atmospheric pressure, and that surfaces which are warmer than surrounding surfaces generally have lower atmospheric pressure. This rule also explains why the doldrums around the Equator exist all year around and move only north and south a little with the seasons.

During the winter months, the weather on the west coast of continents is milder than that on the east coast of continents. On the west coast the air has traveled over the warmer water areas and has been modified by them. On the east coast of a continent the air has traveled over the colder land mass and takes on the characteristics of the cold land mass.

During the winter months, the low temperature causes the air over continental areas to become denser than air over the warmer ocean areas. Since the atmospheric pressure depends on the weight of the air, the pressure increases over the continents during the winter months, and cold anticyclones are formed. When the summer months approach, the anticyclones dissipate and are replaced by areas of relatively low pressure due to warmer air masses. The opposite is true of the ocean areas. During the summer months, the ocean areas are colder than the land mass, and the anticyclones become predominant over the ocean areas.

Over the Arctic and Antarctic regions, and over the glaciated continental areas of Greenland, permanent anticyclonic systems are present near the surface of the earth due to extremely cold air masses. In the equatorial region at the earth's surface, there is an area of permanent low pressure due to the warmer air masses.

MIGRATORY SYSTEMS

General (primary) circulation of the atmosphere, based on an average of wind conditions, is a more or less quasi-stationary circulation. Likewise, much of the secondary circulation depends on more or less static conditions which, in turn, depend on permanent and semipermanent high-pressure and low-pressure areas. Changes in the circulation patterns thus far discussed have been largely seasonal. However, secondary circulation also includes wind systems which migrate constantly, producing rapidly changing weather conditions, especially in the middle latitudes throughout all seasons.

The migratory systems of circulation are associated with air masses, fronts, cyclones, and anticyclones. Air masses and fronts are covered in detail in the next section. They are only introduced here to show their relationship to the secondary circulation of the atmosphere.

Air Masses

The general circulation produces large bodies of air whose physical properties are somewhat homogeneous, a fact upon which the principles of modern weather analysis and forecasting are based. These large bodies of air are called air masses. An air mass is defined as a large body of air whose physical properties, level for level, notably temperature and humidity, are more or less uniform horizontally.

The areas where air masses are formed are called source regions. The designation of an air mass depends on its source region. For instance, if the source region is the open unfrozen polar sea region, in the vicinity of 60° latitude, it is designated as maritime polar.

Air masses migrate from their source regions. As they leave the source regions, they begin to change. The air that remains in contact with the earth's surface for a period of time acquires the characteristics of the underlying surface.

The characteristics of the air mass depend upon its life history, which is determined by the following: The source region, the trajectory (or path) of the air mass after it leaves the source region, the age of the air mass (the time that elapses after the air mass leaves its source region), and its present geographical location.

Fronts

The centers of action bring together air masses of different physical properties. The region of transition between two air masses is called a frontal zone. The primary frontal zones of the Northern Hemisphere are the Arctic frontal zone, the polar frontal zone, and the intertropical convergence zone. The most important frontal zone affecting the United States is the polar front. The polar front is the region of transition between the cold polar air and warm tropical air. During the winter months (in the Northern Hemisphere), the polar front pushes far southward due to greater contrast between the physical properties of the air masses than during the summer months. During the summer months (in the Northern Hemisphere), the polar front moves northward and at times becomes indistinct.

As the term "front" is used in polar front, it actually denotes a frontal zone, which girds the entire earth. Another use of the term "front" is to denote the line of intersection, or boundary, separating two air masses, such as a cold front, warm front, occluded front, and stationary front. These fronts are defined as follows:

1. COLD FRONT.— If a wedge of cold air is underrunning and displacing a warm air mass, the line of discontinuity between the two air masses is called a cold front.

2. WARM FRONT.— When a warm air mass is overriding and replacing a cold air mass, the line of discontinuity is called a warm front.

3. OCCLUDED FRONT.— An occluded front is the condition that occurs when a cold front overtakes and underrides or overrides the warm front.

4. STATIONARY FRONT.— A front with very little movement is called a stationary front. The term "quasi-stationary" is often used for a front that is stationary or nearly so.

## Anticyclones

An anticyclone is an area of relatively high pressure having the wind circulation in a clockwise direction in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The windflow in an anticyclone is slightly across the isobars and away from the center of the anticyclone. (See figure 31.) Anticyclones are commonly called highs or high-pressure areas.

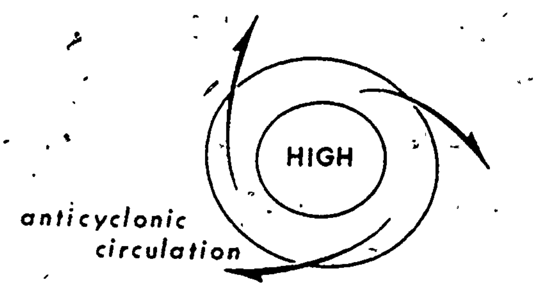


Figure 31.— Anticyclones.

The formation of an anticyclone or the intensification of an existing one is called anticyclogenesis. The decreasing of the intensity of an anticyclone is called anticyclolysis.

The vertical extent of pressure depends greatly on the air temperature. Since density increases with a decrease in temperature, pressure decreases more rapidly along the vertical in colder air than in warmer air.

In a cold anticyclone (such as the Siberian high), the vertical extent is shallow; while in a warm anticyclone (such as the subtropical high), the vertical extent reaches high into the upper atmosphere due to the slow decrease in temperature with elevation.

When thinking of highs, lows, anticyclones, cyclones, and air masses, do not confuse the terms. A cyclone is a low, and an anticyclone is a high. The terms "cyclone," "anticyclone," "low," and "high" refer to the wind circulation and to the atmospheric pressure. A cyclone, for instance, can have in its circulation parts of three different air masses.

An air mass does not always have an anticyclonic circulation at the surface. In the Sahara Desert, for instance, continental tropical air prevails; yet in the lowest levels, the pressure is low and the circulation is cyclonic at certain times (usually in summer) (a thermal low). The circulation and the pressure reverse to anticyclonic flow and high pressure only as one progresses upward through the air mass. Therefore, when speaking of an air mass, use only that term. When thinking of pressure or circulation, use cyclone or low, and anticyclone or high.

## Cyclones

In synoptic meteorology it has been shown that cyclonic and anticyclonic systems are primarily the result of the interactions between different air masses. This is especially true of cyclones which have their origin on the fronts separating the major air masses.

A cyclone is a circular or nearly circular area of low atmospheric pressure around which the winds blow counterclockwise, and slightly across the isobars toward the center in the Northern Hemisphere and clockwise in the Southern Hemisphere. It is commonly called a low or a depression. This use of the word "cyclone" should be distinguished from the colloquial use of the word as applied to the tornado. (See figure 32.)

The formation of a new cyclone or the intensification of an existing one is called CYCLOGENESIS. Cyclogenesis usually occurs with

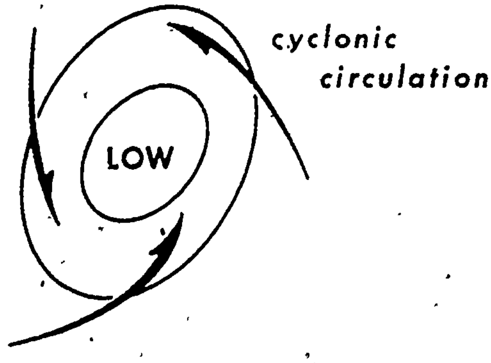


Figure 32.— Cyclone.

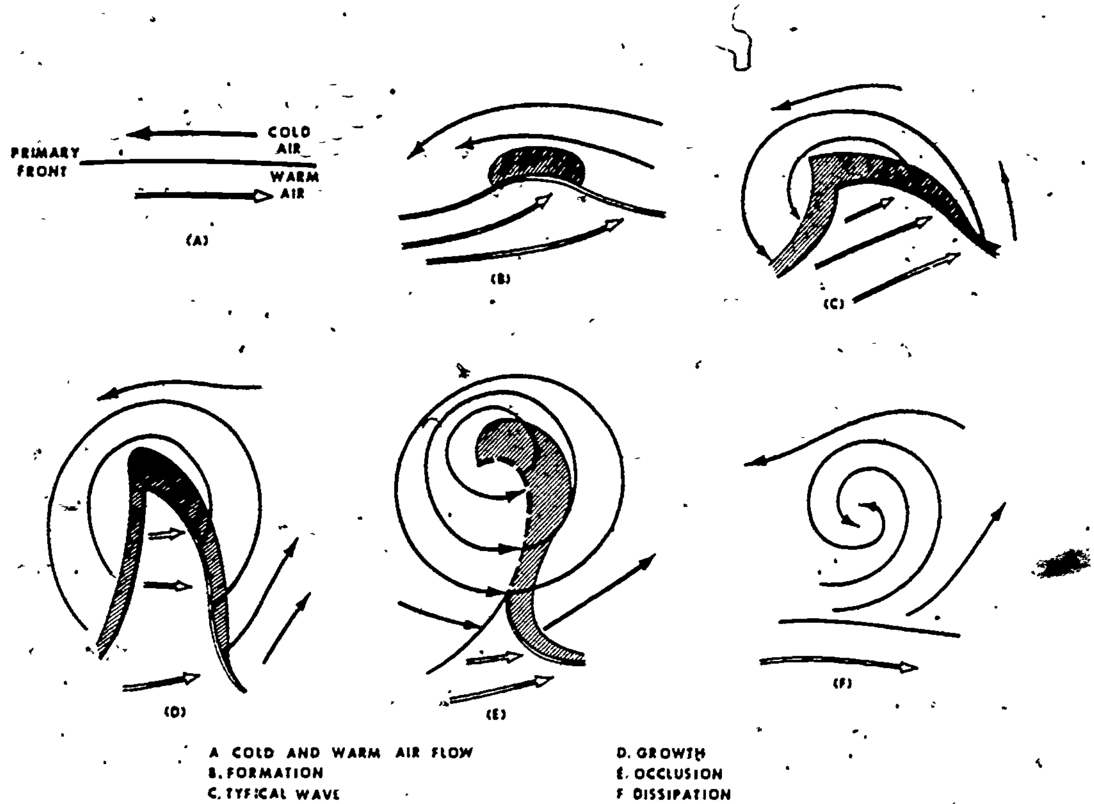


Figure 33.— Life cycle of a wave cyclone.

DEEPENING (a decrease in atmospheric pressure), but the terms are not synonymous. The decrease and eventual extinction of a cyclone is called CYCLOLYSIS. Cyclolysis refers to circulation in the atmosphere and should not be confused with FILLING (an increase in atmospheric pressure), although the two processes usually occur together.

Cyclones in middle and high latitudes are referred to as extratropical cyclones, and the tropical cyclones are referred to as hurricanes, typhoons, baguios, or willy-willies, depending on their geographical location. (Tropical cyclones are discussed in section 5.)

When some temperature or topographical irregularity occurs along the boundary line between two air masses, a wave (the first stage of an extratropical cyclone) develops, with cycloric circulation taking effect. These waves usually develop into cyclones and travel along the frontal zones. The usual stages of development of a cyclone are formation, growth, occlusion, and dissipation. (See figure 33.)

Atmospheric waves may be compared with ocean waves in the following manner. Over the ocean a gentle breeze, which actually represents relative motion between air and water, produces waves. If the wind speed exceeds a certain limit, the tops of the waves are removed in the form of whitecaps. The whitecaps indicate that the discontinuity surface between the air and water has become unstable and the two fluids have begun to whirl together.

In the atmosphere a similar process takes place when the boundary between two dissimilar air masses is distributed by an acceleration of either adjacent air mass. These waves, although different from ocean waves, obey the same physical laws.

When the atmospheric waves become unstable, a condition similar to the formation of whitecaps on the ocean occurs. The portions of two air masses adjacent to their line of mutual contact tend to whirl together. This is called the occlusion process.

The crest of a wave forming along an atmospheric discontinuity occupies the center of a low-pressure area. This accounts for the fact that bad weather is associated with low-pressure areas.

When the polar front moves southward, it is usually associated with the development and movement of cyclones and with outbreaks of cold polar air. The cyclonic circulation associated with the polar front tends to bring polar air southward and warm moist tropical air northward.

During the winter months, the warm airflow usually occurs over water, and the cold air moves southward over continental areas. In summer the situation is reversed.

Large cyclones that form on the polar front are usually followed by smaller cyclones and are referred to as families. These smaller cyclones tend to carry the front farther southward.

In an ideal situation these cyclones come in succession, causing the front (in the Northern Hemisphere) to lie in a southwest to northeast direction.

MONSOON WINDS

The term "monsoon" is of Arabic origin, and means season. The monsoon wind is a seasonal wind that blows from continental interiors (or large land areas) to the ocean in the winter, and in the opposite direction during the summer. The monsoon wind is most pronounced over India, although there are other regions with noticeable monsoon winds. Over India the monsoons blow from the northeast during January and from the southwest in July, and are caused in the winter by the air blowing out of the high-pressure area of Siberia and in the summer by the wind flowing into the low-pressure area over central Asia. (See figure 34.)

In summer the weather associated with monsoon winds is almost constant rain. This condition is caused by mass motion of air from the relatively high-pressure area over the ocean to a low-pressure area over land. When the air leaves the ocean, it is warm and moist. As the air travels over land toward the low-pressure area, it is also traveling from a lower altitude to a higher altitude. The air is lifted mechanically and cooled to its condensation point by this upslope motion.

In winter the weather situation is the reverse of summer. Clear skies predominate during this season. This is caused by the mass motion of air from a high-pressure area over land to an area of lower pressure over the ocean. As the air leaves the high-pressure area over land, it is cold and dry. As it travels over land toward the ocean, there is no source of moisture to induce precipitation. The air is also traveling from a higher altitude to a lower altitude; consequently, this downslope motion causes the air to be warmed at the adiabatic lapse rate. This warming process has a still further clearing effect on the skies.

JETSTREAM

The jetstream is a special circulation; however, since it is so closely associated with secondary circulations of the migratory type, it is discussed here.

The jetstream is a band or belt of winds with a strong westerly component which meanders around the globe. By saying that it has a strong westerly component, it is meant that it flows primarily from the west or from adjacent directions such as northwest or southwest. By saying that it meanders, it is meant that it is not found at the same latitude or elevation all around the earth at the same time, but it has a wavelike trajectory. It may range from 25 to 100 miles in width and up to a mile or two in depth. Sometimes the jetstream is a continuous band, but more often it is broken or split at several points.

Jetstreams are found in both the Northern Hemisphere and the Southern Hemisphere, but much more is known about the predominant one in the Northern Hemisphere. This is the one normally referred to when only the term "jetstream" is used. It is located in the high tropopause along the boundary of the polar front zone where there is extreme horizontal temperature contrast. Normally, there is a break in the tropopause where the jetstream exists, or it may be said that it exists where the tropopause has its greatest slope.

The winds in the jetstream occasionally exceed 250 knots. Most of the time the winds

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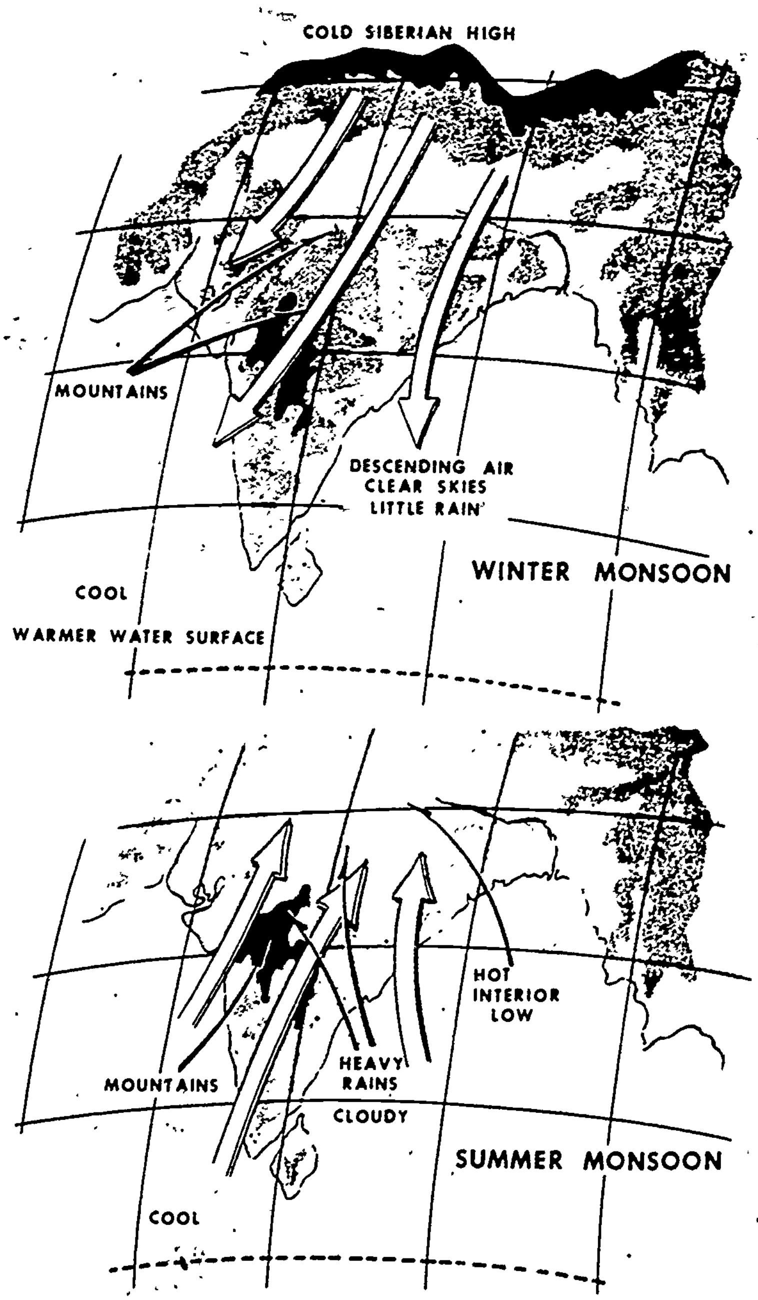


Figure 34.— Monsoon winds.

range from about 100 to 150 knots. However, a band of winds is classed as a jetstream only when the winds in the band have a speed of 50 knots or more. The jetstream is stronger in winter than in summer.

The jetstream is associated with a strong gradient of temperature along both the horizontal and the vertical. It can be found where the tropopause undergoes the greatest change in height. It is closely associated with migratory low-pressure systems and the polar front. Most of the time there are no signs of a jetstream on the surface. The jetstream increases in intensity with elevation to just below the tropopause where its maximum speed is reached. Thereafter, it decreases in intensity again.

The jetstream is very important both in forecasting weather and in flight operations. In forecasting the weather, it is important relative to the development and the movement of fronts and low-pressure systems. In flight operations, it is important as something to be avoided when the flight plan goes against it, and as something that can be used to gain time when the flight plan is with the wind direction. A 150-knot wind can increase or decrease the speed of an aircraft to a large extent, depending on the direction of the flight relative to the wind.

## TERTIARY CIRCULATIONS

Many regions have local weather phenomena caused by temperature differences between land and water areas or by local topographical features. Those weather phenomena which show up as circulations of air and are due to local features are termed tertiary (third order) circulations. A knowledge of these circulations which have a significant effect on the local weather conditions in important for Marine Science Technicians.

### LAND AND SEA BREEZES

There is a daily contrast of heating of local water and land areas similar to the seasonal variation. During the day, the land is warmer than the water area, and at night the land area is cooler than the water area. A slight variation in pressure is caused by this temperature contrast. At night the wind blows from land to sea and is called a land breeze. During the day, the wind blows from water areas to land areas and is called a sea breeze. These breezes are shallow and do not penetrate far inland. Often in the middle and higher latitudes, these breezes are not noticeable, due to stronger winds of other character. (See figure 35.)

### MOUNTAIN AND VALLEY WINDS

During the day, mountain slopes are warmer than the surrounding atmosphere at the same level; this heating effect causes the wind to flow upward from the valley area along the mountain slopes. At night the situation is reversed, and the slopes become colder than the surrounding atmosphere; this cools the atmosphere in the lower levels near the surface of the slopes and causes the wind to flow downward into the valley. Winds ascending a mountain slope are called ANABATIC winds. At times these anabatic winds are unnoticeable due to the effects of vertical convection. The reverse of the anabatic wind is the KATABATIC wind. Hence, the katabatic wind occurs when the wind flows down the slope. (See figure 36.)

### FOEHN WINDS

The foehn wind is a warm, dry wind with a strong downward component on the leeward side of mountains. When air flows up and over a mountain barrier, it undergoes expansion and cools at the dry adiabatic lapse rate (1° C. per 100 meters) until the temperature drops to the dewpoint. Condensation occurs, and a cloud forms above the mountain with possible precipitation on the windward side of the mountain. During the descent of the air on the leeward side of the mountain, heating takes place, due to compression, again at the dry adiabatic lapse rate. These winds are characteristic of the Alps, and also of the Rockies, where they are known as chinook winds.

### FUNNEL EFFECT

Winds blowing against mountain barriers tend to flatten out and go around them. If the barrier is broken by a pass or a valley, the air is forced through the break with considerable speed. Such forcing of wind through narrow valleys is known as the funnel effect. A good example of the funnel effect is the Santa Ana wind of Southern California. This type of wind was discussed in a previous pamphlet in the portion entitled "Bernoulli's Theorem."

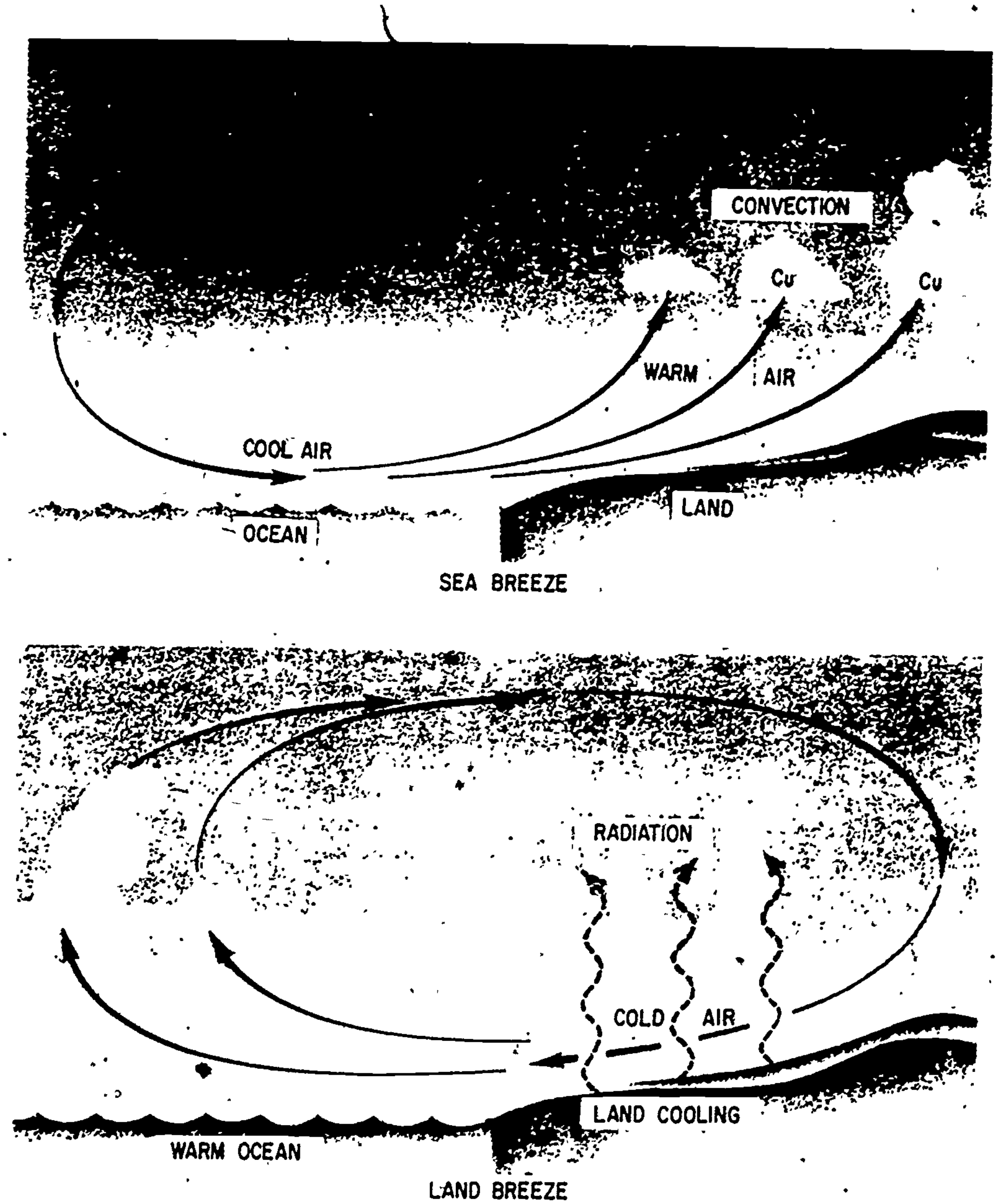


Figure 35.— Circulation of land and sea breezes.

GLACIER WINDS

Glacier winds, or fall winds as they are sometimes called, occur in a great variety in all parts of the world where there are glaciers or elevated land masses that become covered by snow and ice during winter. During winter, the area of snow cover becomes most extensive, permitting a maximum amount of radiational cooling of the surrounding air coming in contact with the snow surfaces. This cooling effect makes the air denser, therefore heavier than the surrounding air. When this air is set in motion, it flows down the sides of the glacier or plateau. Drainage winds of this variety cover a wide range—from light local breezes that descend through the valleys from small isolated glaciers to the violent outbreaks of cold air that rush down the lee side of a continental ice plateau. The latter is caused by the development

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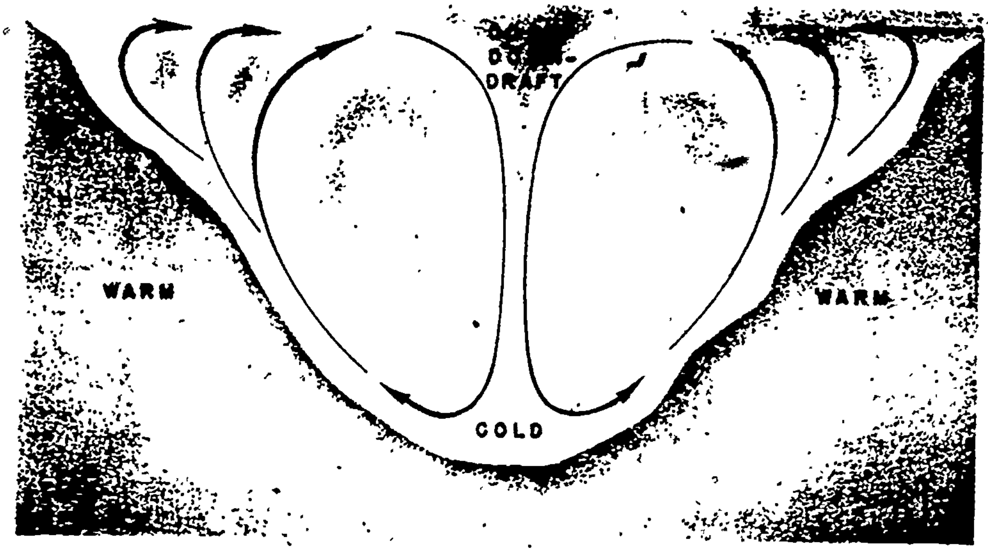
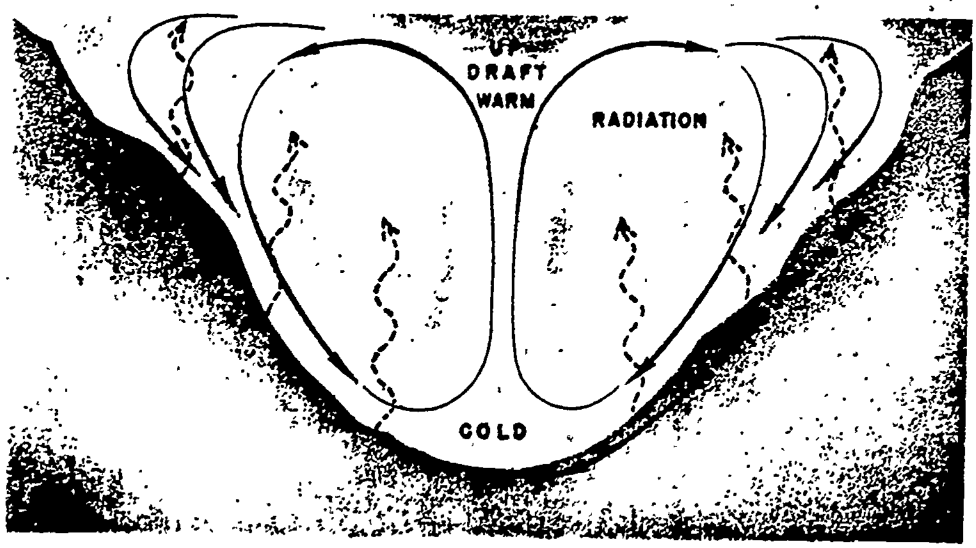



DURING THE DAYTIME HILLSIDES HEAT QUICKLY
THE UPDRAFTS ALONG UPSLOPES—DOWNDRAFTS IN THE CENTER.




DURING THE NIGHT OUTGOING RADIATION COOLS AIR ALONG
HILLSIDES BELOW FREE AIR TEMPERATURE. THE COOLED AIR
DRAINS TO LOWEST POINT OF THE TERRAIN.

Figure 36.— Mountain and valley winds.

of a gradient wind that sets in motion the reservoir of extremely cold air from the high-level snowfields. These winds in many areas occur as violent squalls of short duration when a mass of cold air is released over the edge of a cold plateau and plunges down through an adjacent valley or fjord to sea level.

When a changing pressure gradient sets in motion a large cold air mass over the edge of a plateau, this action sets in motion the strongest, most persistent, and most extensive of the glacier or fall winds. When this happens, the fall velocity is added to the pressure gradient force so that the cold air rushes down to sea level along a front which may extend for hundreds of miles. This condition occurs in winter on a large scale along the edge of the Greenland icecap, where in some places the wind attains a velocity in excess of 90 knots for days at a time and reaches more than 150 miles out to sea.

Since all of the drainage winds are heated adiabatically in their descent, they are predominantly dry. Occasionally, the glacier winds pick up moisture by falling precipitation when they underride warm air. All glacier or fall winds are essentially cold winds even with the adiabatic heating which they undergo, because of the extreme coldness of the air in its source region. Contrary to all other descending winds which are warm and dry, the glacier wind is cold and dry. It is colder, level for level, than the air mass it is displacing. In the Northern Hemisphere the glacier winds descend frequently from the snow-covered plateaus and glaciers of Alaska, Canada, Greenland, and Norway.

## EDDIES AND TURBULENCE

Turbulence is the irregular motion of the atmosphere when the air flows over an uneven surface, or when two currents of air flow past each other in different directions or at different speeds. The main source of turbulence is the friction along the surface of the earth. This is called mechanical turbulence. Turbulence is also caused by irregular temperature distribution. The warmer air rises and the colder air descends, causing an irregular vertical motion of air; this is called thermal turbulence.

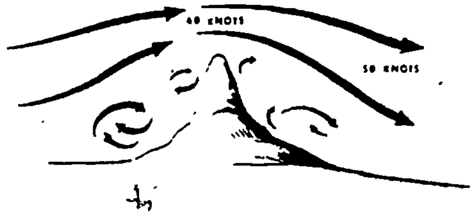


Figure 37.— Eddy winds.

Mechanical turbulence is intensified in unstable air and is weakened in stable. These influences cause fluctuations in the wind with periods ranging from a few minutes to more than an hour. If these wind variations are strong, they are called wind squalls and are usually associated with convective type clouds. They are an indication of approaching towering cumulus or cumulonimbus clouds.

Gustiness and turbulence are more or less synonymous. Gustiness is the irregularity in the wind speed which creates eddy currents disrupting the smooth airflow. Thus, the term "gustiness" is usually used in conjunction with sudden intermittent increases in the wind speed near the surface levels, and turbulence is used with reference to levels above the surface. Gustiness can be measured by wind instruments, whereas turbulence is always an estimation.

An eddy is the more or less circular motion of the wind produced by an obstruction in its path, such as irregularities on the earth's surface (hills and mountains), trees, and buildings. The length of an obstacle and the stability of the air are the factors which determine whether the air will flow around or across the object. Turbulence caused by large objects, such as buildings, is usually a combination of horizontal and vertical eddies. (See figure 37.)

There may be a stationary eddy on the windward side of a mountain if the windward side has a steep slope. The leeward side of mountains has the most pronounced eddy activity, and in most cases violent downdrafts exist. The downdrafts are extremely dangerous to aircraft, and instances are recorded of their having caused aircraft to crash into mountain sides.

# AIR MASSES AND FRONTS

Personnel studying for advancement as Marine Science Technicians must know a great deal about air masses and fronts. In this section a more complete picture of the part that air masses and fronts play in the overall weather story is given. It is readily seen that air masses and fronts are the keys to modern weather analysis and forecasting.

## AIR MASSES

The air-mass concept is one of the most important developments in the history of meteorology. An air mass is a large body of air whose physical properties, particularly temperature and moisture distribution, are nearly homogeneous, level for level. Forecasting is largely a matter of recognizing the various air masses in the weather picture, determining their characteristics, and predicting their behavior.

### AIR-MASS CLASSIFICATION

Air masses have been classified geographically and thermodynamically by Tor Bergeron, a Norwegian meteorologist. His system of classification has become almost universal in usage. The geographical classification, which refers to the source region of the air mass, divides air masses into four basic categories. These are arctic (A) or antarctic, polar (P), tropical (T), and equatorial (E), the first three of which are further divided into maritime (m) and continental (c). Maritime arctic/antarctic air masses are rare, since there is a predominance of land mass or icefields in the polar regions. Virtually all equatorial air masses are considered to be maritime in origin. An air mass is considered to be maritime if its source of origin is over an oceanic surface. If the air mass originates over a land surface, it is considered continental.

An additional air-mass classification is sometimes used along with the four basic categories mentioned above. This is the superior (S) air mass which is an extremely dry air mass and is generally found aloft over the southwestern United States, but is sometimes located at or near the surface.

You can easily remember the types of air masses by using the letters in the word "tapes" to stand for the first letter of each type of air mass.

The thermodynamical classification applies to the relative warmth or coldness of the air mass. A warm air mass (w) is one which is warmer than the underlying surface; a cold air mass (k) is one which is colder than the underlying surface. For example, a continental polar cold air mass is classified as cPk. An mTw classification indicates that the air mass is a maritime tropical warm air mass.

Air masses can usually be identified by the type of clouds within them. Cold air masses usually show cumuliform clouds, whereas warm air masses contain stratiform clouds.

Sometimes, and with some air masses, the thermodynamic classification may change from night to day. A particular air mass may show k characteristics during the day and w characteristics at night.

### AIR-MASS SOURCE REGIONS

The air-mass source region is the area where the air mass originates. The condition which is ideal for the production of an air mass is the stagnation of air over a rather uniform surface (water, land, or icecap) of uniform temperature and humidity. The length of time an air mass stagnates over its source region depends on the surrounding pressures. The air acquires definite properties and characteristics, from the surface up, and becomes virtually homogeneous throughout, and its properties become rather uniform at each level. In the middle latitudes, the land and sea areas with the associated steep latitudinal temperature gradient are generally not homogeneous enough for source

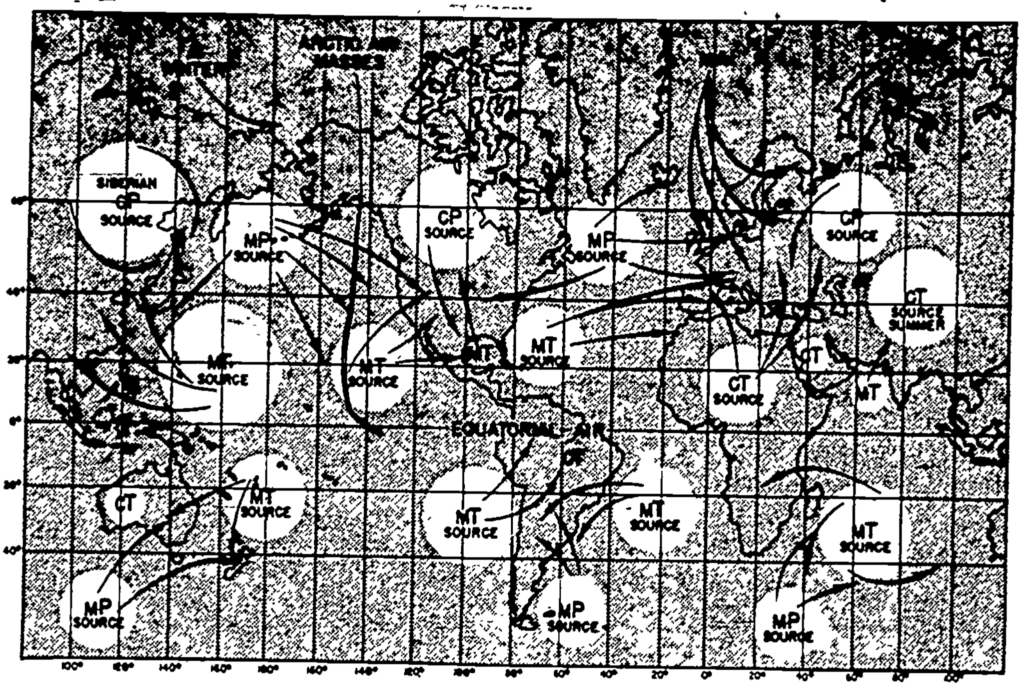



Figure 38.— Air-mass source regions.

regions. These areas act as transitional zones for air masses after they have left their source regions.

The source regions for the world's air masses are shown in figure 38. Note the uniformity of the underlying surfaces; also note the relatively uniform climatic conditions in the various source regions, such as the southern North Atlantic and Pacific Oceans for maritime tropical air and the deep interiors of North America and Asia for continental polar air.

Arctic Air

There is a permanent high-pressure area in the vicinity of the North Pole, within which is found the arctic air-mass source region. In this region there is a gentle flow of air over the polar icefields, allowing the formation of the arctic air mass. The air is characterized by being dry aloft and very cold and stable in the lower altitudes.

Antarctic Air

This air is developed in the antarctic region. It is colder at the surface and other levels than arctic air in fall and winter.

Continental Polar Air

The continental polar source regions consist of all the land areas dominated by the Canadian and Siberian high-pressure cells. In the winter these regions are covered by snow and ice. Because of the intense cold and the absence of water bodies, very little moisture is taken into the air in these regions. Note that the word "polar" when applied to air-mass designations does not mean air at the poles (this area is covered by the words "arctic" and "antarctic"). Polar air is generally found between 40° and 60° latitude and except for that found over northern and central Asia, is generally warmer than arctic air.

Maritime Polar Air

The maritime polar source regions consist of the open, unfrozen polar sea areas in the vicinity of 60° latitude, north and south. Such areas are sources of moisture for polar air masses; consequently, air masses forming over these regions are moist, but the moisture is sharply limited by the temperature.

Continental Tropical Air

The continental tropical source regions can be any significant land areas lying in the tropical regions, generally between 25° north latitude and 25° south latitude. The large land areas found there are usually desert regions, such as the Sahara or Kalahari Deserts of Africa, the Arabian Desert, and the interior of Australia. The air over these land areas is hot and dry.

Maritime Tropical Air

The maritime tropical source regions are the large zones of open tropical sea along the belt of the subtropical anticyclones. High-pressure cells stagnate in this area most of the year. The air is warm due to low latitude and is able to hold considerable moisture.

Equatorial Air

The equatorial source region is the area from about 10° north to 10° south latitudes, within which the thermal Equator is found. It is essentially an oceanic belt which is very warm and has a high moisture content. Convergence of the trade winds from both hemispheres and the intense insolation over this region causes lifting of the air, which is unstable and moist, to high levels. The weather associated with these conditions is characterized by thunderstorms throughout the year.

AIR-MASS MODIFICATION

As soon as the air mass begins to leave the source region, it undergoes modifications. The changes depend greatly on the nature of the surface over which it travels. Starting in the lower levels, the changes in physical properties travel upward through the air mass. The rate of change depends upon the extent of the difference between the original properties and those of the surface over which the air mass travels. How much the air mass changes in physical properties depends upon the rate at which it travels over the new surface and the time that has elapsed since it left its source region.

For example, if a warm, moist body of air moves over cold, dry land, its characteristics are modified; moisture is lost, and the temperature is lowered. If an air mass has recently left its source region, it will not have had time to become as modified as an air mass that has been removed from its source region for a longer period of time.

Modifications of air masses are due to one or more of the following: (1) radiation, (2) evaporation or condensation, and (3) convergent or divergent windflow.

It has been observed that if an air mass has a cyclonic trajectory, the lower layers are predominantly unstable; if the air mass has an anticyclonic trajectory, the lower layers are stable. Dissimilar weather conditions occur with different trajectories of the air mass.

AIR-MASS WEATHER

Within an air mass, weather is controlled primarily by the moisture content of the air, the relationship between surface temperature and temperature of the air mass, and terrain (upslope or downslope). Rising air is cooled; descending air is warmed. Condensation takes place when the air is cooled to its dewpoint. A cloud warmed above the dewpoint temperature evaporates and dissipates. Stability tends to increase if the surface temperature is lowered or if the temperature of the air at higher levels is increased while the surface temperature remains the same. Stability tends to be reduced if the surface temperature remains the same and the temperature aloft is lowered.

Smooth stratiform clouds are associated with stable air, whereas turbulence, convective clouds, and thunderstorms are associated with unstable air.

Winter Air Masses

The following paragraphs primarily describe winter air-mass weather of North America. Significant features of air masses of the rest of the world are also pointed out.

CONTINENTAL ARCTIC (cA).— Continental arctic air, either k or w, is the coldest air over North America; however, the cooling rarely extends above 700 mb (10,000 ft). Most cA air is designated k and has an unstable lapse rate in the lower layers. The stability of cA air, though, depends primarily on its trajectory. If the path of cA air is cyclonic, instability, snow flurries, and low cloudiness result (especially in the Hudson Bay to Great Lakes region). East of the Appalachians, cAk air produces little weather. When cAk air has an anticyclonic trajectory, the weather is fair (as in the Midwest).

Elsewhere in the world, continental arctic air is significant only over western Europe and the Antarctic Continent. The appearance of cA over western Europe is infrequent; when cA air does appear, it is heavily modified and unstable, though quite cold.

The Antarctic Continent is the spawning ground for cA air in the Southern Hemisphere, but this air seldom leaves that continent. When it does leave, it rapidly becomes mP air. The coldest air mass in the world is the antarctic cA air mass.

CONTINENTAL POLAR (cP).— When a cP air mass moves out of its source region over warmer land, the lower layers of the air are gradually heated and the stability is decreased. As long as the air is moving over a snow-covered surface, the decrease in stability does not completely eliminate the stable characteristics acquired in the higher levels at the source region. Usually an outbreak of continental polar air is accompanied by winds of 15 knots or more, and this wind helps decrease the stable conditions in the lower levels.

After the air passes over the snow-covered regions and moves over a surface having a temperature above freezing, rapid changes in air properties normally occur. The surface temperature increases rapidly and soon eliminates the stable conditions that had existed.

Since the heating from below is more rapid than the addition of moisture, the relative humidity is decreased. Under this condition, the condensation level rises and skies are generally clear.

A particularly troublesome situation often arises when the cold air flows from a cold, snow-covered surface to a water surface, and then over a cold, snow-covered surface again. This frequently happens with air crossing the Great Lakes. Air flowing over the water surface is heated rapidly near the surface and may eventually become unstable. Also, water vapor is added quickly to the air by evaporation from the relatively warm water surface. The air becomes saturated, or nearly so. Water vapor may be added to such an extent that steam fog forms. Thus, evaporation may continue from the warm water even after the cold air has become saturated, resulting in condensation. This condensation appears as fog, but due to the instability of the air, the steam is lifted as it forms, growing into clouds. After crossing the lakes, this air again flows over a cold, snow-covered surface. The surface cooling increases the stability and may produce fog at night.

The air may be subjected to forced lift in approaching the Appalachians. This upslope flow causes cooling and condensation and may result in the forming of towering cumulus or cumulonimbus clouds with snow showers. On the eastward side of the mountains, the air descends and warms adiabatically, causing the clouds to be partially or completely dissipated.

Consider how cPk air can become mT air. In winter, when cPk air reaches the warm waters off the southern coast of the United States, its temperature is usually about 10° lower than the water temperature. The air is rather unstable when it reaches the water surface. The same thing happens when the air flows over the Great Lakes, except the Great Lakes are a relatively small area, whereas now the modification occurs over such a large area that a new air mass is formed. Both the temperature and moisture content of the air rapidly increase, beginning in the lower levels and quickly affecting the higher levels. Thus, rapid changes in the weather can be expected as cPk air moves over an mT source region.

After mP air crosses the Rocky Mountains and stagnates in the Great Basin, it often becomes cP air. By the same token, cP air moving out over the Atlantic rapidly modifies to become mP air.

In Siberia, cP air is the coldest air mass on record in the Northern Hemisphere; in the Southern Hemisphere this air mass is unknown.

MARITIME POLAR (mP).— Consider the weather associated with maritime polar air (mP). In its source region, maritime polar air, in general, is characterized by surface temperatures above the freezing point, moderately steep lapse rates, and near saturation up to rather high levels. However, since the air aloft is cold, it has a low capacity for water vapor; hence, the water content may be small even though the relative humidity is high. The weather is characterized by cumulus and cumulonimbus clouds with showers and by good visibility except in shower areas.

North America is affected by maritime polar air which comes primarily from a source region in the North Pacific. This air mass usually results from the modification of cold continental air which has moved from Asia or the frozen arctic. The continental air is heated from below and picks up additional moisture as it moves over the ocean, resulting in a characteristically unstable air mass. The convective activity is increased as the air mass is lifted over the mountain ranges along the western coast of the continent. This lifting results in heavy rain and snow showers with considerable turbulence and icing on the windward side of the mountains. If the trajectory of the air mass as it moves across the ocean is cyclonic, the instability is increased; if it is anticyclonic, the instability is decreased. Maritime polar air may acquire stable characteristics in its lower levels before reaching the continent if it moves over cold ocean currents after its original modification. When this occurs, it is characterized by stratified clouds, fog, and drizzle.

Maritime polar air of Atlantic origin which occasionally affects the eastern coast of North America differs in two respects from that of Pacific origin. Surface temperatures are colder, and the vertical extent of the convective activity is less.

Maritime polar air also affects the south Alaskan coast but seldom reaches the Alaskan interior due to the mountain ranges which it must cross.

In western Europe, mP air masses predominate. They are quite varied in the weather they cause, depending on whether their trajectories are cyclonic or anticyclonic. The most unstable conditions are the rule with a cyclonic trajectory.

In the Southern Hemisphere, mP air is the most prevalent air mass and is quite similar to its Northern Hemisphere counterpart in characteristics and in the weather it causes.

MARITIME TROPICAL (mT).— The mT air which is formed over the Gulf of Mexico is usually conditionally unstable. This instability may be released by frontal or orographic lifting. When mT air is forced up in the eastern mountains of the United States, practically the same types of weather result as were discussed under the Great Lakes effect. However, the weather associated with the mT air is more intense because of the greater quantity of moisture involved, and extends to a higher level. If mT air is forced over mountainous terrain, as in the eastern part of the United States, the conditional instability of the air is released at higher levels. This might produce thunderstorms or at least large cumuliform clouds. These clouds may develop out of stratiform cloud systems and therefore may be encountered without warning by a plane flying within the clouds. Icing may also be present. Thus, as with the Great Lakes effect, a combination of all three hazards (fog, thunderstorms, and icing) is possible.

Now consider the weather associated with maritime tropical warm air (mTm) of Atlantic origin. In winter, when the land surface is relatively cold, the mT air moves northward as mTw. It is cooled from below. This cooling results in more stable conditions near the surface. Due to the high moisture content, condensation occurs (either as fog or as low stratus) particularly at night when radiational cooling plays an important part. In the lower latitudes, the heating effect of the sun usually causes sufficient convective lift to produce cumuliform clouds in the afternoon.

Maritime tropical air of Pacific origin is quite rare in winter, but it causes torrential rains on those rare occasions when it invades the California coast.

In western and southern Europe, the invasion of mT air brings milder weather than in the United States. Low clouds, fog, and drizzle are the normal results with mT, because the air is usually quite stable. This air mass seldom invades eastern Europe.

Maritime tropical air masses of the Southern Hemisphere are very similar to those of the Northern Hemisphere in both characteristics and weather.

In Asia, mT air is frequent over southeastern Asia (including India), but it does not cause much weather. In summer this air is replaced in southeast Asia with equatorial air, and it is this equatorial air which brings with it the monsoon of that region.

CONTINENTAL TROPICAL (cT).— Continental tropical air is entirely absent from the North American Continent in winter. The primary regions with cT air in winter are north Africa and Asia Minor. This air is unstable but quite dry and thus causes little weather, and it does not reach southern Europe in winter.

The only other source of true cT air in winter is the interior of Australia. In the Southern Hemisphere winter, this air is unstable but dry and causes little weather.

SUPERIOR AIR (S).— Superior air is a high-level air mass found over the South Central States. It frequently reaches the surface; and due to subsidence effects, it is the warmest air mass on record in the North American Continent in both seasons.

Summer Air Masses

In summer the arctic front retreats to northern Canada and disappears in the arctic over the North American Continent. In Europe and northern Asia, an outbreak of arctic air is rare, and little needs to be said about this air. In the Southern Hemisphere, the arctic air which leaves the Antarctic Continent is rapidly modified to mP and therefore is of little interest to us here.

MARITIME POLAR.— Over the North American Continent, the whole Pacific coast is usually under the influence of mP air. It is much milder in summer than in winter, and seldom extends east of the Rockies. The coastal weather is generally clear with scattered cumulus.

Along the Atlantic coast the occasional influx of mP brings relief from heat waves, but causes little weather.

In Europe, mP air is quite predominant. It is quite unstable, but usually too dry to cause much shower activity. Maritime polar air is quite rare in Asia, but in the Southern Hemisphere it is the most predominant air mass, encircling the whole Southern Hemisphere.

CONTINENTAL POLAR.— The source region is confined roughly to the northern two-thirds of Canada, but polar air of Canadian origin occasionally invades the United States in summer. When it does, it preserves to a large extent its temperature characteristics. Convective activity in the United States is extensive but mild, confined in height to 700 mb (10,000 feet) or less.

Continental polar air is infrequent over Europe in summer. Occasional invasions of this air come from Russia or the Balkans, and these invasions are marked by warm but relatively stable weather. In northern Asia (Siberia), this air is dominant. Occasionally it may spread as far south as the Himalayas. Continental polar air is entirely absent from the Southern Hemisphere in summer.

MARITIME TROPICAL.— On the west coast, mT air of Pacific origin has little or no influence on the weather, but on the east coast mT air is the most extensive air mass in summer. The mT air is quite warm and quite moist with a dewpoint near or in excess of 70° F. at the surface. Low stratiform clouds are the rule in the mornings, especially along the east coast, becoming convective clouds during the day, with frequent thunderstorms by late afternoon. Despite the thunderstorms, flying conditions are not hazardous because the thunderstorms are easily circumnavigated. Ground fogs are frequent with northward movement of mT air over land. Sea fogs are frequent with movement over water. The famous fogs of the Grand Banks are typical of mT air over a cold ocean current.

When mT air invades southwestern Europe, the weather is somewhat cooler than in the United States because of the cold ocean currents and the stable anticyclonic circulation. Over water, mT has stratiform low clouds, fog, and drizzle. Over land the air is subject to mild convection.

Asian mT air originating over the Pacific is extremely warm, moist, and unstable. Its characteristics are much like equatorial air. Strong convective activity and heavy showers are the rule in summer in southeast Asia. Over the western North Pacific great fog banks form in summer in mT air, much in the same manner and for the same reason as do the fog banks over the Grand Banks of the Atlantic coast.

The mT air masses of the Southern Hemisphere are quite similar to their counterparts of the Northern Hemisphere; that is, on the east coast of South America, south Africa, and Australia, the weather is similar to that on the east coast of North America. On the west coast of South America, Australia, and south Africa, the weather is similar to that on the North American west coast.

CONTINENTAL TROPICAL.— This air is found only during summer, forming over a small area of northern Mexico, western Texas, New Mexico, and eastern Arizona. It can be identified by its extremely high surface temperatures, very low humidities, large diurnal temperature ranges, and rare precipitation. Flying conditions are excellent with respect to weather, but clear air turbulence is extensive.

European cT air masses have their source regions in north Africa and Asia Minor. As they move into southern Europe, much moisture is added and instability showers result. In north Africa and Asia Minor, cT air is present all year round. During summer, the north African air mass is the hottest air mass on record in the world. It is extremely warm and dry, but quite unstable.

In the Southern Hemisphere, cT air is found in summer in South America, Australia, and a small area of south Africa (the Kalahari Desert). The South American cT air is usually modified mT air. The south African cT air mass is small and somewhat cooler than either of the other Southern Hemisphere cT air masses. The Australian cT air is similar in all characteristics to the north African cT air mass.

EQUATORIAL AIR.— Equatorial air is the air on either side of the thermal Equator, with the intertropical convergence zone (ITCZ) separating the Northern and Southern Hemisphere equatorial air. It is warmer than mT air, and more moist at all levels. In India and southeast Asia this air is often referred to as monsoon air. During summer it is characterized by extreme convective activity and heavy showers in both hemispheres.

SUPERIOR.— As was pointed out previously, S air is observed in the Northern Hemisphere both in winter and in summer. The only difference between winter and summer S air is that the temperatures are higher in summer.

AIR-MASS PROPERTIES

In studying air masses, it has been determined that the physical properties of an air mass depend upon its life history.

During the life span of an air mass, some of the physical properties, such as the surface air temperature and humidity, are apt to change frequently and rapidly due to lifting, conduction, radiation, evaporation, or some local topographical feature. Some properties of the air mass remain almost constant for a period of time. An element of an air mass that has little change from day to day is considered as being conservative. A nonconservative property is one that changes frequently and rapidly.

Although a strictly conservative property probably does not exist in the atmosphere, there are certain properties that for a short period of time, and under certain conditions, are so nearly constant that they may be considered as conservative.

The most important physical properties in air masses are those that concern temperature and moisture. The various expressions of temperature and moisture are summarized in table 2. You should learn the significance of the various properties listed in this table.

Since many nonadiabatic processes occur near the surface of the earth, it becomes necessary to study the adiabatic conditions of the upper atmosphere in classifying an air mass. Some authorities differ as to the properties to use in air-mass identification. However, from table 2, you can see that the equivalent potential temperature and the potential wet-bulb temperature are conservative relative to both dry adiabatic and moist adiabatic temperature changes, while other elements are conservative in regard to only one type or nonconservative in regard to both types of temperature change.

In order to understand table 2 better, it is imperative that you learn the definitions of the various properties listed in that table. Temperature, relative humidity, dewpoint, and mixing ratio are defined and explained in the pamphlet about physics. The remaining terms are

Table 2.— Conservative characteristics of the physical properties of air masses with respect to adiabatic temperature changes.

| Property | Conservative with respect to | |
|---|---|---|
| | Dry adiabatic temperature changes | Moist adiabatic temperature changes |
| Temperature | No | No |
| Relative humidity | No | Yes |
| Dewpoint temperature* | Quasi-conservative | No |
| Wet-bulb temperature | No | No |
| Mixing ratio* | Yes | No |
| Potential temperature | Yes | No |
| Equivalent temperature | No | No |
| Equivalent potential temperature | Yes | Yes |
| Potential wet-bulb temperature. | Yes | Yes |

*These two properties are conservative with respect to nonadiabatic temperature changes; therefore, it is advantageous to use these elements in the analysis of surface weather charts.

defined in this section. Most of the following temperature values are obtained from an AROWAGRAM.

Potential Temperature

The potential temperature is the temperature that a parcel of air would have if it were lowered (or raised) dry adiabatically to the 1,000-mb level. The temperature at the desired level, as it appears on an AROWAGRAM, is used for this purpose and is expressed in degrees Celsius.

Equivalent Temperature

The equivalent temperature cannot be determined accurately on the AROWAGRAM. A rough estimate can be obtained by lifting the air parcel adiabatically to the limit of the chart, then bringing the parcel down dry adiabatically to its original pressure level and reading the temperature. The principle involved is realization of all latent heat of condensation.

Equivalent Potential Temperature

The equivalent potential temperature is nothing but the equivalent temperature reduced dry adiabatically to the 1,000-mb level.

Wet-Bulb Temperature

The wet-bulb temperature is the lowest temperature to which the free air can be cooled by evaporating moisture into it. Normally this temperature is a direct-observation element; that is, we simply observe the thermometer and read the temperature directly. Above the surface, this temperature must be found by indirect means. An AROWAGRAM may be used for this purpose, and the wet-bulb temperature is found by raising the parcel dry adiabatically to saturation, and then reducing it along a moist adiabat to the original level from which it was raised. The wet-bulb temperature is normally expressed in degrees Celsius.

Potential Wet-Bulb Temperature

The potential wet-bulb temperature is the wet-bulb temperature raised or lowered along a saturation adiabat to the 1,000-mb level. It too, stands in the same relation to the wet-bulb temperature as the potential temperature does to the temperature. The easiest way to remember the difference between these various expressions is to associate the word "potential" with the 1,000-mb level.

# FRONTS

Since most major changes of the weather are associated with fronts, it is essential for the Marine Science Technician to become thoroughly familiar with them. This requires that he understand the relationship of fronts to cyclones and air masses, and the characteristics of, and the weather associated with, the various types of fronts. He must also know the relationship between fronts and pressure systems. Finally, he must become adept at following frontal movements and anticipating their speeds and the modifications which they undergo along the way.

## RELATION OF FRONTS TO CYCLONES

Every front is associated with a cyclone in a systematic way. The cyclone is a counterclockwise circulation (in the Northern Hemisphere) around a central low-pressure area, about which the fronts move. Cyclones contribute to and partly control frontal movements, but the reverse is not true. The development and the life cycle of cyclones are discussed in the next section of this training course. Suffice it to say here that cyclones are the center of bad weather, and from them branch out the fronts with their bad weather zones.

## RELATION OF FRONTS TO AIR MASSES

In the previous section a front was defined as a boundary, or line of discontinuity, separating two different air masses. From the definition, the close relationship that exists between air masses and fronts can be readily seen. In fact, without the air masses there would be no fronts.

On a surface map a front is indicated by a line separating two air masses; this is only a picture of the surface conditions. These air masses also have vertical extent. (See figure 39.) A cold air mass, being heavier, tends to underrun a warm air mass. Thus, the cold air is below and the warm air is above the surface of discontinuity. The slope of a frontal surface is usually between 1 to 50 (1 mile vertical for 50 miles horizontal) for a cold front and 1 to 300 (1 mile vertical for 300 miles horizontal) for a warm front. For example, 100 miles from


Figure 39.— Vertical view of frontal system (without clouds shown).

the place where the frontal surface meets the ground, the frontal surface might be somewhere between 2,000 feet and 2 miles above the earth's surface, depending on the slope. The slope of a front is of considerable importance is visualizing and understanding the weather along the front. In general, all the cross sections of fronts as shown in this section summarize pictorially all the pertinent features of all types of fronts under average conditions.

### Cold Fronts

A cold front is the line of discontinuity along which a wedge of cold air is underrunning and displacing a warmer air mass. This term is also used, but inexactly, when referring to a cold frontal surface.

There are certain weather characteristics and conditions that are typical of cold fronts. In general, the temperature and humidity decrease, the pressure rises, and in the Northern Hemisphere the wind veers (usually from southwest to northwest) with the passage of a cold front. The distribution and type of cloudiness and the intensity and distribution of precipitation depend primarily on the vertical velocities in the warm air mass. On the basis of this latter factor, cold fronts are classified as slow-moving and fast-moving cold fronts.

SLOW-MOVING COLD FRONT.— With the slow-moving cold front there is a general upglide of warm air along the entire frontal surface except for pronounced lifting along the lower portion of the front. The average slope of the front is approximately 1:100 miles. The cloud and precipitation area is extensive and is characterized by cumulonimbus and nimbostratus clouds, showers, and thunderstorms at, and immediately to the rear of, the surface front. This area is followed by a region of rain and nimbostratus clouds merging into a region of altostratus clouds and then cirrostratus clouds, which may extend several hundred miles behind the front.

The development of cumulonimbus clouds, showers, and thunderstorms is largely dependent on the original instability characteristics of the warm air mass. Within the cold air mass there may be some stratified clouds in the rain area, but there are no clouds in the cold air beyond this area unless the cold air mass is unstable. In the latter case, some cumulus clouds may develop. This type of front is usually slow moving; 15 knots may be considered average. See figure 40 for a cross section through a typical slow-moving cold front.

FAST-MOVING COLD FRONTS.— With the fast-moving cold front there is descending motion of the warm air along the frontal surface at high levels, and the warm air near the surface is pushed vigorously upward. This type of front has a slope of 1:40 to 1:80 miles and usually moves rapidly; 25 to 30 knots may be considered as an average speed of movement. As a result of these factors, there is a relatively narrow but often violent band of weather. If the warm air mass is conditionally unstable and moist, cumulonimbus clouds, showers, and thunderstorms occur just ahead of and at the surface front, and rapid clearing occurs behind the front. Frequently, altostratus and altocumulus cloud layers form and drift ahead of the main cloud bank. The more unstable the warm air mass, the more violent the weather. If the warm air is relatively dry, this type of front may not produce precipitation or clouds. It is with the fast-moving cold front that squall lines are associated.

Figure 41 shows a typical cross section through a fast-moving cold front; it also shows the cloud shield, precipitation shield, and frontal slope (exaggerated in the vertical) associated with this type of front.

Warm Fronts

A warm front is the line of discontinuity where the forward edge of an advancing mass of relatively warm air is replacing a retreating relatively colder air mass. As in the case of the cold front, this term is used inexactly when referring to a warm frontal surface.

Certain characteristics and weather conditions are associated with warm fronts. The winds shift from southeast to southwest or west, but the shift is not as pronounced as with the cold front. The temperatures are colder ahead of the front and are warmer after the passage of the front. Not being greatly affected by daily heating and cooling of the earth's surface, the dewpoint is normally more constant than the temperature through the day except with the passage of a front. Therefore, the dewpoint is a good index of frontal passage. The average slope of a warm front 1:150.

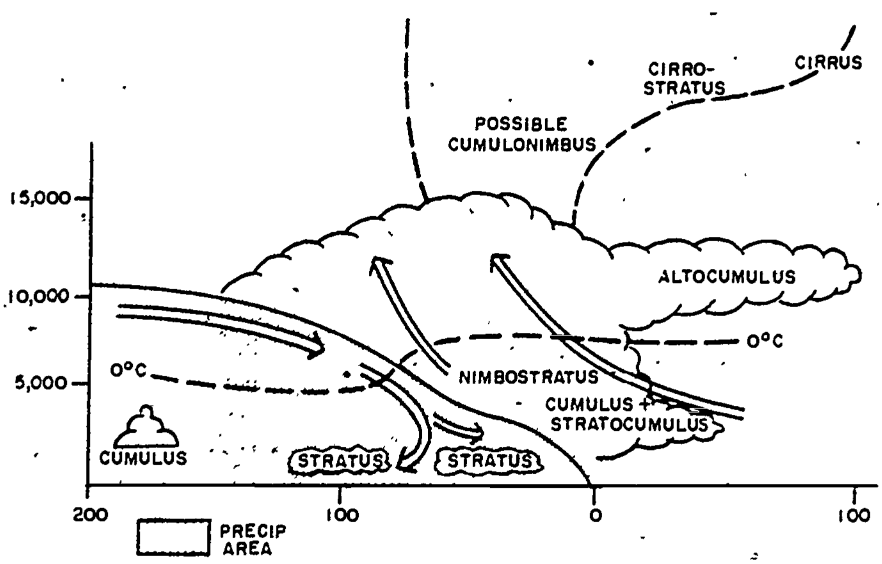



Figure 40.— Vertical cross section of a slow-moving cold front.

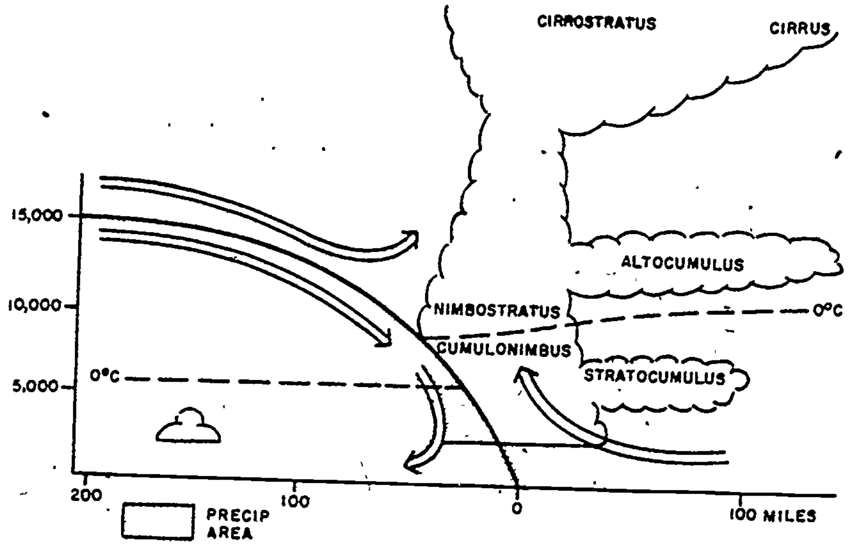



Figure 41.— Vertical cross section of a fast-moving cold front.

A characteristic phenomenon of a typical warm front is the sequence of cloud formations. They are noticeable in the following order: Cirrus, cirrostratus, altostratus, nimbostratus, and stratus. The cirrus clouds may appear 700 to 1,000 miles ahead of the surface front followed by cirrostratus about 600 miles and altostratus about 500 miles ahead of the surface front.

Precipitation in the form of continuous or intermittent rain, snow, or drizzle is frequent as much as 300 miles in advance of the surface front. The precipitation is associated with nimbostratus above the frontal surface and stratus within the cold air. However, when the warm air is convectively unstable, showers and thunderstorms may occur in addition to the steady precipitation. Fog is common ahead of a warm front.

Clearing usually occurs after the passage of a warm front, but under some conditions drizzle and fog may occur within the warm sector. Warm fronts usually move in the direction of the isobars of the warm sector; in the Northern Hemisphere this is usually east to northeast. Their speed of movement is normally less than that of cold fronts; on the average it may be considered to be about 10 knots.

Figure 42 summarizes pictorially the pertinent features of warm fronts under average conditions.

Occluded Fronts

An occluded front occurs when a cold front overtakes a warm front. One of the two fronts is lifted aloft, and the warm air between the fronts is shut off from the earth's surface. An occluded front is often referred to as an occlusion. The type of occlusion is determined by the temperature difference between the cold air in advance of the warm front and the cold air behind the cold front.

WARM TYPE OCCLUSION.— If the air in advance of the warm front is colder than the air behind the cold front, the cold front rides up the warm frontal slope. (See figure 43.)

COLD TYPE OCCLUSION.— If the cold air ahead of the warm front is warmer than the cold air behind the cold front, the cold frontal surface underruns the warm front and the occluded front is called a cold type occlusion. (See figure 44.)

The primary difference between a warm type and cold type occlusion is the location of the associated upper front in relation to the surface front. (See figure 45.) In a warm type occlusion the upper cold front precedes the surface occluded front by as much as 200 miles. In the cold type occlusion the upper warm front follows the surface occluded front by 20 to 50 miles.

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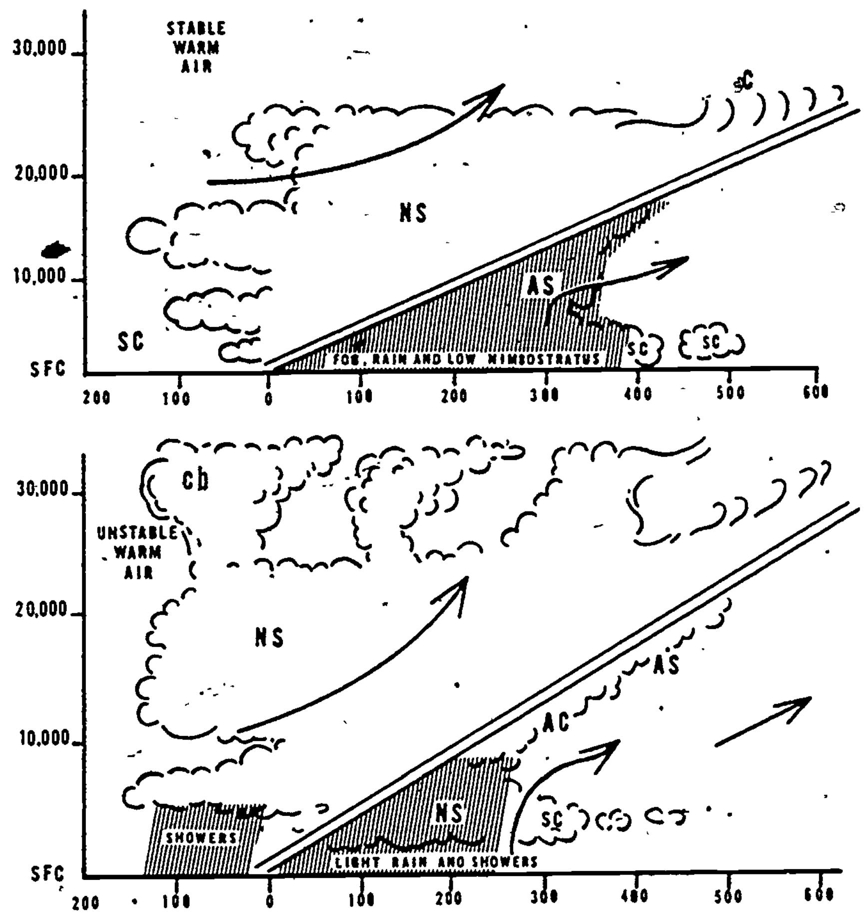


Figure 42.— Vertical cross section of a warm front.

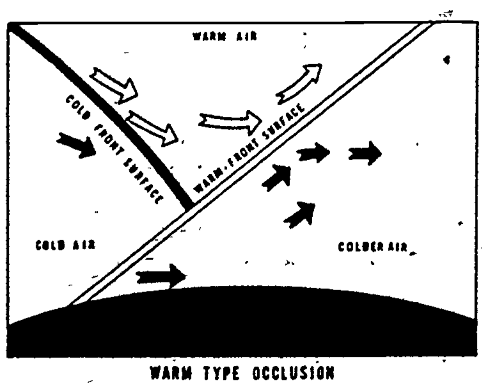


Figure 43.— Vertical cross section of a warm type occlusion.

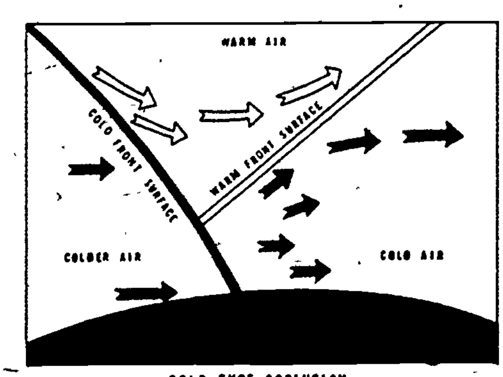


Figure 44.— Vertical cross section of a cold type occlusion.



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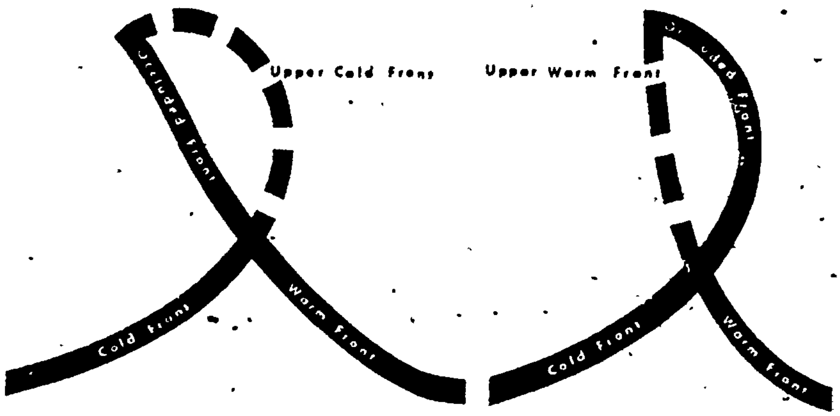


(A) WARM TYPE OCCLUSION (B) COLD TYPE OCCLUSION

Figure 45.— Sketch of occlusions (in the horizontal) and associated upper fronts.

Since the occluded front is a combination of a cold front and a warm front, the resulting weather is that of the cold front's narrow band of violent weather and the warm front's widespread area of cloudiness and precipitation occurring in combination along the occluded front. The most violent weather occurs at the tip of the occlusion. (The tip is the point at which the cold front is overtaking the warm front.)

Stationary Fronts

When a front is stationary, the cold air mass, as a whole, does not move either toward or away from the front. In terms of wind direction, this means that the wind above the friction layer blows neither toward nor away from the front, but parallel to it. It follows that the isobars, too, are nearly parallel to a stationary front. This characteristic makes it easy to recognize a stationary front on a weather map.

The frictional inflow of warm air toward a stationary front causes a slow upglide of air on the frontal surface. As the air is lifted to and beyond its lifting condensation level, clouds form in the warm air above the front.

If the warm air in a stationary front is stable, the clouds are stratiform. Drizzle may then fall; and as the air is lifted beyond the freezing level, icing conditions develop and light rain or snow may fall. At very high levels, above the top of the front, ice clouds are present.

If the warm air is conditionally unstable and sufficient lifting occurs, the clouds are then cumuliform or stratiform with cumuliform protuberances. If the energy release is great (warm, moist, unstable air), thunderstorms result. Rainfall if generally showery.

Within the cold air mass extensive fog and low ceiling may result, where the cold air is saturated by warm rain or drizzle falling through it from the warm air mass above. If the temperature is below 32° F., icing may occur, but generally is light.

The width of the band of precipitation and low ceiling varies from 50 miles to about 200 miles, depending upon the slope of the front and the temperatures of the air masses. One of the most annoying characteristics of a stationary front is that it may greatly hamper and delay air operations by persisting in the area for several days.

PRESSURE AT FRONTS

One of the important characteristics of all fronts is that on both sides of a front the pressure is higher than at the front. This is true even though one of the air masses is relatively warm and the other is relatively cold. Fronts are associated with troughs of low pressure.

(A trough is defined as an elongated area of relatively low pressure.) A trough may have U-shaped or V-shaped isobars.

Friction causes the air near the ground to drift across the isobars toward lower pressure. This causes a drift of air toward the front from both sides. Since the air cannot disappear into the ground, it must move upward. Hence, there is always a net movement of air upward in the region of a front. This is another important characteristic of fronts, since the lifting of the air causes condensation, clouds, and weather. While air motion within an area of high pressure is downward and outward, motion in a frontal zone is inward and upward. (This is the divergence and convergence, respectively, mentioned in section 3.)

Since low-pressure areas are formed along primary fronts when wave development takes place, it is easy to see that a close relationship exists between cyclones and frontal systems.

Every moving cyclone usually has two significant lines of convergence distinguished by thermal properties. The discontinuity line on the forward side of the cyclone where warm air replaces cold air is the warm front; the discontinuity line in the rear portion of the cyclone where cold air displaces warm air is the cold front.

In figure 33, the wave development and formation of a cyclone show that frontal systems are present throughout the different stages.

Anticyclones are usually coexistent with areas of good weather. This is due mainly to divergence. However, frontal systems may at times penetrate the anticyclones to some extent.

## FRONTAL MOVEMENT

The weather is greatly affected by the movement of frontal systems. From the time the front develops until it passes out of the weather picture, it is watched closely. The speed at which it travels and the modifications which it undergoes are important considerations in analyzing and forecasting the weather.

### Speed

The speed of the movement of frontal systems is an important determining factor of weather conditions. Rapidly moving fronts usually cause more severe weather than slower moving fronts. For example, fast-moving cold fronts often cause severe prefrontal squall lines which are extremely hazardous to flying. The fast-moving front does have the advantage of moving across the area rapidly, permitting the particular locality to enjoy a quick return of good weather. Slow-moving fronts, on the other hand, may cause extended periods of unfavorable weather. A stationary front which may bring bad weather can disrupt flight operations for several days in succession.

Knowledge of the speed of the frontal system is necessary for accurate forecasting. If the front has a somewhat constant speed, it makes the forecaster's job comparatively easy. However, if the speed is erratic or unpredictable, the forecaster may err as far as time and severity are concerned. His forecast may never materialize in cases in which the front becomes stationary and dissipates without passing over the forecaster's area.

### Modifications

There are many factors that can modify the movement of frontal systems. In this section only a few of the more important factors are considered.

EFFECT OF MOUNTAINS.— Mountain ranges affect the speed, the slope, and the weather associated with a front. The height and horizontal distance of the mountain range, along with the angle of the front along the mountain range, are the influencing factors. The effect of mountain ranges differs in regard to cold fronts and warm fronts.

As a COLD FRONT approaches a mountain range, the lower portion of the front is retarded as the upper portion pushes up and over the mountain. On the windward side of the mountain, precipitation is increased due to the additional lift as the warm air is pushed up along the mountain slope. After the front reaches the crest of the mountain, the air behind the front commences to flow down the leeward side of the range. If the air on the leeward side of the mountain is warmer than the air in the rear of the cold front, the warmer air is forced away and replaced by the colder air mass. As the cold air descends the lee side of the mountain,

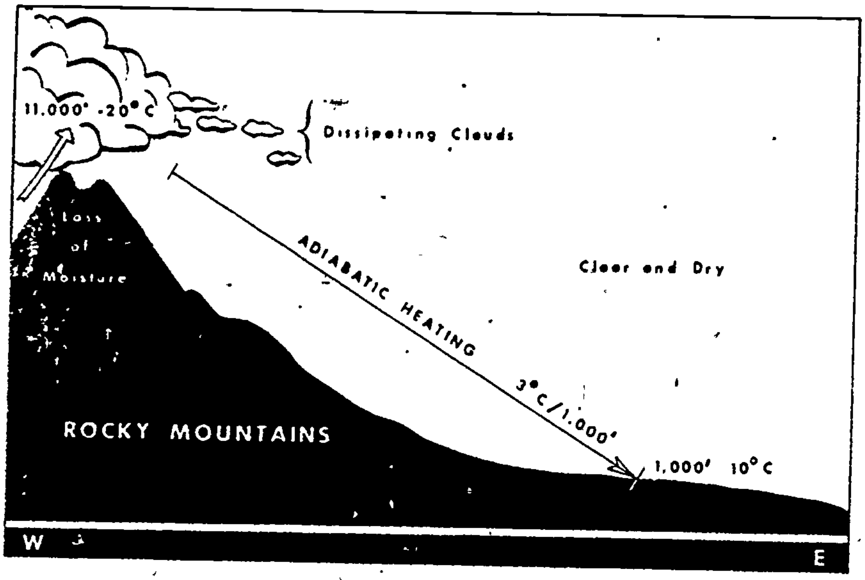


Figure 46.— Effect of adiabatic heating.

the air warms adiabatically (figure 46) and clearing occurs within it. However, since the cold air is displacing warm air, typical cold frontal clouds and precipitation may occur within the warm air if the warm air is sufficiently moist and conditionally unstable. In some cases maritime polar air which has crossed the Rockies is less dense than maritime tropical air from the Gulf of Mexico which may lie just east of the mountains. If the maritime polar air is moving with a strong westerly wind current and the maritime tropical air is moving with a strong southerly wind current, the maritime polar air may overrun the maritime tropical air. This results in extremely heavy showers and violent thunderstorms and is one of the conditions under which tornadoes occur.

If colder stagnant air lies to the lee side of the mountain range, the cold front on passing over the range does not reach the surface and travels as an upper cold front. Under this condition frontal activity is at a minimum. This situation does not continue indefinitely; either the stagnant air mixes with the air above and the surface of separation becomes spread out, or the upper cold front breaks through to the ground with the development of thunderstorms and squalls.

As a cold front passes a mountain range, it may develop a bulge or a wave as a portion of the front is retarded. In the case of an occlusion, a new and separate cyclone circulation may occur at the peak of the warm sector as the occluded front is retarded by a mountain range.

In general, it may be said that the area of precipitation is widened as the front approaches the range and that there is increased intensity of the precipitation area and cloud system on the windward side of the range and a decrease on the leeward side. (See figure 47.)

Consider the effect of a mountain range on a WARM FRONT. When a warm front approaches a mountain range, the upper section of the frontal surface is above the effects of the mountain range and does not come under its influence. As the lower portion of the frontal surface approaches the range, the underlying cold wedge is cut off, forming a more or less stationary front on the windward side of the range. The inclination of the frontal surface above the range decreases and becomes more horizontal near the mountain surfaces, but the frontal surface maintains its original slope at higher altitudes. While the stationary front on the windward side of the range may be accompanied by prolonged precipitation, the absence of ascending air on the leeward side of the range causes little or no precipitation. The warm air descending the leeward side of the range causes the cloud system

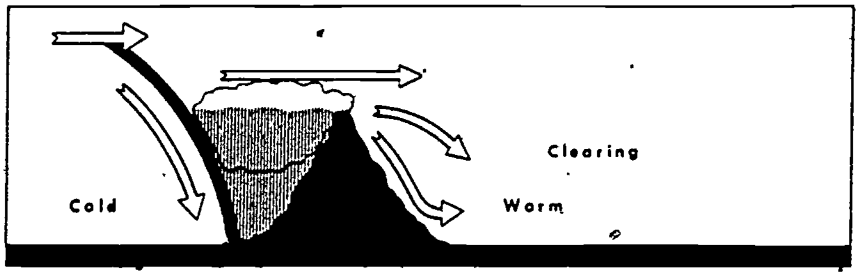


Figure 47.— Effect of mountains on a cold front.

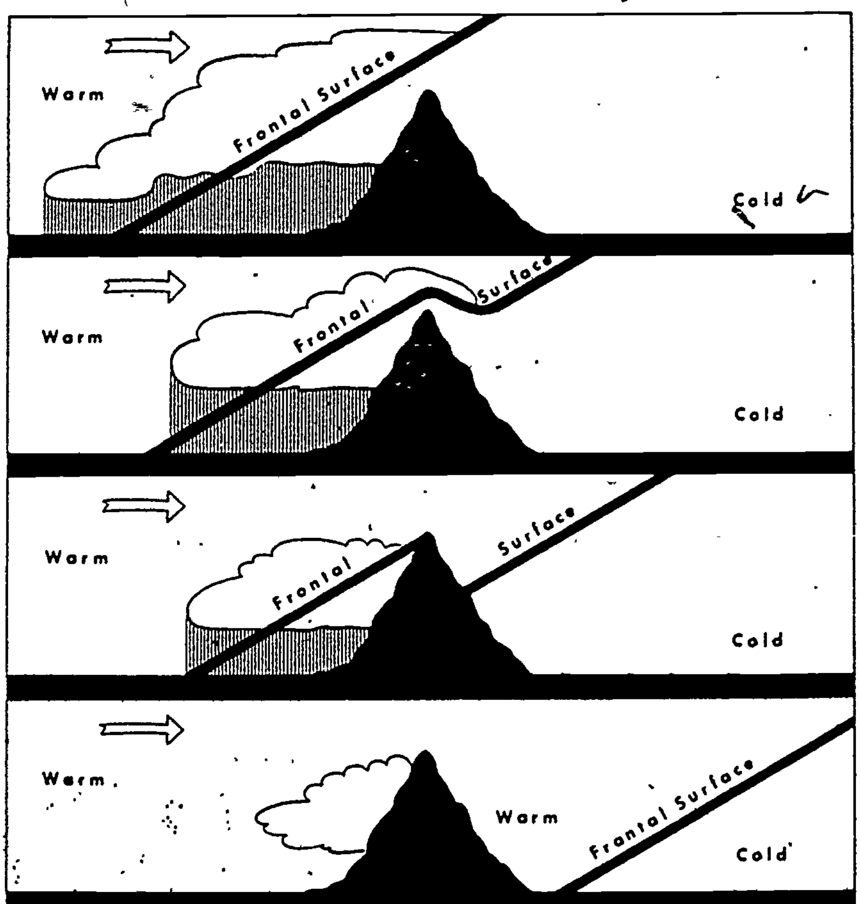


Figure 48.— Effect of mountains on a warm front.

to dissipate and the warm front to travel as an upper front.

Frontogenesis (the formation of a new front or the regeneration of an old front) may occur in the pressure-trough area that accompanies the front. The frontal surface then gradually forms downward as the frontal system moves away from the mountain, and it extends to the earth's surface again.

Therefore, the effect of the mountain range on a warm front is to widen and prolong the precipitation on the windward side of the range, while on the leeward side the precipitation band is narrowed and weakened, or dissolved. (See figure 48.)

Mountain ranges have much the same effect on OCCLUDED FRONTS as they do on warm and cold fronts. Cold type occlusions behave as cold fronts and warm type occlusions behave as warm fronts. The occlusion process is accelerated when an open wave approaches a mountain range because the warm front is retarded while the cold front continues its normal movement until it reaches the mountain range.

EFFECT OF OCEAN CURRENTS.— Ocean currents have a modifying effect on frontal movement. To understand why ocean currents have such an effect, it is necessary for you to consider the movement of the currents.

In middle latitudes, ocean currents carry warm water away from the Equator along the eastern coasts of continents, and carry cold water toward the Equator along the western coasts of continents. The most active frontal zones of the winter season are found where cold continental air moves over warm water off eastern coasts. This situation is noticeable over the Atlantic Ocean off the east coast of the United States. As a cold front moves off the coast and over the Gulf Stream, it becomes intensified, causing wave development to occur near the Cape Hatteras area. This gives the east coast of the United States much cloudiness and precipitation. A similar situation occurs off the east coast of Japan. That area in the Pacific generates more cyclones than any other area in the world.

OTHER EFFECTS.— The movement of a frontal system from one area to another often has a great modifying effect, causing the front to be regenerated in some instances and to be dissipated in others. Transition affects waves and cyclones as well as fronts.

When dissipating extratropical cyclones enter regions of frontogenesis and cyclogenesis, these cyclones are frequently regenerated into active disturbances. This is usually caused by an influx of warm moist air to the east and cold air to the west of the center. In a situation in which a well-defined cyclone, associated with a front (or fronts), moves eastward over the Rocky Mountains, the frontal system is usually weakened by the time it descends the eastern slopes. If there is an influx of warmer moist air from the Gulf of Mexico, the frontal system is regenerated as it moves eastward. If the circulation to the east of the mountain range is such that no moist air is drawn into the cyclone or frontal system, frontolysis (the process of a front weakening or dissolving) takes place.

Frontal systems moving from water to land areas tend to weaken if an influx of moist air is not brought into the situation. On the other hand, a frontal system moving from land areas to water areas is generally regenerated by the influx of moist air. For example, a frontal system may become quasi-stationary in the vicinity of the east coast of the United States. This frontal system is usually oriented in a northeast-southwest direction and occurs mostly during the summer and autumn months, when outbreaks of cP air move southeastward over the States. These fronts usually lose their intensity over the Southern States and movement ceases. Frequently, stable waves develop and travel along this frontal system, causing unfavorable weather conditions. When these waves move out to sea and warmer moist air is brought into them, they become unstable waves and are regenerated as they move across the ocean.

## EASTERLY WAVES AND THE ITCZ

### EASTERLY WAVES

An easterly wave is defined as a wavelike disturbance which moves east to west in the current of the tropical easterlies. When viewed from a horizontal plane, an easterly wave is normally oriented from northeast to southwest. In a vertical plane it may slope to the east or to the west, or it may be vertical. The slope of an easterly wave may change with time. The location of the bad weather associated with an easterly wave is an indication of the slope. The weather associated with easterly waves is showery precipitation and thundershowers. The clouds associated with easterly waves are cumulus congestus and cumulonimbus. They are arranged in parallel bands with layers of altocumulus and altostratus clouds along with higher layers of cirrus clouds connecting the cumulonimbus clouds. Visibility is good except in the areas of precipitation.

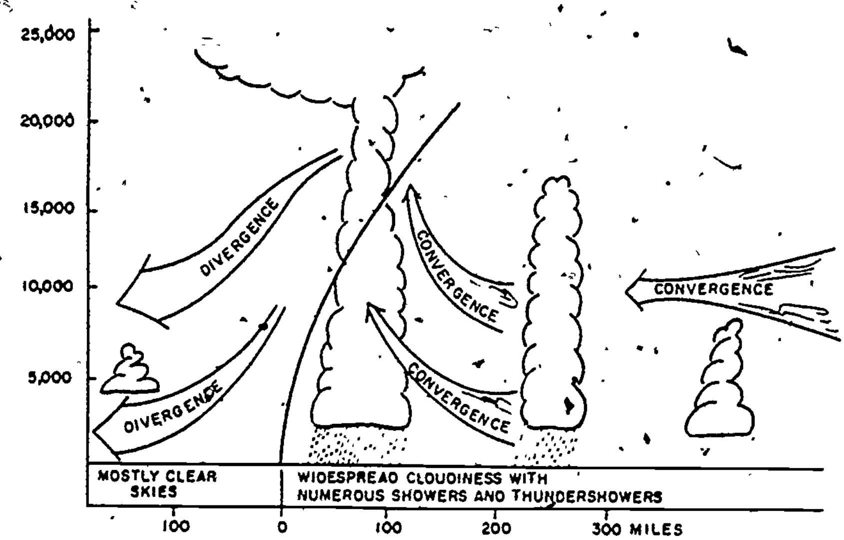


Figure 49.— Vertical cross section of a stable easterly wave.

There are three types of easterly waves—stable, neutral, and unstable.

Stable Wave

This type of wave slopes to the east with height. To the west of the trough line, winds at the surface and aloft are predominantly northeasterly. This area experiences falling pressures; but due to divergence at all levels, fair weather prevails. East of the trough line, the surface and upper air winds veer to the southeast. The intense convergence found in this area produces widespread cloudiness and shower activity. This is the most common type of easterly wave. (See figure 49.)

Neutral Wave

With a neutral wave, the bad weather is symmetrical around the trough line, and the most intense weather occurs along the trough line. This type of wave is vertical (no slope) and is typical of a wave that is intensifying.

Unstable Wave

This type of wave has the most violent weather and is often associated with the development of typhoons and hurricanes. The weather associated with the unstable wave is ahead of the trough line, and the wave slopes to the west with height.

INTERTROPICAL CONVERGENCE ZONE

The intertropical convergence zone (ITCZ) is a weather band in the doldrums that extends around the earth. It is caused by the convergence of the northeast trade winds of the Northern Hemisphere and the southeast trade winds of the Southern Hemisphere. In most cases the ITCZ has no sharp frontal discontinuity, but is a zone varying in width from 50 to 400 miles.

Since the wind shift across the ITCZ varies from place to place due to the different intensities of the two trade winds, the weather band varies correspondingly in width and intensity.

The ITCZ's position varies with the season; it tends to follow the sun. It reaches its northernmost position in late August and its southernmost position in February. The mean position of the ITCZ in the Atlantic is always north of the Equator. In the eastern Pacific it does not change positions appreciably and lies north of the Equator. In the western Pacific, however, it lies across northern Australia in February and is over the Philippines in late August.

The intensity of the weather depends upon the stability of the air masses and the degree of convergence. The continuous formation and dissipation of cumulonimbus clouds result in

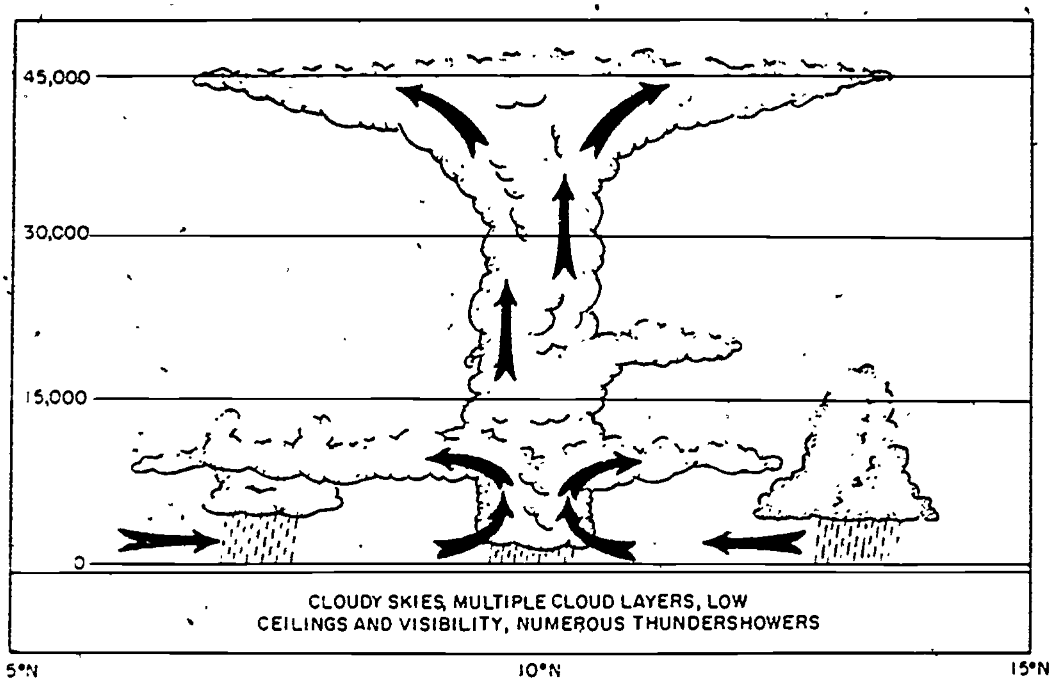


Figure 50.— Weather conditions in an active portion of the ITCZ.

many intermediate and high clouds of the altostratus and cirrus types.

At its worst, the ITCZ is an area of solid cumulonimbus clouds rising to 40,000 feet or more, with thick layers of altostratus extending outward from several layers. Frequently, ceilings and visibilities are lowered to near zero in heavy rain. Under such conditions, turbulence is severe with heavy icing in clouds above the freezing level. (See figure 50.)

At its best, the ITCZ may be merely an area of broken to overcast altostratus clouds, with swelling cumulus clouds below.

# SPECIAL PHENOMENA

This section deals with the hazardous and destructive weather phenomena that continually pose a threat to ships, aircraft, and other structures. The formation, detection, and movement of thunderstorms, tornadoes, waterspouts, dust devils, and tropical cyclones are discussed; in addition, the various emergency weather warnings and conditions of readiness used to minimize damage from these phenomena are explained.

## THUNDERSTORMS

A Marine Science Technician must be cognizant of thunderstorm activity in order to advise pilots as to the best possible routes for flight. Since approximately 44,000 thunderstorms occur daily over the surface of the earth, a pilot will sometimes fly through a thunderstorm or a thunderstorm area. The turbulence within most thunderstorms is considered one of the worst hazards of flying.

Ground personnel also need to be advised of the strong gusty surface winds that are often associated with the thunderstorm.

Much of the information about thunderstorms in this section is based on the findings of the Thunderstorm Project which was conducted in 1946 and 1947 at Orlando, Fla., and Wilmington, Ohio, as a joint project of the weather services of the Armed Forces and the Weather Bureau.

### FORMATION

The thunderstorm represents a violent and spectacular atmospheric phenomenon. The thunderstorm is usually accompanied by lightning, thunder, heavy rain, gusty surface wind, and frequently by hail. A certain combination of atmospheric conditions is necessary for the formation of a thunderstorm. These factors are conditionally unstable air of relatively high humidity and some type of lifting action. Before the air actually becomes unstable, it must be lifted to a point where it is warmer than the surrounding air. When this condition is brought about, the relatively warmer air continues to rise freely until, at some point aloft, its temperature has cooled to the temperature of the surrounding air. In order to bring the warm surface air to a point where it will continue to rise freely, some type of external lifting action must be introduced. Many conditions satisfy this requirement. For example, an air mass may be lifted by heating, terrain, and fronts or convergence.

### STRUCTURE

The fundamental structural element of the thunderstorm is the unit of convective circulation known as a convective cell. A mature thunderstorm contains several of these cells, which vary in diameter from 1 to 6 miles. By radar analysis and measurement of drafts, it has been determined that, generally, each cell is independent of surrounding cells of the same storm. Each cell progresses through a cycle which lasts from 1 to 3 hours. In the initial stage (cumulus development), the cloud consists of a single cell; but as the development progresses, new cells form and older cells dissipate.

The life cycle of the thunderstorm cell consists of three distinct stages; they are the cumulus stage, the mature stage, and the dissipating or anvil stage. (See figure 51.)

#### Cumulus Stage

Although most cumulus clouds do not become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The chief distinguishing feature of this cumulus or building stage is an updraft, which prevails throughout the entire cell. Such updrafts vary from a few feet per second to as much as 100 feet per second in mature cells.

#### Mature Stage

The beginning of surface rain, with adjacent updrafts and downdrafts, initiates the mature

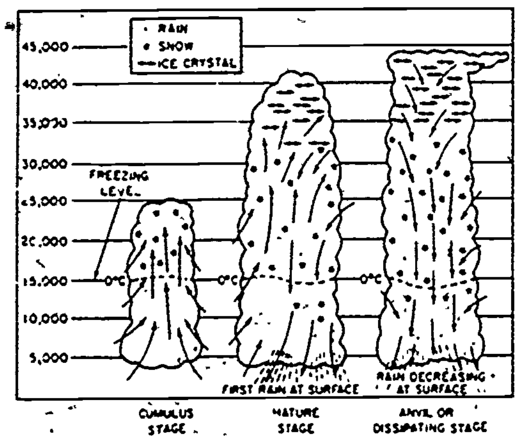


Figure 51.— Life cycle of a thunderstorm cell.

stage. By this time the apex of the average cell has attained a height of 25,000 feet or more. As the raindrops begin to fall, the frictional drag between the raindrops and the surrounding air causes the air to begin a downward motion. Since the lapse rate within a thunderstorm cell is more than the moist adiabatic rate, the descending saturated air soon reaches a level where it is colder than its environment; consequently, its rate of downward motion is accelerated. This is a downdraft.

A short time after the rain starts its initial fall, the updraft reaches its maximum speed. Aircraft measurements made by the Thunderstorm Project show that updrafts increase in speed with altitude up to 25,000 feet, which was the top level of flight. They also show that downdrafts are usually strongest at the middle and upper flight levels, although the variation in speed from one altitude to another is less than in the case of updrafts. Downdrafts are not as strong as updrafts; downdraft speed ranges from a few feet per second to about 40 feet per second. Significant downdrafts seldom extend to the top of the cell because in most cases only ice crystals and snowflakes are present, and their rate of fall is insufficient to cause appreciable downdrafts.

The mature cell, then, generally extends far above 25,000 feet, and the lower levels consist of sharp updrafts and downdrafts adjacent to each other. Large water droplets are encountered suspended in the updrafts, and descending with the downdrafts as rain.

Dissipating (Anvil) Stage

Throughout the life span of the mature cell, more and more air aloft is being dragged down by the falling raindrops. Consequently, the downdraft spreads out to take the place of the dissipating updraft. As this process progresses, the entire lower portion of the cell becomes an area of downdraft. Since this is an unbalanced situation, and since the descending motion in the downdraft effects a drying process, the entire structure begins to dissipate. The high winds aloft have now carried the upper section of the cloud into the anvil form, indicating that gradual dissipation is overtaking the storm cell.

VERTICAL DEVELOPMENT

Measurement

Measurements of the vertical extent of thunderstorm activity were made by personnel of the Thunderstorm Project by using radar equipment with a range-height indicator (RHI). They found that the closest correspondence between the radar-measured top and the actual top occurs during the cumulus stage.

Of the storms observed, those of greatest vertical extent were of the air-mass variety. The few frontal storms observed appeared to be the least in vertical development. Storms of 50,000 feet or over were measured in less than 10 percent of the cases observed. The average of all heights measured was 37,000 feet, and the maximum height measured was 56,000 feet. These figures are from the findings of the Thunderstorm Project only and are based on radar data collected during the summer of 1947 in Ohio. Thunderstorms have been accurately measured as high as 67,000 feet, and it is believed that some severe thunderstorms actually attain a greater height than this.

Drafts and Gusts

Rising and descending drafts of air are, in effect, the structural bases of the thunderstorm cell. A draft is a large-scale vertical current of air that is continuous over many thousands of feet of altitude. Speeds of the drafts are either relatively constant or gradually varying from one altitude to the next. Gusts, on the other hand, are smaller scaled discontinuities associated with the draft proper. A draft may be compared to a great river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or any other random motion of water within the main current.

Considerable data on drafts were collected and tabulated by Project personnel, and certain very definite conclusions can be made. Some of the findings are as follows:

1. The maximum updrafts were found in the middle and upper levels flown.

2. Mean updraft and downdraft velocities increased with heights.

3. Updrafts were generally of greater velocities than downdrafts.

THUNDERSTORM WEATHER

Rain

Liquid water in a storm may be ascending if encountered in a strong updraft; it may be suspended, seemingly without motion, yet in extremely heavy concentration; or it may be falling to the ground. Rain, as normally measured by surface instruments, is associated with the downdraft. This does not preclude the possibility of a pilot entering a cloud and being swamped, so to speak, even though rain has not been observed from surface positions. Rain is found in almost every case of penetration below the freezing level. In instances in which no rain is encountered, the storm probably has not developed into the mature stage.

Statistics show, although heavy rain is generally reported at all levels of a mature storm, that specific altitudes seem to represent the greatest frequency of heavy rain. In all observations the greatest incidence of heavy rain occurred in the middle and lower levels of the storms. The 10,000- to 11,000-foot level showed the greatest frequency of heavy rainfall, and the 5,000- to 6,000-foot level showed the next greatest frequency.

Hail

During the operations of the Project, hail was encountered at a maximum of 10 percent of the traverses at any given altitude. Very seldom was it found at more than one or two levels within the same storm. When it was observed, its duration was very short. The maximum occurrence was found to be at the middle levels for all intensities of hail. However, the area from which the data were taken is far removed from the region of the greatest surface hail, the Great Plains States.

Snow

The maximum frequency of moderate and heavy snow occurred at the 20,000- and 21,000-foot levels. Snow, mixed in many cases with supercooled rain, was encountered at all altitudes above the freezing level. This presented a unique icing problem—wet snow packed on the leading edge of the wing of the aircraft and resulted in the formation of rime ice.

Turbulence

There is a certain definite correlation between turbulence and precipitation. Previously it was believed that precipitation had a dampening effect on turbulence. This was found to be nearly 100 percent in error. It is clearly evident that the intensity of associated turbulence, in most cases, varies directly with the intensity of the precipitation.

Icing

Since icing presents an obvious flight hazard, it is well to analyze data relating to this problem. At the 20,000-foot level, ice was encountered on more than 50 percent of all traverses. The majority of this ice was classified as rime. In no case did the ice accumulate to the degree that safe flight was not possible, but it is believed that this was mainly due to the relatively short duration that the aircraft was subjected to icing conditions in these traverses.

Since the freezing level is also the zone of greatest frequency of heavy turbulence and generally heavy rainfall, this particular altitude appears to be the most hazardous.

Surface Wind

A significant hazard associated with thunderstorm activity is the rapid change in surface wind direction and speed immediately prior to storm passage. The strong winds at the surface accompanying thunderstorm passage are the result of the horizontal spreading out of downdraft currents from within the storm as they approach the surface of the earth.

The total wind speed is a result of the downdraft divergence plus the forward velocity of the storm cell. Thus, the speeds at the leading edge, as the storm approaches, are greater than those at the trailing edge. The initial wind surge, as observed at the surface, is known as the FIRST GUST.

The speed of the first gust is normally the highest recorded during storm passage, and the direction may vary as much as 180 degrees from the previously prevailing surface wind. First-gust speeds increase to an average of about 16 knots over prevailing speeds, although gusts of over 78 knots (90 mph) have been recorded. The average change of wind direction associated with the first gust is about 40 degrees.

## CLASSIFICATION

All thunderstorms are similar in physical makeup; but for purposes of identification, they may be divided into two general groups—frontal thunderstorms and air-mass thunderstorms.

### Frontal

Frontal thunderstorms are most commonly associated with the warm and cold types of fronts.

The warm-front thunderstorm is caused when warm, moist, unstable air is forced aloft over a colder, denser shelf of retreating air. Warm-front thunderstorms are generally scattered; they are difficult to identify because they are obscured by other clouds.

The cold-front thunderstorm is caused by the forward motion of a wedge of cold air into a body of warm, moist, unstable air. Cold-front storms are normally positioned aloft along the frontal surface in what appears to be a continuous line.

Under special atmospheric conditions, a line of thunderstorms develops ahead of a cold front. This line of thunderstorms is known as a prefrontal squall line. Its distance ahead of the front ranges from 50 to 300 miles. Prefrontal thunderstorms are usually intense and appear very menacing. Bases of the clouds are very low. Tornadoes sometimes occur when this type of activity is present.

### Air Mass

Air-mass thunderstorms are subdivided into several types. In this discussion, however, only two basic types are mentioned—the convective thunderstorm and the orographic thunderstorm.

CONVECTIVE.— Convective thunderstorms may occur over land or water almost anywhere in the world. Their formation is caused by solar heating of various areas of the land or sea, which, in turn, provides heat to the air in transit. The land type of convective thunderstorms normally forms during the afternoon hours after the earth has gained maximum heating from the sun. If the circulation is such that cool, moist, convectively unstable air is passing over this land area, heating from below causes convective currents and results in towering cumulus or thunderstorm activity. Dissipation usually begins during the early evening hours.

Storms that occur over bodies of water form in the same manner, but at different hours. Sea storms usually form during the evening after the sun has set. They dissipate during the late morning. An example that combines both types of convective thunderstorms is the situation that exists in Florida. Circulation around the Bermuda high transports moist air over the land surface of Florida during the entire day. The Bermuda high causes air to flow from the east over Florida. Thunderstorms off the east Florida coast at night are caused by warm air advection from the east wind and the warm axis of the Gulf Stream, aided by nocturnal cooling of air above sea level, setting up an unstable lapse rate. During the hours of sunlight, the land surface is considerably warmer than the air; consequently, the air is subjected to heating from below. Convective currents result, and the common afternoon thunderstorm is observed. After sundown, the earth loses its heat. Dissipation occurs, and the apparent movement of the storms to sea takes place. As the circulation causes air to flow over the peninsula at night, the air is cooled by the land surface. As this same air moves out over the warm water, it is heated from below, and cumulus activity occurs. Water, not being subject to such rapid temperature changes as land, retains much of

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the heat it has gained during the day. When the sun rises, the air over the sea surface becomes warmer than the surface, thereby destroying the balance necessary to keep a storm active, and dissipation occurs. As a general rule, convective thunderstorms are scattered and easily recognized. They are relatively high, and visibility is generally good in the surrounding area.

OROGRAPHIC.— As the name implies, orographic thunderstorms form in mountainous regions, particularly adjacent to individual peaks. A good example of this type of storm occurs in the northern Rocky Mountain region. When the circulation of the air is from the west, moist air from the Pacific Ocean is transported to the mountains, where it is forced aloft by the upslope of the terrain. If the air is also conditionally unstable, this upslope motion causes thunderstorm activity on the windward side of the mountains. This activity may form a long, unbroken line of storms similar to a cold front. The storms persist as long as the circulation causes an upslope motion.

From the windward side of the mountains, identification of orographic storms may sometimes be difficult because the storms are obscured by other clouds. From the lee side, identification is positive; the outlines of each storm are plainly visible. Orographic storms, almost without exception, enshroud mountain peaks or hills.

## FLYING CONDITIONS

The safest procedure for pilots, when their flight takes them over thunderstorm areas, is to circumnavigate or fly around the storms. For propeller-driven aircraft, a pilot should be advised against flying through or under thunderstorms, since the violent drafts may cause structural damage to the aircraft. Also, low ceilings and poor visibilities, as a result of heavy precipitation, and severe icing conditions render a flight through or under thunderstorms very hazardous. In the case of most air mass storms, circumnavigation is usually possible. Frontal storms may extend for several hundred miles in a solid line; therefore, a pilot should be advised to fly between individual cells.

The high service ceilings of jet aircraft make it feasible to advise pilots of this type aircraft to fly over or around the tops of thunderstorms. At times it is operationally advantageous and feasible to fly under some types of thunderstorms. Normally, this is a safe procedure over water; but over land it is dangerous, particularly with the orographic type thunderstorm where the terrain may be very rough and violent downdrafts may force the aircraft dangerously close to the surface.

## THUNDERSTORM DETECTION

The information of upper air observations and the surface weather charts gives indications of thunderstorm activity. However, since these charts are normally prepared at 6- and 12-hour intervals, it is understandable that certain weather phenomena may form during the periods when observations for maps and upper air soundings are not scheduled.

Although a synoptic weather map gives definite indications of an approaching front or hurricane, or of the presence of thunderstorms in a specific area, minute-to-minute tracking of these weather phenomena is not possible. From the above-mentioned sources, the exact time of the occurrence of adverse weather is extremely difficult and, at times, impossible to forecast.

Radar has provided meteorology with an additional tool to be used in the collection of atmospheric data. It has been proved that reflection of radar pulses from clouds associated with precipitation permits the continuous tracking of the position of such clouds with respect to the location of a station. Radar methods make it possible to forecast the approach of unfavorable weather with greater accuracy and with less difficulty than can be achieved by other methods.

It is beyond the scope of this training course to discuss the relation between forecasting and radar in detail; however, one of the basic means of presentation should be mentioned—the PPI (Plan Position Indicator). The PPI scan is frequently employed where the tactical conditions require that range and bearing information be obtained concerning objects in or near a horizontal plane centered at the site of the radar station. Not only can the proximity of storms be ascertained, but also their speed, area, and development can be judged accurately by an experienced observer. Within the limitations of the radar equipment used with respect to range, precise short-range forecasts vital to the safety of personnel and equipment can be issued.

Destructive phenomena, such as the thunderstorm, can be detected, and their approach to the ship or station can be timed. In this manner, storm warnings can be given sufficiently early so that storm conditions may be set. With a radar range of 80 to 100 miles, a warning can be issued 5 to 6 hours prior to the arrival of a destructive storm traveling at a speed of less than 20 knots.

The radar echo from a convective thunderstorm of a PPI scope is shown in figure 52. The radar was adjusted for a 25-mile range. The concentric lines are 5-mile markers. The bright area at azimuth 190 and the 8-mile range is a thunderstorm.

The weather map of an area in which convective thunderstorms are prevalent gives no definite indication of the probability of a storm occurring at any given location. All that can be said, following a careful study of the weather map, is that the air in the vicinity of the ship or station is unstable and that thunderstorms will probably occur in the area. The storm picked up on the PPI scope in figure 52 did not appear on the weather map.

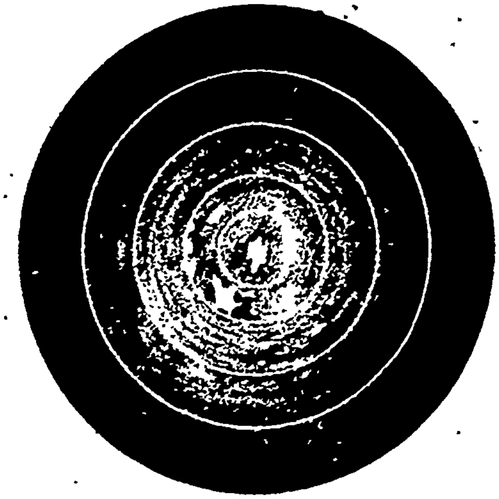

Figure 52.— Radar echo of a thunderstorm.

## TORNADOES, WATERSPOUTS, AND DUST DEVILS

### TORNADOES

A tornado is an exceedingly violent whirling storm with a small diameter, usually a quarter of a mile or less. The length of the track of a tornado on the ground may be from a few hundred feet to 300 miles; the average is less than 25 miles. Data from recent tornado studies indicate that the velocities of tornadic winds are in the general range of 150 to 300 miles per hour. A large reduction of pressure in the center due to the spiraling of the air seems to cause buildings in the path of the storm to explode. The speed of the storm over the earth's surface is comparatively slow—usually 25 to 40 mph.

Forecasting the occurrence of tornadoes has progressed relatively fast since the late 1940's. It is now possible for forecast centers to outline an area of several hundred square miles wherein tornado activity is expected. It is not possible to forecast the occurrence of a tornado in a specific place. This is due, in part, to the size of tornadoes, their erratic movement, and their localized nature.

Most of the tornadoes in the United States occur in the late spring and early summer, and are associated with thunderstorm activity and heavy rain.

Although much has been written on tornadoes, little of this material has offered a really satisfactory explanation of their cause or mode of formation. Tornadoes have been observed with various synoptic situations and usually are associated with overrunning cold air. Practically all meteorologists agree that tornadoes are the result of extreme instability and consequently steep lapse rates in the atmosphere. Statistics show that the majority of tornadoes appear about 75 to 180 miles ahead of a cold front along the prefrontal squall line. Figure 53 shows the various stages of development of a tornado.

A situation that is noticeably favorable to tornado activity is cold air advection aloft. When mP air moves across the United States, it becomes heated in the low levels from the Western Plateaus. Having a density equal to or less than the mT air moving northward over the Mississippi Valley, the mP air rides up over

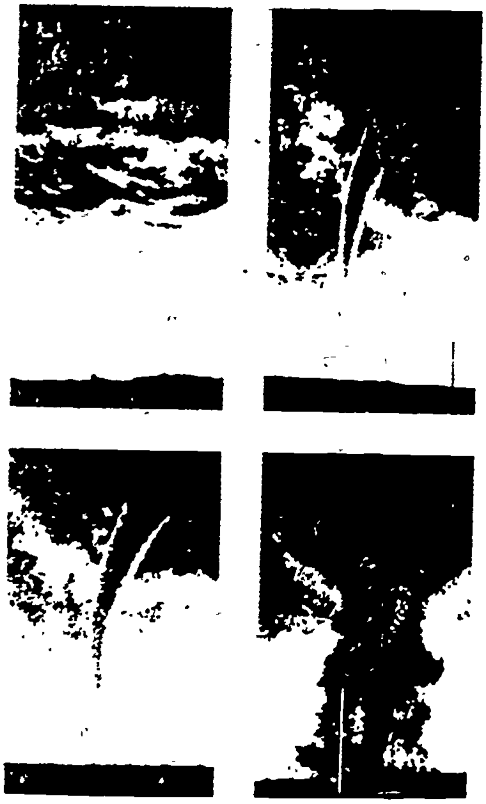

Figure 53.— Stages of development of a tornado.

the mT air. The mP air still maintains low temperatures at higher altitudes; this causes extreme instability.

The following conditions may indicate possible tornado activity:

1. Pronounced horizontal windshear. (Wind shear is the rate of change of wind velocity with distance.)

2. Rapidly moving cold front.

3. Strong convergence.

4. Marked convective instability.

5. Dry air mass superimposed on a moist air mass. Abrupt change in moisture content, usually below 10,000 feet.

6. Marked convection to the minus 10° C. isotherm.

WATERSPOUTS

Waterspouts are tornadoes that form over ocean areas. They may be divided into two classes. One is the true waterspout in which the vortex forms at the cloud and extends to the surface. This type occurs mainly in advance of a squall line. The second type, often called the pseudo-waterspout, originates just above the water surface and builds upward; this type is identical with whirling dust often seen on deserts.

DUST DEVIL

Dust devils, phenomena of whirling, dust-laden air, are caused by intense solar radiation, which sets up a steep lapse rate near the ground. They are best developed on a calm, hot afternoon with clear skies, and in desert regions. As the intense surface heating sets up a steep lapse rate, a small circulation is formed when the surrounding air rushes in to fill the area of the rising warm air. This warm ascending air carries dust, leaves, and other small material to a height of a few hundred feet.

## TROPICAL CYCLONES

Each year many lives are lost and millions of dollars in property damage occur in the wake of the most destructive of all weather phenomena, the tropical cyclone. Although the wind velocities associated with these storms are less than in a tornado, the tropical cyclone covers hundreds of times the area and lasts many times longer than the tornado. The total damage, as a result of these storms, is many times greater than that of tornadoes.

Tropical cyclones occur in many localities throughout the world and are known by various names. In the Atlantic area, tropical cyclones are known as hurricanes. In the North Pacific they are known as typhoons. In Australia they are known as willy-willies, and in the Philippines they are baguios. For tracking and statistical purposes, these storms are given feminine names to help identify them, but a fully developed tropical cyclone by any name means havoc and destruction.

The military services and governmental agencies have become so concerned with these storms that the Navy and Air Force continually maintain weather reconnaissance squadrons for the primary duty of tracking these storms. These squadrons penetrate the storms at various levels to determine the storm's intensity, location, and direction of movement. In addition to these squadrons, radar sites are located along the coastlines and on islands to track the paths of these storms.

The Marine Science Technician is frequently called upon to track tropical cyclones on charts and, with the long ranges of aircraft flights, to aid in advising pilots on routes to fly in order to avoid these storms. Thus, it is necessary for you to have an understanding of the classification, characteristics, and formation of these storms.

## CLASSIFICATION

Tropical lows are similar to the extratropical lows which form on the polar front, except that frontal systems are not associated with these lows. These tropical lows are classified according to the maximum wind speed produced by the circulation of the wind.

### Tropical Disturbance

Tropical lows are classified as tropical disturbances when sighted as isolated cyclonic circulations. Only weak surface winds are present in this state. All violent tropical cyclones start as tropical disturbances, but not all tropical disturbances develop into tropical cyclones.

### Tropical Depression

A tropical low producing maximum surface winds up to 33 knots is classified as a tropical depression. At this stage, these lows can be located on a surface synoptic chart by an isobaric pattern producing one or more closed isobars.

### Tropical Storm

A tropical low producing surface winds of 34 to 63 knots inclusive is classified as a tropical storm.

### Tropical Cyclone

A tropical low producing surface winds of 64 knots or more is classified as a tropical cyclone, representing the fully developed hurricanes and typhoons.

## FORMATION

Tropical lows develop over ocean areas and are never found closer than 5 degrees to the geographical Equator, thus indicating that Coriolis force is an important factor in their development. Areas of unsettled weather, such as may be found along the ITCZ (intertropical convergence zone) and an intensifying easterly wave, are conducive to the formation of tropical lows. Most hurricanes originating in the southern North Atlantic and in the Caribbean area form on easterly waves, and typhoons of the western Pacific generally develop along the ITCZ.

A combination of additional heating (warmer than normal water surface temperature) and surface convergence with divergence aloft is the probable triggering mechanism for the formation of a cyclonic circulation. After the cyclonic circulation is established, the tropical low may develop rapidly to tropical cyclone force. The inflow (convergence) of air at the surface is reduced at this time, and the outflow (divergence) aloft continues unchecked. This reduces the pressure in the center of the low which, in turn, increases the pressure gradient. This increase in pressure gradient eventually, through a balancing process, results in an increase in wind speed around the low.

## STAGES OF DEVELOPMENT

The energy that sustains tropical cyclones comes from the energy that is released through the latent heat of condensation. Therefore, in order to exist, a tropical cyclone must have warm air with a high moisture content. This air is lifted by convergence and by the instability of the air until it condenses. It is at this time that heat is liberated. If a tropical cyclone passes over land and the source of moisture is cut off, the storm soon dissipates. If the storm passes into higher latitudes over water and the source of heat is disrupted, the storm assumes the characteristics of an extratropical cyclone.

The average life span of these storms is about 6 days from the time they form until they enter land or recurve to the higher latitudes. Some storms last only a few hours, and a few last as long as 2 weeks. The evolution of the average storm from birth to dissipation has been divided into four stages.

Formative

The formative stage begins when the cyclonic circulation develops, and it ends when the circulation reaches tropical cyclone intensity. The development of tropical lows in this stage can be a slow process, requiring days for even a weak cyclonic circulation to begin; or it can be explosive, producing a well-formed eye within 12 hours. The "eye," found at the center of the circulation, is a roughly circular area of comparatively light winds and fair weather. Winds remain below 64 knots during this formative stage, and the strongest winds are likely to be in one quadrant only. In the formative stage the surface pressure drops to about 1,000 millibars in the center.

Immature

This stage is marked by the intensification of the storm. In this stage the pressure drops rapidly to well below 1,000 millibars. Winds of tropical cyclone force form a tight band around the center, usually with a radius of no more than 20 to 30 miles. The cloud and precipitation patterns change from disorganized squalls to narrow organized bands spiraling inward. In this stage, only a small area is involved, usually an area of less than 60 miles in diameter.

Mature

At this stage the surface pressure is no longer falling and the maximum wind speeds are no longer increasing. Instead, the circulation expands in horizontal extent during the mature stage, which may last a full week. The radius of winds of cyclone force may increase to 200 miles during the mature stage.

Decaying

The tropical cyclone reaches the decaying stage when the circulation moves over land and dissipates, or when it moves far enough north or south (to higher latitudes) to assume the characteristics of an extratropical cyclone.

CHARACTERISTICS

As we all know, there are no two weather phenomena that are exactly alike. In the case of tropical cyclones, no two are the same size or have the same wind velocities. There are many differences in tropical cyclones, but all of them do have certain characteristics which make them a distinct type of weather phenomenon.

Size

As previously mentioned, the size of tropical lows can vary considerably. On an average, during the immature stage, the area being affected by the storm has a diameter of about 60 miles, increasing to 400 miles or more at the time of maximum maturity.

Circulation

As with all low-pressure areas, the winds of a tropical cyclone revolve around the center in a counterclockwise direction in the Northern Hemisphere and in a clockwise direction in the Southern Hemisphere. The velocity of the surface winds increases toward the center of the storm, reaching a maximum just before entry into the eye or center. The velocity of the surface wind varies considerably from one storm to another and also with the stage of development. It is not uncommon to find maximum winds in the mature stage as high as 150 knots.

Eye

A peculiarity of the tropical cyclone is the calm center, called the eye. When the eye passes over a given locality, the wind, which has been extremely violent, suddenly decreases to a much lower speed and at times becomes calm, and the precipitation stops. After the eye passes over an area, the violent winds begin again and blow from the opposite direction. The diameter of the eye in an average mature storm is about 15 miles, much less in the immature storm stage. However, the diameter may attain 40 miles, or more, in a large tropical cyclone.

Clouds

The cloud system associated with a tropical cyclone may appear similar to an approaching warm front. Around 1,000 miles in advance of the storm center, there is an abundance of cirrus clouds. As the storm approaches, cirrostratus, altostratus, altocumulus, and nimbostratus clouds appear. At the outer portion of the area being affected by the storm circulation,

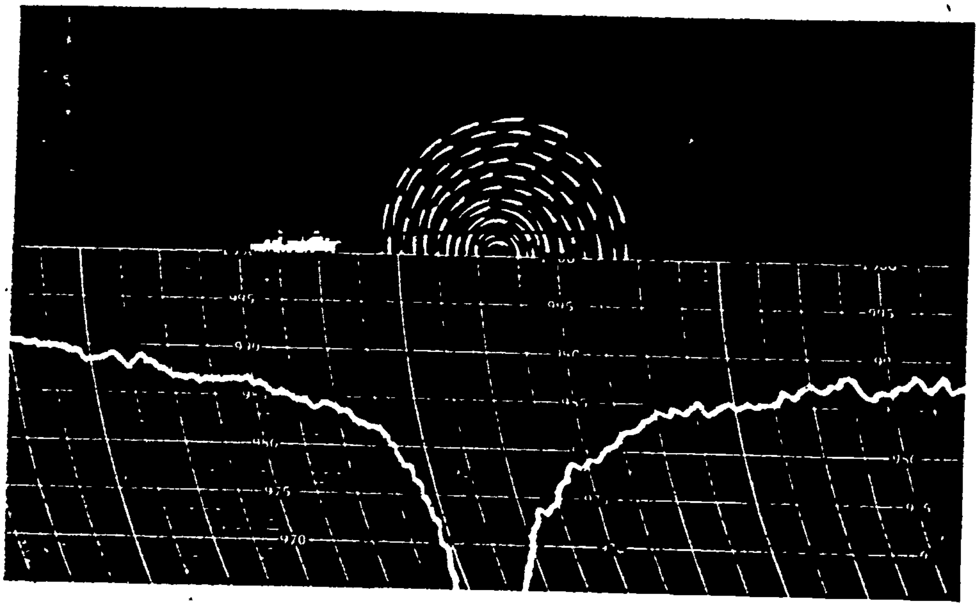

Figure 54.— Barograph trace with tropical cyclone.

there may be considerable cumulus and cumulonimbus clouds producing heavy showers and thunderstorms. Bands of very dense clouds, mostly nimbostratus, seem to spiral toward the center of the storm. The center, or eye, usually shows a marked thinning of the clouds, and the sun is often visible.

A pecular feature of the tropical cyclone is: During its life cycle, all the clouds of the three cloud stages (etages) are represented.

Precipitation

As the storm approaches, precipitation usually begins as showers and thunderstorms well in advance of the storm center. The precipitation becomes very heavy continuous rain that persists until the storm has passed the locality, except for a brief clearing as the eye passes. The amount of rainfall in a tropical cyclone is very hard to determine. Rain gage measurements give only a poor approximation of the rainfall in these storms, since the wind drives the rain horizontally and picks up water that has already fallen to the ground. The amounts of precipitation also vary considerably from one storm to another. Recorded precipitation has been as low as a trace, in spite of winds of 120 mph. On the other hand, it has been as great as 100 inches, which is 3 or 4 times the amount of the annual average precipitation of most areas of the Temperate Zone.

Pressure

The pressure in the centers of mature tropical cyclones averages about 950 to 960 millibars. The lowest pressure ever recorded in the eye of a tropical cyclone was around 890 millibars. Although the pressure in the center of these storms is very low, a falling barometer does not give warning of approaching tropical cyclones far in advance of the center, as previously believed. Instead, the pressure decreases slowly, as it does in various other situations, until well within the storm where it then drops very rapidly, reaching a minimum in the eye. In figure 54, the barograph trace is superimposed on the diagram of the storm. Notice that if the ship is guided by barometric readings only, it is well within the storm area before the significant drop in pressure occurs.

Movement

In general, tropical cyclones move around the outer periphery, or edge, of the subtropical high-pressure areas on the equatorward side. At first, this direction is usually westerly, recurving to northwest, north, and then northeast on the western side of these subtropical highs (in the Northern Hemisphere). The paths of these storms can, and often do, vary considerably. One storm may follow an expected path, while the movement of another storm may be very erratic. In certain cases, these storms have been known to make leaps in their paths of motion. In other cases, a storm has split, and two separate storms have moved off in separate paths.

The average speed of movement of these storms is about 11 knots before recurving and about 16 knots after recurving.

Sea Condition

Tidal waves may be associated with tropical cyclones when the slope of the ocean bed and the contour of the coastline are favorable. In the Northern Hemisphere the most disastrous tidal waves occur where there is a gentle sloping ocean bed and a bay to the right of the path of motion of the storm.

A well-known sign of an approaching tropical cyclone in the open sea is the long, low, heavy swell that travels far in advance of the storm. This heavy swell is often observed as much as 1,000 miles in advance of the center of the storm. The wind waves and sea that are found within the storm are usually mountainous, but are fairly regular as far as direction is concerned. The wave directions are usually only at a slight angle to the wind direction in the body of the storm. Within the eye, the wave height is still mountainous; but the wave direction is totally confused, making for a particularly hazardous navigation problem. Wave heights being equal, the most dangerous waters for a ship are those where the wave direction is confused.

STRUCTURE

In horizontal extent, tropical cyclones are very similar to the extratropical lows found in the Temperate Zone. Tropical cyclones may be found on a surface synoptic chart enclosed in an isobaric pattern that is almost round in the case of slowly moving storms and extremely oblong in the case of rapidly moving storms. The winds and weather that occur in connection with these storms are seldom symmetrical; that is, they are frequently more violent in one sector than in another. For this reason, these storms have been divided into two parts—the right semicircle and the left semicircle. These semicircles are designated with respect to the direction in which the storm is moving. For example, if a tropical cyclone is moving westward, the northern semicircle is the right semicircle.

Right Semicircle

The right semicircle is frequently referred to as the dangerous semicircle. The winds blow in the same general direction in which the whole storm is moving; therefore, the force of the wind is increased by the speed of the storm itself. The right front quadrant is the most dangerous quadrant in the storm.

Left Semicircle

The left semicircle is frequently referred to as the safe or navigable semicircle. In this sector the winds blow in a direction roughly opposite to the storm's motion. Do not be fooled by the term "safe." All sectors of tropical cyclones are extremely dangerous. Safe, in this case, simply means less dangerous than the right semicircle. The lower left rear quadrant of the storm is usually the least dangerous.

Vertical Extent

A tropical cyclone is constructed of very heavy masses of clouds that may extend as high as the tropopause.

CLIMATOLOGICAL DATA

Tropical cyclones (Northern Hemisphere) occur most frequently during the summer months. The months of greatest frequency in the western North Pacific are July, August, September, and October. In the southern North Atlantic the greatest frequency is during August, September, and October. (See figure 55.)

The western North Pacific tropical cyclones (typhoons) surpass the tropical cyclones of the Atlantic in number and intensity.

During June the tropical cyclones (hurricanes) of the Atlantic seem to originate mostly in the western Caribbean; during July, August, and September the majority of them form in the Cape Verde area. The principal originating area is again in the Caribbean during October and November.

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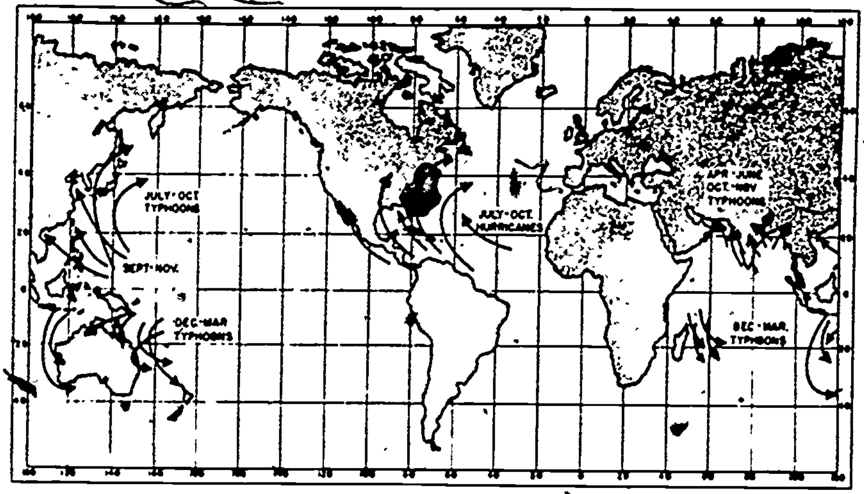


Figure 55.— Typical hurricane/typhoon tracks.

Generally speaking, the tropical cyclone season in the Northern Hemisphere is from May to November, with the greatest frequency during September and October.

No tropical cyclones have even been reported in the eastern South Pacific and the South Atlantic.

TRACKING

Since tropical cyclones are among the severest of all storms and cause such extensive damage to personnel and property, each tropical cyclone must be closely observed and tracked, and all possible precautions taken to safeguard personnel and equipment.

There are several methods by which tropical disturbances (and the following stages of their development) are tracked. At strategic locations, aircraft squadrons of the Air Force and the Navy are assigned to weather reconnaissance duty. They penetrate the storm at various levels and determine the storm's intensity, location, and direction of movement.

The storms can be tracked by radar, using methods similar to those used for tracking thunderstorms. A storm is apparent on a PPI scope as a huge mass of cloud echoes, far more intense and covering a much greater area than echoes from other weather phenomena. When the storm appears on the radarscope, the cloud echoes sweep around in concentric circles or tight spirals. (See figure 56.)

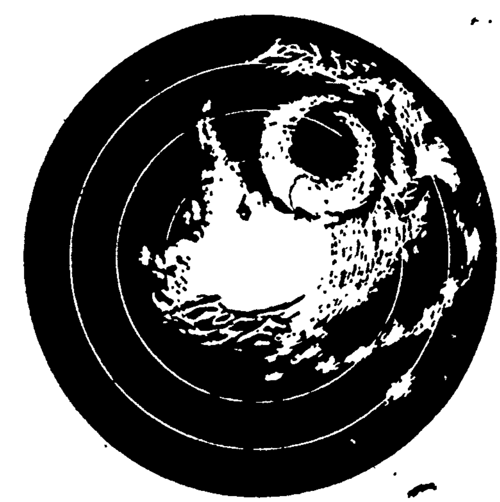

Figure 56.— Hurricane as represented on a radarscope.

More recently, the Navy and the National Weather Service have used some automatic weather buoys in tropical ocean areas. There are several types of these automatic weather stations. Some of them are expendable and some are permanent installations anchored to the ocean floor. These automatic weather stations furnish weather reports from parts of the oceans where weather reports are sparse. These automatic weather



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stations make early detection of tropical cyclones in the formative stage easier through analysis of their transmissions.

## EMERGENCY WEATHER WARNINGS

In the previous portions of this section, you have learned how various hazardous and destructive weather phenomena develop. It was noted that a tornado may affect only a small area, whereas a mature tropical cyclone covers many hundreds of square miles. These weather phenomena, regardless of their size, are a continued and potential threat to ships, aircraft, and stations in their path. Extensive material damage and personnel injuries may result from flying objects, sustained high winds, gusty winds, hail, and lightning. For this reason, it is of the utmost importance that timely and accurate warnings be issued, so that the proper condition of readiness may be set.

The procedures for forecasting and issuing destructive weather warnings are beyond the scope of this pamphlet but it is necessary for Marine Science Technicians to have an understanding and knowledge of the terminology and criteria used for various wind warnings and conditions of readiness.

### WIND WARNINGS

Warnings of winds associated with closed cyclonic circulations of tropical origin were discussed in this section under tropical cyclones. Warnings of winds associated with weather systems located in latitudes outside tropical regions, or by systems of tropical origin other than closed cyclonic circulations, are expressed in the following terms:

1. SMALL CRAFT WARNING.— This term is used to indicate winds up to 33 knots (used in coastal and inland waters only).

2. GALE WARNING.— This term is used to indicate winds between 34 and 47 knots.

3. STORM WARNING.— This term is used to indicate winds of 48 knots or greater.

### CONDITIONS OF READINESS

With approaching destructive force winds, it becomes necessary to take precautions to avoid or minimize loss and damage to material and injury to personnel. The precautionary action to be taken is dictated by the proximity of the destructive force winds. The CONDITION OF READINESS indicates the distance in time from the ship or station of the possible threat of destructive force winds. These conditions of readiness are as follows:

1. Gale/Storm/Hurricane (Typhoon) Condition IV.

Trend indicates a possible threat of destructive winds of force indicated within 72 hours.

2. Gale/Storm/Hurricane (Typhoon) Condition III.

Trend indicates a possible threat of destructive winds of force indicated within 48 hours.

3. Thunderstorm / Tornado / Gale / Storm / Hurricane (Typhoon) Condition II.

Destructive winds of force indicated are anticipated within 24 hours or, in the case of thunderstorms or tornadoes, are reported or expected in the general area.

4. Thunderstorm / Tornado / Gale / Storm / Hurricane (Typhoon) Condition I.

Destructive winds of force indicated are imminent.

### COASTAL WARNING DISPLAYS

To supplement written and broadcasted military and National Weather Service warnings, a simplified system of coastal displays has been put into effect. These display signals, as shown in figure 57, are as follows:

1. SMALL CRAFT WARNING.— One red pennant displayed by day and a red light over a white light at night to indicate winds up to 33 knots and/or sea conditions dangerous to small craft operations are forecast for the area.

2. GALE WARNING.— Two red pennants displayed by day and a white light above a red light at night to indicate winds ranging from 34 to 47 knots are forecast for the area.

3. STORM WARNING.— A single square red flag with a black center displayed during daytime and two red lights at night to indicate winds ranging from 48 to 63 knots are forecast for the area.

4. HURRICANE WARNING.— Two square red flags with black centers displayed by day and a white light between two red lights at night to indicate that winds of 64 knots and above are forecast for the area.

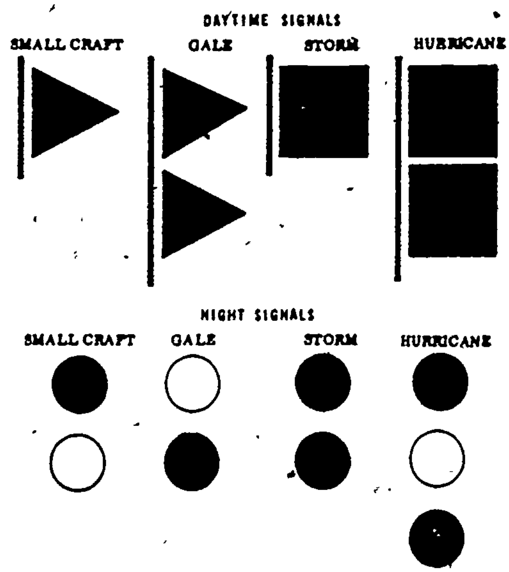


Figure 57.— Coastal warning displays.

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# INSTRUMENTS

# AND

# EQUIPMENT

A correspondence course pamphlet consisting of original material developed at the Coast Guard Institute and excerpts from:

| | |
|---|---|
| Aerographer's Mate 3 & 2 | NAVPERS 10363-C |
| Aerographer's Mate 1 & C | NAVPERS 10362-A |
| Instruction Manual for Obtaining Oceanograhic Data | N.O. Pub. 607 |
| Naval Ships Technical Manual | 9280 Section |
| Teletypewriter Equipment and Operation | NAVPERS 10228-D |
| Manual for Oceanographic Operations | CG 410 |
| STD Instruction Manual | 9040 Model |
| Salinometer Instruction Manual | 6220 Model |

U.S. COAST GUARD INSTITUTE
OKLAHOMA CITY, OKLAHOMA

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PAMPHLET NO. 463

TABLE OF CONTENTS



WARNING

THE MATERIAL IN THIS PAMPHLET IS FOR TRAINING ONLY. IT SHOULD NEVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, OR OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. ALWAYS CHECK THE LATEST DIRECTIVES AND PUBLICATIONS ON THE JOB.

# WEATHER OBSERVATIONAL EQUIPMENT AND INSTRUMENTS

The purpose of this section is to discuss weather observational equipment used to measure temperature, pressure, wind, and precipitation. Many of these instruments are already familiar to you as a Marine Science Technician. Our specific purpose is to describe these instruments and how they operate and to explain how you should maintain them.

## STANDARD AIR THERMOMETER

Liquid-in-glass thermometers are the type used as standard air thermometers. The standard air thermometer consists of a small glass tube terminating in a bulb filled with a suitable thermometric fluid (figure 1). Since mercury and alcohol have a much greater coefficient of expansion for each degree change in temperature than the glass of the thermometer tube or bulb, either is an excellent thermometric fluid. As the fluid contracts or expands in volume with changing temperatures, the fluid column within the glass bore of the tube falls or rises. The changing height of the column is a measure or indication of the temperature changes to which the thermometer is exposed. If the height of the column is read against a suitable temperature scale engraved on the tube, the thermometer can be used to indicate temperature values at the instant of observation. The range of the standard air thermometer is from -20° F to +120° F.

Handle the standard air thermometer carefully to avoid breakage of the glass tube which contains the thermometric fluid. It is important that you keep the thermometer stem and bulb clean and free of dirt, dust, and salt spray. Clean the stem and bulb by wiping with a soft cloth.

During rains or snows accompanied by high winds, the thermometer may become wet. The presence of moisture on the dry bulb causes an erroneous indication of the free air temperature. If you observe moisture on the bulb, wipe it off carefully 10 to 15 minutes before taking a reading.

The metal back upon which the thermometer is mounted at times becomes tarnished. Remove and clean the metal at least once every 3 months, or more often if necessary. Under no condition should you use an abrasive as the cleaning agent. Clean the metal back with a soft cloth soaked in a solution of bicarbonate of soda. Wash and dry the back thoroughly after cleaning. Upon reassembly, apply a drop of light oil to the brass mounting screws.

Frequently, the black pigment in the etched graduations on the scale becomes worn and makes reading difficult. To renew the etchings, remove the thermometer from the metal back, carefully clean and dry the thermometer tube, then rub the

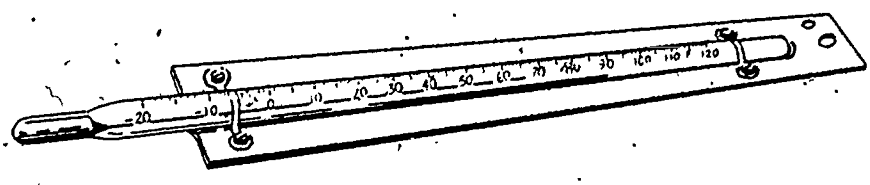


Figure 1.— Standard air thermometer.

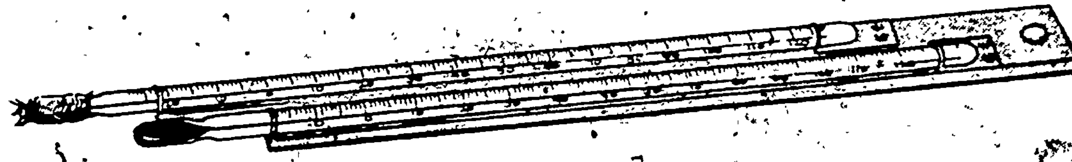


Figure 2.— Standard psychrometer.

stem or back (as the case may be) with a soft cloth saturated with a mixture of ivory black or lampblack, and varnish until the graduations are readable. Remove excess pigment by rubbing the parts of the thermometer lightly with a piece of tissue paper.

If the mercury column in the thermometer becomes separated, attach a psychrometer sling to the metal backing of the thermometer and whirl. If the whirling has no effect, tap the bulb of the thermometer against the heel of the fleshy part of the hand. The slight jarring effect should reunite the mercury column. If this fails, heat the bulb of the thermometer tube gently by placing it near a light bulb. The heating forces the liquid into the top of the tube until the entire column is united. Leave a small space at the top of the tube while heating; otherwise, the thermometer will break. Never attempt to reunite the mercury by heating the bulb over an open flame. If all methods fail to reunite the column, replace the thermometer.

Since mercury freezes at -39° F and becomes sluggish at -35° F, after -35° F a standard air thermometer no longer indicates accurate air temperatures. For this reason, an alcohol standard air thermometer should be substituted for the mercury air thermometer when the temperature is expected to fall to and go below -35° F.

## THE SLING PSYCHROMETER

A psychrometer has as its basic construction two standard mercury-in-glass thermometers, identical with the air thermometer, secured as a unit to a metal back or support. The two thermometers of a psychrometric unit (figure 2) are alike, with one bulb mounted an inch and a half lower than the other. The upper bulb is termed the dry bulb; the lower, the wet bulb (covered by a woven muslin wick secured above and below the bulb with a strong thread). The primary objective is to obtain the temperature readings of the dry-bulb and the wet-bulb thermometers, and then calculate the difference between the two readings. The difference is called the depression of the wet bulb, which is used to find relative humidity, dewpoint, and vapor pressure. Observations are interpreted by consulting appropriate psychrometric tables or computers.

The standard psychrometer, when used as a portable handwhirled instrument, is termed a SLING psychrometer, shown in figure 3. The sling consists of a wooden grip, with a swivel head and harness type snap or spring clip for attaching to the top hole of the psychrometer frame.

When not in use, the sling psychrometer should be hung on a suitable hook in a secure position in the instrument shelter.

For a check on humidity, remove the psychrometer from the instrument shelter and take it to a clear and open place, preferably exposed to the wind. Never touch the bulb or stem in handling or expose it to the direct rays of the sun while making an observation. Moisten the wick of the wet-bulb thermometer with clean water at the time you make an observation. Stand in a clear shady place facing into the wind and hold the psychrometer as far in front of the body as possible. Rotate the psychrometer with the wrist. For the best results, whirling should produce airflow of not less than 15 feet per second. Bring the psychrometer to a stop without any sharp jar and bring to eye level. Then read both thermometers to the nearest tenth of a degree, reading the WET-BULB thermometer FIRST. Repeat the whirling and make other readings until two successive wet-bulb readings are the same.

If, however, the temperature is high and the relative humidity is low, or it is expected that the final temperature of the wet bulb will be 32° F or less, moisten the wet bulb thoroughly several minutes before taking a reading so that a drop of water will have formed on the end of the bulb. This reduces the temperature of the wet bulb

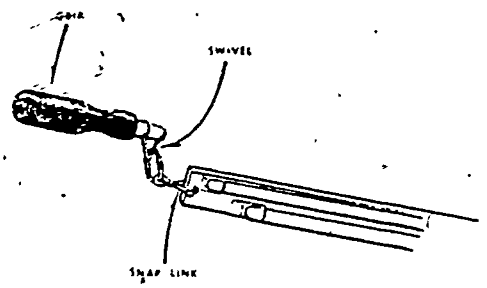



Figure 3.— Sling attachment.

without danger of the wick drying out before the temperature reaches its lowest point. In areas where the temperature is high and the humidity low, use precooled water for moistening the wet bulb to avert premature drying of the wick. Water can be precooled for this purpose by storing it in a porous jug.

Replace the wick on the psychrometer's wet-bulb thermometer at least once a month and more often when local atmospheric conditions cause a rapid collection of dirt and foreign matter on the wick. Psychrometers used on board ship collect salt very rapidly, and daily replacement of the wick may be necessary to obtain accurate readings.

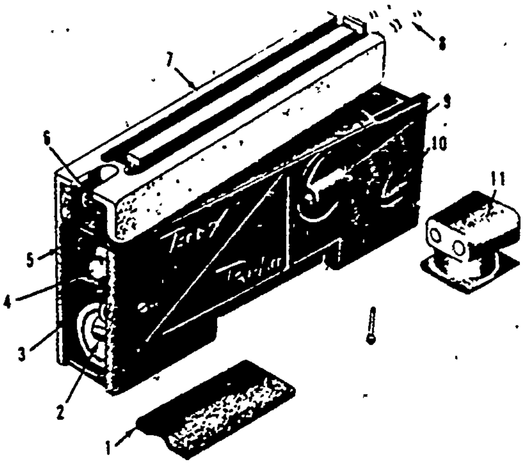
The stainless steel metal back upon which the thermometers are mounted should be cleaned at least once every 3 months, or more often if necessary. Excess lubricant, dirt, and other foreign matter should be removed from the psychrometer sling at least once a month.

Once each month, place one or two drops of MIL-O-6085 oil on the sling psychrometer swivel link. Do not overlubricate.

HAND ELECTRIC PSYCHROMETER (ML-450A/UM)

The hand electric psychrometer (ML-450A/UM) is a portable instrument used to obtain free air temperature and the wet-bulb temperature. (See figure 4.)

Although the psychrometer is constructed primarily of noncorrodible materials, prolonged exposure to weathering, salt air, stack gases, and other corrosive elements shorten the useful life of the instrument. The instrument should therefore be sheltered when not in actual use.




1. Sliding door.
2. Spring contact.
3. Battery compartment.
4. Water bottle.
5. Bottle compartment.
6. Hinge pin.
7. Thermometer holder.
8. Wet-bulb wick.
9. Knob.
10. Exhaust ports.
11. Sliding air intake.

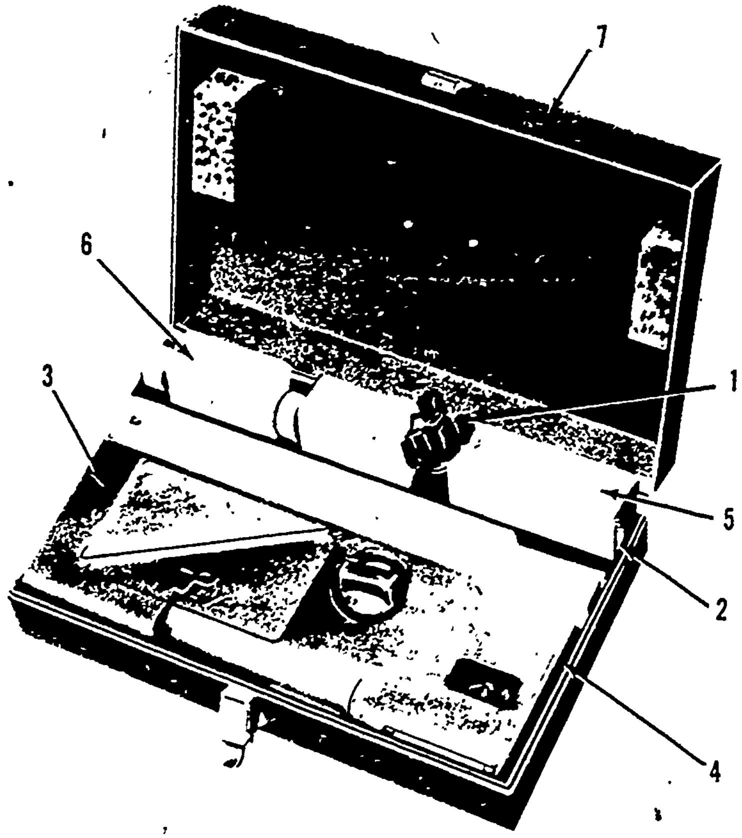
Figure 4.— Hand Electric Psychrometer (ML-450A/UM)

The two thermometers comprising the psychrometer have a range from plus 10° F to plus 110° F. The psychrometer comes with a carrying case and three water bottles. With the exception of the three standard flashlight batteries which supply the power, it is ready for operation as issued. (See figure 5.)

The electric hand psychrometer (ML-450A/UM) requires very little maintenance. For proper operation, keep the instrument free of dirt and other foreign matter.

When the instrument is not to be used for a prolonged period of time, remove the batteries from the case because batteries will corrode and damage the instrument.

When cleaning the instrument, wash all plastic parts with a mild soap and warm water; rinse with clear water and dry. Wash the thermometers with a mild soap and warm water; rinse with clear water and dry. Wipe electrical contacts with a clean lint-free cloth. If necessary, use fine sandpaper to remove corrosion




1. Neck strap.
2. Spare thermometers.
3. Psychrometer.
4. Instructions and tables.
5. Box (extra wick, thread, and lamp).
6. Two-ounce bottle.
7. Carrying case.

Figure 5.— Hand Electric Psychrometer in carrying case.

or pitting. No lubrication is necessary for this instrument; no special tools are required for its overhaul.

Batteries

Three size-D (standard flashlight) dry cell batteries are required. To insert the batteries, remove the sliding door at the end of the case and rotate the spring contact from the battery compartment to the bottle compartment. Insert the batteries with a minimum of inclination of the instrument from the horizontal to avoid distortion of the contact at the far end of the compartment. Insert the batteries so that the center contact enters the compartment first. After the batteries are in place, rotate the spring contact to its original position on the end battery and replace the sliding door.

Replacing the Wick

To replace the wick, first remove the sliding air intake exposing the thermometer bulbs. Then remove the wick. Slip a length of wicking over the bulb. Secure it at the top of the bulb with a thread at the constriction between the bulb and the stem, using a loop and square knot. Form a loop in a second thread and place it at about the middle of the bulb, stretching the wick firmly and snugly against the bulb. Tie with a double loop and square knot. Clip the ends of the thread and cut off the excess wicking about one-eight inch below the bottom of the bulb.

Removing and Replacing Thermometers

If either thermometer is damaged, it is necessary to remove both thermometers and replace them with a matched pair. To remove and replace the thermometers, first remove the air intake and the thermometer retainers. Then lift out the thermometers. After this, remove the rubber bushings from the bulb ends of the thermometers and the bushings from the other ends of the thermometers.

Place the longer bushings on the bulb end of the new thermometers so that they are flush with the end of the thermometer holder. This seals the small holes in the air intake when it is slid into position.

CAUTION: Position the rubber bushings on the thermometer so that the retaining clamps rest on them. Otherwise, the pressure of the retaining clamps may break the thermometers.

Replace the thermometers, positioning them so that the graduations are visible and so that both mercury columns are magnified when viewed from the same position. Replace and tighten the thermometer retaining clamps.

Reuniting the Mercury Column

If the mercury column of either thermometer separates, make an effort to reunite the mercury column. To do this, remove the thermometer as described earlier. Gently heat the thermometer bulb under a light bulb to gradually force the mercury to the top of the tube. Care must be taken so that the mercury does not cause the thermometer to burst. Upon cooling, the mercury should recede as a united column.

Replacement of Lamp

To replace a lamp, first remove the sliding air intake and retaining screw that keeps the thermometer holder in the correct position. Then raise the unrestrained end of the thermometer holder upward to provide access to the lamp. Finally, remove the red filter and change lamps, replace the filter, secure the thermometer holder, and replace the air intake.

Inspections

Inspect for cracks or breaks in the plastic parts. Inspect threaded holes and screws for wear and inspect the fan for damage. Inspect the thermometers for cracks and separated mercury columns. Inspect the carrying case for damage, and the motor shaft for smoothness of rotation.

Repair or Replacement

Replace all plastic parts that are broken, cracked, or have missing or damaged threaded inserts. Replace damaged screws. If the motor shaft does not turn freely or if the fan is damaged, replace the motor and fan assembly. If the contacts on the contact block do not contact the motor terminals correctly, bend them carefully to insure good electrical contact. If one thermometer is broken, replace both thermometers with a new matched set. Also replace a carrying case that is damaged beyond use.

Troubleshooting procedures for the hand electric psychrometer are listed in table 1.

Testing the Psychrometer

To test the psychrometer, first install fresh battery cells. Then turn the control knob on the rheostat-switch in a clockwise direction. The motor should run, causing the fan to draw air into the sliding air intake and force it out of the exhaust ports. If this does not happen, the battery cells are improperly installed. Proper installation of the battery cells should correct the trouble.

As the control knob is turned in the clockwise direction, illumination should increase. If it does not, check the rheostat-switch and lamp. If either is defective, replace it.

## PRESSURE INSTRUMENTS

### ANEROID BAROMETERS

Mercurial barometers are quite accurate, but they are expensive and are not easily transported. For numerous practical purposes, they are replaced or supplemented by a mechanical instrument known as the aneroid barometer. The term "aneroid" means without liquid. The aneroid barometer, then, is a liquidless barometer, utilizing the change in shape of an evacuated

Table 1.— Troubleshooting chart for Psychrometer ML-450A/UM.

| Trouble | Probable cause | Remedy |
|---|---|---|
| Fan does not operate or runs slowly, but lamp lights. | Fan hitting side of case . . .<br>Defective motor or fan loose on shaft. | Loosen fan motor mounting screws and reposition assembly.<br>Replace motor and fan assembly. |
| Motor does not operate or runs slowly; no illumination. | Weak battery cells . . . . . .<br>Battery cells improperly installed.<br>Defective switch . . . . . . . | Replace cells.<br>Install battery cells correctly.<br>Replace rheostat-switch. |
| Illumination not variable, but motor operates. | Defective rheostat-switch . .<br>Defective lamp . . . . . . . . . | Replace rheostat-switch.<br>Replace lamp. |
| Air forced out of intake port. | Battery cells improperly installed. | Install battery cells correctly. |
| Wet-bulb temperature does not stabilize after 2 1/2 minutes. | Weak battery . . . . . . . . . .<br>Defective motor . . . . . . . . .<br>Damaged fan blade . . . . . . | Replace battery.<br>Replace motor and fan assembly.<br>Replace motor and fan assembly. |
| Dry-bulb temperatures of both thermometers do not match (wick removed). | Separated mercury column .<br>Broken thermometer . . . . . | Reunite or replace.<br>Replace with a new matched set. |

metal cell to measure variations in atmospheric pressure.

The aneroid barometer gets its name from the pressure-sensitive element used in the instrument. It is an aneroid, which is a thin-walled metal capsule or cell, sometimes called a diaphragm, that has been either partially or completely evacuated of air. The aneroid is usually made of beryllium copper or phosphor bronze. Most aneroid cells in the currently used aneroid barometers are self-supporting and do not require external or internal springs to prevent the crushing of the cell walls by atmospheric pressure.

In a common type of single aneroid cell barometer, the top of the evacuated cell is secured to a suitable linkage which transmits the motion of the aneroid to an index hand or pointer, which indicates the pressure. (See figure 6.)

Precision Aneroid Barometer (AERO-1936-USN)

This precision aneroid barometer is standard equipment for shore stations.

Of precision design and manufacture, the precision aneroid barometer is constructed to accurately indicate atmospheric pressure in millibars.

The pressure element of the precision aneroid is a Sylphon cell, which consists of a bellow-shaped metal cell having 13 corrugations and an internal spring to provide pressure calibration. This element is sensitive to minute variations in atmospheric pressure. The Sylphon cell is connected to an indicating pointer or index by means of a quadrant gear and lever system in such a manner that the movement of the cell, for a given change in atmospheric pressure, is greatly magnified by the linkage and is transmitted to the index hand or pointer with a minimum of friction in the moving parts. The instrument has a range from 880 to 1,050 mb, and it is accurate to 0.67 mb.

The precision aneroid barometer is compensated for temperature changes; therefore, the indicated readings require no temperature corrections as are required for the mercurial barometer.

Aneroid barometers utilize spring pressure to balance the effect of the air pressure on the

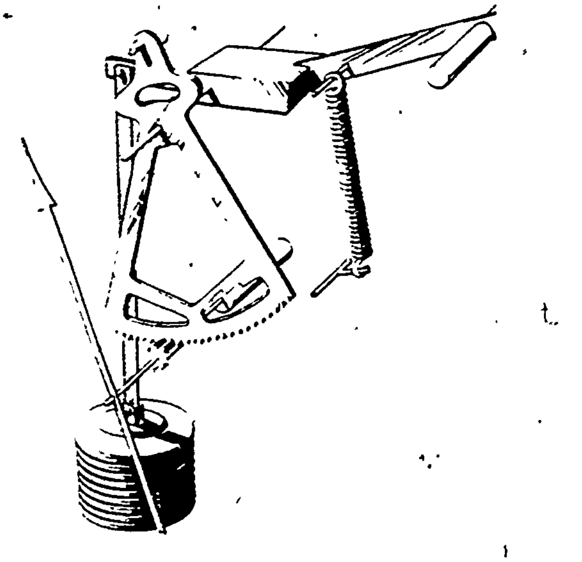


Figure 6.— Simple diagram of the aneroid barometer.

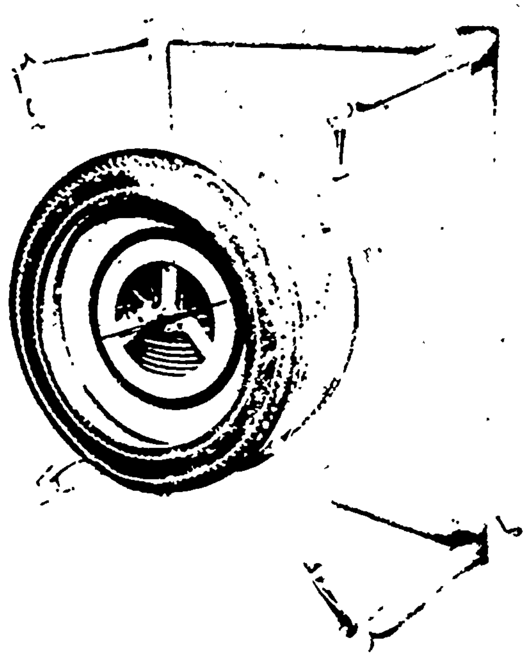


Figure 7.— Precision aneroid barometer (AERO-1936-USN).

Sylphon cell. Therefore, no corrections for effect of latitude (gravity) need be applied.

The pressure element, dial, and linkage are mounted on a sturdy metal frame that, in turn, is shock-spring suspended from the aneroid case. This spring suspension minimizes the effect of jars or shocks that would otherwise affect the linkage and index setting of the barometer.

A screwdriver adjustment, located at the base of the Sylphon cell, is provided to make adjustments to the pressure readings of the instrument.

The precision aneroid barometer, when properly calibrated and set to station pressure, may be used for observational purposes in lieu of the mercurial barometer.

After the precision aneroid barometer is installed in a permanent location, a series of comparative readings are taken. These comparative readings are the differences between the station pressure taken from the aneroid barometer and the station pressure from the mercurial barometer. These differences are logged and the algebraic mean is computed to determine an acceptable instrument correction. This correction is then posted on or near the instrument and applied to subsequent station pressure readings.

When adjusting the setting of the aneroid barometer, use a small screwdriver and remove one-half of the apparent error in reading on the first adjustment. Tap the case lightly to permit the linkage and index hand to settle to the new setting. Obtain a current station pressure from a corrected reading of the mercurial barometer and note the amount of remaining error in the aneroid. Again adjust to remove one-half of the remaining error, tap the case, and allow the hand and linkage to settle. In this manner, a field maintenance technician may adjust a precision aneroid to a correction of zero.

In mounting the aneroid barometer, keep it away from areas where it might be exposed to sudden shocks or rapid thermal changes, but place it in an area easily reached by the observer. Before each reading, tap the case slightly to remove the drag effects of linkage friction. To minimize the effects of vibration on shore stations, and to minimize the effects of pitch, roll, and vibration in ships, shock-mount the precision aneroid barometer. (See figure 7).

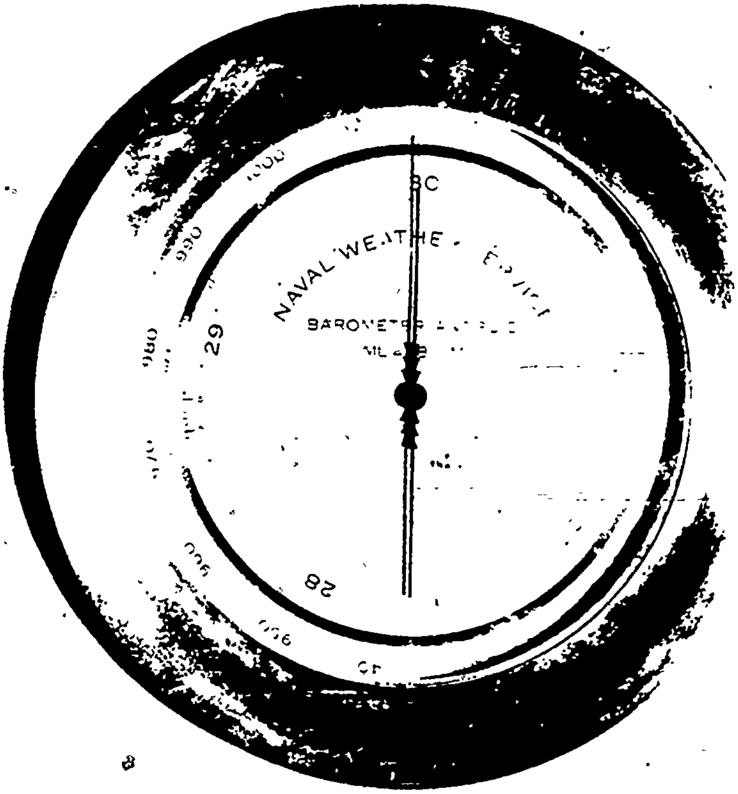


Figure 8.— Precision Aneroid Barometer (ML-448/UM).

Precision Aneroid Barometer (ML-448/UM)

The precision aneroid barometer (ML-448/UM) is used aboard ship and in the Semi-Automatic Meteorological Station AN/GMQ-14(). The principles of operation are identical with those of the precision aneroid barometer (AERO-1936-USN). The only authorized field adjustment to be made on this instrument is the current pressure adjustment. This adjustment is made in the same manner as that for the AERO-1936-USN aneroid barometer. The ML-448/UM (figure 8) has a range of pressure from 910 to 1,060 mb and in the normal range of sea level pressures is accurate to within 0.67 mb. Outside the normal sea level pressure range, it is still accurate to within 1.0 mb.

OPEN-SCALE BAROGRAPH (ML-3)

A barograph is a pressure instrument that is used to obtain a continuous graphic picture of atmospheric pressure. The standard barograph used today is the 4-day open-scale barograph, ML-3 (AERO-1932-USN). It makes a continuous autographic record of the variations in barometric pressure.

The open-scale barograph (sometimes referred to as the MICROBAROGRAPH) (figure 9) is an instrument for the visible recording of minute changes in barometric pressure. Two Sylphon elements (aneroid cells) mounted one above the other in tandem are enclosed in a cylindrical case with a thumbscrew adjustment knob at the top controlling the setting or adjustment of the pressure element and hence, the pen setting. The tandem element magnifies the motion resulting from the expansion or contraction of the Sylphon cells with atmospheric pressure changes. The lever linkage system further magnifies the scale value of the pressure element movement that is transmitted to the pen arm which carries the pen. A continuous record of the pressure is made on a chart which is graduated for every 1-mb change in pressure

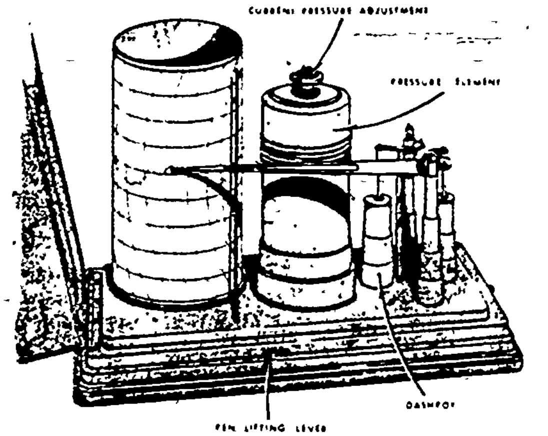



Figure 9.— Open-scale barograph (ML-3).

and can be read fairly accurately to one-tenth of a millibar. The chart is mounted on a drum operated by a high-grade, 8-day clock, geared to produce one chart revolution in 4 days.

The open-scale barograph is sensitive to jars and shocks. Dashpots are used to minimize the effects of jars insofar as possible. The dashpots are two oil-filled cylinders in which a piston in each moves to retart or dampen sudden movements of the pen arm due to shock. The dashpot pistons do not affect the normal variations and changes in the pen arm setting produced by changes in atmospheric pressure.

The microbarograph has a range from 965 to 1,050 mb and an accuracy to within 0.68 mb.

Operation

We shall now describe the following operating procedures: mounting, inking the pens, filling dashpots, winding the clock, changing the chart, time-checking the instrument, making the current-pressure adjustment, and making the time adjustment.

In MOUNTING a microbarograph, observe the same kind of care as that afforded any barometer. Mount it on sponge rubber inside the weather office, near the mercurial barometer, and away from sources of shock or sudden temperature changes. The surface on which the microbarograph is placed should be firm and level.

When INKING the pen, do not fill the pen more than half full. Use the prescribed #10 instrument ink only. This ink is hygroscopic and collects moisture readily; hence, we have the precaution not to fill the pens more than half full. Ink the pen frequently and check the ink at every 6-hourly time check. During periods of high humidity such as rainy or foggy days, the ink may absorb a great deal of moisture and the pen may overrun. When this occurs, take a piece of blotter and very gently absorb the ink from the pen, and replace the ink with a fresh supply. This action assures a neat and legible trace; it also prevents the pen and pen arm from becoming soiled with ink.

Check the DASHPOTS frequently, at least at every chart change. Keep the dashpots filled with dashpot oil to within three-eights inch from the top at all times. Do not fill the dashpots above the specified level, since the pistons may cling to the top of the fluid.

Wind the CLOCK at every chart change, that is, every 4 days. Wind the clock fully, but take care not to overwind it. Although no specified number of turns are given, about 14 half-turns usually suffice. Remember the clock movement is for 8 days, and the chart is changed every 4 days. Underwind rather than overwind.

The CHART CHANGE is made at the standard synoptic hour closest to noon every 4 days beginning with the first day of each month. In making the chart change, make sure that the chart fits snugly around the drum, that the chart is not bent or otherwise mutilated, and that it rests firmly against the bottom of the drum. Make all the correct entries and notations on the chart in accordance with current instructions.

TIME-CHECK the microbarograph at every 6-hourly synoptic observation. If you cannot make

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the time-check at the prescribed time for a particular reason, make it at the next succeeding 3-hourly observation. The time-check mark should consist of a careful upward stroke of the pen arm of about two printed divisions (2 mb) on the chart.

Make the CURRENT PRESSURE ADJUSTMENT whenever the instrument is in error more than 1.5 mb. Adjust the pressure by turning the knurled thumbscrew on top of the case protecting the Sylphon cells, but do not attempt to correct more than half the error at a time. When adjusting the pressure for half the error at a time, tap the instrument lightly after you have turned the screw. Then wait a few minutes and repeat the process until zero correction is attained.

When a TIME ADJUSTMENT is indicated (record trace is in error by more than one-fourth of a chart division), disengage the pen from the chart, lift the drum off the gears, and turn it clockwise so that the time is fast. Then set the drum back into the gear and turn it counterclockwise until the pen tip indicates the correct time. When making this counterclockwise turn, bring the pen very close to the chart, but not quite engaged with the paper. When satisfied that the time is correct, engage the pen. The counterclockwise turning of the drum in this time adjustment takes up the slack in the gears and assures that the time remains correct.

### Maintenance

Only two maintenance functions are permitted on the microbarograph: cleaning and lubrication. Dust the entire instrument with a soft (camel's-hair) brush, being especially careful when dusting the linkage system.

Part of the cleaning function concerns the pen. If the pen fails to make a fine clear line, it may need cleaning or replacing. To remove the pen, shift the pen away from the chart, using the pen shifting lever. Draw the pen from the pen arm by a steady pull in line with the arm. If the pen is not easily removed by a light pull, carefully loosen the prongs that secure it to the pen arm, using a knife edge. The effective pen arm length of 7 5/8 inches must be maintained when the pen is replaced. When removing or replacing the pen, be careful not to bend the pen arm.

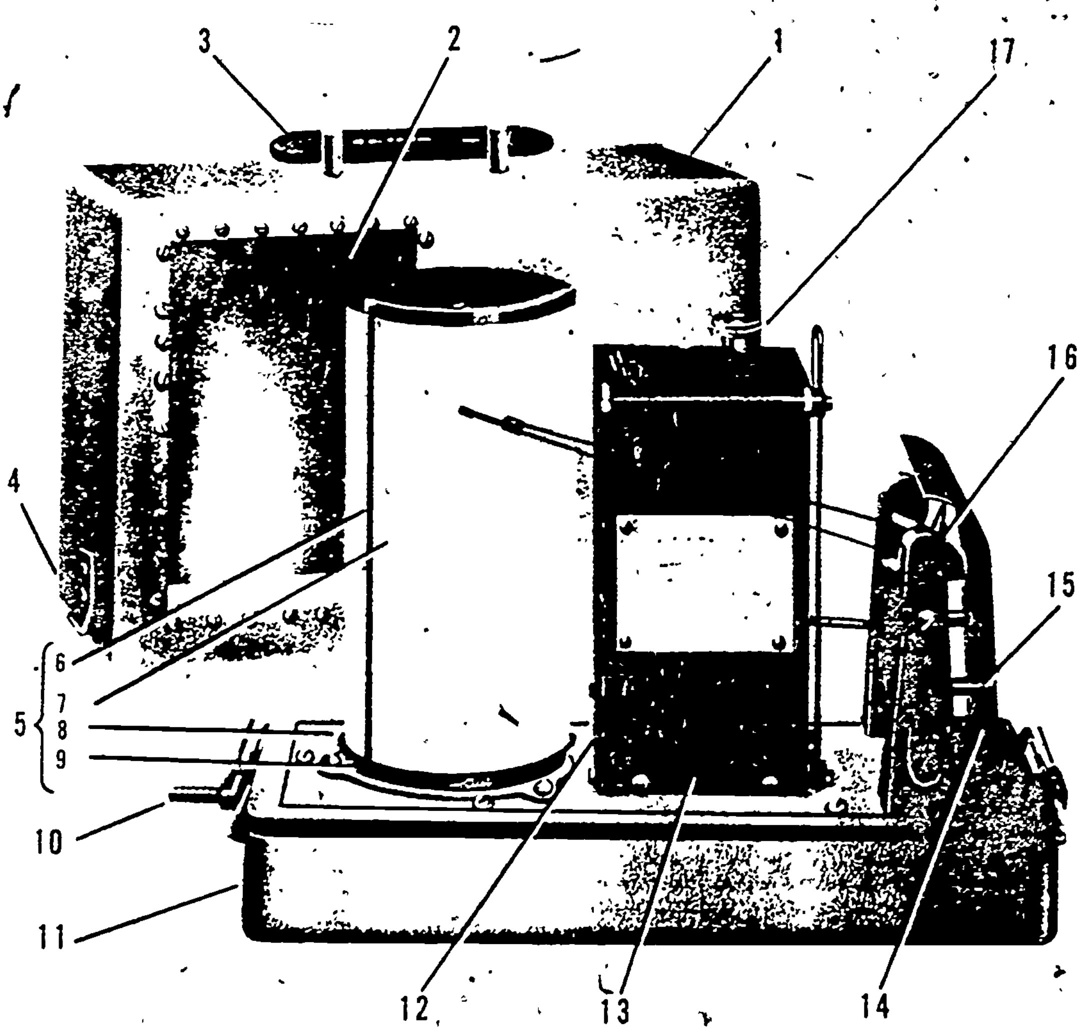
Wash the pen in warm soapy water, rinse it in clear water, and dry. If washing has not removed all the dry ink, soak the pen in the ink (*10 instrument) with which it is normally used, and then wash it as described above.

Lubricate the pivots of the linkage system once every 6 months with one small drop of MIL-L-6085 (clock type) oil. Apply the drop with a toothpick in order to avoid putting too much oil on the parts, and wipe away any excess.

When the instrument shows an erratic correction from one time-check to another, shifting back and forth from a plus correction to a minus correction, notify the supervisor. The instrument is likely defective and needs replacing. When the microbarograph continues to indicate a time error, notify the supervisor. He may desire to make an adjustment with the chart drive gears of the drum. Do not attempt this adjustment yourself, unless you are shown how to make it.

### MARINE BAROGRAPH

The purpose of the marine barograph is to register and record the atmospheric or barometric pressure encountered on board ships at sea. Because of the magnified scale, high sensitivity, and accurate temperature compensation, it is also often referred to as a microbarograph. The instrument is designed to maintain its precision through the varied and exacting conditions encountered in marine use. Its record is neither interrupted nor rendered inaccurate by pitch, roll, or vibration of the ship. An adjustable, grease-filled damping cylinder provides a means of preventing rise and fall of the ship from causing a corresponding wavy trace on this chart. The unit, as seen in figure 10, is quite portable and can record pressure either in its immediate vicinity or at some remote external point while located within a pressurized cabin system. This barograph has a total usable range of 170 mb or TWICE the actual chart width over which the entire range has been calibrated and has been compensated for temperature.




1. Case.
2. Plastic sheet.
3. Handle.
4. Latch.
5. Chart drive assembly.
6. Chart clip.
7. Chart.
8. Chart cylinder.
9. Chart drive mechanism.
10. Hose connector.
11. Base.
12. Element assembly.
13. Element cover.
14. Mechanism shield.
15. Spacer.
16. Pen shaft assembly.
17. Adjustment knob.

Figure 10.— Marine barograph.

The airtight case locks to the base by means of two latches. When it is in place, a flexible rubber tube running to the hose connector from a remote source provides the means by which "topside" readings are recorded independently of the cabin pressure surrounding the instrument.

The marine barograph has three principal sections within the gasketed case: the chart drive assembly, the element assembly, and the pen shaft mechanism assembly. The last two sections are of no interest to the regular user-observer of the instrument.

The chart drive assembly consists of a chart drive mechanism, a chart cylinder, a chart, and a chart clip. The chart drive mechanism is an 8-day, spring-wound clock with antibacklash gears and a self-contained key. The removable cylinder is driven at the rate of one revolution in 108 hours (4 1/2 days) through additional anti-backlash gears. As a result, vibration and shock do not make the chart record irregularly as a result of play in the cylinder drive system. Inside the cylinder top is a knurled nut which permits removal of the cylinder for winding the clock. The 108-hour, 965- to 1,060-mb chart is held in place by a chart clip.

The element assembly, which is covered by the element cover, is the center section. It consists of a pair of vertically mounted bellows whose outboard ends are secured to brackets. These brackets are moved apart or together by the adjustment knob on top for zeroing the pen position. The inboard ends are flexibly connected to a beam which moves as pressure variations affect the bellows. Between the two flexible connections is a temperature compensation device, which is adjusted to correct temperature change errors occurring throughout the element assembly.

The pen shaft mechanism is the right-hand section under the mechanism shield. The shield and its spacers are to protect the mechanism from damage as the case is removed or replaced. The mechanism includes range and linearity adjustments, the damping device, and the temperature compensating lever which compensates for changes in temperature. The damping device is a set of cylinders with a thin layer of special fluid. The damping and spring loading make it possible for the barograph to be subject to tilting up to 22 1/2° in any direction and not vary more than ±0.3 mb from the true reading. Normal accuracy is within ±0.3 mb of true pressure. Also, the instrument may be carried about by its handle without any preparation. If rougher treatment is anticipated, the pen arm should be secured.

## Operation

Daily Use.— This barograph needs very little attention. It records barometric pressure on a 108-hour chart and can be read at any time by interpolation to within one- to two-tenths of a millibar. Be sure the chart heading is filled out before it is removed from the instrument's location.

Winding and Chart Changing.— Every time you change a chart, wind the clock. Approximately 8 pulls of the key is enough. Then reinstall the cylinder and chart. Be sure there is enough ink in the pen nib.

Pen and Ink.— Very little ink is needed; a half-full pen should suffice. In fact, in damp weather the nib may appear to become fuller, because the instrument ink is hygroscopic and absorbs moisture. As this absorption continues, the trace becomes paler because of dilution. Wash and re-ink. A wide trace is caused by dust accumulated on the point or a dull or bent point.

Use Beyond Chart Range.— The normal barograph chart has a range of 965 to 1,060 mb. When approaching any extreme pressure condition which may carry the pen off the chart, turn the adjustment knob to move the pen about 40 mb away from the close edge of the chart. When the condition is passed, reset by the exact same amount and mark the affected portion of the chart accordingly. The total calibrated range is 915 to 1,085 mb.

Plastic Sheet Window.— Use a damp cloth to clean the plastic sheet window in the case. Do not use a solvent cleaner or a dry cloth, as either can damage the plastic pane.

## Maintenance

Very little maintenance is required for the marine barograph. Under normal operating conditions this instrument should be cleaned well once a year. The element cover should be removed only to clean out any bulky dirt, cobwebs, etc. Do not wipe out this mechanism. Check the pen for wear or roughness and replace as necessary. Clean and oil the chart drive mechanism annually. Do not attempt this oiling locally unless you are properly instructed in the method of doing it.

## MERCURIAL BAROMETER (FORTIN)

In 1643 Torricelli, an Italian physicist, made the first crude barometer. The mercurial barometers that are used today operate on the same principle. In the construction of the barometer, a long glass tube, open at one end and closed at the other, is filled with mercury.

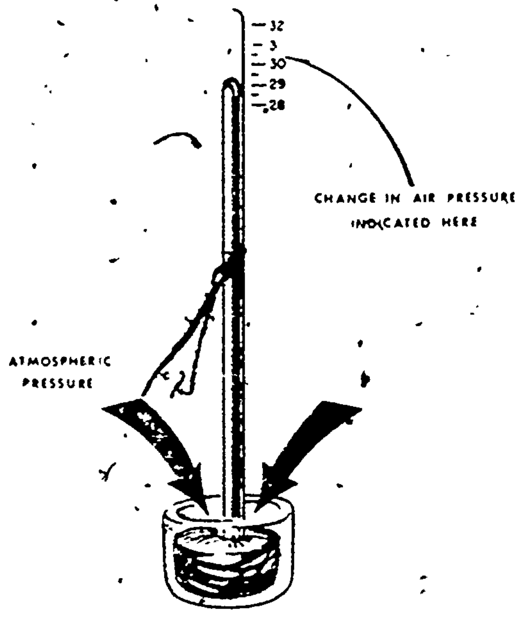



Figure 11.— Principle of the mercurial barometer.

The open end is sealed temporarily and then placed into a basin (cistern) of mercury, after which the end is unsealed. This allows the mercury in the tube to descend, leaving a nearly perfect vacuum at the top of the closed end of the tube.

When the atmospheric pressure is increased, the mercury in the cistern is forced into the glass tube. As the atmospheric pressure is decreased, the mercury in the tube flows into the cistern. The height of the mercury column in the tube is therefore a measure of the air pressure. (See figure 11.)

Description

The mercurial barometer (ML-512/GM) consists principally of a column of mercury in a glass tube enclosed in a brass casing, a mercury cistern, and scales for determining the height of the mercury. (See figure 12.)

Glass Tube and Brass Casing.— The glass tube is 34 to 35 inches long, about 0.25 inch in internal diameter, and clear and free from optical defects. The top of the glass tube is sealed and is filled with mercury except at its upper end (this end is evacuated), and the open

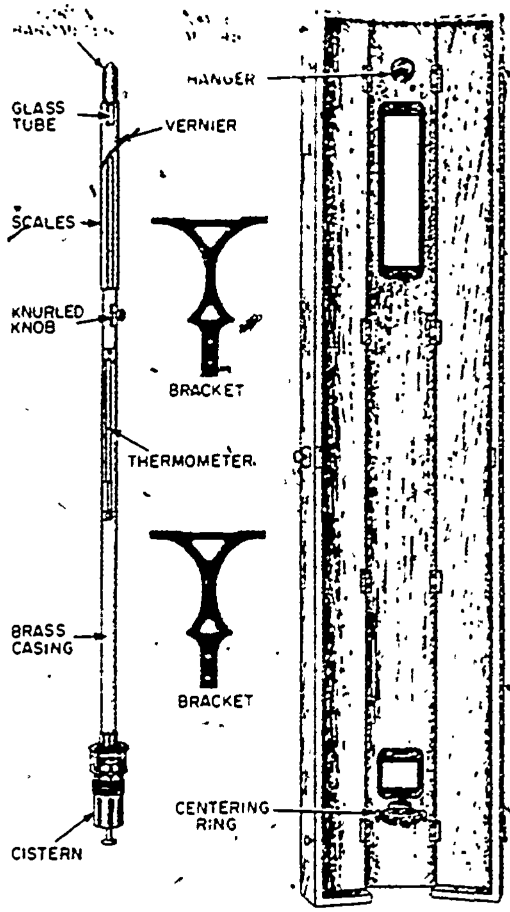
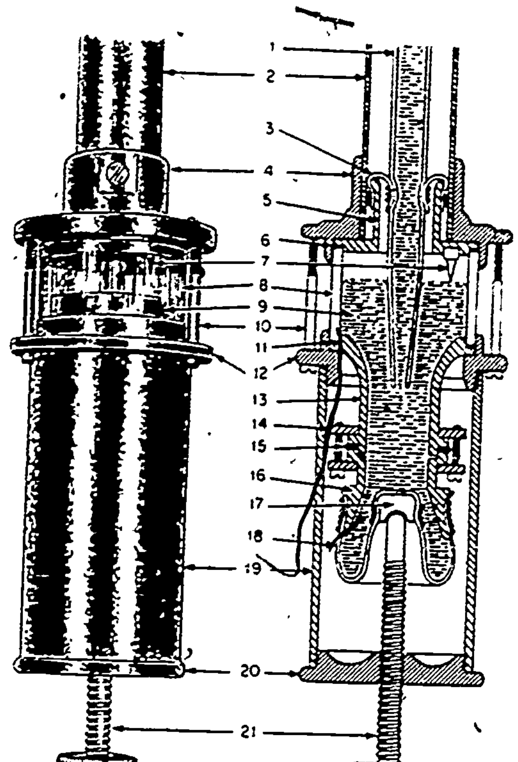



Figure 12.— Fortin mercurial barometer (ML-512/GM) with mounting case, ML-48.

bottom end is immersed in a reservoir of mercury in the cistern.

The glass tube is supported vertically in the center of a tubular brass casing. The top of this casing is provided with a brass swivel ring by which the instrument is supported in use. This brass casing encloses and protects the glass tube, carries the scales by which the height of the mercury column is determined, provides a track for the movable vernier, and provides a mounting base for the thermometer.

The glass tube is joined to the cistern by a piece of soft kid leather which is folded in a special manner, tied securely to the constricted portion of the tube, and then tied to the top of the mercury cistern.




1. Glass tube.
2. Brass casing
3. Leather joint.
4. Top flange.
5. Flanged cylinder.
6. Leather gasket.
7. Ivory point.
8. Glass cylinder.
9. Mercury.
10. Long screws
11. Leather gaskets.
12. Lower flange.
13. Upper curved cylinder.
14. Split-ring clamp.
15. Leather gasket.
16. Lower curved cylinder.
17. Wooden bearing.
18. Leather bag.
19. Cistern housing.
20. Screwcap.
21. Adjusting screw.

Figure 13.— Exterior and cross section view of a Fortin barometer cistern.

Cistern.— The mercury cistern (figure 13) consists of a small flanged boxwood cylinder (5), a short glass cylinder (8), two curved cylinders (13 and 16) made of boxwood, and a kid leather bag (18). The ivory point (7) projects downward from the roof of the cistern. The mercury cistern is enclosed in a metal cistern housing (19) that is closed by a screwcap (20) at the bottom which carries the adjusting screw (21). Prior to each observation, this adjusting screw is used to raise or lower the level of mercury in the cistern so that the ivory point just perceptibly touches the surface of the mercury.

The leather joint and leather bag are porous to air, but impervious to mercury. This permits the cistern air pressure to be identical with that outside, but prevents mercury leakage.

Mounting Case.— The mounting case (ML-48 ( )) is a rectangular box of mahogany or plywood. The cover of this case is split longitudinally through the center and each side is hinged to the back. With the cover open, the barometer is completely exposed, so that all parts are accessible and adjustments can be made easily. A metal hanger inside the case near the top and a centering ring near the bottom provide means for suspending the barometer. Two openings in the back of the case are fitted with white opal glass or heavily pigmented white Plexiglas to facilitate reading the scales and observing the cistern level. Two brackets are provided for mounting the case on a wall, post, or other suitable vertical surfaces.

Scales.— The Fortin barometer has two scales. One is the stationary scale, which allows reading of the barometer to the nearest 0.05 of an inch (also graduated in millibars, but not read). The other is an adjustable scale, called the vernier, which is graduated so as to allow reading the barometer without interpolation to the nearest 0.002 of an inch.

## Maintenance

Preventive maintenance for the Fortin barometer consists largely of cleaning, minor adjustments, and daily inspections. These inspections include checking for cracks in the glass tube or cylinder; damage to the wooden case; loose screws in case brackets, hanger, and centering ring of the case; and condition of the mercury column. If a cracked tube, mercury leakage, or other damage that may affect the accuracy of the instrument is discovered, it becomes necessary to request a replacement barometer and to ship the defective barometer to NAS, Norfolk or NAS, Alameda for overhaul.

The barometer and case should be kept clean by wiping with a soft, clean cloth. Occasionally, the scales may be wiped clean and a thin coat of high grade clock or instrument oil applied. Do not use a commercial polish on the scales or use heavy pressure when wiping them.

The only repairs that may be performed locally are changing a broken thermometer and repairing a damaged wooden case.

MERCURIAL BAROMETER (TONNELOT)

The Tonnelot barometer is comprised of a windowed case and gimbal mount supporting an assembly consisting of the cistern assembly, mercury tube, scale, thermometer, and casing tube. The windowed case protects the instrument and is provided with top and bottom case hangers for mounting the instrument. The gimbal mounting permits the barometer to be extended forward out of the case. The brass casing tube houses the mercury tube and supports the scales, thermometer, vernier slide and adjustment knob, gimbal rings, and cistern assembly.

The operating principle of the Tonnelot barometer is identical to that of the Fortin barometer. The significant difference between the instruments is that the Tonnelot barometer has a fixed cistern, and the Fortin barometer's cistern, as was stated earlier in this section, must be adjusted to the reference point (ivory tip) for each pressure observation.

The Tonnelot barometer is a delicate instrument and is easily damaged, especially during shipment. For this reason the Naval Weather Service has gradually been replacing this barometer with the more durable Fortin barometer.

WIND MEASURING INSTRUMENTS

WIND MEASURING SET (AN/UMQ-5( ))

The wind measuring set (AN/UMQ-5( )) (figure 14) is the standard equipment designed to provide a visual indication and/or printed record of wind direction and speed values. Various options of the system are provided to permit continuous recording of wind direction and speed values at several measuring sites.

Components

A set includes a minimum of one transmitter, one support, and one recorder or indicator. A maximum of six recorders and/or indicators can be used with each transmitter.

Transmitter (ML-400( )/UMQ-5).- The transmitter (figure 14 (A)) is a vane mounted on a vertical suport. The tail of the vane brings the nose into the wind. The nose consists primarily of a screw type impeller directly coupled to a tachometer-magneto. The magneto's voltage output is directly proportional to the wind speed and is connected to the plug in the transmitter's vertical support through brushes and slip rings and then down to the indicator or recorder whose voltmeter automatically indicates or records the voltage in knots. Motion of the vane is transmitted mechanically to a synchro located inside the enlarged section of the vertical support.

The transmitter is placed on top of a connector housing. The electrical cable leading from the housing through the support then goes to any one, or all, of the combination of six repeaters, whether all indicators, or all recorders, or a combination of them. A follower synchro then converts the electrical energy into wind direction indication or recording. The transmitter is designed to carry the six repeaters.

The transmitter vane alines itself to within 3° of the true wind direction when displaced 8° from the true direction of a 4.4-knot wind. The wind speed is accurate to within ± 1.5 knots for winds of 3 knots to 40 knots and ± 3 knots for winds of 40 to 120 knots.

Indicator (ID-300( )/UMQ-5).— The ID-300 ( ) indicator (figure 14 (B)) consists of two units: the panel assembly and the mounting case, which holds the panel assembly. The panel assembly contains the wind direction indicator and the wind speed indicator positioned in two 4-inch dials, the lighting circuits, and the double-range switch for the speed section. The wind direction indicator consists of a synchro follower on whose rotor shaft is mounted a pointer that indicates wind direction values on a 360° circular scale. The dial is graduated at the cardinal and intercardinal compass points as well as every 5° from north. The wind speed indicator is a precision, high-shock type voltmeter whose pointer indicates wind speed in knots on a scale whose ranges are 0 to 60 knots or 0 to 120 knots. The scales are circular about an arc of approximately 270°. Selection of ranges is accomplished by the use of the double-range switch to change the range from 0 to 60 knots to 0 to 120 knots. The lighting circuit consists of a rheostat, transformer, and seven 6-volt dial lights.

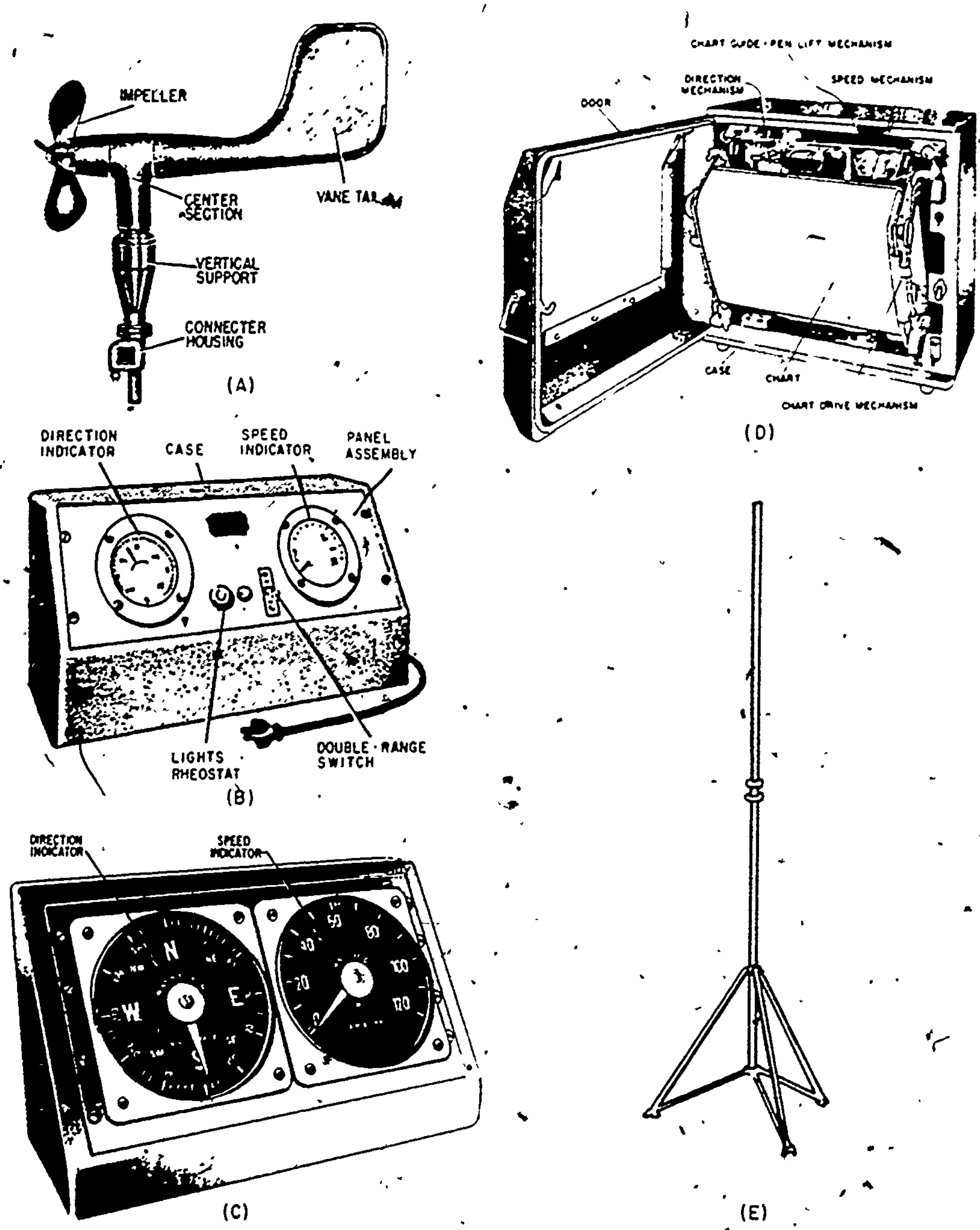



Figure 14.— Wind Measuring Set (AN/UMQ-5( )). (A) Transmitter, (B) Indicator (ID-300( )/UMQ-5), (C) Indicator (ID-586/UMQ-5), (D) Recorder, and (E) Support.

This indicator is accurate to within ± 2° in wind direction and ± 1.2 knots on the 0- to 120-knot wind speed range.

Indicator (ID-586/UMQ-5).—The ID-586 indicator (figure 14 (C)) consists of a speed indicator (voltmeter) and a direction indicator (synchro) mounted on a panel which is inserted in a case. The two indicators position their pointers on 8-inch dials. A six-tapped dummy load resistor is attached to the terminal board mounted in the bottom of the case. No panel lighting or dual-range circuits are installed in this indicator. Each of the indicating assemblies (speed and direction) is removable and may be installed individually.

This indicator is accurate to within ± 2° in wind direction and ± 1.2 knots in wind speed.

NOTE: This indicator may not be used in conjunction with the wind measuring set (AN/UMQ-5D).

Recorder (RD-108( )/UMQ-5).— The RD-108( ) recorder (figure 14 (D)) basically consists of a direction mechanism, speed mechanism, chart drive mechanisn, chart guide-pen lift mechanisms, chart, and case. A description of each is given in the following paragraphs.

The recorder is accurate to within ± 4° in wind direction and ± 1.2 knots in wind speed.

Wind Direction Mechanism: The wind direction mechanism consists of a synchro follower which positions the pen through a gear train which converts 540 wind degrees of synchro rotation to approximately 62° of pen rotation, corresponding to 540 wind degrees of the chart. Whenever wind conditions are such that the pen would run off the chart in recording wind direction, a repositioning mechanism is energized. This mechanism removes power from the synchro, drives the pen to the approximate center of the chart, and then returns power to the synchro so that recording is continued after the pen is displaced 360 wind degrees toward the middle of the chart.

The repositioning mechanism consists of the following:

1. An induction motor mechanically coupled to the synchro-pen gear train.

2. A power control relay which removes power from the synchro stator circuit during repositioning.

3. Limit switches.

4. Two relays which remove power from the synchro motor and control the direction of rotation of the repositioning motor so that the pen is always driven toward the center of the chart when the motor is energized.

The direction inking system consists of the pen and stationary ink tank. The pen is designed to fit into a pen holder attached to the synchro gear train and has a small tube which fits into the ink tank and feeds ink by capillary action to the penpoint, which rests on the chart.

Wind Speed Mechanism: The wind speed mechanism consists of a voltmeter mechanism which drives the wind speed pen across the speed section of the chart. Also included in the speed section is a six-tapped dummy load resistor connected across a terminal board. The pen and inking system of the speed section is identical to that of the direction section.

Chart Drive Mechanism: The chart drive mechanism is a removable, self-contained assembly consisting of a frame and various mounted parts. The assembly contains the chart drive motor, drive gear train, drive roll, idler roll, chart trough, removable take up reel, takeup motor, and hinged panel. Also mounted on the assembly are the speed change gears, chart drive ON-OFF switch, takeup motor microswitch, and the plug through which power is introduced to the mechanism. When the mechanism is seated inside the recorder case and the chart drive switch is in the ON position, the chart drive motor moves the chart across the drive roll and under the pens at a rate determined by the change gears selected. The chart is rerolled on the takeup reel by the takeup motor.

Chart Guide-Pen Lift Mechanism: The chart guide-pen lift mechanism is an assembly which guides the chart across the drive roll, holds the chart drive mechanism in place, and provides a mounting for the illuminating lamps and the direction and speed scales. The assembly is pivoted so that it may be lifted to gain access to the chart drive mechanism and ink tanks and to lift the pens off the chart.

Chart: The strip type chart is divided into two main channels. The right channel is for the recording of wind speed and is graduated every 2 knots from 0 to 120 knots. The left channel is for the recording of wind direction and is graduated every 10° over a 540° range. The entire chart is 100 feet long and 10 3/4 inches wide. Direction letters representing the cardinal compass points (N-E-S-W-N-E-S) are printed above the appropriate numerical direction values. The chart is designed for use with the 3-inches-per-hour chart speed, and the time lines are graduated to 10 minutes and numbered every hour. Holes on either side and in the center of the chart provide positive drive between the chart and the sprocket drive roll. The chart has a running time of approximately 15 days when used on the 3-inches-per-hour chart speed.

The recorder chart speeds are 1 1/2, 3, or 6 inches per hour, depending on the change gears selected.

Case: The case is made of cast aluminum and has a hinged door. The door contains a plastic window large enough for viewing the indication scales, pens, and 7 inches of the past record. It also is provided with a rubber gasket to insure a tight fit when the door is closed. A recess at the bottom rear of the case has connections for the power and intercomponent cables.

Support.— The support (figure 14(E)) is of the tripod type design, having a tubular upright mast and three legs constructed of tubular steel tubing. Each leg is equipped with a mounting foot. The top of the support is provided with a clamp to hold the transmitter securely in place when mounted. Wires may be run through the center of the mast into the transmitter connector housing. The support may be tilted for servicing the transmitter. A guy plate is provided for the attachment of guy wires, if necessary.

Another support is used with the AN/UMQ-5( ) system. It is very similar to the support shown in figure 14 (E), with only minor changes in fittings and provisions for a conduit built into it.

Model Differences.— Transmitters ML-400B and ML-400C are identical to earlier models, except that they are larger in the synchro section to allow for the use of six repeaters.

The ID-586 indicator has no predecessor. The ID-300B and ID-300C indicators are identical with older models with the exception of the resistance strip to allow for the adjustments needed when from one to six repeaters are used.

The RD-108B and RD-108C recorders differ from earlier models primarily in the relay system to allow for the one to six repeaters running from the same transmitter. The recorder that is available with the AN/UMQ-5D has a pen stop arrangement that prevents the pen from catching in the center holes of the chart.

Operation

Installation of Chart Speed Change Gears.— The recorder is equipped with chart drive gears to give a chart speed of 3 inches per hour, which matches the time graduations of the chart supplied. (See figure 15(A).) Change gears to provide a chart speed of 6 inches per hour or 1 1/2 inches per hour are mounted on a stud on the left side plate of the chart drive mechanism. The change gear arrangements given in the equipment handbook show the combination of gears to obtain the different rates of chart speed. To change the rate of chart speed, consult the equipment handbook.

Installation of Chart.— Install the chart according to figure 15 (B). Cut the chart corners as shown in figure 15 (A). Wind several turns of the tapered end around the takeup reel before installing the reel in the chart drive mechanism.

Installation of Chart Drive Mechanism.— Lift up the operation levers (figure 15 (C)). Place the chart drive mechanism in the recorder so that the pivot slots in the mechanism side plates are seated on the pivots mounted in the case. Return the mechanism to its normal operating position. Lower the operation levers over the chart drive roll.

Installation of Ink Tanks and Pens.— Fill both ink tanks about three-fourths full through the pen opening; use the ink and ink tank filler furnished with the recorder as shown in figure 15 (D). Do not use standard writing inks. Keep the bottle tightly capped to prevent dirt from getting into the ink.

Raise the scale plates and insert the ink tanks in the receptacles on top of the speed and

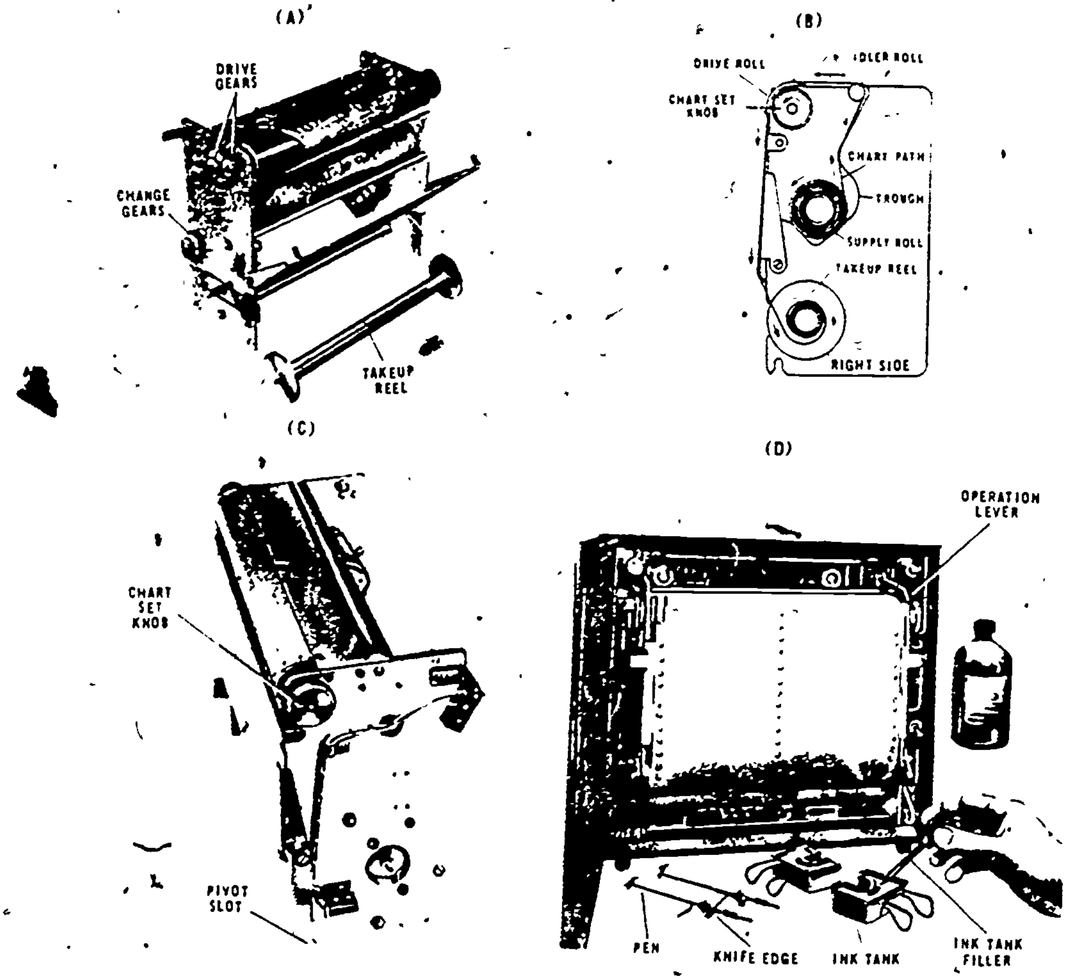



Figure 15.— Recorder RD-108( ) views. (A) Recorder chart drive mechanism (left side view), (B) chart threading diagram, (C) recorder chart drive mechanism (right side view), and (D) filling ink tanks.

direction mechanism assemblies, and see that they are under the spring clips.

Set the pen elements in the pen element forks (penholder) by seating the knife edges of the elements into the slots of the fork.

NOTE: The ink tanks and pens may be installed or removed for servicing when the chart drive mechanism is removed, is tilted forward, or is in its operating position.

Zeroing Speed Pen.— With the chart drive mechanism installed and a chart installed in the drive mechanism, loosen the thumbscrew securing the speed pen zero adjustment lever and adjust the speed pen to read zero on the chart (not the scale). Disconnect the leads from the synchro follower for this adjustment.

Filling Pens.— Fill the pen with the pen filler furnished with the recorder.

First compress the bulb of the pen filler; then lay the flat side of the soft rubber tip on the chart. Insert the penpoint into the hole in the rubber tip and let the filler suck in ink from the ink tank through the pen. The pen feeds from the ink tank by capillary action once it is filled.

Remove the pen element from the filler. The pen should rest lightly on the chart.

Swing the pen across the chart a few times. If it does not write properly, the pen probably has an air bubble in it, in which case the pen filling operation must be repeated.

NOTE: Do not apply power to the recorder when the direction pen is being swung.

Be sure that the pen is properly seated and that it does not rub on the ink tank. Also, check to see that it does not rub on the indication scales and the pen lift bar when they are in their operating positions. The indicating flag above the pen must not touch the scale plate.

NOTE: The pen element is correctly balanced at the factory when full of ink and will stay off the chart until the pen is filled.

Setting Chart to Time.— With the power cable connected and all power switches in the ON position, turn the chart set knob until the correct time line on the chart is under the pens. (See figure 15 (C).)

NOTE: After time setting the chart, do not tilt the chart drive mechanism forward; power supplied to the chart drive motors will be interrupted, thus losing the time setting.

Unrolling Chart for Examination.— To unroll the chart record from the takeup reel while the chart mechanism is operating, grasp the chart on either side, near the takeup reel, and pull the chart from the reel. Be careful to keep the chart straight and taut as it is allowed to rewind on the reel.

Removing Chart from Takeup Reel.— Remove the chart from the takeup reel by first removing the reel from the recorder. Then pull the plain flanged end from the core of the reel. Slide the chart off the core.

Transmitter and Indicators.— The transmitter requires no operating procedures. The only operation necessary for Indicator ID-300 is the adjustment of the light rheostat and switching the range selector switch as desired. Indicator ID-586 requires no operating procedures.

Maintenance

The wind measuring set (AN/UMQ-5( )) is one of the best types of wind equipment in current use. This equipment generally requires very little maintenance. The maintenance of this equipment consists mostly of inspection and lubrication.

Transmitter Maintenance.— Once a week (or more often during severe weather conditions) visually inspect the transmitter for evidence of physical damage, such as broken impeller, rust, and weakened mast. Under normal conditions the equipment should require lubrication every 2 years. However, in subtropic or polar climate the equipment may need lubrication more often.

Indicator Maintenance.— The only service inspection required for the indicators is an observation of their operation to detect erroneous readings or failure of lamps.

Recorder Maintenance.— In recorders, repair or replace only the light bulbs, pens, ink tanks, chart drive motors, and chart drive switches. Replacement of other recorder parts requires the use of overhaul facilities and personnel.

When cleaning the recorder, DO NOT clean electrical parts. Clean the mechanical parts as follows:

Wash exterior painted surfaces and the window with soap and water; rinse and dry thoroughly. Do not wash the inside of the case. Do not clean the windows with a solvent, since minute cracks may result.

Clean the ink tanks by prying off the covers, removing them from the recorder, and washing the parts in warm water. Rinse and dry thoroughly. If washing does not remove all of the dried ink, loosen the remainder by soaking in alcohol; then wash as before. Be sure the vent holes in the cover are open and that the cover is not bent in removing.

Clean the pen element by blowing water or alcohol through it with the pen filler. Loosen clogged ink particles that block the pen by running a fine piano wire through the tube and then cleaning as above.

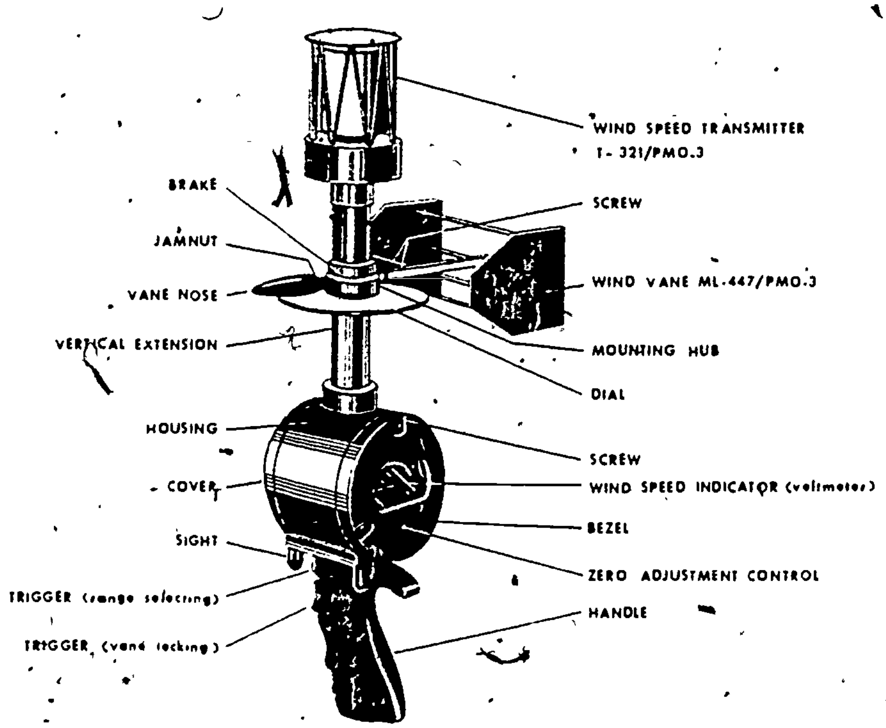



Figure 16.— Wind Measuring Set AN/PMQ-3( ).

Lubricate the recorder every quarter. This interval is established for operation on a 24-hour basis under moderate climatic conditions. Whenever climatic conditions necessitate more frequent intervals for general servicing, shorten the lubrication interval accordingly. Avoid over-lubrication, which is injurious to the recorder. Inspect the equipment after lubrication. Remove all excess oil, as it tends to collect dust or to gum up. Apply oil by dipping a toothpick in the oil and applying it to the surface to be lubricated. Remove excess oil with a clean, lint-free cloth.

The pen elements are properly balanced when they are full of ink, and the balance adjustment should not be changed unless necessary. Whenever rebalancing is required, screw the two balance weights as necessary along the shaft on the rear of the pen to rebalance. The pen balance should be such that when the chart is tapped lightly with one finger, the pen bounces up and down on the chart. A pen pressure that is too heavy on the chart causes the pen to drag toward the center of the chart or noticeably reduces the speed of response of the pen. Accordingly, if maximum response speed is desired, the pen pressure must be no greater than is necessary for satisfactory inking. Handle the pen element carefully; a bent element causes incorrect readings.

WIND MEASURING SET (AN/PMQ-3( ))

Operation

The wind measuring set (AN/PMQ-3,-3A, -3B, and -3C) is a portable hand anemometer which indicates direction to 360° and speed from 0 to 60 knots. The wind, upon striking the small cylindrical turbine (figure 16), causes the turbine to rotate. The turbine is wired to a small electrical generator, which produces a voltage proportional to the speed of the turbine. The voltage is transmitted to the indicator, which is a voltmeter graduated in knots instead of volts. The indicator has 2 scales, graduated

Table 2. Troubles and remedies (wind speed system—AN/PMQ-3( )).

| Trouble | Probable cause | Remedy |
|---|---|---|
| No pointer movement 0-60 range or 0-15 range. | Defective detector . . . . . . .<br>Defective speed indicator . . . | Replace detector<br>Replace indicator. |
| No pointer movement 0-60 range only. | Defective speed indicator . . . | Replace indicator. |
| No pointer movement 0-15 range only. | Defective switch or defective speed indicator. | Connect the terminals of the switch together; if indication is obtained, replace trigger assembly. If no indication is obtained, replace indicator. |
| Pointer does not rest on zero when turbine is stationary. | Speed indicator not properly zeroed. | Turn zero set adjustment located on the front of the indicator. |
| Sluggish pointer movement. | Dirty or damaged speed indicator. | Replace indicator. |

from 0 to 15 knots and from 0 to 60 knots. The upper trigger on the handle controls the scale to be used.

NOTE: On the 3B and 3C models, the range-change switch is a separate toggle switch to prevent inadvertent use of the low scale in high winds with consequent damage to the indicator.

Wind speed indications are accurate within 1 knot in the range of 0 to 10 knots, 1 1/2 knots in the range of 11 to 40 knots, and 2 knots in the range of 41 to 60 knots. The vane alines itself in a 4-knot wind when displaced 5° from the wind direction.

The direction unit is a twin-tailed assembly with a pointer, which faces into the wind. The direction is read from the azimuth plate in whole degrees. To make an accurate direction reading, it is necessary to orient the instrument on a known bearing. The lower trigger is a spring-loaded brake used to lock the rotor on a given setting after exposure to the wind, and is also for convenience in reading.

The equipment is issued ready for use and comes stowed in a carrying case containing a spare wind speed transmitter and a spare wind vane. The instrument should always be replaced in this carrying case after use. Special care should be taken in removing the anemometer from the case and replacing it in the case, because damage may easily result to the wind vane section.

Maintenance

In the care and maintenance of the wind measuring set (AN/PMQ-3( )), no special service tools are needed. In inspecting the equipment, make certain that the turbine and vane are free to rotate and that there is pointer movement when the turbine is rotated. Check for freeness by holding the instrument in its operating position and walking at a moderate rate of speed in an area where there is no air movement. If the vane assumes the correct position and there is a speed indication on both scales, it is probable that the instrument is in a satisfactory condition. If trouble develops in the wind speed system, correct the trouble by replacing a component with another known to be in good condition.

When the wind speed indicator does not indicate "0" when the turbine is stationary, make an adjustment at the zero adjustment control screw (figure 16) to bring the pointer indication exactly to zero. See table 2 for a list of additional maintenance problems and their remedies.

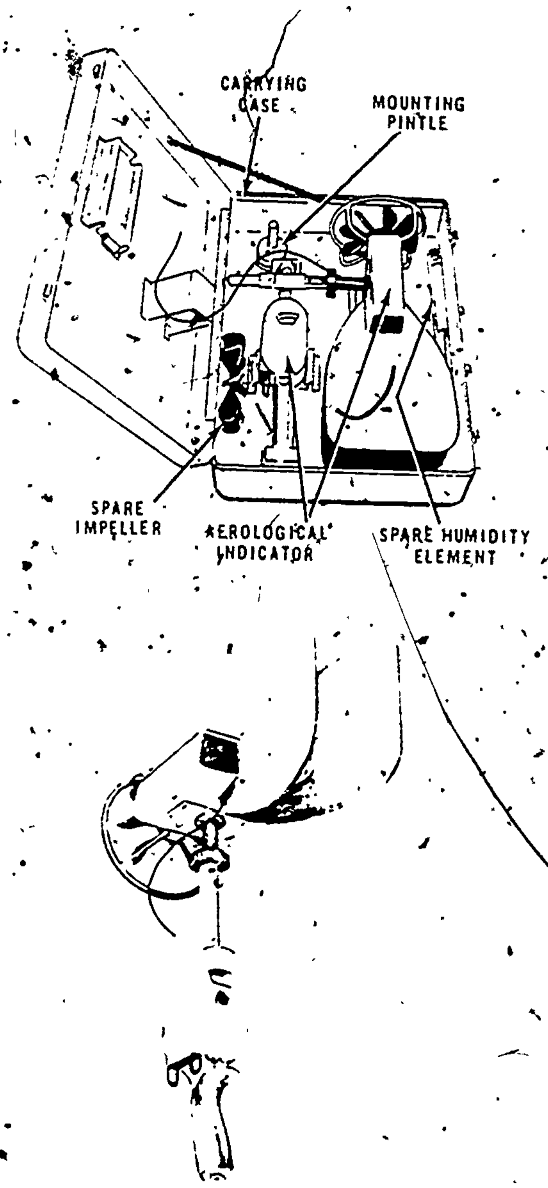



Figure 17.— Meteorological Measuring Set (AN/PMQ-5( )).

No lubrication or cleaning is required by the operator, except that he should lubricate the wind-speed transmitter every 6 months or at any time the turbine appears to be running sluggishly.

Check with your supervisor as to how to lubricate the transmitter; or in the absence of a supervisor, consult the handbook for the instrument.

METEOROLOGICAL MEASURING SET (AN/PMQ-5( ))

The meteorological measuring set (AN/PMQ-5( )) is designed to measure and to indicate atmospheric pressure, temperature, relative humidity, ~~wind~~ direction, and wind speed. The equipment is light in weight and portable and is especially adapted to use under circumstances in which it is exposed for only a few minutes to the weather conditions it is designed to measure. It is equipped with locking devices whereby the measurements are retained for examination and recording at the convenience of the observer. The equipment comes complete with a carrying case. (See figure 17.)

Wind indicating equipment aboard most ships is shown in figure 18. The various components have different locations on different ships.

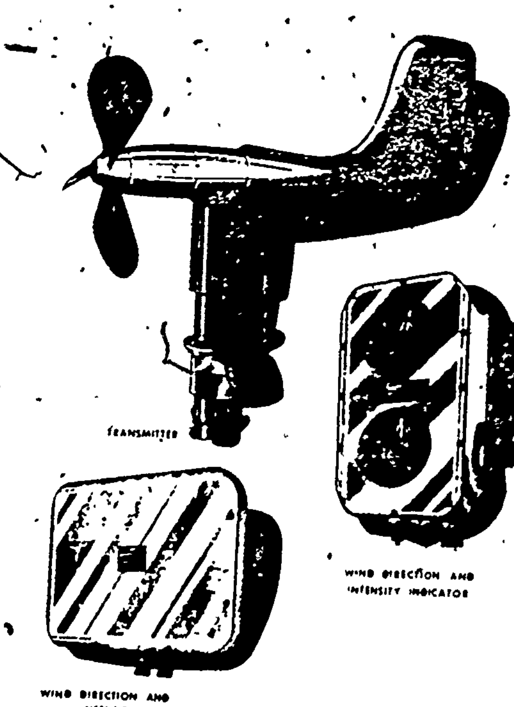



Figure 18.— Shipboard Wind Indicating Equipment.

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## FOUR-INCH RAIN GAGE (ML-217)

Precipitation measurements are made from samples caught in gages or from samples taken from representative areas when the catch of solid forms in the gage is not representative.

The standard meteorological instrument for measuring RAINFALL is the nonrecording plastic rain gage consisting of a 4-inch diameter collector ring and funnel, which fit over the top of a tripod-mounted overflow container, and a clear plastic measuring tube. The rainfall drains from the collector ring through the funnel into the measuring tube, which has graduations in the wall for direct reading to the nearest hundredth of an inch. (See figure 19.)

The depth of water in the tube is determined at the time of each regular 6-hourly observation and at the time of the midnight observation. The tube, when full, holds 1 inch of rainfall. In the event that more than 1 inch falls between the above-mentioned observations, the excess drains into the overflow container. At the next observation, empty the measuring tube and then pour the amount collected in the overflow container into the measuring tube and measure this amount.

The depth measurement of the water equivalent of the SOLID FORMS of precipitation, such as snow, sleet, hail, and freezing rain, is more difficult to obtain. The rain gage can be used, provided the collector ring and measuring tube are removed. The solid forms are collected in the overflow container.

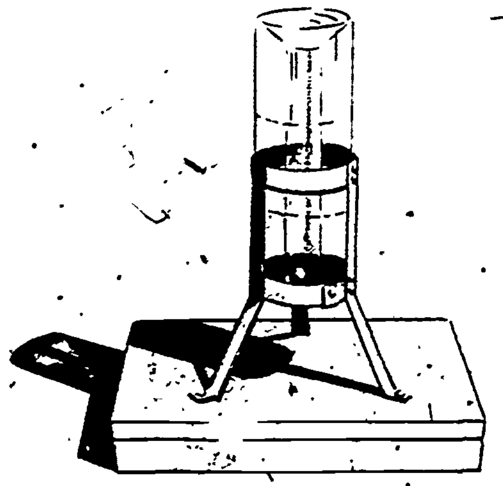

Figure 19.— Standard 4-inch rain gage.

The rain gage probably requires as little maintenance as any other meteorological instrument. About the only maintenance required for the standard 4-inch rain gage is to keep it clean at all times and make sure it is mounted firmly.

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# DECK EQUIPMENT

In this section, we will cover some of the deck equipment associated with oceanographic observations, such as winches, wire rope, the oceanographic platform and A-frame, blocks, counters, and the oceanographic weight. Other equipment, such as bottle racks, wire angle indicator, and related equipment will be covered when we discuss the type of observational program involved.

## WINCHES

In the field of oceanography, there are many different applications for winches of all sizes, but in this course we will restrict our coverage to the winches that are presently used by the Coast Guard.

The Coast Guard uses two basic types of winches for routine observations: bathythermograph and oceanographic. The bathythermograph (BT) winch is used primarily for temperature versus depth observations, but it can also be used for other observational programs that do not place a large strain on the winch or its wire rope, such as small net tows and bottom sampling with the Scoopfish. Newer Coast Guard vessels are equipped with the Electronic Bathythermograph Hoist, Model GEAD-3, manufactured by Skagit Corp., while the older vessels are equipped with the E6/S winch (figure 20). Other BT winches (figure 21) may be in operation, but at the present time these two winches have the widest usage.

The Coast Guard now uses four different oceanographic winches—three models manufactured by Northern Line (figures 22 and 23) and one model manufactured by Jered (figures 24,

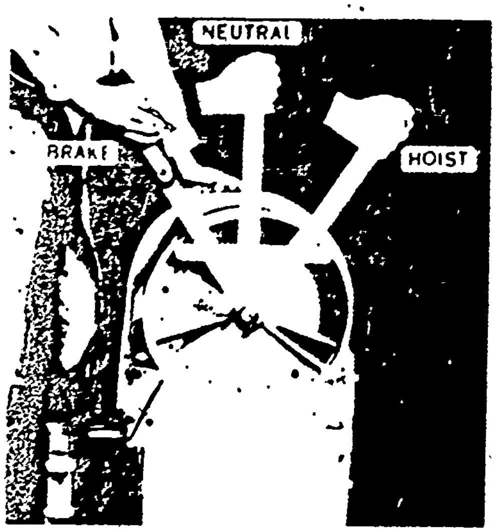


Figure 20.— E6/S BT winch operating positions.

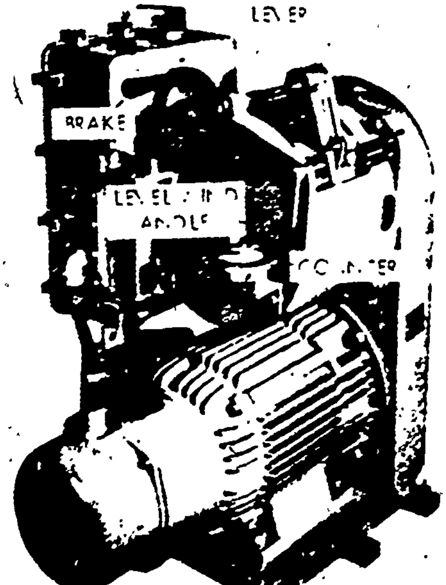

Figure 21.— ACCO Equipment Division BT winch.

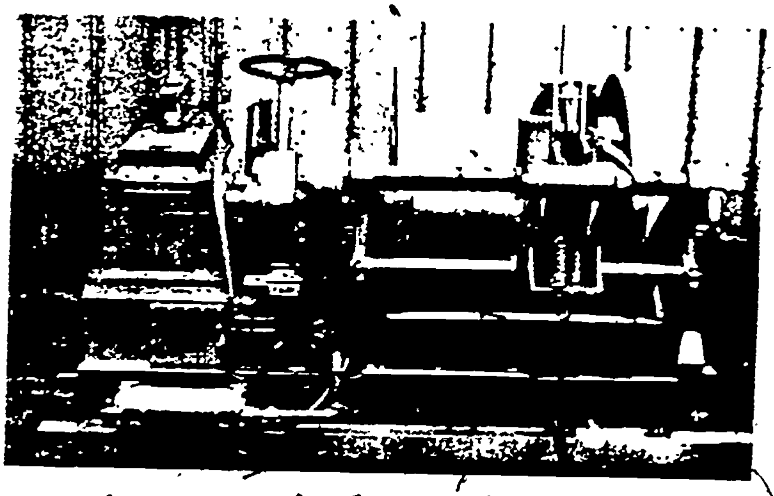

Figure 22.— View of Northern Line winch Model 1210-CGHW Showing Drum and Fairlead.

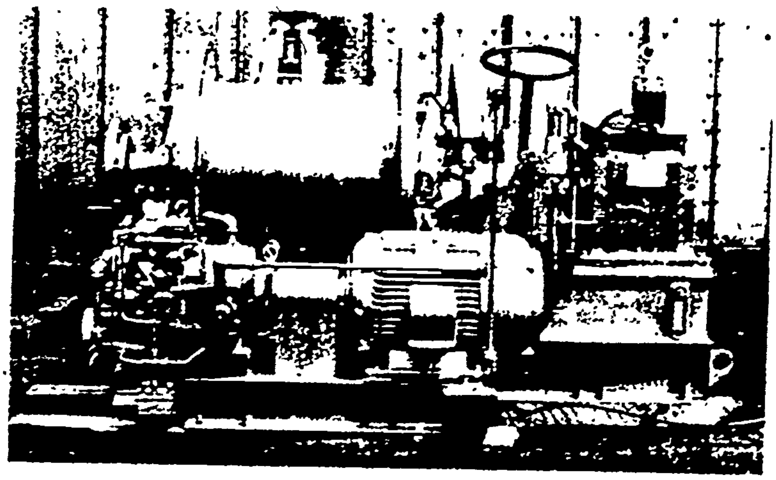

Figure 23.— View of Northern Line winch Model 1210-CGHW Showing Power Unit and Operator's Station.

25, and 26). All four winch models are good winches and will accomplish the job for which they are designed when they are properly operated and maintained.

The proper operation of these winches is a matter of operator's common sense and the individual piece of machinery. By "common sense", we refer to practical judgments about the sea state, type of observation, and the work load, as well as to any other factor that affects the day-to-day operation of the winch. One of the most common causes of winch failure or loss of equipment over the side can be traced to the biggest common sense factor of them all—excessive speed! SLOW THAT WINCH DOWN! The type of operation and the sea state will govern the winch speed, but it is safe to say NEVER EXCEED 100 meters per minute. By "piece of machinery", we refer to the design characteristics as well as those operational characteristics peculiar to a particular winch.

The proper maintenance of winches includes lubricating and maintaining the winch in an operative condition and keeping the winch area clean. Routine preventative maintenance is required both at sea and in port. Since your job at sea

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1. Line Meter Counter
2. Line Speed Indicator
3. Counter Reset
4. Operating Switches
5. Hydraulic Motor
6. INHAUL-PAYOUT Control Handle
7. Control Manifold
8. Hydraulic Pump
9. Oil Filter
10. Reservoir.
11. Meter Light and Heater Switches
12. Brake Limit Switch
13. Brake Hand Wheel

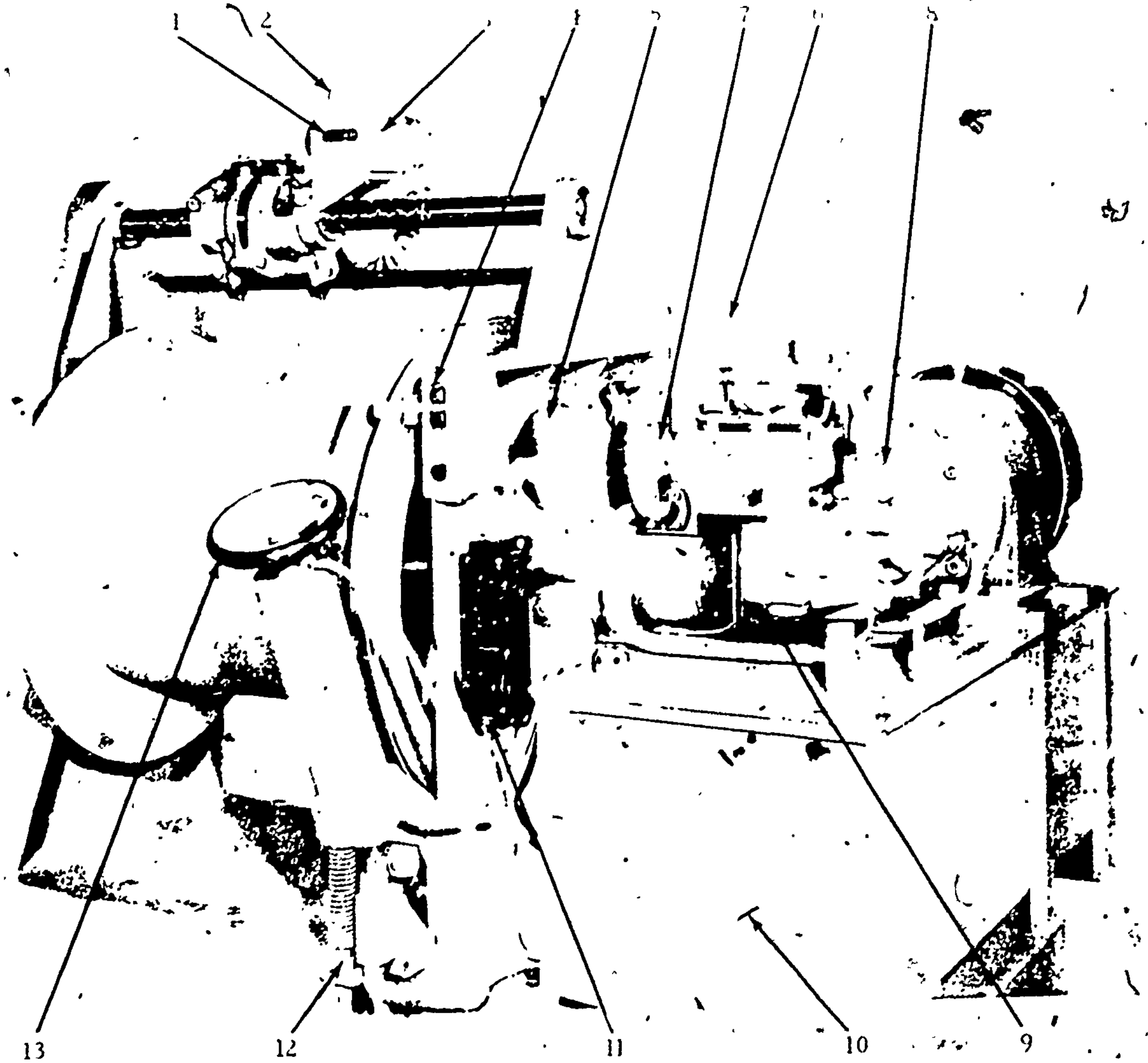


Figure 24.— Jered Hydrographic Winch—Front View.

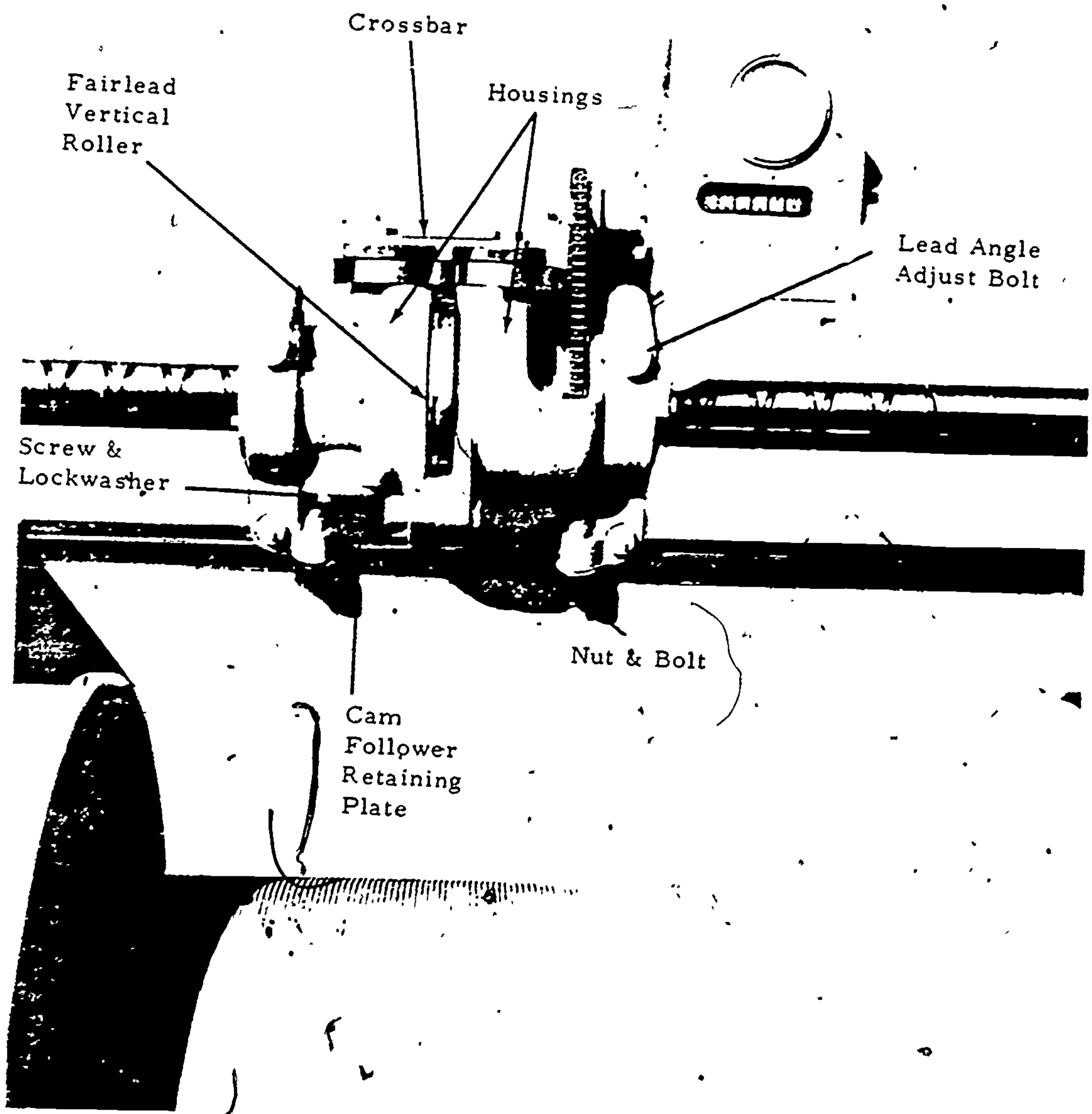


Figure 25.— Lead Head Adjustments on the Jered winch.

1. Electric Motor
2. Electrical Junction Box
3. Meter Light Wiring
4. Lead Head
5. Lead Screw
6. Drive Chain and Sprocket Cover
7. Brush and Slip Ring Assembly
8. Cable Drum
9. Brake Band
10. Oil Heater
11. Heat Exchanger
12. Temperature Actuated Regulating Valve

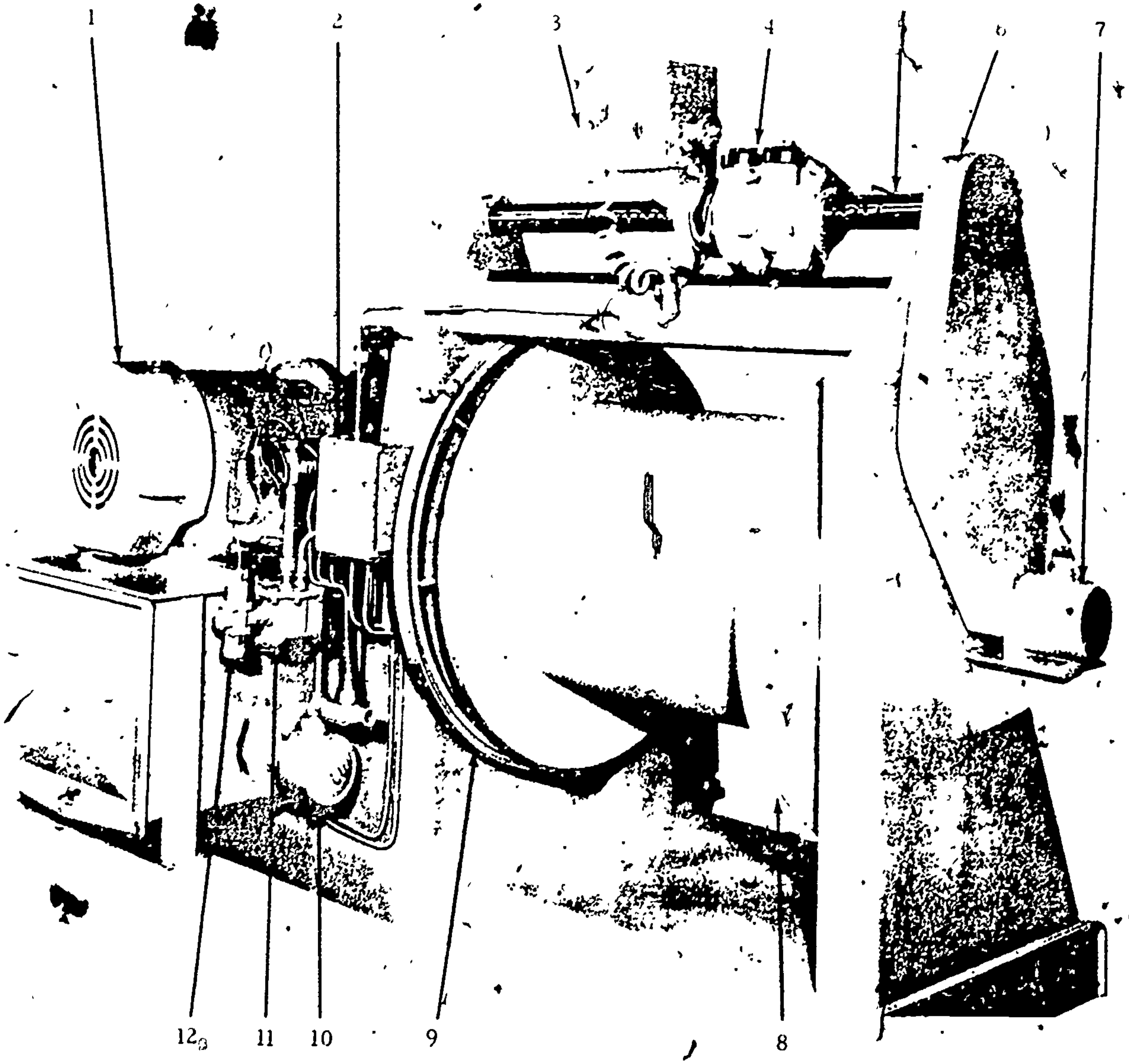


Figure 26.— Jered Hydrographic Winch—Rear View.

will be governed by your operational work load, you should plan to undertake any major repairs or maintenance projects while in port. You should report any mechanical irregularities to the head of the engineering department. Remember that the technical manuals for your particular winch are your best guide for the proper care of your equipment.

You, as an MST, must know your winch and how it operates. Be sure you know the braking system and how it works, because there is no time for second guessing the situation during oceanographic operations. The lack of knowledge of your winch can result in loss of gear or personal injury. Know where the controls are, what their functions are, and how they react. Test your equipment before each operation. Again, the best source of information is the technical manuals. The combination of knowledge and experience develops the skill you require to operate, or instruct others to operate, a winch.

## WIRE ROPE

Wire rope is used on many different jobs in oceanography, such as lowering; hoisting; and rigging platform stays, platform life lines, and many special arrangements in support of oceanographic observations. To perform these jobs successfully, you must have a working knowledge of wire rope.

This section contains useful information on the subject of wire rope. It discusses types of wire rope and their characteristics, construction, and usage. Instruction also is provided on various procedures applicable to the care and handling of wire rope.

### PARTS

Wire rope consists of three parts: wires, strands, and core. (See figure 27.) In the manufacture of rope, a number of wires are laid together to form the strand. Then a number of strands are laid together, usually around a central core, to form the rope.

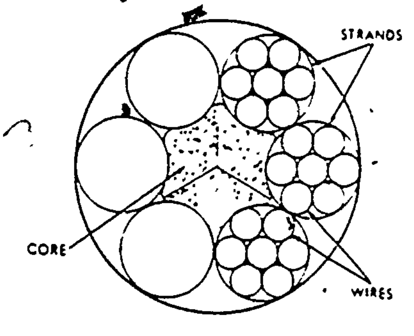


Figure 27.— Parts of wire rope.

### CONSTRUCTION

The basic unit of wire rope construction is the individual wire, which may be made of steel, iron, or other metal, in various sizes. In making a rope, the number or wires to a strand will vary, depending on the purpose for which the rope is intended. Wire rope is designated by the number of strands per rope and the number of wires per strand. Thus, a 6 x 19—1/2" rope will have 6 strands with 19 wires per strand, but will have the same outside diameter as a 6 x 37—1/2" wire rope, which will have 6 strands with 37 wires of much smaller size per strand. Wire rope made up of a large number of small wires is flexible, but since the small wires are easily broken, the wire rope is not resistant to external abrasion. Wire rope made up of a smaller number of larger wires is more resistant to external abrasion but it less flexible.

The central core—the element around which the strands are laid to form the rope—may be a hard fiber (such as manila, hemp, or sisal), a wire strand, or an independent wire rope. Each type of core serves the same basic purpose, that of affording support to the strands laid around it.

A fiber core offers the advantage of increased flexibility. In addition, it serves as a cushion to reduce the effects of sudden strain and acts as a reservoir for the oil necessary for lubrication of the wires and strands to reduce friction between them. Wire rope having a fiber core is used in places where no severe heat is involved and where flexibility on the part of the rope is important.

A wire strand core not only provides more resistance to heat than a fiber core, but also adds about 15 percent to the strength of the rope. On the other hand, the wire strand makes the rope less flexible than when a fiber core is used. This type of rope is used in places where hot work is involved.

An independent wire rope core is a separate wire rope over which the main strands of the rope are laid. It usually consists of six 7-wire strands laid around either a fiber core or a wire strand core. This type of core gives the rope additional strength, provides support against crushing, and supplies maximum resistance to heat.

Wire rope may be obtained either galvanized (coated with zinc) or plain (uncoated). Two methods are used to galvanize wire rope. These two methods are the hot dip and the electrolytic process. The hot dip method reduces the strength, since an elevated temperature is involved. This tends to draw some of the temper from the wire. The electrolytic process is simply an electroplating process and does not involve any raise in temperature; therefore, it has little or no effect on the properties of the wire. Galvanizing helps protect the rope against corrosion, but it also makes the rope stiffer and reduces the strength by as much as 10 percent.

Wire rope may be fabricated by either of two methods. If the strands or wires are shaped to conform to the curvature of the finished rope prior to laying up, the rope is termed PREFORMED. If they are not shaped before fabrication, the rope is termed NONPREFORMED. When cut, preformed wire rope tends not to unlay, and it is more flexible than nonpreformed wire rope. With nonpreformed wire rope, the twisting process produces a stress in the wires, and when it is cut or broken the stress causes the strands to unlay. In nonpreformed wire, unlaying is rapid and almost instantaneous, and could cause serious injury to someone not familiar with it.

## GRADES OF WIRE ROPE

Wire rope is manufactured in a number of different grades, three of which are: mild plow steel, plow steel, and improved plow steel.

Mild plow steel rope is tough and pliable. It can stand up under repeated strain and stress, and has a strength of from 200,000 psi to 220,000 psi. These characteristics make its use desirable for cable tool drilling and other purposes where abrasion is encountered.

Plow steel wire rope is unusually tough and possesses great strength. This steel has a tensile strength of 220,000 to 240,000 pounds per square inch (psi). This rope is suitable for hauling and hoisting and is used extensively on buoy tenders.

Improved plow steel rope is one of the best grades of rope available. It is stronger, tougher, and more resistant to wear then either plow steel or mild plow steel. Each square inch of improved plow steel can stand a strain of 240,000 to 260,000 pounds.

## WIRE ROPE LAYS

The term lay refers to the direction of the twist of the wires in a strand and the strands in the rope. In some instances both the wires in the strand and the strands in the rope are laid in the same direction, and in other instances in the opposite direction, depending on the intended use of the rope. Five different lays of wire rope currently in use are illustrated in figure 28. The following explanations will help you to recognize and identify each of the five types shown.

RIGHT REGULAR LAY: In this type the wires in the strands are laid to the left, while the strands in the rope are laid to the right.

LEFT REGULAR LAY: In this case, the wires are laid up to the right to make the strands, and the strands are laid up to the left to form the rope. (In this lay, each step of fabrication is exactly opposite from the right regular lay.)

RIGHT LANG LAY: Here the wires in the strands and the strands in the rope are both laid up to the right.

LEFT LANG LAY: With this type the wires in the strands and the strands in the rope are also laid in the same direction, but in this instance the lay is to the left (rather than to the right as with right lang lay).

REVERSE LAY: The wires in one strand are laid up to the right, the wires in the adjacent strand are laid up to the left, the wires in the next strand are to the right, and so forth, with alternate directions from one strand to the other. Then all strands are laid up to the right.

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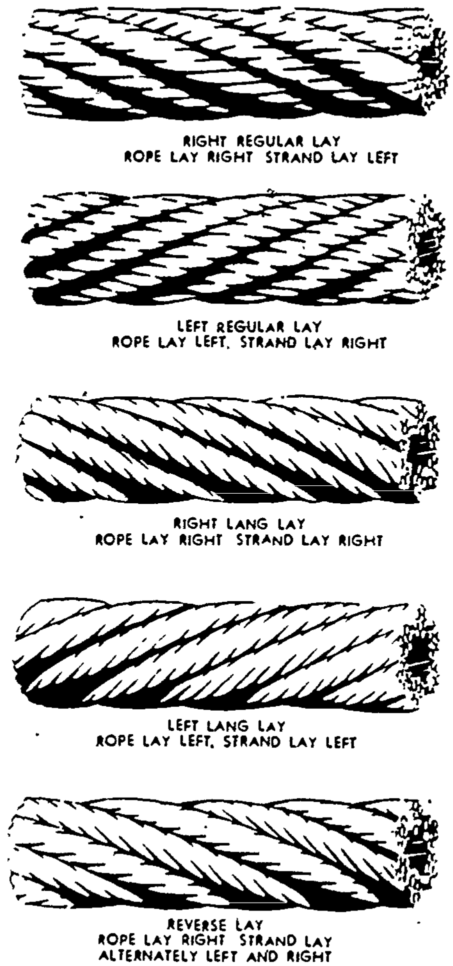


Figure 28.— Typical wire rope lays.

TYPES OF WIRE ROPE

While the main types of wire rope used throughout the Coast Guard consist of 6, 7, 12, 19, 24, or 37 wires in each strand with 6 strands laid around fiber or steel centers (figure 29), the wire rope that we are primarily interested in is the type installed on cutters for oceanographic work.

Most of the original oceanographic wire rope installations were of the 7 x 19—3/16" diameter stainless steel wire—preformed aircraft cord. Experience has indicated that 3 x 19—3/16" diameter stainless steel wire has many advantages over the 7 x 19 wire. Therefore, most new installations of oceanographic wire are of the 3 x 19 type of construction.

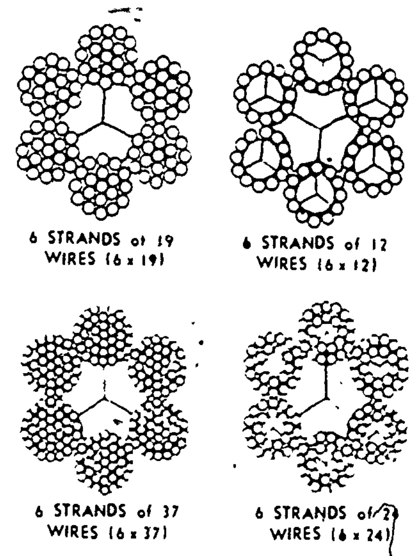


Figure 29.— Arrangement of strands in wire rope.

MEASURING WIRE ROPE

Wire rope is designated as to size by its diameter in inches. The true diameter of a wire rope is considered as being the diameter of the circle which will just enclose all of its strands. The correct and incorrect methods of measuring wire rope are illustrated in figure 30. Note, in particular, that the CORRECT WAY is to measure from the top of one strand to the top of the strand directly opposite it. The wrong way, as you will note, is to measure across two strands side by side. Use calipers to take the measurement; if they are not available, a crescent wrench will do.

To ensure an accurate measurement of the diameter of a wire rope, always measure the rope at three places at least 5 feet apart. Use the average of the three measurements as the diameter of the rope.

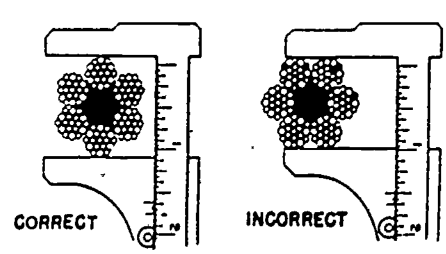


Figure 30.— Correct and incorrect methods of measuring wire rope.

WIRE ROPE FAILURE

Some of the common causes of wire rope failure are listed below:

1. Subjecting the rope to severe or continuing overload.

2. The rope overriding or cross-winding on drum.

3. Operating the rope over sheaves and drums of inadequate size.

4. Operating the rope over sheaves and drums with improperly fitted grooves or broken flanges.

5. The rope jumping off sheaves.

6. Using rope of incorrect size, construction, or grade.

7. Improperly attaching the rope to fittings.

8. The rope dragging over obstacles.

9. The rope kinking.

10. Subjecting the rope to acid fumes.

HANDLING AND CARE

To render safe, dependable service over a maximum period of time, wire rope must be given the care and upkeep necessary to maintain it in good condition. Various procedures applicable to the care and handling of wire rope are given in the following subsections. It is recommended that you not only study these procedures carefully but, what is more important, that you also put them into practice on your job. They will help you do a better job NOW, and in the long run will result in a longer useful life of the wire rope.

Coiling and Uncoiling

Once a new reel of wire has been opened, it may be coiled or faked down like line. The proper direction of coiling is COUNTERCLOCKWISE for LEFT LAY wire rope and CLOCKWISE for RIGHT LAY rope. Because of the general toughness and springiness of wire, however,

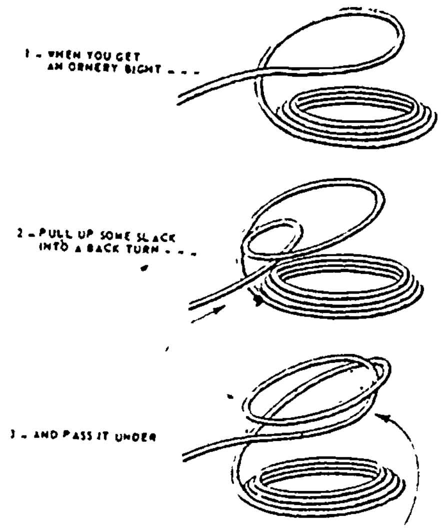


Figure 31.— Throwing a back turn to make wire lie down.

it has a tendency now and then to resist being coiled down. When this occurs, it is useless to fight the wire by forcing down the stubborn turn; it will only spring up again. But if you throw it in a back turn, as shown in figure 31, it will lie down properly. When faked down, a wire rope will run right off like line; but when wound into a coil, it must always be unwound.

You will find that wire rope has a strong tendency to kink during uncoiling, or unreeling, especially if it has been in service for a long time. Keep in mind that a kink can cause a weak spot in the rope, which will wear out quicker than the rest of the rope.

A good method for unreeling wire rope is to run a pipe or rod through the center and mount the reel on drum jacks or other supports so that the reel is off the ground (see figure 32). In this way the reel will turn as the rope is unwound,

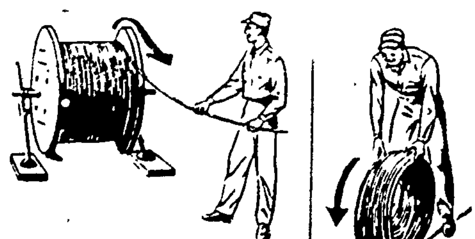

Figure 32.— (Left) Unreeling wire rope. (Right) Uncoiling wire rope.

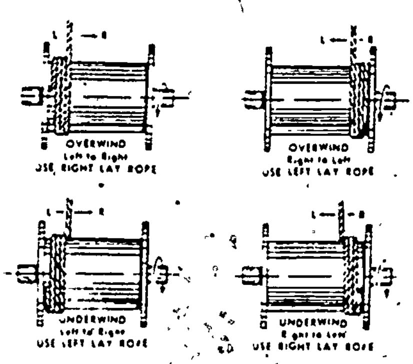


Figure 33.— Drum winding diagrams for selection of proper lay of rope.

and the rotation of the reel will help keep the rope straight. During unreeling, pull the rope straight forward, as shown in figure 32, and try to avoid hurrying the operation. As a safeguard against kinking, NEVER unreel wire rope from a reel that is stationary.

To uncoil a small coil of wire rope, simply stand the coil on edge and roll it along the ground like a wheel or hoop, as illustrated in figure 32. NEVER lay the coil flat on the floor or ground and uncoil it by pulling on the end, because such practice is likely to cause kinks or twists in the rope.

To re-reel wire rope back onto a reel or a drum, you may have difficulty unless you remember, that it tends to roll in the opposite direction of the lay. A right lay wire rope, for example, tends to roll to the left.

Closely observe figure 33, which shows drum winding diagrams for selection of the proper lay of rope. When putting wire rope onto a drum, you should have no trouble if you are familiar with the methods of overwinding and underwinding shown in the illustration.

When wire rope is run off one reel to another reel, or onto a winch or drum, it should be run from TOP TO TOP or from BOTTOM TO BOTTOM, as shown in figure 34.

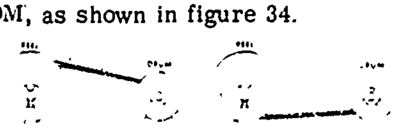

Figure 34.— Transferring wire from reel to drum.

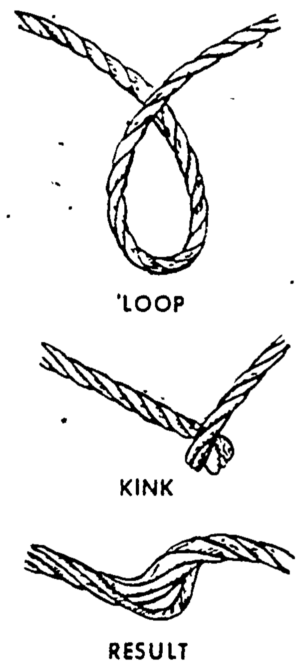


Figure 35.— Kinking in wire rope.

Kinks

If a wire rope becomes kinked (see figure 35), never try to pull out the kink by putting a strain on either part. As soon as you notice a kink, uncross the ends by pushing them apart. (see step 1 in figure 36.) This reverses the process that started the kink. Now turn the bent portion over and place it on your knee or some firm object and push downward until the kink straightens out somewhat. Then lay it on a flat surface and pound it smooth with a wooden mallet.

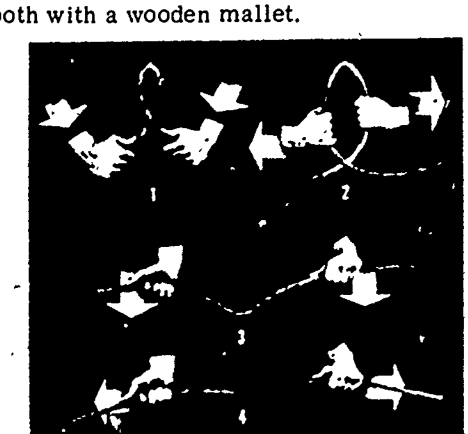


Figure 36.— The correct way to take out a kink in wire rope.

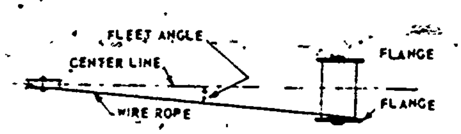


Figure 37.— Fleet angle.

If a heavy strain has been put on a wire rope with a kink in it, the rope can no longer be trusted. Cut out the kinked part and splice the ends together.

Reverse Bends

Whenever possible, drums, sheaves, and blocks used with wire rope should be placed so as to avoid reverse or S-shaped bends. Reverse bends cause an unnecessary amount of shifting of the individual wires and strands, increasing wear and fatigue. Where a reverse bend is necessary, the blocks and drums affecting the reversal should be of larger diameter than that ordinarily used and should be spaced as far apart as possible.

Size of Sheaves

It is not possible to prescribe an absolute minimum size for wire rope sheaves, owing to the number of factors involved. Experience has shown, however, that the diameter of a sheave should NEVER BE LESS THAN 20 TIMES THE DIAMETER OF THE WIRE ROPE.

Another thing to remember in connection with sheaves and drums is to keep the FLEET ANGLE as small as you can. The fleet angle is formed by running wire rope between a sheave and a hoisting drum whose axles are parallel to each other, as shown in figure 37. Too large a fleet angle can cause the wire to climb the flange of the sheave and may even break the flange. It can also cause the wire to climb over itself on the drum. When setting up the sheave and drum, keep them far enough apart to make the fleet angle small. About 15 times the width of the drum should be the minimum distance between the drum axle and the sheave axle. This will ensure that the fleet angle is no more than 1 1/2 to 2 degrees. (The width of the drum is measured from flange to flange.)

Seizing and Cutting

Great care is exercised in the manufacture of wire rope to lay each wire in the strand and each strand in the rope under uniform tension. If the ends of the rope are not secured properly, the original balance of tension will be disturbed and maximum service will not be obtained, because some strands will carry a greater portion of the load than others. Before cutting steel wire rope, place three sets of seizing on each side of the point where the rope is to be cut.

To make a temporary wire rope seizing, wind on the seizing wire uniformly, using tension on the wire. After taking the required number of turns as in step 1 in figure 38, twist the ends of the wires counterclockwise as in step 2. Grasp ends with end-cutting nippers and twist up slack as in step 3. Do not try to tighten seizing by twisting. Draw up on seizing as in step 4. Again twist up the slack, using nippers, as in step 5. Repeat steps 4 and 5 if necessary. Cut ends and pound them down on the rope as in step 6. If the seizing is to be permanent, or if the rope is 1 5/8 inch or more in diameter, use a serving bar of iron to increase tension on the seizing wire when putting on the turns.

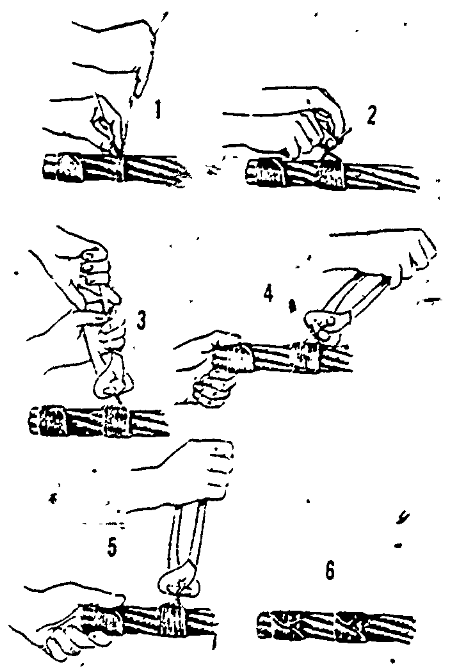


Figure 38.— Putting temporary seizing on wire rope.

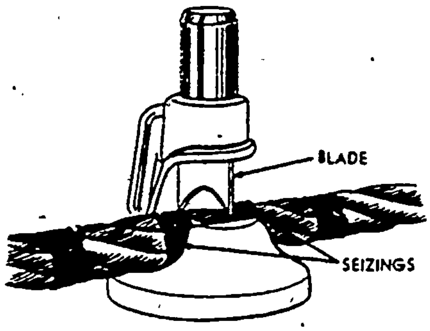


Figure 39.— Hammer-type wire rope cutter.

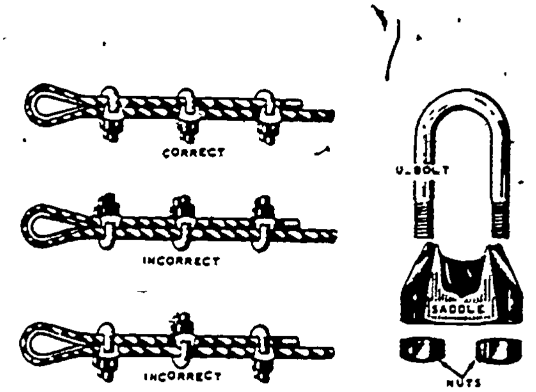


Figure 40.— Use of wire rope clips.

Wire rope can be cut successfully by a number of methods. One effective yet simple method is that of using a hammer-type wire rope cutter (see figure 39). (Remember that all wire must be seized before it is cut.) For best results in using this method, place the rope in the bottom of the cutter, as illustrated, so that the blade comes between the two central seizings. With the blade down against the rope at the location of the cut, strike the top of the blade sharply several times with a sledge hammer.

Wire rope can be cut easily with a hydraulic wire rope cutter. This device works basically like a hydraulic jack; as you pump the handle, a cutter comes down and cuts the wire rope.

Bolt cutters are suitable only for cutting wire of fairly small diameter, but the oxyacetylene torch will cut wire of any diameter. Other cutting tools include the hacksaw and cold chisel, but with them the cutting operation is slower.

Inspecting for Wear

You should frequently inspect wire rope for fishhooks, kinks, and worn and corroded spots. Worn spots show up as shiny flattened surfaces. To determine the wear, you must know (1) the original diameter of the wire rope, (2) the present diameter of the wire rope at the worn place, and (3) the diameter of a single wire in one of the strands of the wire rope. The original diameter of the rope is shown in the ship's records. Find the actual diameter by measuring with a micrometer or vernier caliper, as shown in figure 30. Now, subtract the measured diameter of the wire rope from the original diameter. If the difference is half the diameter of the single wire, the safe working load of the wire rope is reduced materially. If the difference is equal to or greater than the diameter of the single wire, replace the rope. Even if no worn spots are apparent, measure wire rope occasionally to determine the overall wear. Take three or four measurements at intervals of several feet and find the mean. The same rule applies here as with worn spots: Replace the rope if the outer wires are worn to one-half their original diameter.

Rusting and corrosion of the wires and deterioration of the fiber core sharply decrease the strength of a rope. It is impossible to estimate accurately the loss in strength from these effects.

Wire Rope Clips

A temporary eye splice may be put in wire rope by using clips. A single clip, as shown in figure 40, consists of three parts: U-bolt, roddle (or saddle), and nuts. The correct and incorrect methods of applying these clips to wire rope are shown in ~~figure 40; the second~~ incorrect method shown is the most common. Notice that the CORRECT way is to apply the clips so that the U-bolts bear against the bitter end, that is, the short end of the rope. If the clips are attached incorrectly, the result will be distortion or mashed spots on the live end of the rope. An old rule to remember is "never saddle a dead horse".

In applying the clips, make sure the distance between them is equal to six times the diameter of the rope. After a rope is under strain, tighten the clips again. Tighten the clips on operating ropes every few hours and inspect the ropes carefully at points where there are clips. Pay particular attention to the wire at the clip farthest from the eye, as vibration and whipping are dampened here and fatigue breaks are likely to occur.

To obtain maximum strength in a temporary eye splice, use the correct size and number of wire clips. The size is stamped on the saddle between the two holes. A thumb rule for determining the number of clips required for various sizes of rope is to multiply the diameter of the rope by 3 and add 1; stated as a formula, this means:

$$3D + 1 = \text{number of clips}$$

As an example, if the rope has a diameter of 1 inch, determine the number of clips as follows:

$$3 \times 1 + 1 = 4 \text{ clips}$$

In case the answer contains a fraction, use the next largest whole number.

The clips should be properly spaced to provide a good hold on the rope. To determine the correct distance between the clips, multiply 6 times the diameter of the rope. Here, as in determining the number of clips, if the answer contains a fraction, use the next largest whole number.

An improved type of wire rope clip which has been developed is shown in figure 41. This type has a few advantages over that shown in figure 40. In the improved type, both halves are identical and provide a bearing surface for both parts of the rope. Thus, the clip cannot be put on wrong, and it will not destroy the wire. It also allows a full swing with a wrench.

Inspect and tighten wire rope clips at regular intervals. Also, after comparatively long use, the clips should be removed and the rope examined for broken wires. If any are present, the damaged part should be removed and a new attachment made.

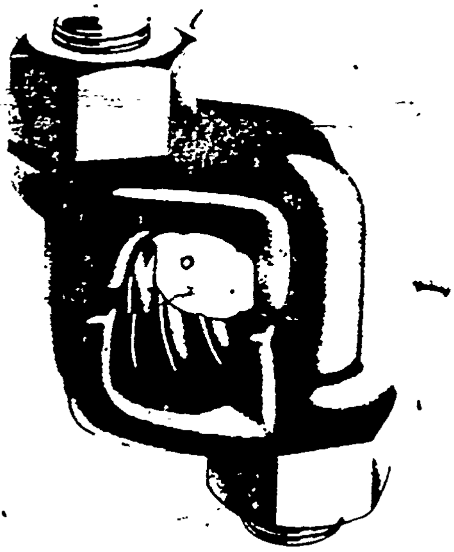

Figure 41.— Improved type wire rope clip.

While only 2 wire clips are required on 3/16" wire to make a safe temporary eye splice, a minimum of 3 wire clips is recommended to assure proper wire alignment. A similar condition exists when you make a temporary eye splice using a Nicopress sleeve (figure 42); only 1 sleeve is required, but the use of 2 sleeves is recommended to ensure that no equipment loss results because of an improper sleeve application. Space the Nicopress sleeves in the same manner recommended for spacing wire clips.

Figure 42 shows the Nicopress tool and sleeves used for making temporary eye splices in wire rope. Also shown are thimbles, swivels, wire clips, and shackles. These are a few of the tools and equipment commonly used when you are working with oceanographic wire rope.

This section has covered wire rope in general; more detailed information may be found in Chapter 27 of the Naval Ships Technical Manual. Additional information about oceanographic wire rope may be found in CG 410 or N. O. Pub. 607.

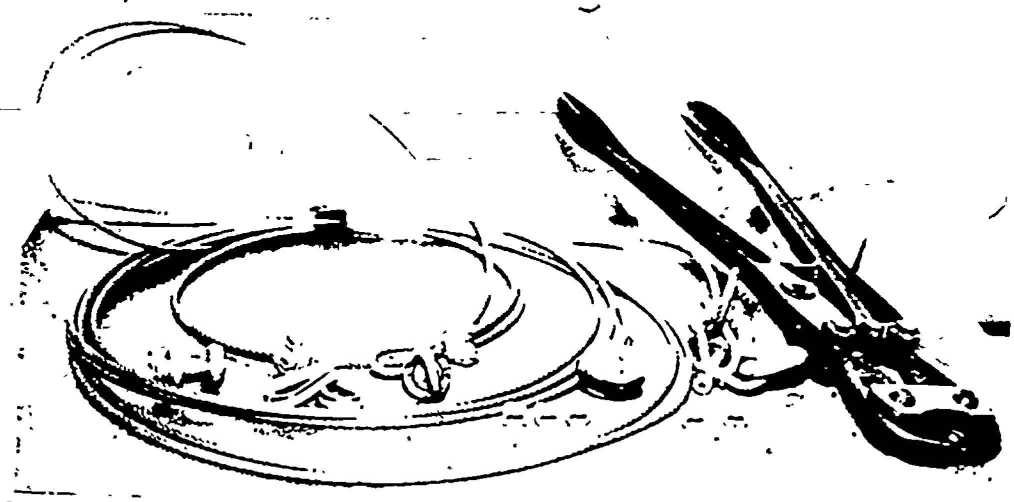

Figure 42.— The Nicopress tool and sleeves, wire rope, thimbles, swivels, wire clips, and shackles.

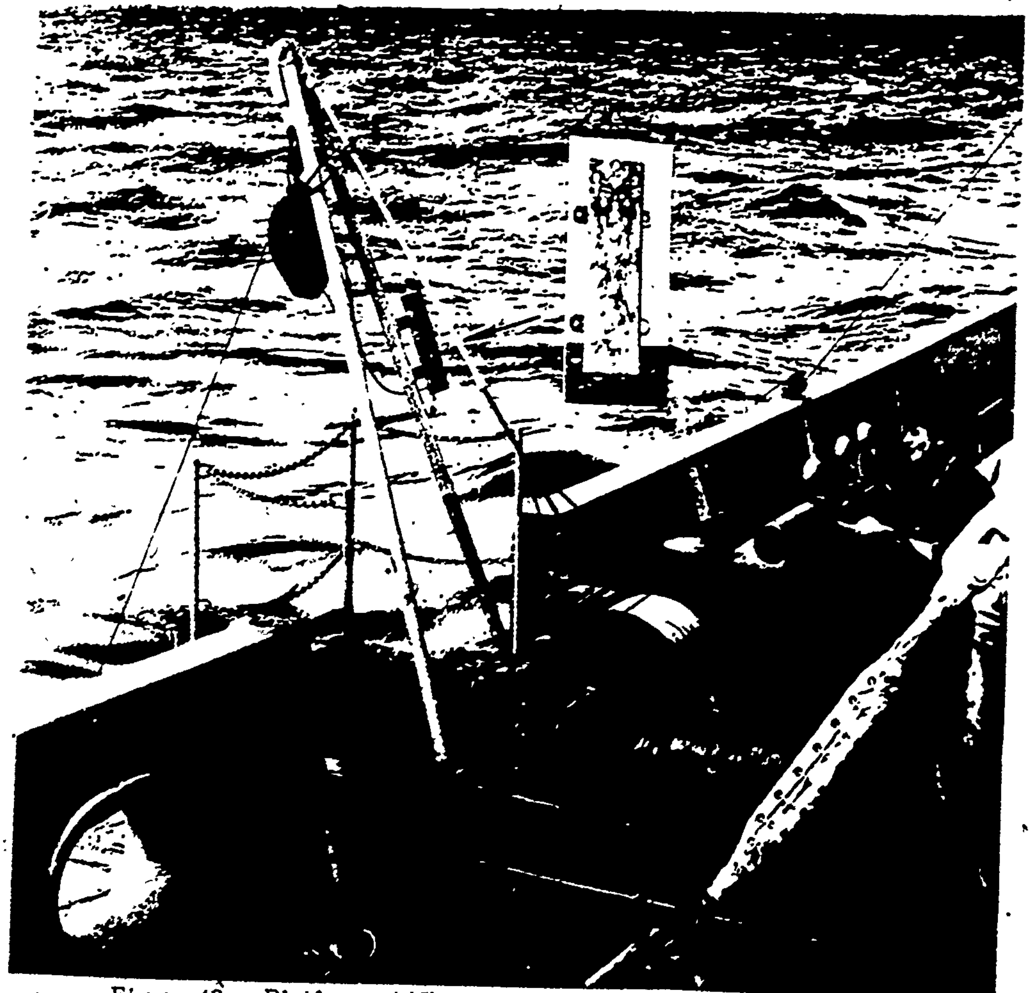

Figure 43.— Platform, A-Frame, meter wheel, and counter block.

## PLATFORM RIGGING

The platform, gallows, meter wheel, counter cable, counter (see figure 43), and oceanographic weight are all part of a completed rigging necessary for most hydrographic work performed by Coast Guard vessels.

### Platform

The rigging of the oceanographic platform is not a difficult task if done properly. A great deal of time and energy may be saved by keeping the platform in good repair and the rigging fittings well lubricated. As you rig the platform in the working position, ensure that all bolts and pins are securely in place. An improperly sized fitting can cause slack in the rigging that may well result in warped connecting points.

Upon completion of a cruise, the disassembling of the platform rigging is nearly as important as the assembling. At the time of disassembling, you should clean the various connections, inspect the rigging for wear or other weak points, and relubricate the various fittings as required. By following this procedure and noting any discrepancies, you will know the condition of your equipment and what needs to be replaced and will assure yourself a smooth and rapid rigging the next cruise.

### Gallows

After the platform is in position, rig the gallows (A-frame). As you rig the gallows, exercise the same care that you did in rigging the platform. The height of the gallows and the wire angle have an effect on your ability to work with equipment that you must place on, or retrieve from, the oceanographic wire. If the gallows is too high and the wire angle is too large, the equipment is difficult to reach; inversely, if the gallows is too low and the wire angle is too small, damage to equipment can result or the wire can become fouled, or even sheared, by the platform or the ship's hull.

Considerations other than equipment safety are necessary; personal safety should always be FIRST. If the gallows is high, never over-reach your position while working with equipment on the platform. If the gallows is low, be mindful of the dangers to you or your men by a low meter wheel and running wire.

### Meter Wheel

After you have positioned the gallows, you may rig the meter wheel (block). The meter wheel is a diamond-shaped roller bearing block combining some of the features of both blocks in figures 44 and 45. Normally rig the meter wheel from the top of the gallows by using a shackle. Pass the shackle through a ring secured to the gallows while passing the shackle screw pin through the round eye of the meter wheel swivel. (See figure 46.)

A properly rigged meter wheel will swing freely from the gallows. This swinging action will prevent the wire from jumping the meter wheel sheave even if your ship is pitching or rolling moderately.

Care and maintenance of the meter wheel is important to the success of your oceanographic program. Check the wheel for ease of movement before each cruise and each cast. To prevent the wheel from binding, lubricate it periodically. The wheel has grease fittings that permit quick and proper lubrication with a grease gun. You must judge the frequency of lubrication that your work load requires; however, it is recommended that you purge the wheel prior to the first hydrographic station, after each station, and before subsequent hydrographic stations if weather conditions are bad or the time between stations is long. Unless the wheel is binding or visual inspection reveals a problem, an annual disassembly for inspection of the bearings and internal wear should ensure trouble-free service of a meter wheel.

### Counter

A counting device is required for most oceanographic work. The oceanographic winch is usually equipped with a counter that indicates the amount of wire payed out, and the meter wheel is usually equipped with a direct counter. In addition to these counting devices, a remote counter is required equipment. The remote counter, which is normally rigged on the gallows, provides the most accurate measurement of cable payed out. The remote counter's required maintenance is minor; keep the counter clean and well greased.

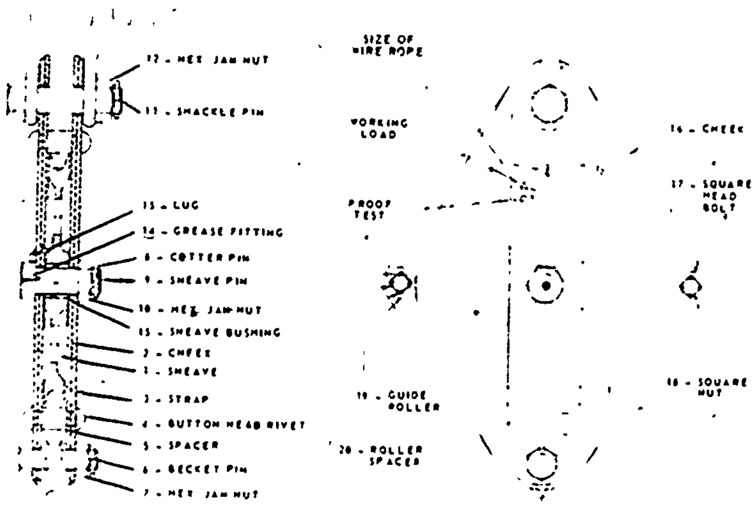


Figure 44.— Diamond block.

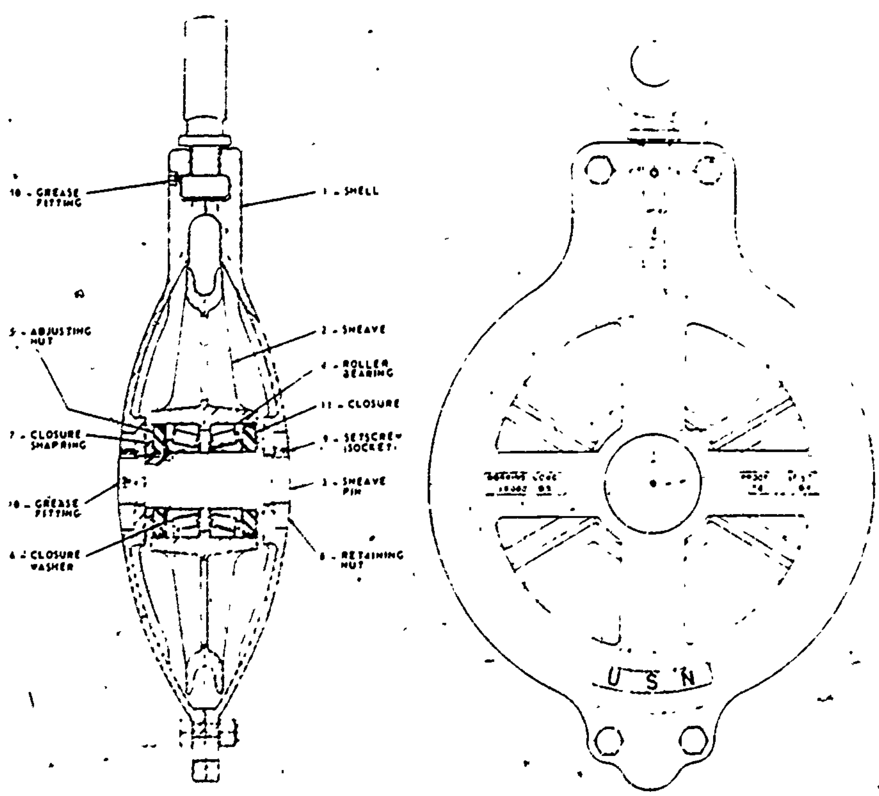


Figure 45.— Roller bearing block.

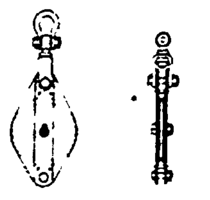


Figure 46.

Counter Cable

A counter cable is used to connect the remote counter to the meter wheel. A properly rigged counter cable has sufficient slack to prevent excessive strain on the connections at the meter wheel or counter during periods of bad weather or large wire angles. These connecting cables are available with a plastic coating to reduce corrosion and to increase service life. With proper lubrication and proper fitting connections, the counter cable will perform well, but always have a spare one aboard for each cruise.

Weight

An oceanographic weight completes the basic platform rigging and is used to stabilize the oceanographic wire. This weight usually consists of a metal block about 24 inches long with an eye-ring at each end. The weight does not require maintenance, but painting it a light color—white or yellow— will make it prominent as it nears the water's surface.

PLATFORM AREA SAFETY

Since deck safety has such a broad base, we will restrict this section to the areas of safety associated with oceanographic work.

While the safety of deck equipment is very important, the safety of personnel is ALWAYS the prime consideration. Under normal operating conditions, personnel observing the following minimum safety requirements should be able to function in a safe and proficient manner. The important thing to remember about safety of any nature is that a basic knowledge of the job and/or equipment coupled with common sense results in safe and efficient performance under normal operating conditions.

When you analyze the nature of any assigned task for possible types of personal injury, you should determine your need for appropriate safety equipment. When you are subject to head injury, wear a hard hat. If your feet are liable to injury, wear safety shoes. When working on the platform, wear a work-type vest, because you are often subject to falling over the side. In a situation requiring you to remove outboard life lines, wear a harness with an attached safety line in addition to the life vest. If sufficient personnel are available, they should hand-tend this safety line; otherwise, secure the line to the ship.

With these recommended precautions in mind, an ideal oceanographic team conducting a Nansen cast would be outfitted as follows:

1. Safety officer - hard hat.

2. Oceanographic supervisor - hard hat, safety shoes, and life vest.

3. Platform man - hard hat, safety shoes, life vest, and swimmer's harness.

4. Bottle passer - hard hat, safety shoes, and life vest.

5. Winch operator - hard hat.

Rig the swimmer's harness and the attached safety line in such a fashion to allow a man falling from the platform to hit the water and still have some slack line. The reason for this length of line is to prevent the man from being stopped short and incurring bodily harm from the fall or from striking the side of the ship. A properly tended line will prevent the man from being drawn into the screws and will facilitate hauling the man aboard.

The handling of oceanographic wire is an ever-present safety hazard. To minimize this hazard, you should always wear gloves to protect your hands from fish hooks that may have developed in the wire. A useful device to aid in fending the wire away from the platform during periods of low wire angles is a leather arm guard. The platform man should have this device laced to his forearm when he is either lowering or retrieving a Nansen cast.

The position of the oceanographic platform aboard your vessel may present hazards to both personnel and equipment. High wire angles may result in a situation that requires the platform man to overextend his reach. To prevent this hazard, reduce the wire angle by a boat hook; however, for added leverage, a hook on the end of a line fair-led through a block works extremely well.

As mentioned previously, one of the duties of the platform man is to fend the wire from the platform. This action prevents the equipment on the wire from striking the platform and also reduces the possibility of severing the wire on the platform edge. The possibility of severing or fouling the wire on the edge of the platform can be greatly reduced if a roller assembly is installed on the outboard edge of the platform.

The platform's position may also bring about a pendulum situation. This is a situation that results when a heavy object is positioned on the end of the oceanographic wire. As the object breaks the surface, the rolling action of the ship sets the object in motion, swinging it back and forth. Extreme caution is required in this situation. Simply applying force on the wire may dampen the swinging action; more positive measures may be required, such as a man positioned at a lower level with a means to fend the object off. A light rod or boat hook with a C-clamp attached can be effective in some cases.

The pendulum effect can cause extensive damage to deep-sea reversing thermometers, STD sensing units, sonar pingers, and bottom sampling equipment. Be aware of the dangers to both your men and your equipment, because you require both to perform a successful observational program.

If you are the oceanographic supervisor or the man working on the platform, one of the best ways to insure a safe working area is to conduct a personal check of all safety keepers, cotter pins, and shackles. Be sure that the shackles are safety wired.

In closing this area of instruction, remember that the suggestions in this section are for the most part MINIMUM requirements, and at no time are they to be considered all inclusive. The Commandant, as well as area, district, and unit commanders, issues Instructions and Notices for YOUR safety and the safety of your equipment. Know WHAT to do and WHEN to do it!

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# OCEANOGRAPHIC EQUIPMENT AND INSTRUMENTS

## WATER SAMPLERS

To know the ocean is to analyze its contents. One of a Marine-Science Technician's most important jobs is collecting water samples for analysis.

The simplest, and perhaps the earliest, water sampler is nothing more than an ordinary bucket. As an effective water sampler, the bucket is restricted to surface samples. Water drawn from a bucket sample is of little or no value for oxygen or nutrient analysis.

The need for uncontaminated water samples from the ocean's surface to various depths below the surface has fostered many varied sampling devices. History indicates that the first sampling device was a bottle invented by Hooke in 1611. Since then, more than 50 types have been developed and used by different researchers over the years. Experience has shown that a simple but rugged design was called for. The equipment used for water sampling must withstand the rigorous ocean environment.

### NANSEN BOTTLE

The sampler that has the widest usage in the Coast Guard today is the Nansen bottle. This sampler was developed in the latter part of the 19th century by the famed Norwegian arctic explorer and oceanographer, Fredtjof Nansen.

The Nansen bottle (figure 47) is a metal reversing water sampler with a 1.25-liter capacity. The bottle is fitted at both ends with tapered plug valves that are joined with a connecting rod. This arrangement allows the bottle to withstand the great pressures of deep water. At any desired depth the bottle can be reversed (figure 48), closing the valves and obtaining a water sample for that particular level.

While the Nansen bottle is simple in both operation and construction, it requires proper maintenance and preparation prior to use. Before you use a Nansen bottle on a station, check it carefully for proper operation of parts. Lubricate the valves with silicone stopcock grease to insure smooth movement as well as a watertight seal. Lubricate all moving parts with penetrating oil to give free action. Test the bottle-releasing mechanism for proper action. If it is weak, the bottle may trip prematurely during lowering of the cast. If the release mechanism is too stiff, the bottle may not reverse when it is tripped. The air vent holes should be free of any foreign material and the vent screw should turn smoothly. Smooth action of the drain petcock is also required.

A Nansen bottle spare-parts kit is available through regular supply sources and should be part of your ship's allowance list. This kit contains spare clamps, springs, washers, pins, and necessary tools to effect minor repairs and general maintenance.

### NISKIN BOTTLE

Another water sampler that is becoming more useful in oceanographic work is the Niskin bottle (figure 49). The Niskin bottle comes in various sizes and can easily be adapted for a variety of observations requiring larger samples than those provided by a Nansen bottle. A Niskin bottle with a 1.7-liter capacity is available and can be used for quality control sampling required with STD operations. This size bottle requires a barrel type messenger as a tripping device. While the Niskin bottle is a sturdy piece of equipment, it is subject to breakage if not handled

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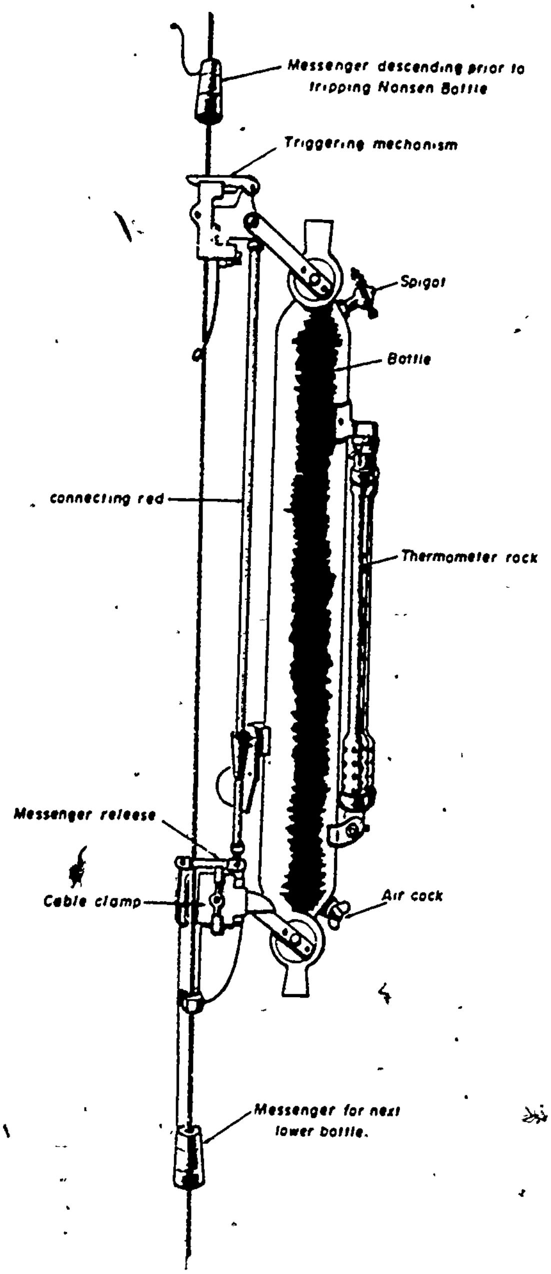


Figure 47.— Nansen Bottle in Position.

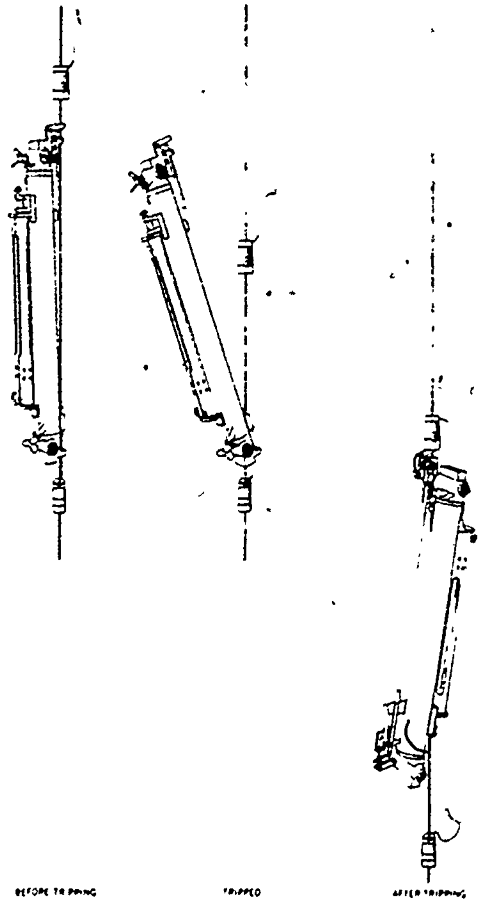

Figure 48.— Nansen bottle in three positions— before, during, and after tripping.

with care. Usual repair of a bottle consists of gluing the bottle to the mounting mechanism.

## ROSETTE MULTI-SAMPLER

The General Oceanics Rosette Multi-Sampler (Model RMS-12) is an electrically actuated set of sampling bottles mounted on an underwater triggering unit that allows the bottles to close sequentially on command from a shipboard deck unit. The sampler can be used alone or on the same sea cable with most Bissett-Berman STD Measuring Systems. Monitoring the STD system's strip-chart plotter during a cast enables a sampler to be triggered as it passes through an area of interest to an observer. The RMS-12 contains twelve 1.7-liter sampling bottles (figure 50).

The Rosette Multi-sampler system is comprised of a deck unit, underwater triggering unit, and samplers. The Rosette deck unit supplies power and actuation signals to the triggering unit through a single-conductor sea cable. The samplers can be fitted with reversing thermometer frames (figure 49C). When this system is used with an STD system, the Rosette deck unit is electrically interconnected between the STD deck unit and the sea cable, and the Rosette underwater triggering unit is electrically interconnected between the sea cable conductor and the STD underwater unit. When the Rosette sampler is triggered, the STD system is automatically cut out of the system for approximately five seconds to actuate and recharge the sampler mechanism. When using

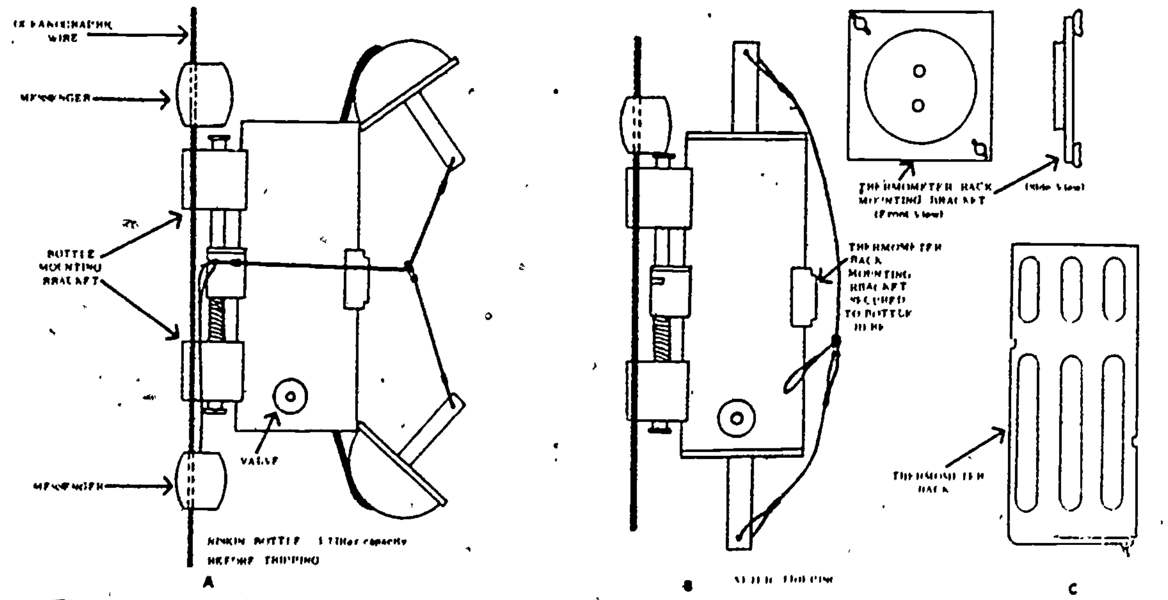


Figure 49.— Niskin Bottle (A) before tripping, (B) after tripping, and (C) thermometer frame.

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Figure 50.— Rosette Multi-sampler mounted on a 9006 STD prior to lowering.

reversing thermometers, wait ten minutes for the thermometers to equilibrate at each sampling depth at which they are used before triggering the sampler.

Maintenance of the multi-sampler is limited to washing down the samplers and the deck unit with fresh water after each immersion and to ensuring that the releasing pins are free from foreign matter and are well lubricated with a silicone spray. On a weekly basis, remove the top plate of the underwater triggering unit by unscrewing the six allenhead screws in order to enable thorough cleaning of all releasing pins, springs, plastic pins, and pin slots in the upper plate. Apply silicone grease to the allenhead screws before replacing the top plate.

## TEMPERATURE MEASURING EQUIPMENT

### SEA SURFACE TEMPERATURE

The temperature of the sea water surface is one of the most common temperature measurements observed today. The method most frequently used to measure this temperature is to immerse the bulb end of an ordinary thermometer into a water sample collected in a bucket and to read the resulting temperature. Another common method of measuring sea water surface temperature is to measure the temperature at the sea water intake. The need for improved equipment and methods of temperature measurement is widely recognized.

#### Bucket Method

The types of thermometers used for measuring bucket temperatures vary from the ordinary air sensing type to the special construction type. An observation program that demands great accuracy requires special construction of the thermometers such as an expanded scale, for more accurate readings. The accuracy of a temperature reading depends upon the construction and markings of the thermometer; therefore, it is recommended that you estimate to the nearest one-tenth of the scale's value; e.g., if the scale is marked for each 2.0 degrees, you should estimate the value to the nearest 0.2 degree.

The recommended procedure for measuring surface sea water temperature by the bucket method is to obtain the sample forward of any overboard discharges, move the bucket to a shaded area protected from the wind if possible, immerse the bulb-end of the thermometer into the sample and swirl it until the temperature has stabilized, and then read the thermometer while the sensing bulb is still immersed in order to prevent an erroneous reading caused by evaporation. A minimum of two readings should be taken to insure a valid temperature measurement.

#### Sea Water Intake Method

Sea water intake temperatures may be used if necessary; however, it is recommended that a periodic comparison be made between the intake reading and the readings obtained by the bucket method. A series of such readings at different cruising speeds of your vessel will indicate an even better comparison, and any difference that appears to be consistent should be used to correct readings obtained by the intake method.

### SUBSURFACE TEMPERATURE

The measurement of subsurface water temperature is a more difficult task than the measurement of surface water temperature. In this course we will cover the subsurface temperature measuring methods most commonly used in the Coast Guard. These methods involve four types of measuring instruments: the deep-sea reversing thermometer, the mechanical bathythermograph, the expendable bathythermograph, and the salinity-temperature-depth measuring system.

#### Deep-Sea Reversing Thermometer

Deep-sea reversing thermometers are used in conjunction with water sampling bottles. These thermometers are very expensive and require delicate handling. The purpose of these thermometers is to measure in situ water temperatures by reversing the thermometers at a desired depth, at which time the mercury that has entered the stem will indicate the temperature of the water at that particular depth.

These thermometers' operation is simple, but their construction requires delicate handling. There are basically two types of deep-sea reversing thermometers—the protected and the unprotected (figure 51). Each thermometer actually consists of two instruments—the main

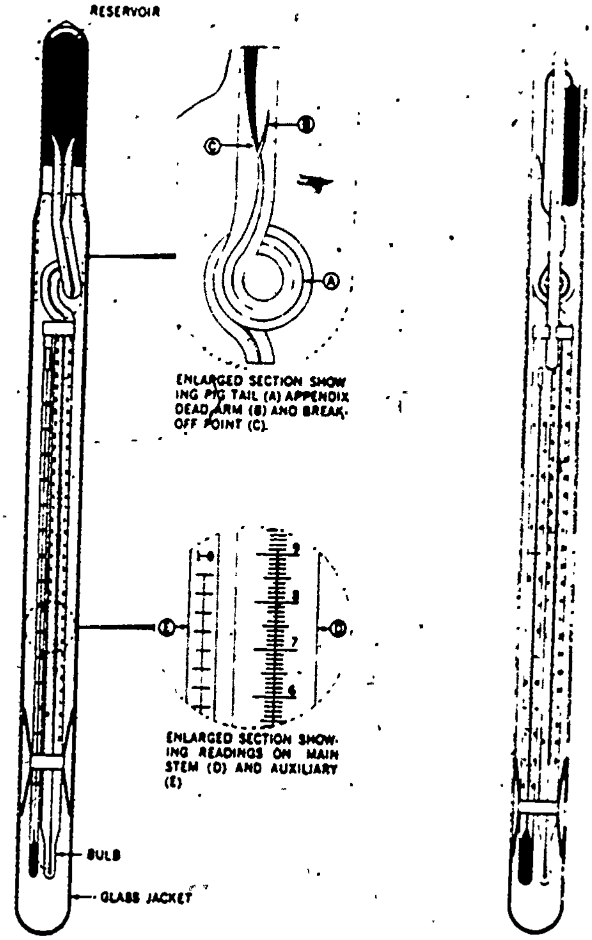


Figure 51.—Deep Sea Reversing Thermometers.

thermometer and the auxiliary thermometer. The main thermometer is the reversing instrument that indicates the water temperature, while the auxiliary is an ordinary thermometer used to indicate ambient temperature conditions used for correcting the main thermometer reading.

The main thermometer is essentially a double-ended thermometer. In the upright or lowering position, it has a large reservoir of mercury at the lower end connected by means of a fine capillary to a small bulb at the upper end. The capillary is constricted and branched just above the reservoir. This branching point is called the appendix dead arm. The function of the appendix dead arm is to provide a means of separating the mercury in the reservoir. Above the appendix dead arm, the thermometer is bent in a 360° loop, referred to as the pigtail, and then continues straight and terminates with the bulb at the upper end.

The main thermometer is so constructed that in the upright or lowering position mercury fills the reservoir, the capillary, and sometimes part of the bulb, depending upon the temperature. When the thermometer reverses, the mercury column breaks at the appendix dead arm and descends into the bulb, filling it and part of the stem, thus indicating the temperature at the depth of reversal. The mercury remains at this reading until the thermometer is returned to the upright position; then the mercury drains from the bulb and back into the reservoir.

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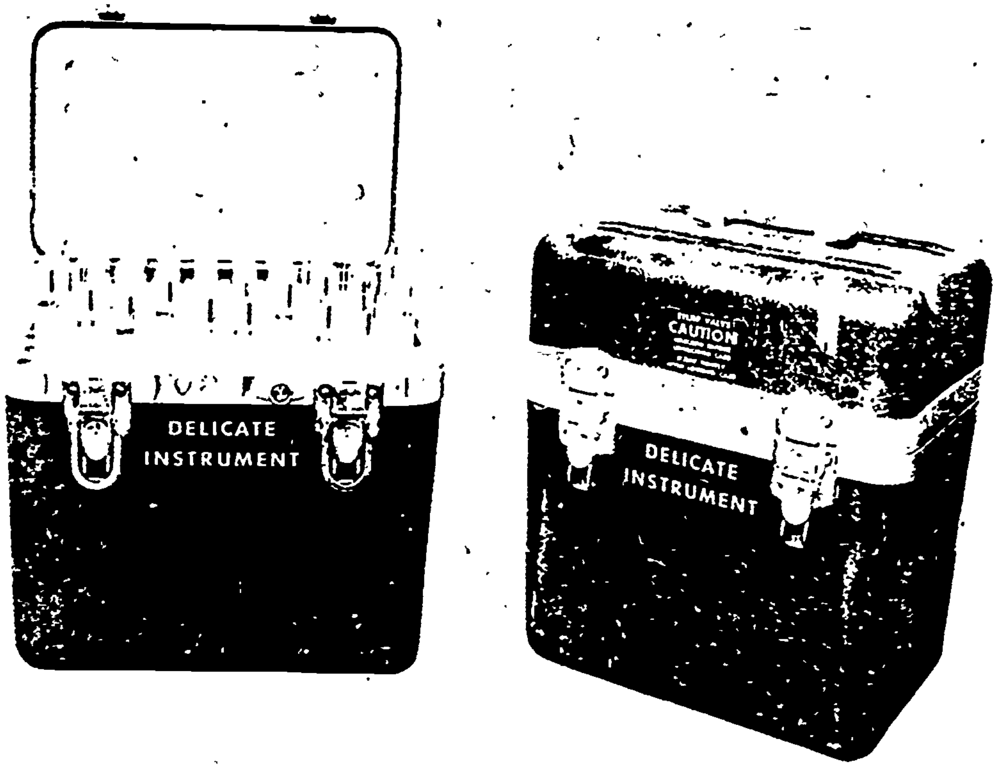


Figure 52.— Special carrying cases
for storing and transporting thermometers.

The protected and unprotected thermometers are similar in basic construction; however, the protected thermometer is enclosed in a sealed glass jacket that protects the thermometer from hydrostatic pressure. The space surrounding the reservoir of the main thermometer is filled with mercury to insure good thermal sensing qualities, thereby giving a true reading of the surrounding water parcel. The unprotected thermometer has a glass jacket; but unlike the protected thermometer, the unprotected thermometer is subjected to hydrostatic pressure because there is an opening at one end to allow direct contact with the water. The readings indicated by the unprotected thermometer are a result of both water temperature and water pressure. The unprotected thermometer is very useful for determining the depth at which the thermometers were reversed. This depth is called thermometric depth and is compared to desired depth to determine accepted depth.

When you are handling reversing thermometers, take care NEVER to allow a thermometer to lay on its side. The reason for this is that the construction of these thermometers is such that, if they are in a horizontal position, the mercury in the main thermometer may become separated. This separation can trap gas in the stem and cause the instrument to malfunction. For this reason, thermometers are always transported from one vessel to another by hand-carrying.

A special carrying case (figure 52) is made for the storage and transport of these thermometers. These cases are padded with shock absorbent material and have compartments for either 48 or 60 thermometers. The thermometers are placed in the case with the reservoir end down; however, if the air temperature is expected to drop to -10° C or lower, the thermometers should be reversed to prevent damage to the auxiliary thermometers. The reversing thermometers should be reversed once each 24 hours to insure satisfactory functioning of these instruments. If no observational programs are expected within a 5-day period, the exercise period may be reduced to once every 48 hours.

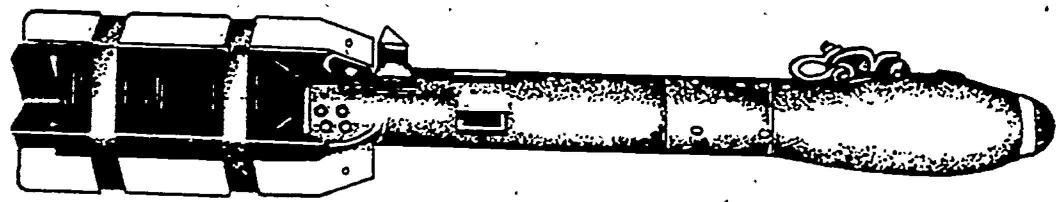

Figure 53.— Bathythermograph (BT).

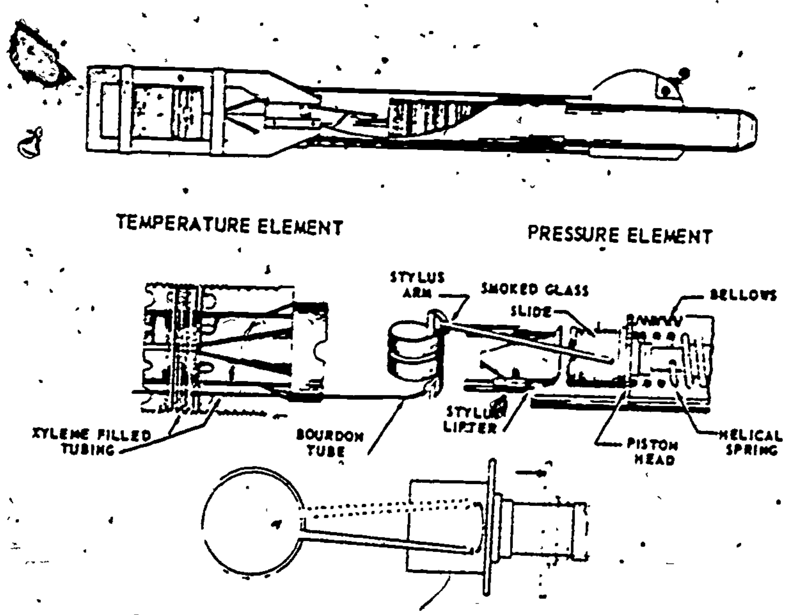


Figure 54.— BT temperature and pressure elements.

In N. O. Pub. 607, there is a chapter about manipulating malfunctioning reversing thermometers. The only malfunction that is considered to be correctable aboard ship is the malfunction referred to as FTD (fails to drain). This is the condition that exists when the mercury does not properly empty out of the bulb when the thermometer is righted. This condition is easily recognized and should be handled as outlined in N. O. Pub. 607.

Mechanical Bathythermograph (BT)

The best single index to subsurface conditions is the temperature distribution in the upper layers of the ocean. An important instrument for measuring this distribution is the bathythermograph (BT), a device which records the sea temperature variation with depth. The mechanical BT can be operated at ship speeds up to 18 knots, with the best operation at speeds of 12 knots or less. The mechanical BT is a brass, torpedo-shaped fish containing sensing elements for measuring temperature and pressure, and a recording slide coated with a stable gold alloy. (See figures 53 and 54.)

The thermal element, corresponding to the mercury column in a glass thermometer, consists of about 45 to 50 feet of fine copper tubing filled with xylene. The tubing is wound around inside the tail fins of the BT and comes into direct contact with the sea water. As the xylene expands or contracts with the changing water temperature, the pressure inside the tubing increases or decreases. This pressure change is transmitted to a Bourdon tube, a hollow brass coil spring which carries a recording stylus at its free end. The stylus records the movements of the Bourdon, as it expands or

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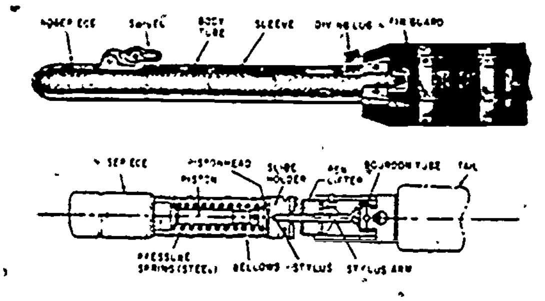

Figure 55.— The BT and its parts.

contracts with changing temperatures, on a coated glass slide. The slide is held rigidly on the end of a coil spring enclosed in a copper bellows (sylphon cell). For a view of the bellows and a further breakdown of construction, refer to figure 55.

Water pressure, which increases in proportion to depth, compresses the sylphon as the BT sinks. This depression of the sylphon pulls the slide toward the nose of the BT at right angles to the direction in which the stylus moves to record a combined record of temperature versus depth (pressure). The maximum depth range of a BT varies and is stamped on the nose of the BT.

Since external pressure slightly affects the internal pressure of the xylene in the Bourdon and since temperature changes also influence the movement of the sylphon, each instrument must be carefully calibrated by the manufacturer.

A temperature of 105° F will bring the recording stylus up against a stop pin; if this temperature is exceeded, permanent deformation of the brass coil of the Bourdon will occur and the calibration of the instrument will be ruined. For this reason always keep the BT out of the sun and away from the vicinity of firerooms, steampipes, and other sources of heat. An instrument that has been overheated may have the stylus arm jammed by the pen lifter bar in the high temperature position. If another BT is aboard, use it and turn in the damaged instrument for adjustment. If a spare is not available, gently lift the stylus arm from the pen lifter bar and let it swing back to the low temperature side. The temperature calibration will henceforth be in error as a result of deformation of the Bourdon.

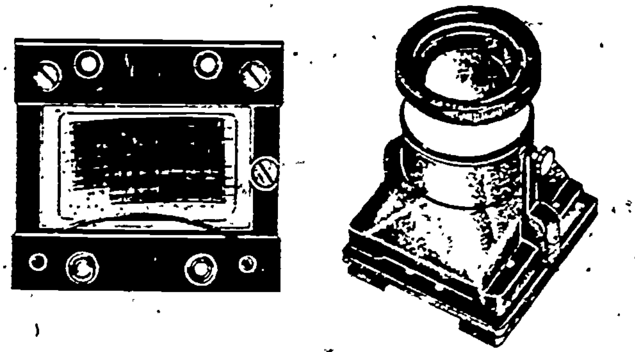

Figure 56.— Grid mount assembly and slide viewer.

The BT is an accurate measuring instrument; and while the construction is reasonably rugged, the internal mechanisms are delicate. Careful handling is essential to maintain the accuracy of the measuring elements.

After each period of use, rinse the BT with fresh water. Never store a BT that is being withdrawn from the water without thoroughly rinsing it. Rinse the interior of the BT with one-half cupful of grade III rust preventive compound each week. Place the BT in a clean bucket with the tail fins down. Slide the sleeve forward toward the nose, pour in the compound, and close the sleeve. Then cover the four ports in the body, shake the BT and turn it over on its nose and back several times so that every part is covered. Let the compound drain out. The compound can be used several times as long as it is clean. Do not oil the BT; fresh water rinses after each use and rust preventive compound rinses weekly comprise all the lubrication necessary.

A special grid is supplied with each BT for converting the stylus trace to values of temperature and depth. These grids are not interchangeable between instruments. It is the design of the grid that compensates for the external pressure forces acting on the sylphon and the Bourdon tube.

A BT slide viewer and grid mount such as that shown in figure 56 is used. The BT slide, as seen through the viewer, is shown in figure 57.



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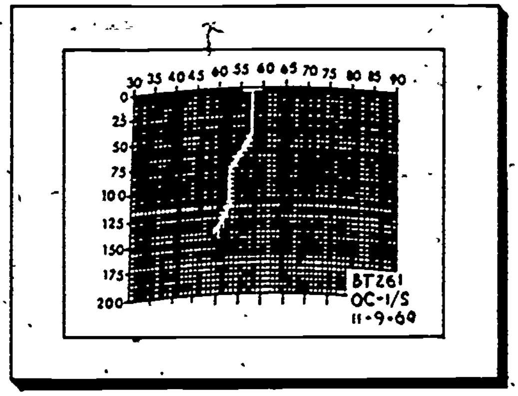


Figure 57.— BT slide as seen through the viewer.

BT slides are packed in plastic boxes of 50 each. The slides have a very stable alloy coating on one side; nevertheless, handle the slides by the edges only. Inspect the slides when opening a new box, and report any defects in accordance with current NavShipSysCom instructions.

Slides currently in use are of two types: smoked glass, which has been in use since the BT was designed in 1938, and staballoy, a glass slide coated on one side with a stable gold alloy. The staballoy slides are now replacing the older smoked glass slides; however, you may encounter both types.

When you remove used slides from the BT after making an observation, label them, rinse them in fresh water, and return them to the plastic box. BT slides are a standard stock item in the electronics system and are obtained through any normal supply channel.

Figures 58 and 59 show how a slide is inserted in the BT and how the slide is marked. These procedures will be covered in greater detail in the pamphlet covering observational procedures.

It is advisable to check the BT from time to time for temperature and depth errors. Most errors result from exceeding the maximum temperature and depth range and from improper handling. To discover malfunctions, compare the traces of two BT's which have been lowered in the same water. Determine temperature errors by immersing the thermal elements of the BT

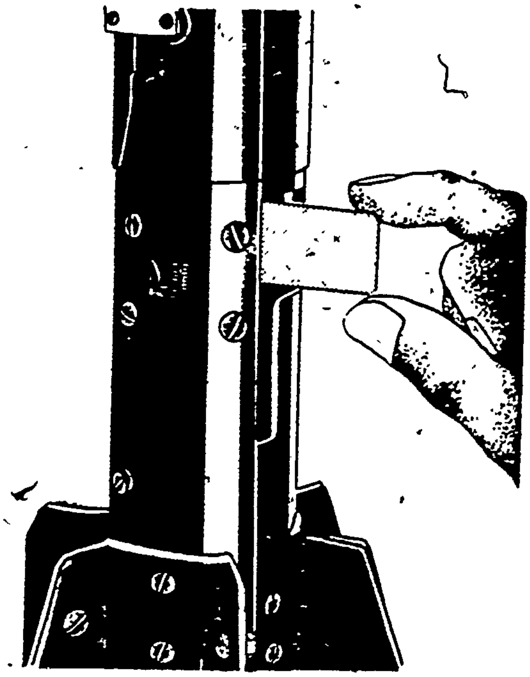

Figure 58.— Inserting the slide.

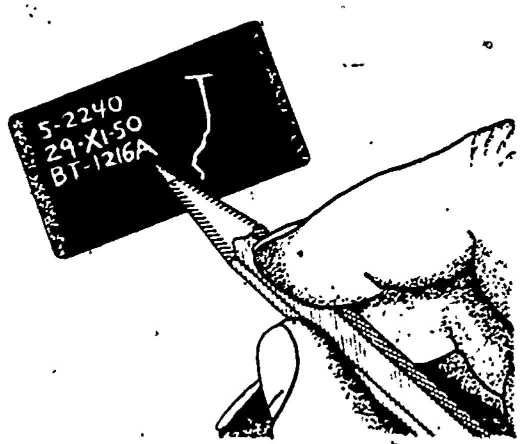


Figure 59.— Marking the slide.

in a bucket of water and measuring the water temperature with a bucket thermometer. Determine depth (pressure) errors when the ship is hove-to and lower the BT with a zero wire angle.

Use the following limits of error as a guide in determining need for repair or recalibration:

1. The temperature of the BT differs from the bucket temperature consistently by 4° F or more.



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2. The temperature of the BT shifts erratically from reading to reading, as compared to the bucket temperature or another BT.

3. The BT shows double traces over the entire length of the trace.

4. The BT shows a depth error of more than 10 feet for a 200-foot instrument, 20 feet for a 450-foot instrument, or 40 feet for a 900-foot instrument.

5. The stylus is dull and consistently produces a wide trace regardless of cleaning.

6. The date of the last calibration is more than 18 months past.

If the BT exceeds any of the above limits, or fails to operate satisfactorily, turn it in to the nearest Bathythermograph Repair Facility along with all its accessories, including grids and grid mount assembly. The addresses for the existing repair facilities are as follows:

1. Bathythermograph Repair Facility
   Boston Naval Shipyard
   Boston, Mass. 02129

2. Bathythermograph Repair Facility
   Mare Island Naval Shipyard
   Vallejo, California

3. Bathythermograph Repair Facility
   Pearl Harbor Naval Shipyard
   Navy #128
   c/o Fleet Post Office
   San Francisco, California

Requests for BT replacements should be submitted to NavShipSysCom in accordance with existing instructions.

Complete descriptions of the mechanical BT, slide, grid, and related equipment, along with instructions for taking a BT observation can be found in NAVOCEANO Pub. No. 606-c, Oceanographic Office Observers Manual — Bathythermograph Observations.

Expendable Bathythermograph

Expendable bathythermographs have recently been evaluated as a replacement for the mechanical bathythermograph. This program has resulted in instrumentation that is far superior to mechanical bathythermographs in accuracy, utilization, and total cost per reading.

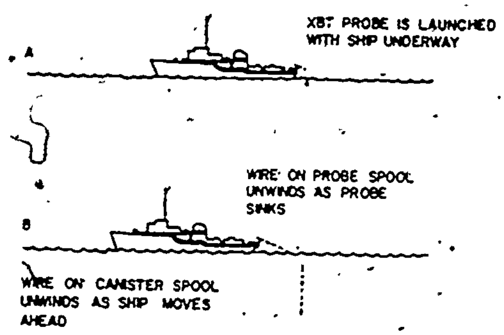

Figure 60.— Launching the XBT.

Shipboard Expendable Bathythermograph.— The Bathythermograph Set AN/SSQ-56, which is built by the Sippican Corp., is an automatic method for obtaining and recording ocean temperature data from shipboard while underway (figure 60). The system, which can be operated in virtually any sea state without changing the ship's normal mode of operation, obtains a complete temperature profile to a depth of 1,500 feet in 90 seconds. Temperature readout is in ° F and feet, unless the optional ° C and meters chart is used.

The basic units of the system and their relationship are shown in figure 61. The units are the probe (the expendable portion of the system), the launcher, and the recorder (figure 62). Once the probe has been manually released from the launcher, the system automatically records the temperature profile to the maximum depth rating. Up to 200 profiles can be made on a single roll of chart paper.

The probe release function requires an operator to be stationed at the launcher. No standby is required at the recorder after checkout unless communication of information from individual probe drops is necessary.

In operation, the expendable canister is placed in the launcher and the breach is closed (figure 63). This action results in a waterproof electrical connection between the recorder and the probe. To launch the probe, pull a pin which

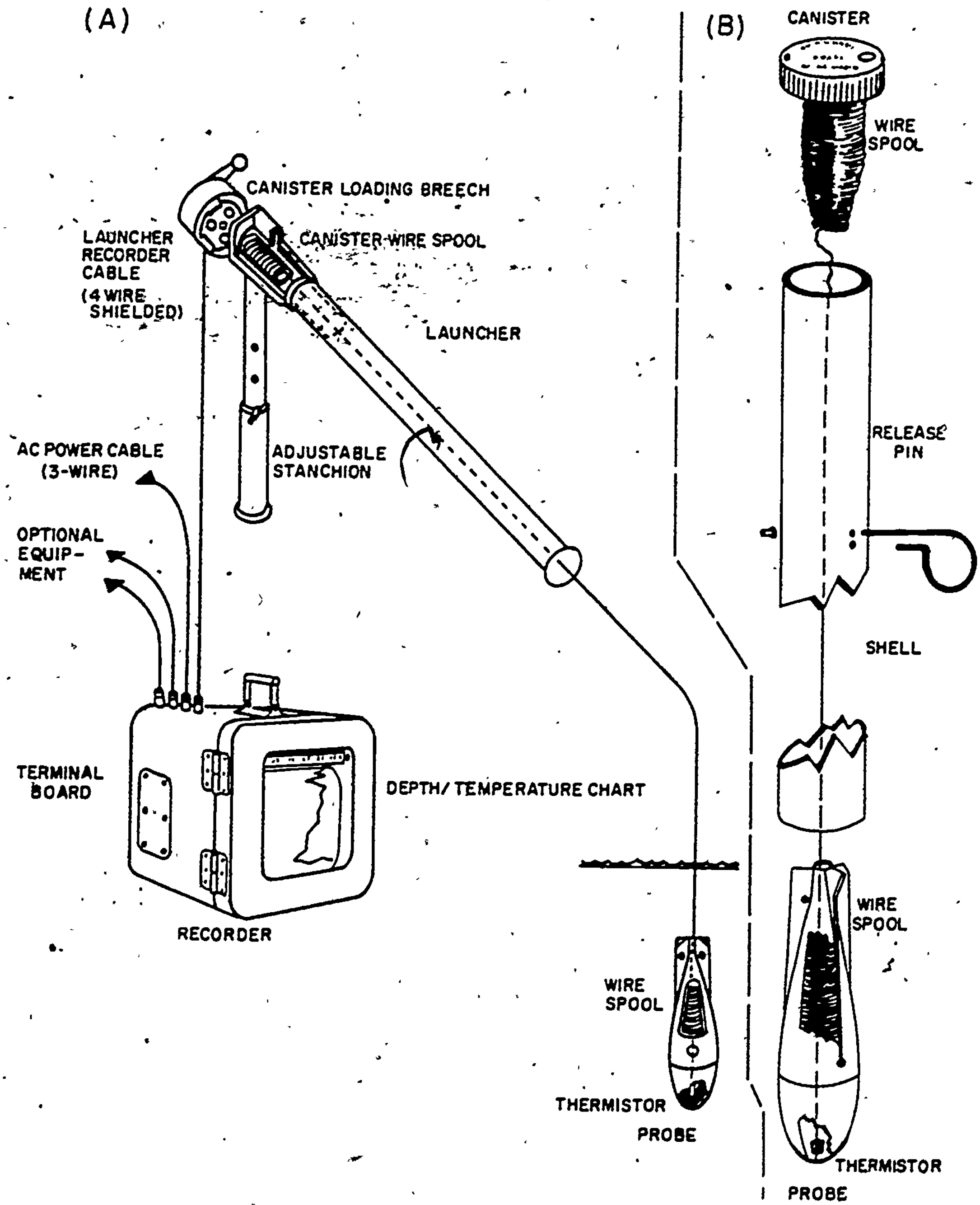


Figure 61.— System relationship of units for AN/SSQ-56.

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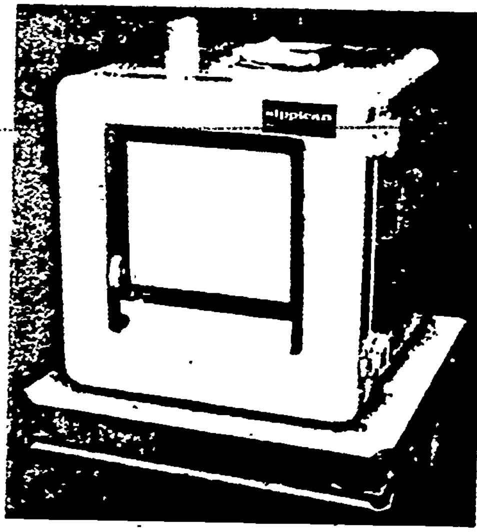

Figure 62.— Recorder.

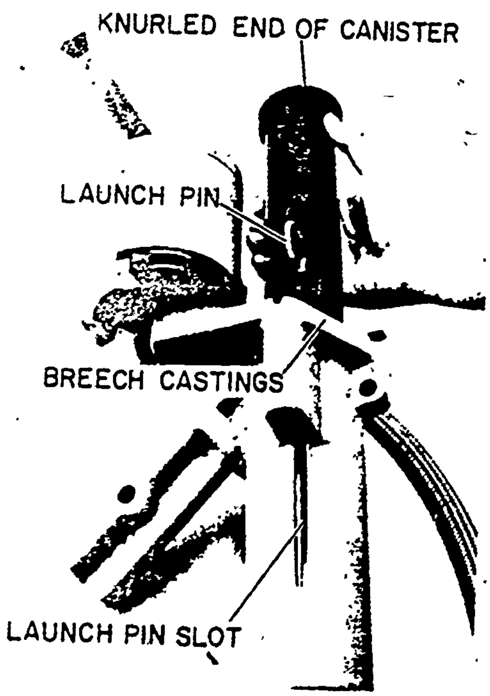


Figure 63.— Loading canister in breech.

protrudes from the launcher and holds the probe in place. The probe is then free to fall from the canister and down the launch tube. As the probe, which is wire-linked back to the launcher, strikes the water, an electrode triggers the recorder. The probe then descends at a known rate. Both the probe and the canister in the launcher contain specially wound spools of wire. Since the wire is spooling from both ends, it remains stationary in the water and the ship is free to proceed with virtually no restrictions on speed or maneuvering.

A thermistor in the probe measures temperature variations in the water to a depth of 1,500 feet, at which time the wire in the probe and in the canister (for a ship proceeding at 30 knots) is expended and breaks. The empty canister is left in the launcher to protect the contacts and is discarded prior to another launch. The resulting strip chart is used in the usual manner. The tolerances and equipment for this system are listed in table 3.

A cost effectiveness study comparing accuracy, utilization, and cost of mechanical bathythermographs and XBT's was conducted to determine whether the new system could effectively replace standard bathythermographs. The results of this study show a significant cost, accuracy, and utilization improvement for the XBT system. An important factor in this study was the cost of fuel expended in speed changes necessary to obtain mechanical bathythermograph readings during certain tactical situations.

Expendable bathythermograph systems have been discussed for some time as an alternative to mechanical bathythermographs. Not until recently, however, has the technology been available to build such a system at a reasonable cost. The following three major factors are involved:

1. The determination that the terminal velocity of a probe falling through water is reproducible enough, under all environmental conditions, to enable the use of time as a measure of depth in lieu of a depth sensor.

2. The ability of thermistor manufacturers to produce large quantities of reproducible, inexpensive thermistors with fast response characteristics.

3. The ability of wire manufacturers to produce extremely long lengths of special wire with no pinholes.

Table 3.— Tolerances and equipment associated with the AN/SSQ-56.

TOLERANCES

SYSTEM

| | |
|---|---|
| Temperature range | 28° to 96° F or -2° to 35° C |
| Temperature accuracy | ±0.4° F full range or ± 0.2° C |
| Depth range | 0 to 1500 feet with T-4 probe |
| Depth accuracy | ± 2% or 15 feet, whichever is greater |
| Deployment cycle time | 90 seconds for 1500-foot drop |
| Ship speed | 0 to 30 knots |
| Gradient resolution | 63% of a step change in temperature in 3 feet; 95% of a step change in temperature in 9 feet |
| Full-scale pen travel | 1 second |
| Operating modes | (a) Check mode<br>(b) Launch mode<br>(c) Measure mode<br>(d) Reload mode |

RECORDER

| | |
|---|---|
| Power supply requirements: | |
| Nominal | 120 VAC 60 Hz, 1-phase, 25 watts |
| Range | 107 - 127 VAC 57 - 63 Hz |
| Accuracy | ± 0.2° F |
| Chart (available in °C and meters or °F and feet) | 200 probe drops per chart |

EQUIPMENT

| Package | Equipment | Size | Weight |
|---|---|---|---|
| Cardboard carton | Probes (12 per carton). | 14 1/4 x 11 1/4 x 17 1/4 in. | 38 lb<br>17.3 kg |
| Wooden container | Launcher (with 100 ft. cable) | 62 x 12 1/4 x 10 1/4 in.<br>158 x 31.1 x 26 cm | 110 lb<br>64.4 kg |
| | Calibration canister. | --- | 50 kg |
| | Canvas cover safety chain. | --- | --- |
| Wooden container | Recorder (with power cable). | 16 x 20 1/2 x 18 in.<br>40.6 x 52.1 x 45.7 cm | 57 lb<br>25.9 kg |
| | Extra chart paper. | --- | --- |
| | Instruction manual. | 2 copies | --- |

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Figure 64.— Bathythermograph Transmitter Set AN/SSQ-36.

The XBT system in its present configuration is being installed in certain ships to support special programs. General fleet introduction will proceed subsequent to the development and evaluation of an appropriate recorder and an inboard launch capability. Experience gained from present installations indicates that launch through a hull opening well aft and above the waterline may be the optimum solution.

The new system will not only provide a marked improvement tactically, but will provide more reliable and easily processed data for such applications as environmental prediction programs.

Airborne Expendable BT (AN/SSQ-36).— Bathythermograph Transmitter Set AN/SSQ-36 (BTS) is an expendable unit designed to be dropped into the sea from an aircraft. When

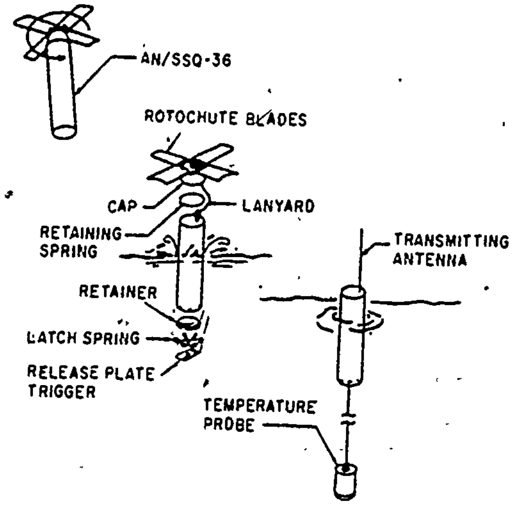


Figure 65.— Sequence of operation.

deployed, the BTS detects and transmits sea water temperature data to the dispensing aircraft or another suitable receiving station.

The design of the unit is such that all operating adjustments and preparations for use are made at the time of manufacture. For this reason, no preflight checking or adjustment is required. Likewise, since the equipment will be expended in operation, neither maintenance nor service will be required in normal usage.

This system determines sea water temperature from depths of sea level to 1,000 feet. It transmits this information to a receiving aircraft for recording an interpretation. (See figure 64.)

The drop limitations from the aircraft range from a maximum speed of 150 knots at a minimum altitude of 150 feet to a maximum speed of 250 knots at 500 feet.

When the BTS has cleared the launching tube of the aircraft, a rotochute (an assembly of four autorotational blades) opens to stabilize and slow the descent of the BTS. When the BTS strikes the water, the rotochute is jettisoned. (See figure 65.)

Upon entering the water, the lower section of the BTS becomes flooded, permitting the sea water battery to activate. Approximately 5 seconds later the transmitter section of the BTS emits a continuous, unmodulated, VHF

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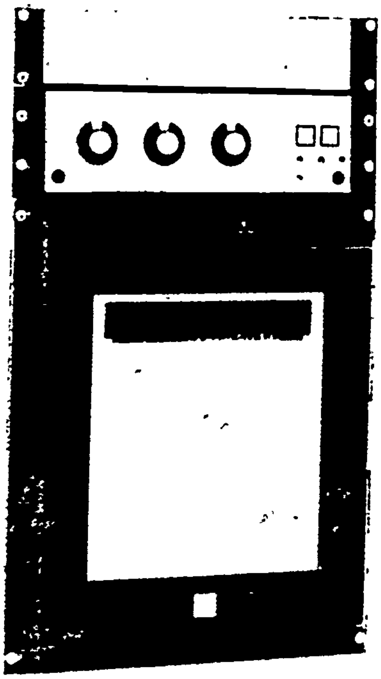

Deck Equipment

Underwater Unit

Figure 66.— Model 9040 Salinity-Temperature-Depth Measuring System, Overall View.

carrier signal. After transmitting the carrier for approximately 30 seconds, a timing circuit releases the temperature probe, permitting it to descend at a constant rate. Simultaneously, the VHF carrier signal is modulated by an audiofrequency signal generated within the descending probe. This audiofrequency signal varies directly in frequency with changes in the water temperature environment of the descending probe.

The probe descends at a constant rate of 5 feet per second until its terminal depth of 1,000 feet has been reached. The receiving aircraft records temperature variations transmitted by the BTS. Integration of the known time rate of the probe descent with water temperature data provides accurate recordings of the sea water temperature/depth relationship. An automatic timing circuit causes transmission to cease after approximately 6 minutes.

The BTS incorporates an automatic scuttling device consisting of a water-soluble plug in the outer casing below the waterline. When the plug dissolves, water is permitted to enter the watertight compartment, causing the BTS to sink. The floating period of the BTS is a function of water temperature; the plug dissolving more rapidly in warm water than cool water. In no case, however, is the dissolving time less than 15 minutes nor more than 15 hours.

A detailed description of individual components is contained in the handbook accompanying the equipment.

Salinity-Temperature-Depth Measuring System

The Salinity-Temperature-Depth (STD) Measuring System currently used in the Coast Guard is the Model 9040 system that replaces the Model 9006 system. The STD is manufactured by the Bissett-Berman Corporation and consists of a compact, rugged, underwater unit and a cabinet containing surface deck terminal equipment (figure 66). The underwater unit is equipped with precision transducers which sense salinity,



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temperature, and depth data. Solid-state electronics in the underwater unit convert the sensed parameters into a composite FM data signal which is transmitted through a sea cable to the surface deck terminal equipment for processing and recording. The deck terminal equipment separates individual data signals from the FM composite signal and records salinity and temperature data as a function of depth on pressure-sensitive paper in the plotter.

Functional Description.— Figure 67 is a block diagram of the Model 9040 STD system. The system consists of the underwater unit connected via a winch system to the surface deck terminal equipment. The winch system consists of the sea cable, slip rings, and connecting cable. External 115 VAC line power is converted in the deck equipment to regulated 28 VDC for the signal converter electronics and to 150 ma constant current for the underwater unit. With

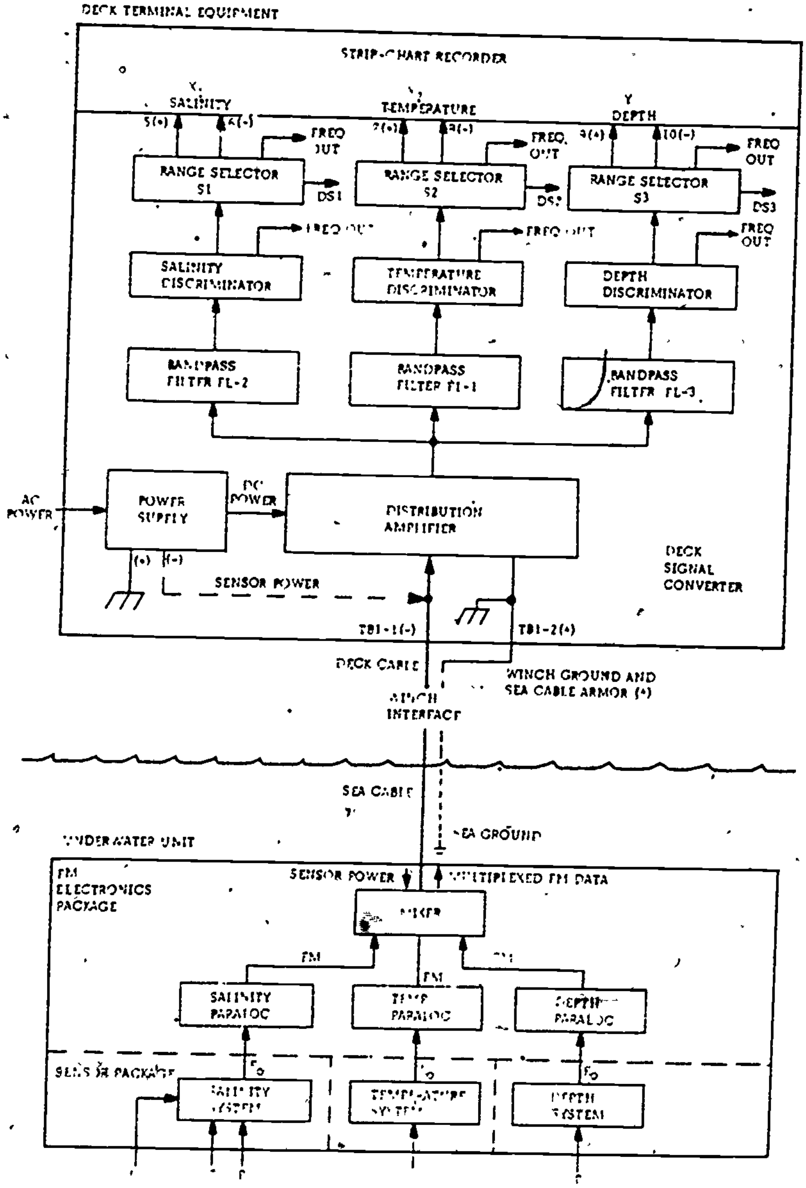


Figure 67.— Model 9040 Salinity-Temperature-Depth Measuring System, Block Diagram.

power applied, the STD equipment automatically measures and records the sensed variables of seawater properties.

The underwater unit consists of the salinity, temperature, and depth sensors; a Bissett-Berman PARALOC oscillator (which is an integral part of each sensor); and a mixer circuit. The salinity, temperature, and depth transducers and their associated solid-state electronics are located in the sensor package section of the underwater unit. The Paraloc circuits, the salinity system balance amplifier, and the mixer are located in the FM electronics section of the underwater unit.

Seawater salinity is determined in situ by sensing conductivity, temperature, and pressure. Conductivity is measured by sensing the conductivity of dissolved solids in the seawater which provide an inductive loop that couples two transformers in the conductivity head. Seawater conductivity is a complex function of temperature, pressure, and salinity; and in the Model 9040 system, automatic compensation is continuously applied for the effect of temperature and pressure changes, as well as for a temperature effect on depth. These compensations provide an output which is a direct function of salinity alone and which is directed to a Paraloc that generates an FM signal which is an analog of the measured salinity.

The Paraloc is an AC voltage-to-frequency converter which operates within a fixed FM bandwidth that is established for each measured parameter. Output signal changes from the Paraloc are directly proportional to input voltage variations. The result, then, of a change in seawater salinity is an FM signal, the frequency of which increases with increasing salinity and decreases with decreasing salinity. This signal is applied to the mixer.

The temperature transducer is a platinum-resistance thermometer which forms one leg of a bridge. It is completely protected from strain caused by ambient pressure and, even at great depths, maintains a short response time. Variations in temperature change the resistance of the platinum conductor and, consequently, change the voltage dropped across it. This voltage is applied to a Paraloc circuit, which generates an FM signal analogous to the voltage differential created by changes in temperature. This signal is transmitted to the mixer.

The depth system incorporates a pressure transducer containing a strain-gage bridge which is in balance at zero psi and becomes increasingly unbalanced as pressure increases. Resistance changes in the bridge circuit are converted to a frequency analog in the Paraloc and are transmitted to the mixer.

The underwater signal mixer receives and regulates power from the deck terminal equipment and transmits it to the sensors. It also multiplexes and amplifies FM signals from the Paralocs and transmits them up the sea cable to the deck terminal equipment. Multiplexing all data into an FM composite signal permits continuous and simultaneous transmission of all sensor data to the deck unit in a single conductor sea cable.

The mixer receives 150 ma constant current from the deck power supply and converts it to regulated voltage. Constant current instead of constant voltage is supplied from the deck, because variations in cable impedance would cause variations in line drops, with subsequent variations in the voltage supplied to the sensor systems. The current remains constant and does not change due to cable drop. The incoming constant current is regulated to 6 VDC and 28 VDC in the mixer and is supplied to the sensor and Paraloc circuits.

The signal converter unit contains the power supply, the distribution amplifier, and a discriminator for each sensor. These components are all plug-in circuit board modules. A band-pass filter at the input of each discriminator accepts a specific sensor signal and rejects the others in the FM composite signal. Separate salinity, temperature, and depth front panel range-selection controls provide for expanded range switching of each sensor data channel to allow the extreme accuracy of each signal to be displayed within the resolution of the recorder.

The front panel of the signal converter unit also contains a POWER ON switch for applying power to the STD system and a TEST/OPERATE switch for selecting operating mode of the signal converter unit. In OPERATE mode, the switch connects the input of the distribution amplifier to the sea cable and the output to the TEST jack for monitoring the composite data signal during normal operation. In TEST position the distribution amplifier receives its input from the TEST jack rather than from the sensors, permitting insertion of signals from an oscillator for routine maintenance checks.

The power supply circuit is functionally divided into a constant voltage supply and a constant current supply. The constant voltage section provides regulated +28 VDC to the signal converter electronics regardless of load variations. The constant current section provides regulated 150 ma current to the underwater unit as long as line impedance does not exceed 250 ohms. The power supply is energized by means of the POWER ON switch located on the front panel of the signal converter.

Amplification of the FM signal from the underwater units is accomplished in the distribution amplifier, which provides a low impedance output to drive the discriminators. This unit also separates data signals from the DC power which enters the distribution amplifier from the power supply. The distribution amplifier accommodates the composite input, amplifies the signal, and provides three output connections to the salinity, temperature, and depth filters leading to the discriminators. A fourth amplifier output is available for future installation of a fourth sensor channel, such as sound velocity.

The bandpass filters assigned to each discriminator are used for separating the sensor signal from the amplifier FM composite signal.

A separate discriminator plug-in card is provided for each parameter. All discriminator cards are identical and may be interchanged. In the discriminator, the accepted data signal is amplified in a preamplifier circuit and is then applied to a Schmitt trigger to produce a square-wave output whose frequency is the same as the sensor input. This square wave lights the front panel lamp over the range switch and is also supplied to one of the front panel test jacks for monitoring or for recording by external devices. The lamp provides an indication that the sensor is functioning within its band and that its signal is being received at the deck unit.

The square-wave output is further shaped in the discriminator and then applied to the frequency-to-DC converter, which produces a 0-10 mv output. This voltage is furnished to the plotter inputs to provide a record of salinity, temperature, and depth.

Table 4.— Range of Salinity.

| SALINITY Switch Position | Range Selected |
|---|---|
| 1 | 30.0 ppt to 32.0 ppt |
| 2 | 31.5 ppt to 33.5 ppt |
| 3 | 33.0 ppt to 35.0 ppt |
| 4 | 34.5 ppt to 36.5 ppt |
| 5 | 36.0 ppt to 38.0 ppt |
| 6 | 37.5 ppt to 39.5 ppt |
| 7 | 30.0 ppt to 40.0 ppt |

The salinity range switch on the front panel provides a 0-10 mv DC input to the plotter for any of the selected salinity ranges. There are seven ranges for the full range of 30-40 ppt, or expanded segments of the full range, as shown in table 4.

The temperature range switch provides a 0-10 mv DC input to the plotter for any of the selected temperature ranges. There are eleven ranges available for the full range of -2° C to + 36° C, or expanded segments of the full range, as shown in table 5. It should be noted here that switch positions 10 and 11 indicate temperatures above + 36° C and that position 11 indicates a temperature below -2° C. These last two scales are marked as indicated for readability purposes only and do not reflect an accuracy beyond that of -2° C to +36° C.

The depth range switch provides a 0-10 mv DC input to the plotter for any of the selected depth ranges. There are three ranges available for the full range of 0-3000 meters, or expanded

Table 5.— Range of Temperature.

| TEMPERATURE Switch Position | Range Selected |
|---|---|
| 1 | - 2°C to + 3°C |
| 2 | + 2°C to + 7°C |
| 3 | + 6°C to +11°C |
| 4 | +10°C to +15°C |
| 5 | +14°C to +19°C |
| 6 | +18°C to +23°C |
| 7 | +22°C to +27°C |
| 8 | +26°C to +31°C |
| 9 | +30°C to +35°C |
| 10 | *+34°C to +39°C |
| 11 | *-10°C to +40°C |

*System accuracy is guaranteed only from -2°C to +36°C. Ranges are marked as indicated for readability purposes only.

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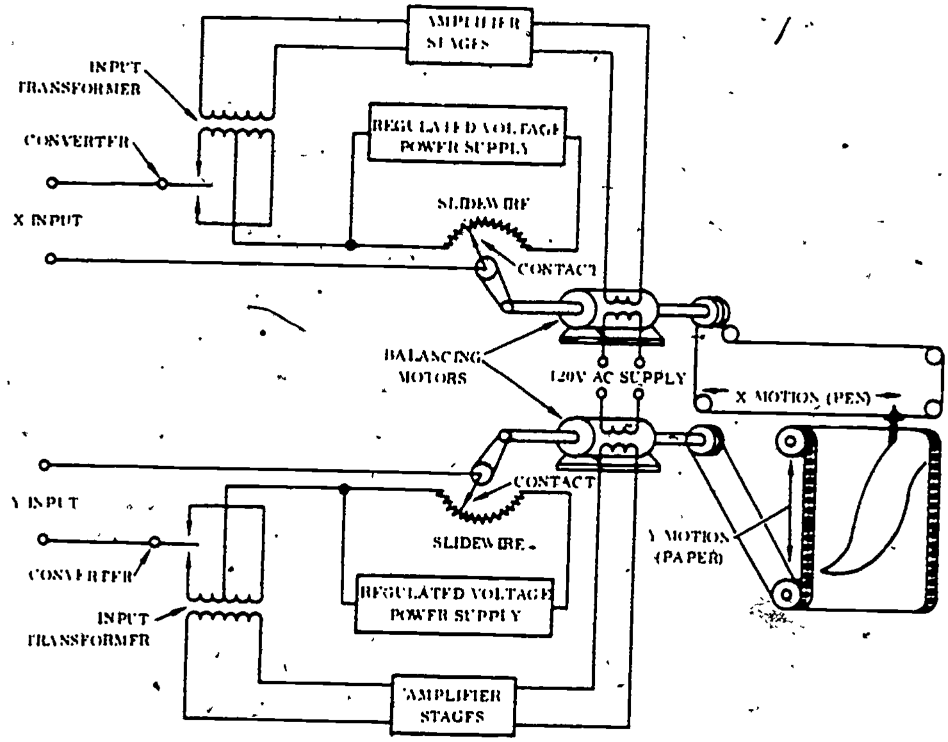


Figure 68.— Plotter Simplified Functional Diagram.

segments of the full range. These ranges are 0-750 meters, 0-1500 meters, and 0-3000 meters in switch positions 1, 2, and 3, respectively.

The discriminators drive a two-stylus strip chart plotter, which is equipped with three servo-amplifiers drive styli (commonly referred to as "pens") to record salinity and temperature. The difference between styli and pens is that pens leave a trace with ink, whereas in this case, the trace is caused by the pressure of the stylus on pressure-sensitive chart paper. The third servo-amplifier controls the chart drive mechanism, which moves the chart as a function of depth. The front panel of the plotter is equipped with a LINE switch that applies or removes power to the plotter. The individual solid-state servo-amplifiers each contain a power ON/OFF switch, damping controls, and a gain (sensitivity) control with coarse and fine adjustments.

The basic operating principles of the plotter are illustrated in figure 68. (Note that only one X function is shown; there are actually two X-functions, but both are identical so far as plotter operation is concerned.) Because all three systems operate at the same time and in the same manner, the following description of one of the null-balancing systems applies equally to the other two.

The essential parts of each null-balancing system are: (1) the null balancing measuring circuit, (2) the null-detector amplifier, (3) the balancing motor and linkage, and (4) the display system, that is, the plotting and indicating devices. The measuring circuit consists of an adjustable calibrated electromotive force (EMF) which is connected in opposition to the EMF being measured. If these two EMF's are not equal, an "error" or unbalance current flows and is detected by the amplifier's input circuit. The calibrated EMF is obtained from a measuring slidewire whose movable contact is positioned by the balancing motor until the calibrated EMF is equal to the EMF being measured.

Any error, that is, any difference between the EMF being measured and the calibrated EMF,



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is converted to VAC by means of a synchronous chopper and is then amplified by means of the amplifier. After amplification, the error signal is applied to the control winding of the reversible balancing motor, which then works through the mechanical linkage to adjust the calibrated EMF. The current in the driving coil of the synchronous converter is so phased that the amplified signal on the control winding is substantially in quadrature with the voltage applied to the line winding of the balancing motor. Thus, maximum motor torque is obtained for any unbalance in the measuring circuit.

The system is sensitive to the direction of error current so that the motor always adjusts the calibrated EMF in the proper direction to reduce the magnitude of the error current. The motor continues to drive until the error current is so small that the amplified signal will no longer produce motor rotation. Amplification is such that this occurs when the error current is substantially zero and the calibrated EMF differs by only a negligible amount from the EMF being measured. A null or balance condition then exists.

While adjusting the calibrating EMF, the motor also drives the display system. Therefore, the pointer and stylus position of either X function or the pointer position of the Y function directly indicates the calibrated EMF and hence the EMF being measured. The indicator scale of each function is marked in terms of the variable producing the measured EMF.

The $X_1$ stylus plots the salinity trace; the $X_2$ stylus plots the temperature trace. Both styli move from right to left and move full scale on the chart paper. Thus, the extreme right-hand stylus position corresponds to a zero-millivolt input from the discriminators, and the extreme left-hand position corresponds to the 10-millivolt input from the discriminators.

The chart drive moves the chart down on increasing voltage input. Thus, with the bottom of the chart at the bottom of the chart table, the input from the discriminators is maximum (10 millivolts) and with the bottom of the chart at the top, the input is zero millivolts.

Physical Description.— The underwater unit, figure 66, is a pressure housing that is constructed to withstand environmental effects of the ocean. The housing contains the sensor electronics. Redundant pressure seal design, where at least two independent sealing mechanisms are used on each penetration of the housing, eliminates the possibility of flooding. The underwater unit design enables up and down casts to be recorded with essentially the same accuracy.

Major components of the underwater unit are the FM and sensor electronics package and the sensing elements. A removable end cap permits access to the plug-in electronics package. The sea cable electrical connector is mounted on the end cap. An eye in the end termination permits lifting the underwater unit. The seawater sensing elements are protected by a metal guard ring encircling the sensor bulkhead.

The end cap is secured by six socket-head cap screws and is removable for gaining access to the electronics. A water tight connector on the end cap provides the electrical connection for sensor power and for data signals between the underwater unit and the single conductor sea cable.

The upper electronics (figure 69) contains the FM electronics package, which is comprised of six circular plug-in circuit cards. The six circuit cards, in descending order are: mixer, depth Paraloc, temperature Paraloc, operational amplifier, salinity Paraloc, and balance amplifier.

The lower electronics (figure 69) contains circular plug-in cards consisting of: salinity, second order temperature compensation, and temperature-depth circuits. The temperature, pressure, and salinity bridge compensation circuits are also mounted on these cards.

All seawater sensing elements are mounted at the lower end of the housing and are sealed with redundant pressure seals to ensure maximum protection against flooding. The sensing elements consist of a conductivity sensor, two platinum-resistance thermometers, two thermistor probes, and two strain-gage pressure transducers. The sensors are identified in figure 70.

The deck terminal equipment (figure 71) is housed in a metal cabinet with top and rear access doors. The cabinet is designed for bolt mounting

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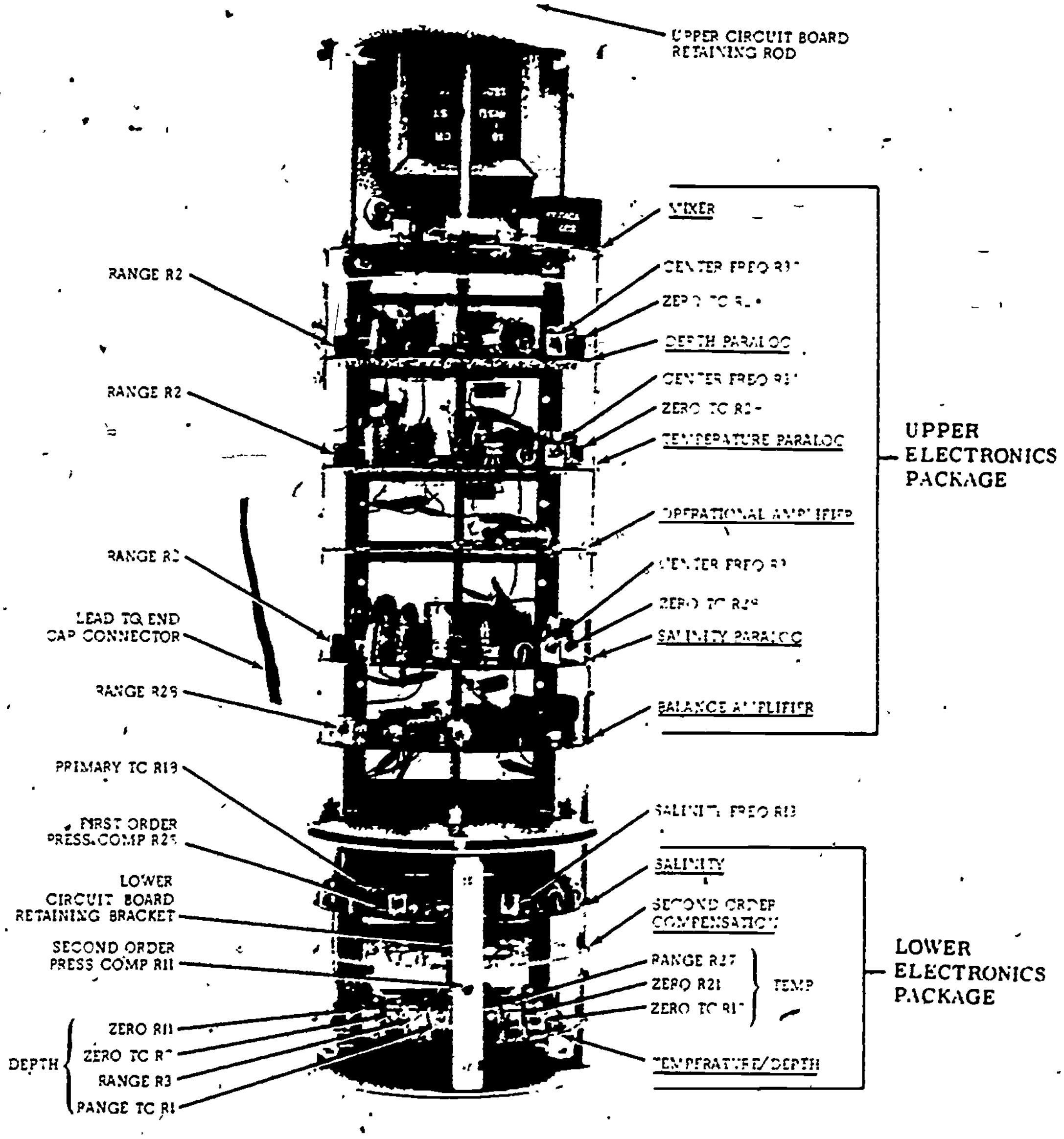


Figure 69.— Underwater Unit Electronics and Adjustments.

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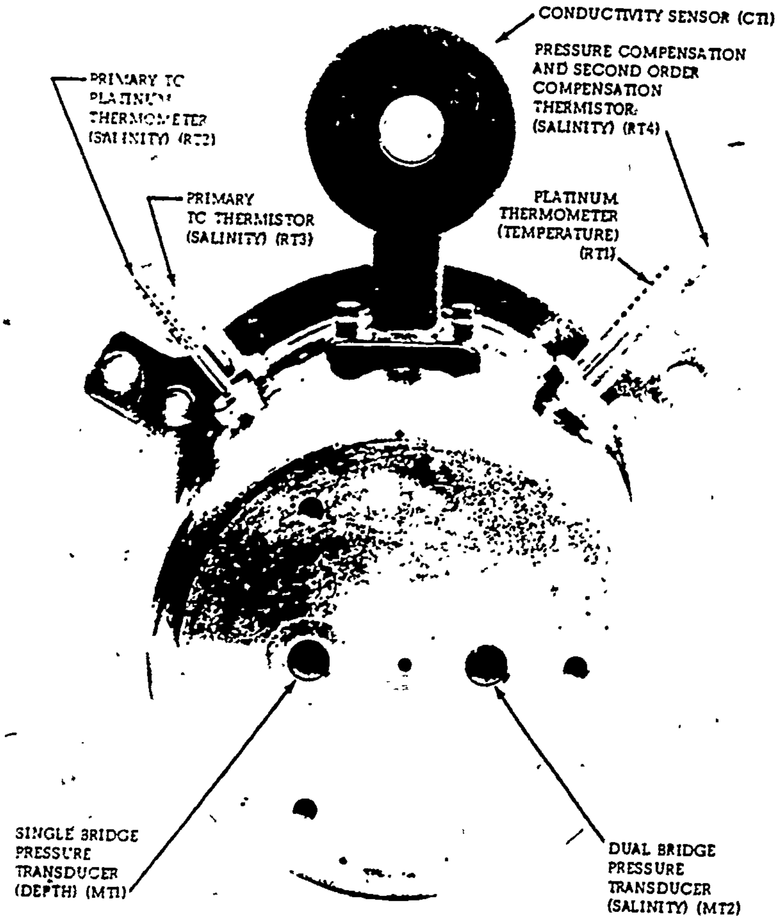


Figure 70.— Underwater Components.



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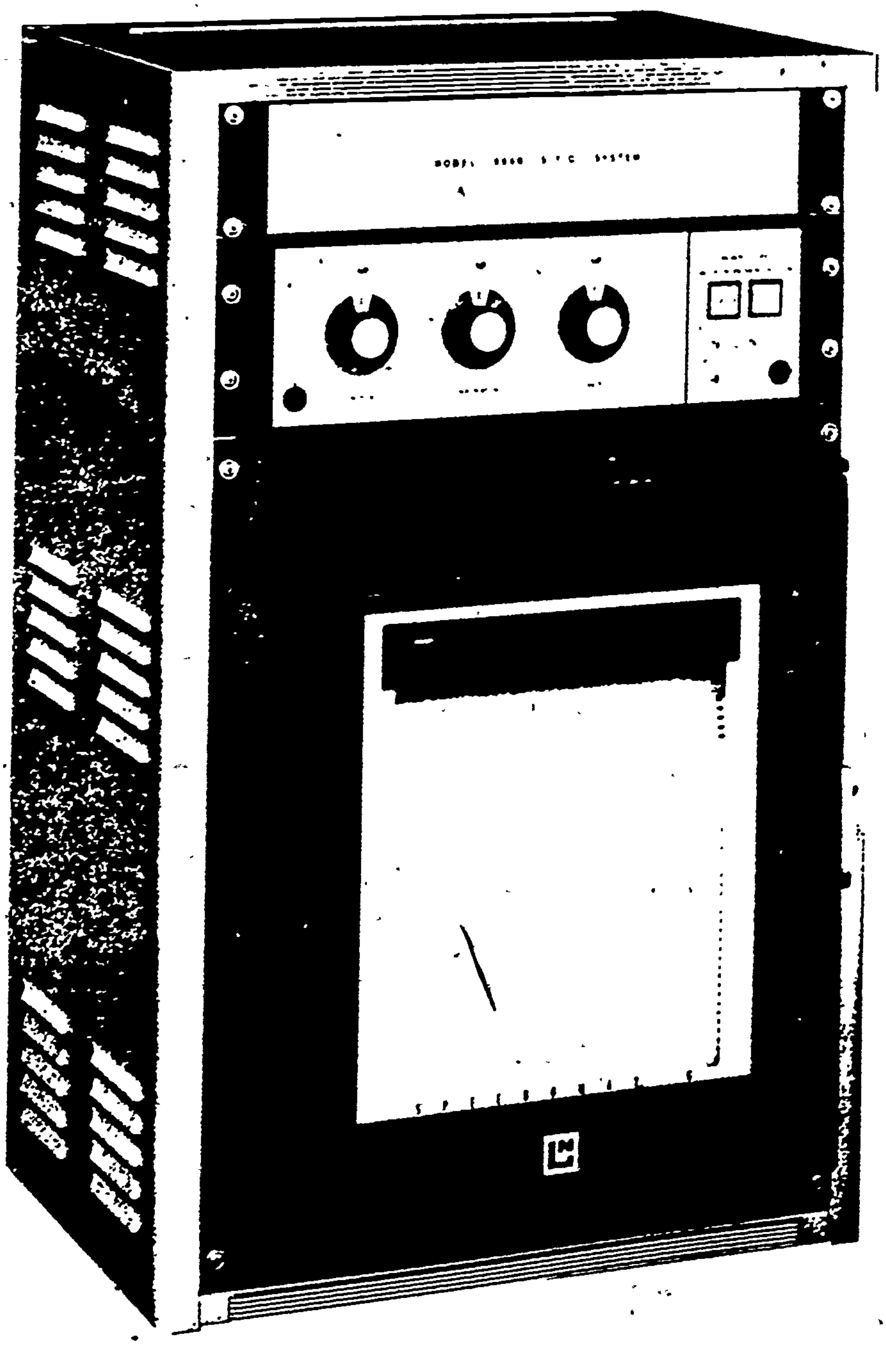

Figure 71.— Deck Terminal Equipment.

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Table 6.— Inspection Requirements.

| COMPONENT | INSPECT FOR | CORRECTIVE ACTION |
|---|---|---|
| Deck terminal equipment | Loose or missing hardware; accumulated dirt; dents | Clean, repair, or replace component |
| Cabling and wiring | Breaks, shorts, grounded leads; faulty insulation or terminals; improper clamping or support; inadequate lacing or tying; excessive slack or tension | Repair or replace damaged wire |
| Electrical connectors | Corroded or bent contacts; bent pins; dirt or oil on contacts | Clean, repair, or replace |
| Resistors, fixed and variable | Swelling, charring, and discolorations; loose pigtails; cracked or loose solder joints | Determine cause and replace as necessary |
| Capacitors | Leakage; loose pigtails; cracked or loose solder joints | Determine cause and replace as necessary |
| Printed circuit boards | Broken or loose eyelets; melted plastic; cracks | Repair or replace as necessary |
| Semiconductor devices | Broken or loose leads | Replace as necessary; use heat sink on connections when soldering |
| Transformers | Overheating; leaking; broken or loose wire connections | Repair or replace as necessary |
| Surface and underwater units | Dirt and fouling; loose or missing hardware | Clean and repair components as required |
| Temperature probes | Cleanliness | If very dirty, clean as described in text. |
| Conductivity head | Cleanliness; cracks in plastic jacket | If very dirty, clean as described in text. If cracked jacket, replace head. |
| Sensor electrical connectors | Cracks; bent pins; cleanliness | Repair, replace, or clean as required. Lubricate with lubriplate prior to connecting |
| Plotter gears, rails | Wear and dirt | Clean dirty bearing surfaces with a lint-free cloth dampened in trichlorethylene |
| | Noisy operation | Relubricate if parts are dry |
| Plotter slidewire | Dirt | Clean as directed in text. |

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on a table or other suitable surface and is provided with lifting lugs at the top. The cabinet is vented to allow cooling air circulation for the signal converter unit and plotter.

The signal converter unit is contained in a rack mount enclosure constructed from anodized aluminum. The front panel has a POWER ON pushbutton switch, a TEST/OPERATE pushbutton switch, and separate rotary switches for salinity, temperature, and depth range selection, with indicator lamps mounted above each range switch. The front panel also contains four standard weatherproof, bayonet-type connectors, commonly referred to as BNC connectors, for monitoring the FM composite sensor signal or the separate sensor frequencies. The interior of the enclosure contains a power fuse and plug-in circuit cards consisting of the power supply, the distribution amplifier, and three linear-frequency discriminator cards (salinity, temperature, and depth). Terminal strips at the rear panel provide connections for the sea cable and plotter. Access to the cabinet is gained through a hinged top panel or a removable back panel.

Operation.— The theory of operation given in the following paragraphs traces the power from the deck terminal equipment to the underwater unit back to the recorder of the deck terminal equipment.

The deck terminal equipment that provides power to the system and processes data signals from the underwater unit is comprised of a signal converter and a strip-chart recorder (plotter) enclosed in a cabinet. The signal converter (figure 67) is energized when 115-VAC, 60-Hz, single-phase power is applied through the POWER ON switch to the power supply module. The power supply module furnishes 150-ma constant current through interconnecting cabling to the underwater unit and +28 VDC to the distribution amplifier module and the discriminator modules in the signal converter. The deck signal converter has front panel range switches for changing the plotter measuring circuits from range to range as the salinity, temperature, and depth vary during the cast.

The 150-ma current turns on the mixer and Paralocs in the FM electronics, providing excitation to the salinity, temperature, and depth sensing circuits located in the underwater unit. The salinity, temperature, and depth data is then supplied to the Paralocs, which provide output frequencies that vary in proportion to the sensed data. The Paraloc frequencies containing the sensor data are multiplexed in the mixer and supplied to the sea cable.

The FM composite signal is transmitted up the sea cable and is received by the deck signal converter, where it is amplified by the distribution amplifier and applied to individual bandpass filters assigned to each discriminator. The filters separate the salinity, temperature, and depth frequencies from the FM composite signal and apply the separate frequencies to their respective discriminators. In each discriminator, the sensor frequency is amplified by a preamplifier circuit and is applied to a Schmitt trigger, the varying-frequency square-wave output of which is fed to a lamp driver circuit, to the front panel frequency output jacks, and to a flip-flop (multivibrator). The lamp driver amplifies the signal to illuminate an associated front panel lamp.

The flip-flop further shapes the Schmitt trigger square wave and applies a symmetrical square wave at half the input frequency to a power amplifier driving the frequency-to-DC converter. Output of the frequency-to-DC converter is a DC level proportional to the measured salinity, temperature, or depth parameter. Resistors on the range switches scale this output in 0-10 mv increments to drive the plotter $X_1$, $X_2$, and Y input circuits. Data is recorded on pressure-sensitive chart paper.

Maintenance.— Preventive maintenance of the equipment consists of routine inspection, cleaning, and lubrication to ensure that the equipment is maintained at optimum operating efficiency.

Inspect the system for evidence of damage, wear such as deterioration, and scratched or corroded surfaces. It is especially important to check buildup of sea organisms (fouling) on the conductivity sensor of the underwater unit. Keep this sensor clean to prevent loss of accuracy. The inspection period should be established as a function of the system's operating time. If operation is nearly continuous, inspections should be more regular than if the STD is used only occasionally. For normal operation, when the equipment is used at irregular intervals each week, perform the inspection procedures in table 6 on a weekly basis.

Table 7.— Cleaning Materials and Lubricants

| FUNCTION | MATERIALS |
|---|---|
| General Cleaning | Commercial Household Detergent |
| Cleaning Temperature Sensor Probe | 0.3 Normal Hydrochloric Acid |
| Cleaning Salinity Sensor Head | Bottle Brush |
| Cleaning Plotter Slidewire | Benzine or Trichlorethylene |
| General Plotter Lubrication | Leeds & Northrup Recorder Oil (medium weight, nondetergent) or equivalent |
| Lubricating Underwater Connector | Silicone grease |
| O-Ring Lubricant | Silicone grease or Barum grease (Parker O-Lube or equivalent) |

Clean the underwater equipment and deck terminal equipment as instructed in the following paragraphs. Table 7 contains a list of cleaning materials.

Rinse the underwater equipment with fresh water after each immersion. It is especially important to maintain the sensor probes and conductivity head free from excessive fouling caused by seawater and organic material.

Clean the sensor head hole only when visual inspection indicates that it is very dirty. Use any commercial household detergent and a bottle brush.

When a visual inspection indicates that a temperature probe is very dirty, clean it by filling a suitable container with 0.3 normal hydrochloric acid, placing the underwater unit in a position with the probe pointing down, and soaking the probe until the deposits are loosened. Then, brush the probe with soft brush or cloth and rinse it with fresh water.

Clean the connectors and coat them internally with silicone grease in order to exclude seawater and make it easier to install and remove connectors.

The deck enclosure and modules are fabricated from aluminum alloy and are protected by a clean anodized finish. If, after prolonged use and exposure, the finish becomes scratched, you can retouch it with commercially available brush-on chemical films such as clean iridite or alodine. Wipe clean the finish with lint-free dry cloth as needed.

Keep the interior of the plotter cabinet and the amplifiers dust-free by periodic vacuum cleaning. Wipe up spilled lubricants with a lint-free cloth. Clean the slidewire only when operation of the plotter is impaired by dirt on the slidewire. Periodic cleaning as a preventive maintenance procedure is neither required nor recommended as long as the plotter is operating satisfactorily. If cleaning is required, remove the slidewire cover by twisting the cover counterclockwise. Clean the slidewire with a clean lint-free cloth dampened in trichlorethylene.

The plotter requires periodic lubrication at the points shown in figure 72. Most points are lubricated with an oil can, but the pen slide bars are lubricated by a light wiping with an oily cloth. The gears are lubricated using a No. 3 or 4 artist's brush dampened with oil. A medium weight nondetergent oil is recommended for lubricating the plotter. Exercise caution to ensure that the slidewires are NOT oiled. Wipe clean all points to be oiled before you lubricate them, and wipe up all excess lubricant with a clean lint-free cloth.

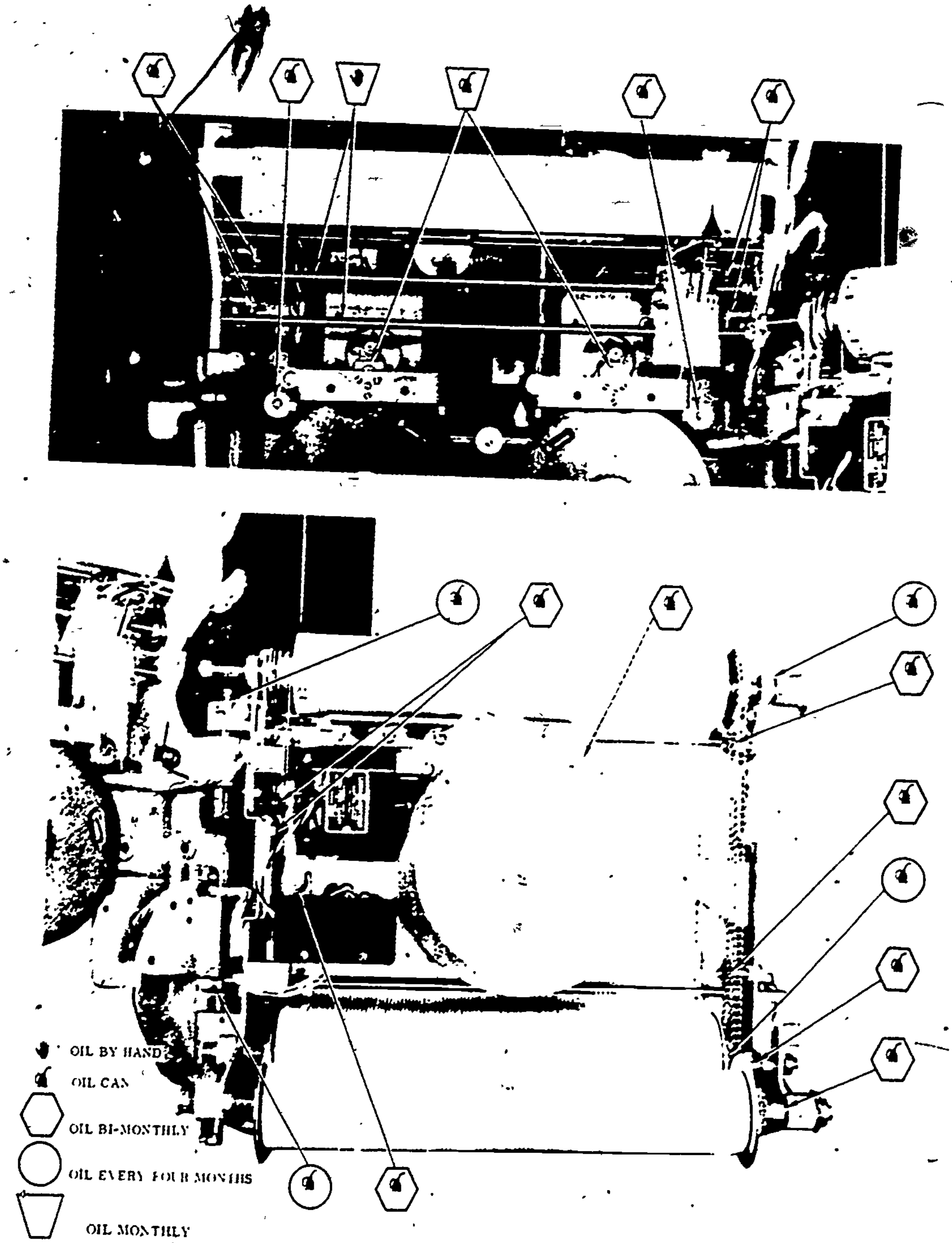


Figure 72.— Lubrication Points.

HOUSING REMOVAL

1. Remove six cap screws that secure end cap.

2. Lift off end cap and disconnect electrical lead from electronics.

3. Loosen three set screws around upper periphery of card cage that center and secure cage within housing.

4. Remove five cap screws that secure housing to base of underwater unit.

5. Lift housing from base. One method is to place unit upside down (place on cloth to protect O ring surface), and lift the base from the housing by grasping the guard ring.

CAUTION

Remove electronics carefully, lifting straight up, so as not to damage the circuit boards.

6. To remove card cage from base, remove three screws from base of cage and unplug.

HOUSING INSTALLATION

1. Installation of the housing is essentially the reverse of installation. One method is to place the housing on the floor, bottom end up. Then, with the card cage firmly secured to the base, and the cylindrical liner installed over the electronics, lower the electronics into the housing. The housing can be secured to the base while the unit is upside down.

2. Tighten three centering set screws around upper periphery of card cage.

3. Connect electrical lead from electronics to end cap connector.

4. Inspect O ring mating surface and install end cap. Secure cap screws to torque of 110 inch-pounds.

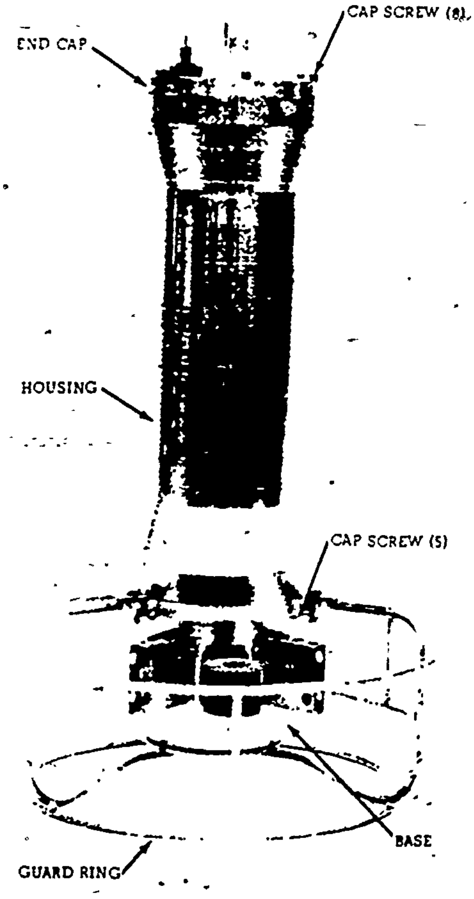


Figure 73.— Underwater Unit Disassembly Procedure.

If the underwater unit has leaked and seawater has reached the interior of the housing, clean the equipment immediately. If leakage amounts to only a few drops, wipe off the moisture. However, if any degree of flooding has occurred, rinse all components that have been in contact with seawater immediately with distilled or fresh water followed by an alcohol rinse. The following is the recommended procedure for emergency cleaning and drying of a flooded underwater unit:

1. Remove the housing from the base. (See figure 73.)

2. Rinse all components and the interior of the housing and base with distilled water or fresh water to dissolve and carry away salt deposits. Drain off the water and rinse in alcohol to absorb any remaining moisture.

3. Remove three screws that secure the card cage to the base and carefully bend the cage away from the base. Exercise caution to prevent straining the electrical leads from the sensors.

4. After thoroughly rinsing the cavity in the base with water and alcohol, disconnect electrical connectors to the depth transducers and carefully rinse the pins and mating holes in the female connector with water and alcohol.

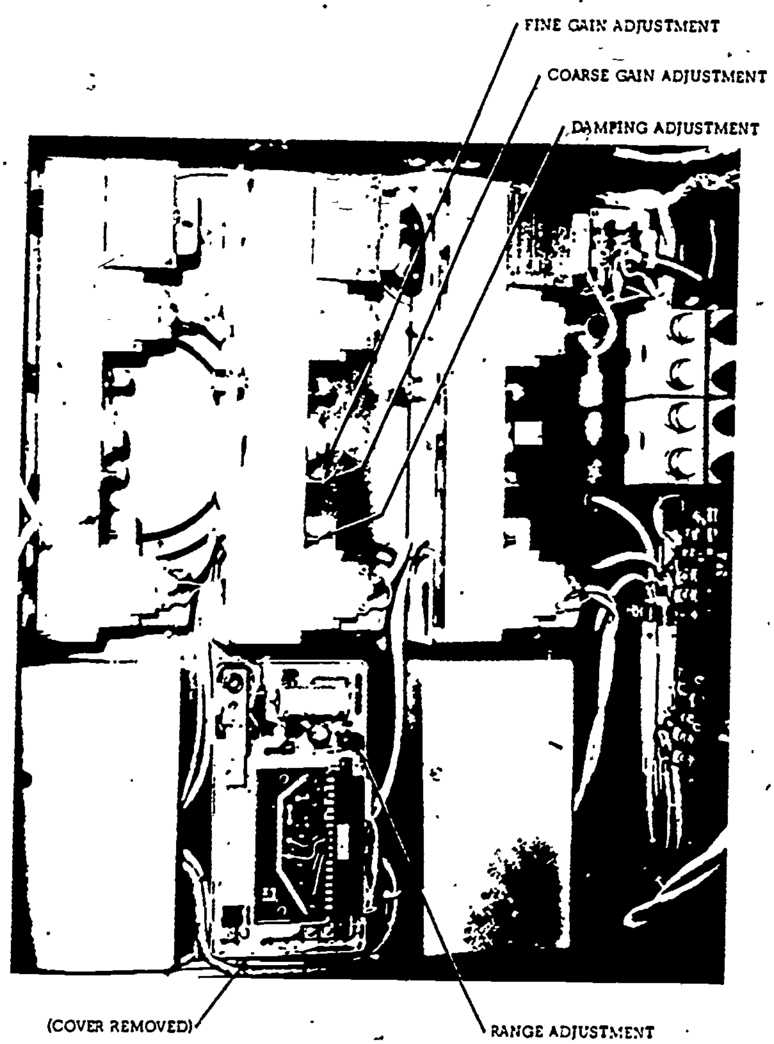


Figure 74.— Plotter Amplifier Adjustments.

5. Dry all components thoroughly. An oven set at a MAXIMUM of 50° C may be used to hasten the drying operation.

6. After the instrument is dry, test it functionally to determine if damage has been incurred. If damage has been incurred, replace or repair the damaged parts as required.

7. Examine the housing, base, and end cap for damage such as cracks and fractures. Replace these parts if they are damaged. Examine the "O" rings and seats. Replace any faulty O-rings and refinish any damaged seats.

8. After determining the cause of leakage and taking remedial action, reassemble the underwater unit.

Figures 74 and 75 are presented here to indicate the location of some of the internal mechanisms and adjustments that can be performed on the 9040 STD terminal equipment.

## BOTTOM SAMPLERS

While the use of bottom samplers is limited in the Coast Guard to special projects, a Marine Science Technician should be familiar with some

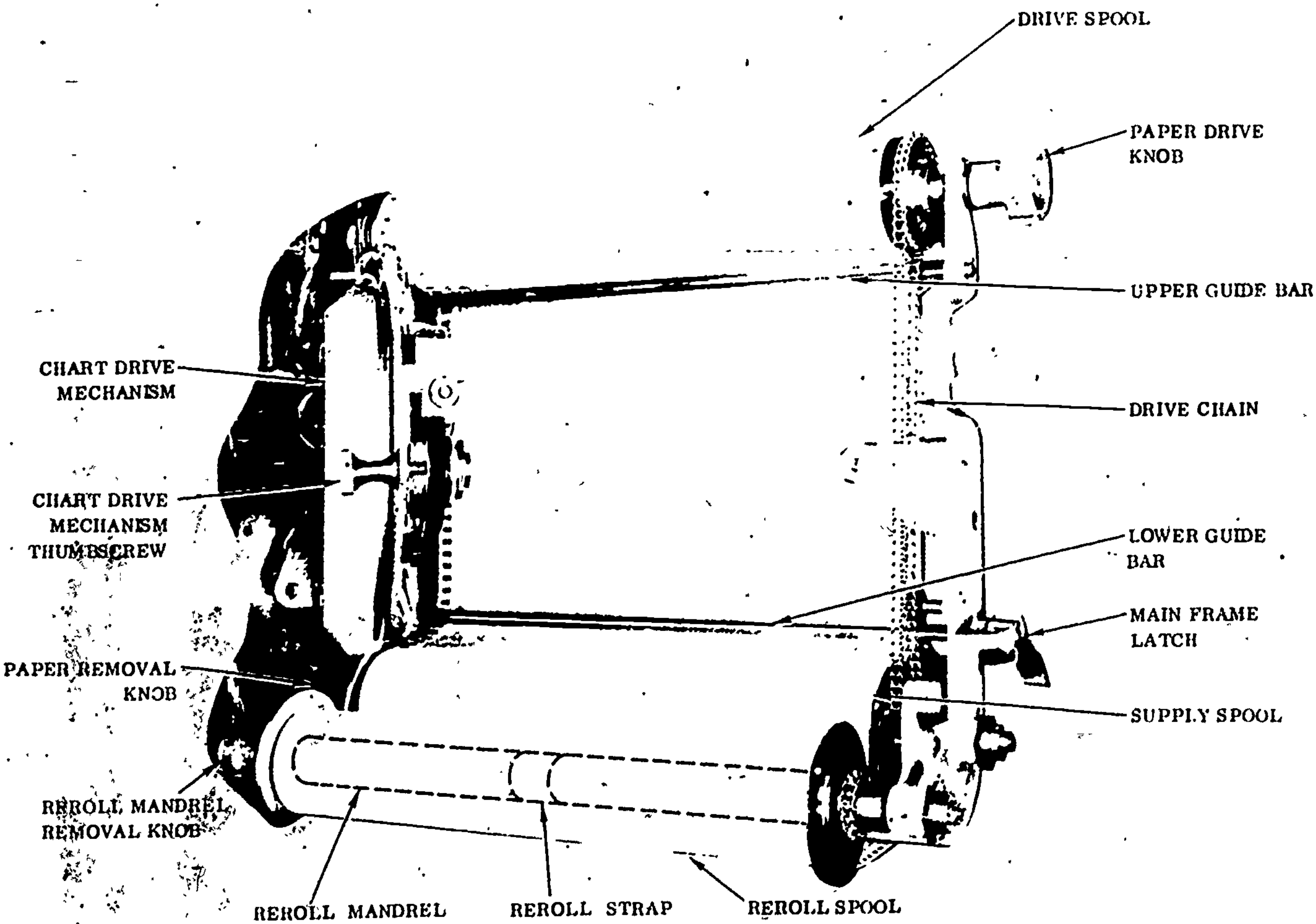


Figure 75.— Chart Paper Installation.

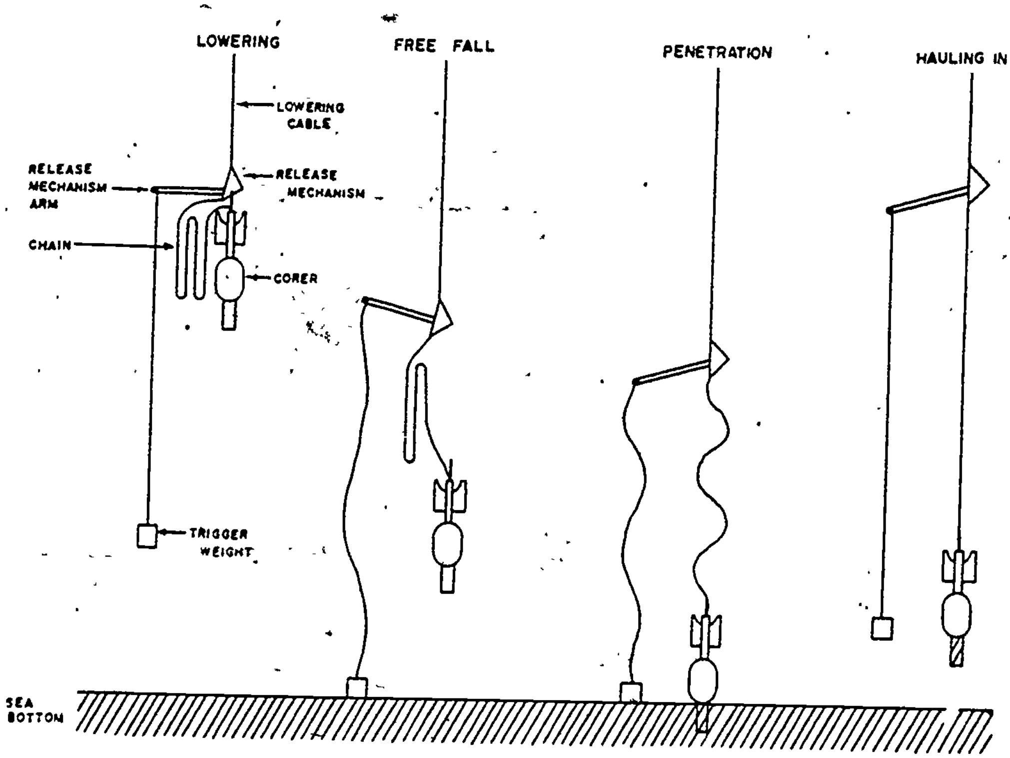


Figure 76.— Principle of operation of gravity-type corers.

of the equipment currently in use by the oceanographic community. For this reason, this course will cover a few of the more commonly used bottom samplers used by the U. S. Naval Oceanographic Office.

Collecting marine sediments involves the use of a variety of samplers, which fall into three basic categories: (1) corers, (2) snappers or grabs, and (3) dredges. Selection and use of the proper device will depend on the nature of the investigation, the character of the bottom, the depth of water, and the shipboard equipment available for lowering and retrieving the sampler. For example, if the investigation has to do with the strength of the sediment or its ability to support equipment, the sample should be obtained with one of the larger corers so that engineering properties as well as size and composition analyses can be made. On the other hand if previous reconnaissance indicated the character of the bottom to be hard and rocky, perhaps a dredge or grab sample will verify this condition. Where the depth of water is great and the sediments are unconsolidated, excessive washout may eliminate the use of certain devices.

CORERS

A typical coring device consists of interchangeable core tubes and an upper assembly. The upper assembly provides support for the drive weights and the core tubes. These corers essentially are driven into the ocean floor by gravity, and the bottom sample is retained in the core tube. The time involved in a coring operation is dependent on water depth and the speed at which the wire is payed out and retrieved. The length of the core collected will be governed by the penetrability of the bottom, the length of the corer, the amount of weight on the device, and the design of the corer. In areas of predominately rocky or coral bottoms, it may be impossible to obtain a core.

Two types of coring devices being used are the gravity-type and piston-type. Both types of corers achieve their penetration of the ocean floor by gravity; i.e., when the release mechanism is tripped, the specific gravity of the device is great enough to cause the corer to free-fall rapidly through the water and strike the bottom with enough force to penetrate the ocean floor (figure 76).

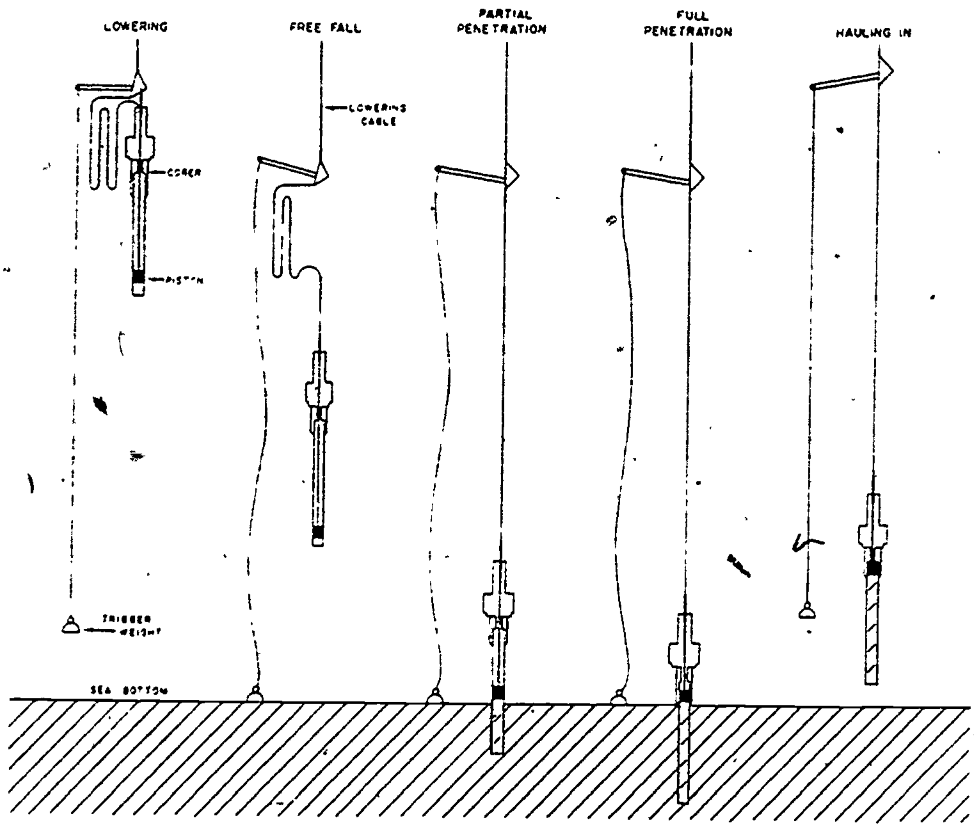


Figure 77.— Principle of operation of piston-type corers.

Interest in obtaining undisturbed core samples has resulted in the development of several piston-type bottom coring samplers. These piston-type corers are designed to offset the downward force of the coring device on the sediment. The piston inside the coring tube reduces distortion to the upper layers of the core sample, promotes greater penetration of the ocean floor, and, according to some authorities, provides a more representative sample of the bottom sediment column in situ (figure 77). Piston-type corers rigged without the piston mechanism are gravity corers. Sometimes in an emergency when a release mechanism is not available, gravity corers are rigged without the device; but the speed at which the corer sinks through the water is limited by the payout speed of the winch, and true free-fall speed is not achieved.

Phleger Corer

The Phleger corer, a gravity-type corer, is designed to obtain cores up to 4 feet in length. It is widely used for collecting marine sediments because of its small size and weight. The corer has an overall length of 3 or 5 feet—3 feet if the 12-inch coring tube is used and 5 feet if the 36-inch tube is used. The corer is usually operated from an oceanographic winch using 5/32- or 3/16-inch oceanographic wire.

The Phelger corer assembly (figure 78) consists of the following components:

1. The main weight (80 lbs.), which is comprised of the upper tube, the main body weight, check valve, tail fin assembly, and bail.

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Figure 78.— Phleger corer assembly.

2. Coring tubes, 12-and 36-inch.

3. Core catcher.

4. Cutting edge.

5. Release mechanism with a 20-foot chain.

6. Trigger line and weight.

7. Plastic liner, 1 1/2-inch outside diameter, with end caps.

8. Spare parts and 2 shipping cases.

In general, the Phleger corer requires very little maintenance, but each corer's storage case contains spare core tubes, core catchers, and cutting edges. After each lowering, all sediment should be removed from the corer by washing, and any damaged parts should be replaced. The core-catcher springs are delicate and must be inspected for free-play action. The core cutter may be dented if the core hits a hard or rocky bottom. When the coring operation is completed, any sediment on the corer should be removed by washing, and the entire device should be rinsed in fresh water and stored in the core assembly shipping case.

Kullenberg Piston Corer

The Kullenberg piston corer currently used is a modified version of the original Kullenberg corer. The modified version is designed to collect cores up to almost 12 feet in length. It is widely used both as a piston corer and a gravity corer, and it can be lowered with an oceanographic winch using 5/32- or 3/16-inch oceanographic wire.

The Kullenberg piston corer assembly consists of the following components (figures 79 and 80):

1. Upper assembly or weight stand consisting of main body tube, adapter, bail, and collar.

2. Cast lead weight, four to six 50-pounders.

3. Coring tubes, 2-inch inside diameter, in two lengths—5 1/2- and 11 1/2-feet.

4. Core catcher.

5. Core cutting edge.

6. Piston equipped with a single leather cup washer and a swivel fitting for attaching the lowering wire.

7. Wire clamp release mechanism with a trigger line and a trigger weight (40 to 80 pounds).

8. Plastic liner, 2-inch outside diameter, with end caps.

9. Miscellaneous spare parts and wooden shipping case.

In general, the Kullenberg corer requires very little maintenance. The corer's storage case contains spare parts. If the core cutter becomes dented or chipped or the core catcher springs become damaged, replace the part.

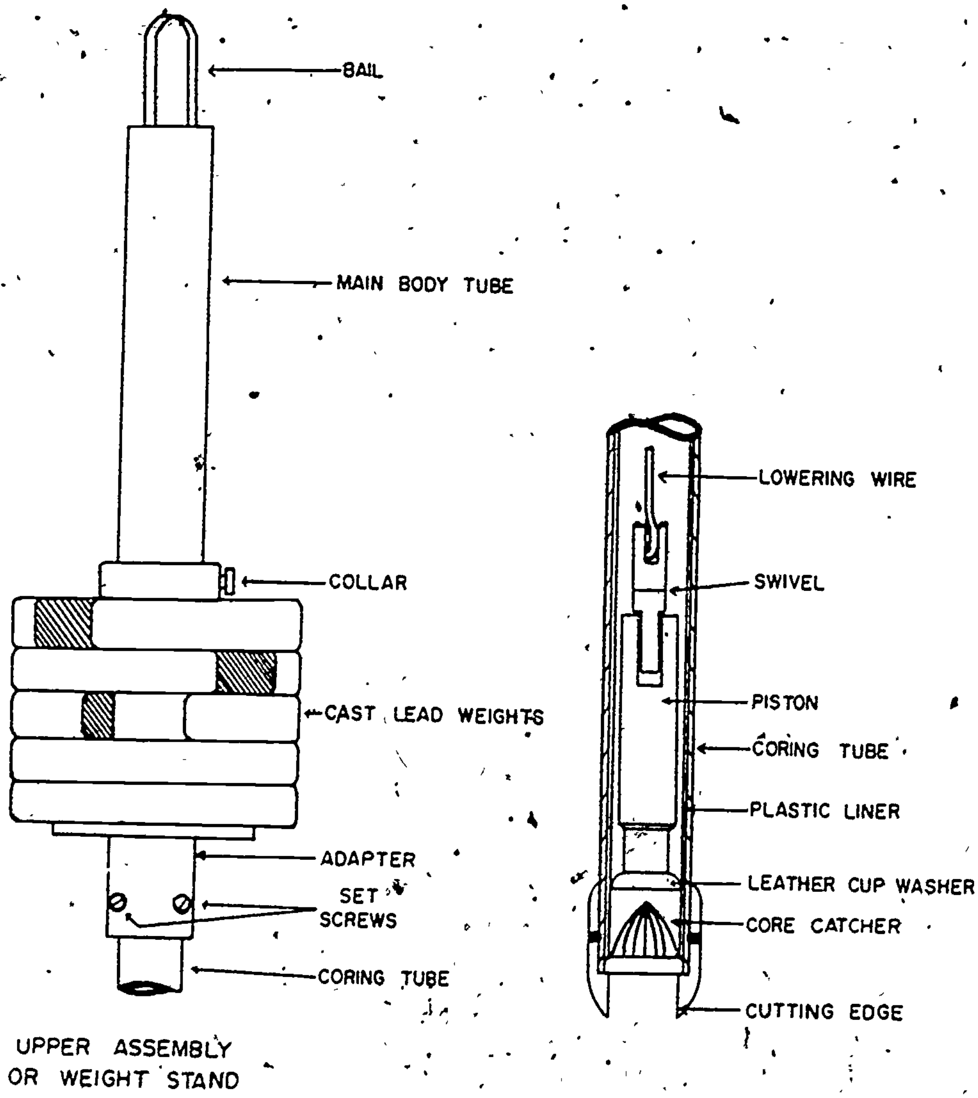


Figure 79.— Kullenberg piston corer assembly.

If the piston leather cup washer becomes worn, put a new washer on the piston. After completion of the operation, the corer (especially set screws and movable fittings) should be rinsed with fresh water, dried, and oiled lightly. Store the equipment in the shipping case.

Ewing Piston Corer

The Ewing piston corer is designed for use where longer cores are desired. It is the largest corer in use by the U. S. Naval Oceanographic Office, and several modified versions that weigh up to 2,000 pounds have been been built. Because of their weight and size, Ewing piston corers are operationally limited to ships equipped with a large winch carrying at least 1/2-inch wire, a boom or crane capable of supporting the corer, and sufficient deck space to assemble the corer.

The Ewing corer (2,000-pound) assembly consists of the following components (figure 81):

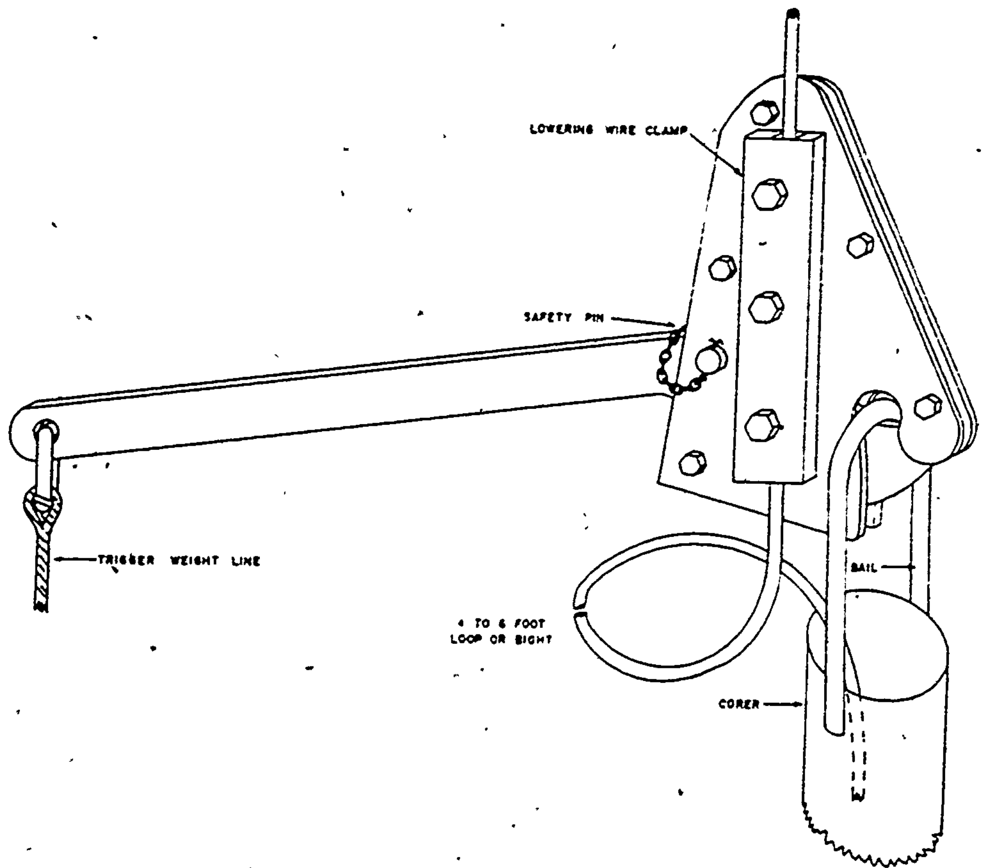


Figure 80.– Kullenberg piston-corer release mechanism.

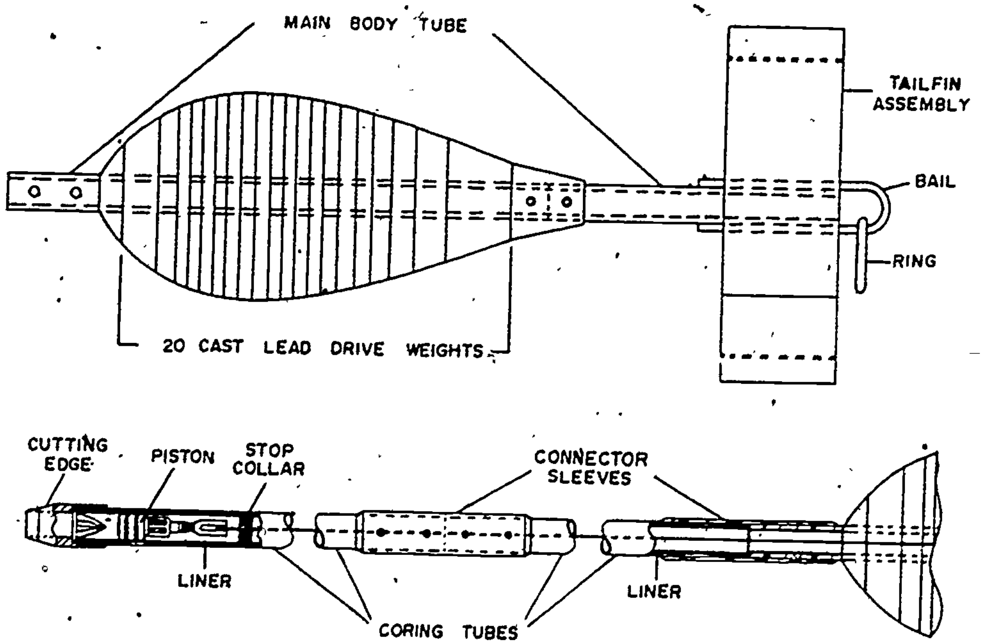


Figure 81.– The Ewing corer (2,000 pound) assembly.

1. The main weight, which includes the main body tube, the tail fin assembly, bail, ring, and 20 shaped cast lead drive weights. The overall length of the main weight is about 5 feet.

2. Coring tubes, which are seamless steel tubing of 2 3/4-inch outside diameter and 2 1/2-inch inside diameter, are 20 feet long. Each end of a tube is drilled and tapped to take stainless steel set screws.

3. Coring tube connector sleeves.

4. Piston with three leather washers and a check valve.

5. Piston stop collar.

6. Core catcher.

7. Cutting edge.

8. Tripping release mechanism and trigger line.

9. Trigger weight (250- to 300-pound), consisting of a coring device such as the Kullenberg piston corer rigged as a gravity corer.

10. Plastic liner in 20-foot lengths with caps.

11. Miscellaneous spare parts.

Owing to its sturdy construction, the Ewing corer generally requires little maintenance; however, when the corer attains only partial penetration, the remaining portion of the core may fall over of its own weight and bend the coring tube beyond repair. In addition, cutting edges are often damaged by striking hard or rocky bottom, but they can be hammered or filed back into shape or replaced. After a coring operation is completed, wash down all parts and lightly grease all threaded surfaces.

## Hydro-Plastic Piston Corer

The Hydro-Plastic (PVC) piston corer is a special-purpose corer designed by the U. S. Naval Oceanographic Office to obtain semi-undisturbed core samples. The corer utilizes a high impact grade of polyvinyl chloride (PVC) plastic for the coring barrel or tube. This lighter coring tube has several advantages. It collects a larger diameter core sample, it has a high retention of sediment interstitial water during storage, it has good sediment penetration, and it can be sectioned easily for sediment engineering property analysis. The PVC corer is widely used both as a piston corer and as a gravity corer, and it can be lowered with an oceanographic winch using 5/32- or 3/16-inch wire.

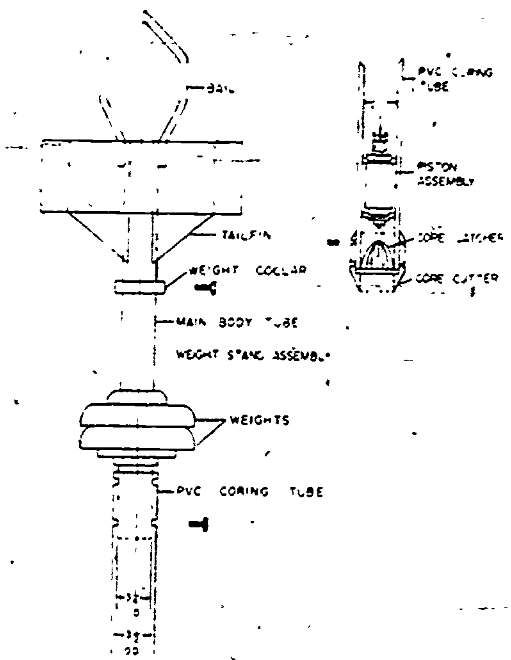


Figure 82.— The Hydro-Plastic (PVC) piston corer assembly.

The Hydro-Plastic piston corer consists of the following components (figure 82):

1. Weight stand assembly, which includes the main body tube, tail fin, bail, weight collar, and six cast lead weights (50 pounds each).

2. Plastic coring tubes (PVC), available in random lengths up to 20 feet; plastic caps for the coring tube, and adhesive for sealing caps on the tubes.

3. Piston assembly.

4. Core catcher.

5. Cutting edge.

6. Drill jig.

7. Wire tripping release mechanism (same as the Kullenberg corer).

8. Trigger weight and trigger line.

9. Spare parts, bolts, and shipping case.

The Hydro-Plastic corer requires very little maintenance. Spare parts are contained in the storage case. To protect the weight stand assembly, the core catcher, and the core cutter from deterioration, wash them and rinse them with fresh water to remove sediment. Coat these parts lightly with oil or, as conditions warrant, wire-brush them and paint them with red lead.

Boomerang Sediment Corer

The Boomerang sediment corer is a gravity corer that requires no wire or winch for launching and retrieving. It is designed to obtain cores up to 4 feet in length from water depths as great as 6,700 meters. This corer is especially adaptable to those situations where the wire on the ship's winches will not reach the ocean floor because of excessive depths.

The Boomerang corer assembly consists basically of two components: (1) The ballast component, which consists of the float retaining shell, ballast weight, steel core barrel with nose piece, and pilot weight (figure 83) and (2) the float component, which consists of a 10-inch diameter fused glass sphere containing a flashing assembly and a nylon net bag (rigged with purse string, rubber band, nylon line for stretching net bag, and a float-release-arm ring), a core liner valve/release mechanism tube with 6-foot nylon tether line, a core catcher, and a hollow rubber ball (figure 84). The items of the float component, which are recoverable, are installed in the ballast component, which is expendable.

The complete assembly is shipped with a 48-inch CAB (Cellulose Acetate Butyrate) plastic liner in the core barrel and with plastic caps taped over the ends of the core barrel. The float-release arm and the pilot weight are connected by a wire, and the pilot weight is held snugly against the ballast weight with a hose clamp.

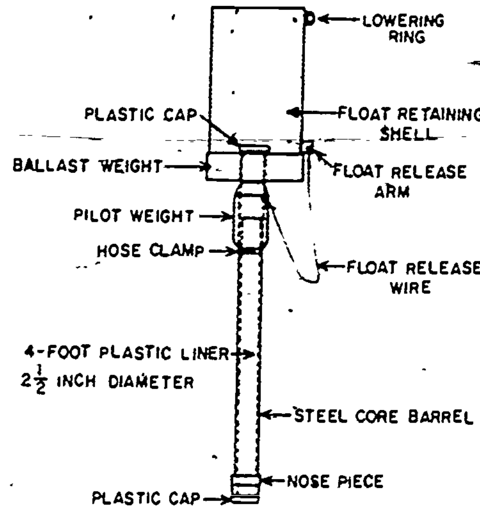


Figure 83.— Boomerang corer ballast component.

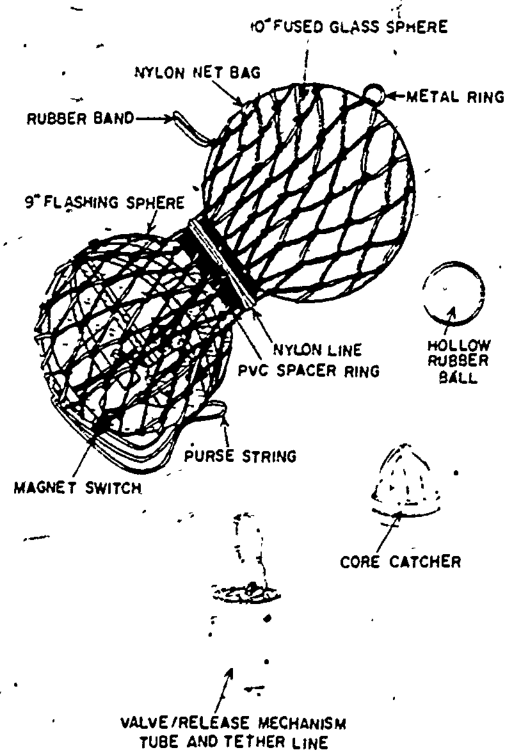


Figure 84.— Boomerang corer float component.

After being rigged to take a core, the complete assembly is dropped overboard into the ocean; it free-falls and its core barrel is driven into the ocean floor by gravity (figure 85). As the Boomerang core barrel penetrates the

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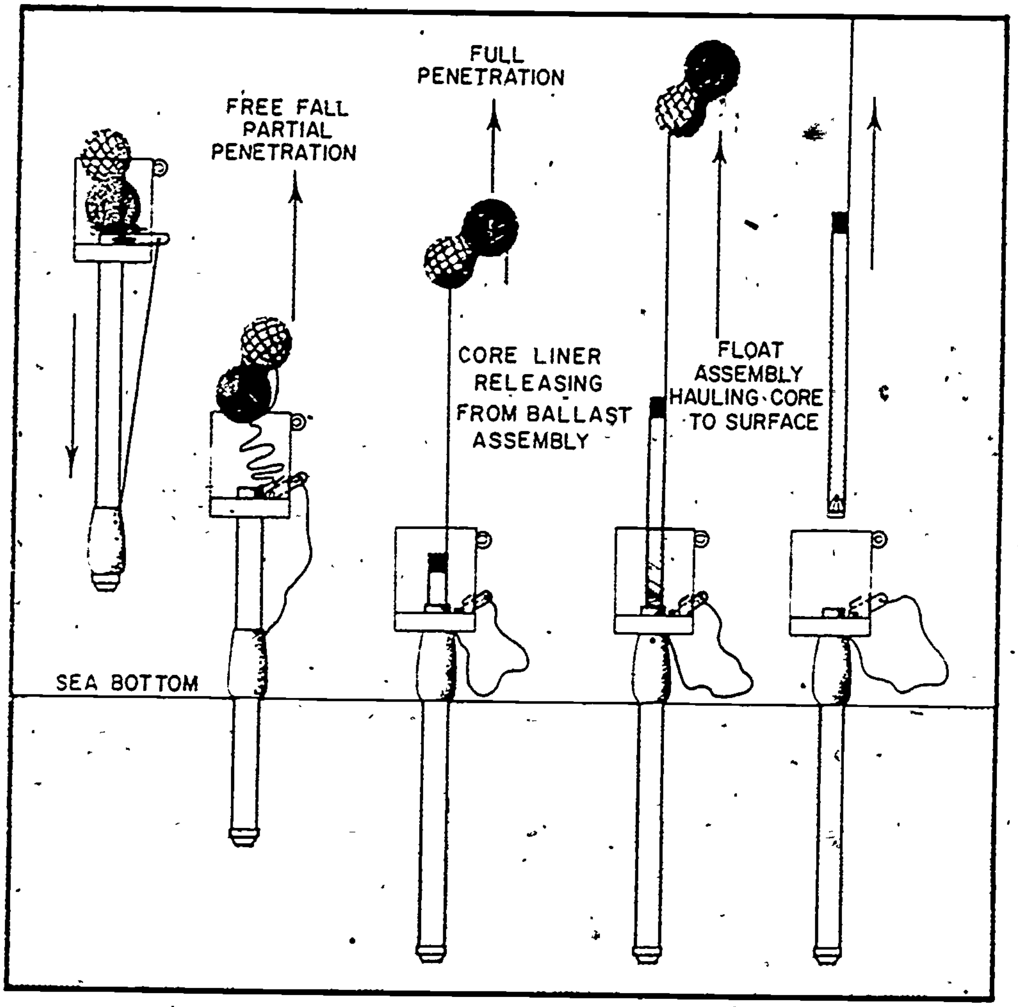


Figure 85.— Principle of operation of Boomerang gravity-type corer.

ocean floor, the float component with the sediment core liner is released from the ballast component. The float component then rises to the surface with the core. The ballast component remains on the ocean floor.

In general, the Boomerang corer requires very little maintenance since the ballast component is never recovered. The float component, however, usually is recovered and should be kept and matched with another ballast component. The following maintenance should be performed on the items in the float component:

1. Nylon lines and net bag - Rinse with fresh water and dry before storing.

2. Spheres and spacer - Rinse with fresh water.

3. Core catcher - Rinse with fresh water, dry, and oil lightly.

4. Valve/release mechanism tube - Rinse with fresh water, dry, and oil lightly.

SNAPPER OR GRAB SAMPLERS

Various snapper or grab samplers are used to obtain small samples of the superficial layers of the ocean bottom. These samplers are excellent for sampling surface sediments, but

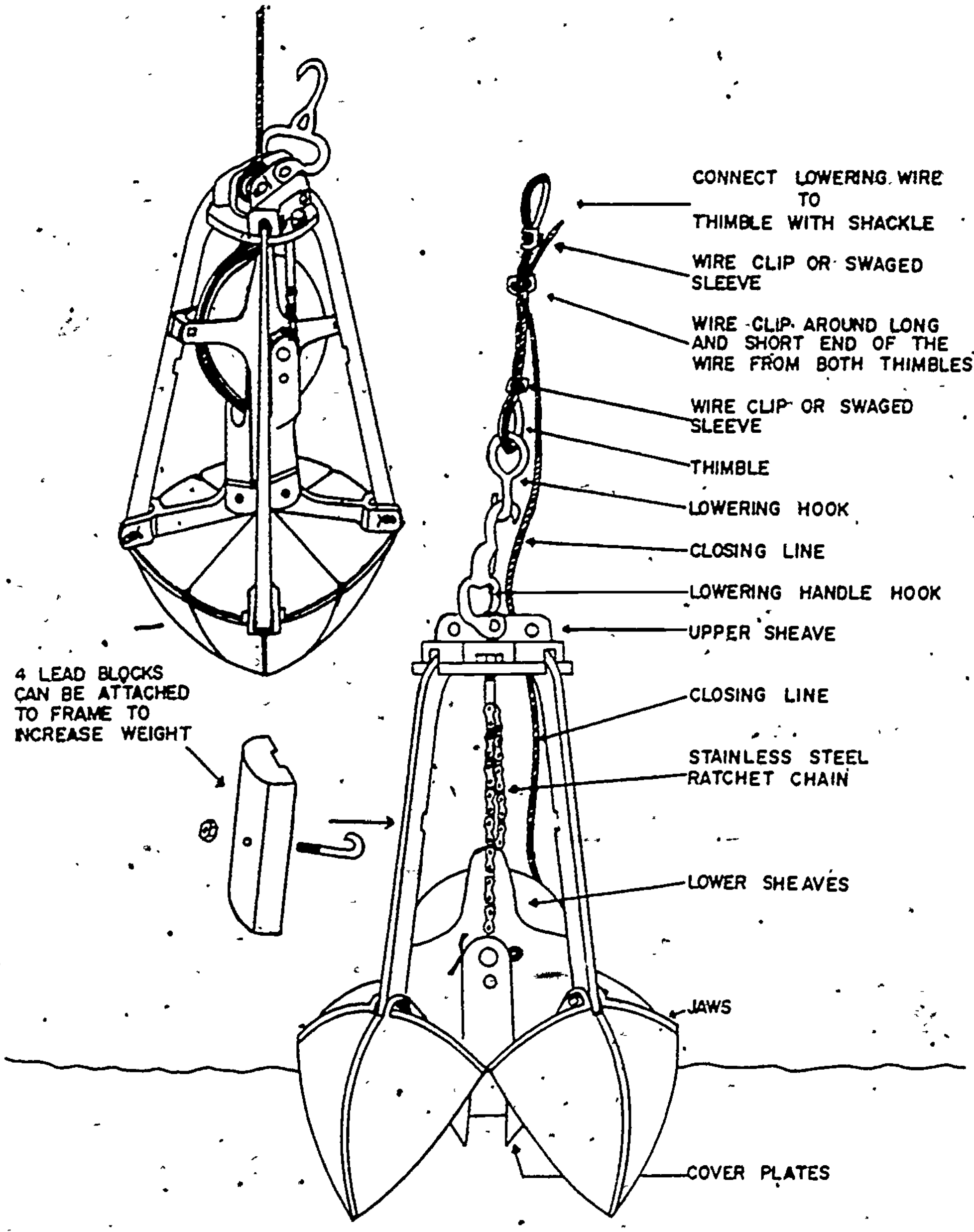


Figure 86.— Orange Peel bucket sampler.

they do not provide an undisturbed sample showing structure and microlayering. Examples of these bottom samplers include the Orange Peel bucket sampler, the Clamshell snapper, the Van Veen bottom sampler, and the underway Scoopfish.

Orange Peel Bucket Sampler

The Orange Peel bucket sampler, a grab sampler, derives its name from its resemblance to the segments of a peeled orange (figure 86). The sampler weighs 45 pounds and can be equipped with four lead blocks to increase its weight to approximately 120 pounds. It holds between 200 and 300 cubic inches of sediment when full; however, the fine portion of the sample is subject to washing. Hence, the sediment obtained may not be completely representative of the bottom. The Orange Peel bucket sampler generally is operated from the oceanographic winch using 3/16-inch wire.

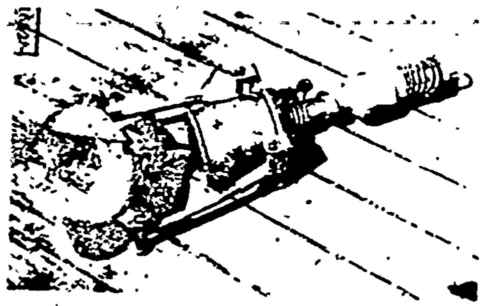

Figure 87.— Clamshell snapper.

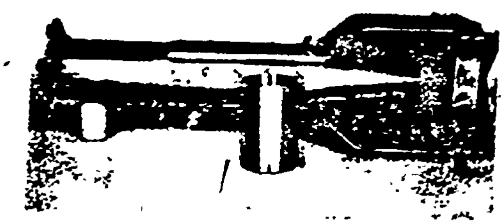

Figure 88.— Scoopfish underway sampler.

After each lowering is completed, wash the remaining sediment from the sampler, rinse with fresh water, dry, and lubricate all moving parts. Check the cotter pins and the ratchet chain links, tighten the sheave bolts and the weight bolts, and when necessary, wire-brush the sampler and paint it to prevent corrosion.

Clamshell Snappers

Two general types of clamshell snappers are used by NAVOCEANO. One, shown in figure 87, is about 30 inches long and weighs about 60 pounds. The other is only 11 inches long and weighs only 3 pounds.

The larger clamshell snapper is ruggedly constructed of stainless steel. The cast snapper jaws are closed by heavy arms actuated by a strong spring and a lead weight. In the open position, a foot device extends below the jaws so that it strikes bottom first and triggers the snapper. The impact moves the arms up, releasing the jaws, which snap shut with considerable force. The jaws trap about a pint of bottom material. This snapper is equipped with tail fins and is lowered from an oceanographic winch with 5/32-inch wire.

The small type clamshell snapper, called a mud snapper, is attached to the bottom of a sounding lead by means of a hole drilled in the lead. The jaws are actuated by a spring, and the tension on the spring can be adjusted by tightening or loosening a screwcap. The jaws are held open by engaging two trigger pins within the jaws. The mud snapper may be operated in shallow water by hand lowering or it may be lowered from a bathythermograph or oceanographic winch.

Very little maintenance is required for the clamshell snappers. After the operation is completed, wash off any remaining sediment, rinse in fresh water, dry, and lubricate any moving parts.

Scoopfish Underway Bottom Smapler

The Scoopfish (figure 88) is designed to obtain a sample without stopping the vessel. It is ideal for rapid reconnaissance sampling of surface sediments, but it does not adequately sample very coarse (gravel or larger) sediments. The sampler weighs 11 pounds and is 15 inches long. It has the capacity to collect 10 cubic inches of bottom sediment. It is lowered from a bathythermograph winch in depths less than 100 fathoms from a ship underway at speed not over 15 knots. When the sampler is being lowered, care must be taken that the nose lid is not prematurely tripped as the sampler enters the water. The scoopfish is allowed to fall freely in the same manner as a bathythermograph.

Maintenance of the Scoopfish is limited to a wash down with fresh water and lubrication of all moving parts. The Scoopfish is used where numerous samples are to be obtained in a limited time.

Van Veen Bottom Sampler

The Van Veen bottom sampler is shown in figure 89. It weighs approximately 74 pounds and is capable of collecting 200 or 300 cubic inches of sediment sample. Because the jaws of the sampler overlap, a sample obtained from considerable depth can be brought to the surface with little loss by washout.

When the sampler is being lowered, care must be exercised as it is entering the water,

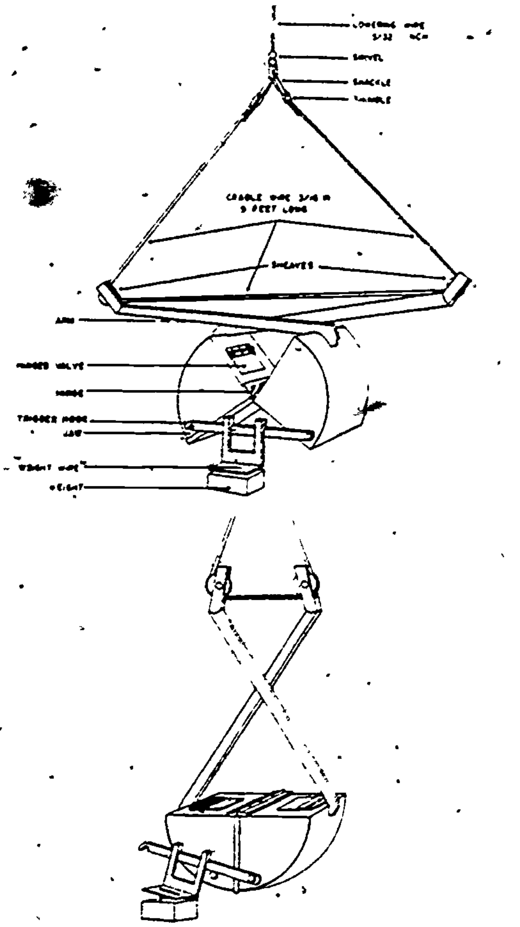

Figure 89.— The Van Veen sampler with modified trigger.

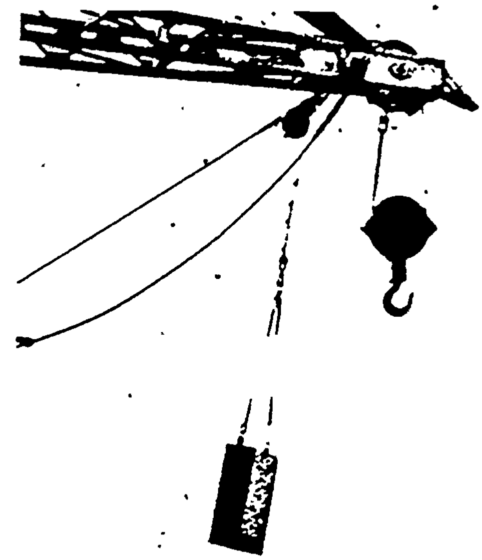

Figure 90.— Box shaped dredge.

because any appreciable decrease of tension on the lowering wire will trip the sampler prematurely. Lowering speed should be maintained at about 60 meters per minute.

Van Veen samples are placed in jars or canvas bags and are labeled. When the lowering program has been completed, the sampler is rinsed with fresh water and is dried, and all moving parts are lubricated.

## Dredges

Dredging operations for bottom sediments are usually conducted only when coring and grab sample devices have failed to obtain a bottom sample. Dredges used aboard ships include triangular shaped, box shaped (figure 90), and pipe dredges.

Dredges are constructed of 1/4-inch or heavier steel plate, and they vary in size and weight. The forward end of the dredge is open and the aft end is covered with a heavy grill which is designed to retain a certain size material.

The dredge is operated from a heavy duty winch or boom using 1/2-inch diameter lowering wire. During dredging operations, the ship is lying to as the dredge is lowered; then the ship slowly tows the dredge along the bottom at 2 or 3 knots.

While the dredge is being towed, the deep sea dynamometer should be used and should be watched for irregular tension on the towing wire. If the tension is very irregular, the dredge probably is skipping, and more wire should be payed out to increase the scope. Also, if rocky irregularities such as ledges are encountered, the dredge will tend to foul. If this occurs, the ship is stopped and, if possible, the ship is reversed and maneuvered to free the dredge. If this maneuver fails, a weak link in the dredge bridle usually gives way and upsets the apparatus, thus dumping the sample, freeing the dredge, and saving both the dredge and the lowering wire.

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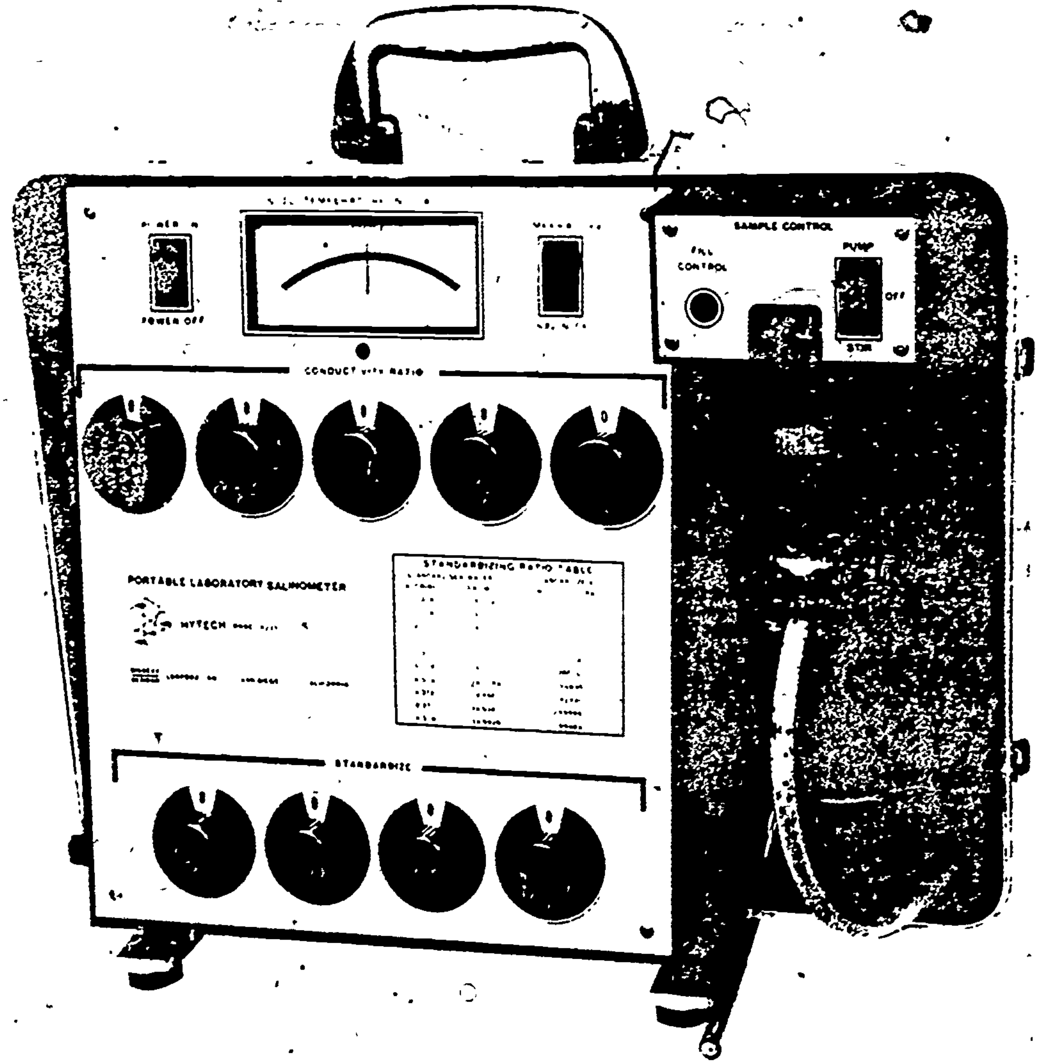
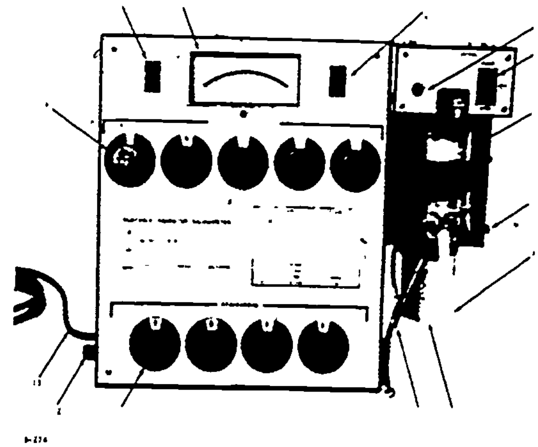


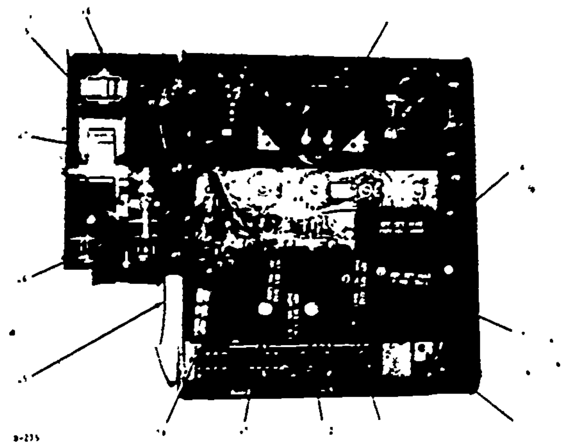
Figure 91.— Model 6220 Laboratory Salinometer.

Rocks and representative samples of other bottom material obtained should be packed in wooden boxes, canvas bags, or sample jars, and then be labeled. A fresh water washdown of the equipment after each operation is the only maintenance required other than periodic painting and inspection for weak points in basic construction.

## SALINOMETER

One type of portable induction salinometer now used by the Coast Guard is the Bissett-Berman Corporation Model 6220 Portable Laboratory Salinometer (figure 91). It is a precision instrument for measuring the salinity of sea water samples. The Model 6220 is a conductivity-type measuring device which utilizes an inductively-coupled conductivity sensor to establish a conductivity ratio between an unknown sample and a standard at approximately 35 ppt salinity. Actual salinity is then easily and quickly determined by reference to a set of tables. A dual-element platinum thermometer and its associated circuitry sense the temperature of the sample and apply appropriate compensation. For temperature differences up to ±3° C





1. AC Power Switch
2. Null/Temperature Indicator
3. Temperature/Salinity Switch
4. Fill Control
5. Pump/Off/Stir Switch
6. Sample Cell
7. Vacuum Control
8. Fill Tube
9. Overflow Jar
10. Drain Tube
11. Standardize Dials
12. AC Power Fuse
13. AC Power Cord
14. Conductivity Ratio Dials
15. Stirrer Motor
16. Stirrer Drive Belt
17. Null/Temperature Indicator
18. Ratio Transformer Module (A1A5)
19. Power Supply Module (A1A3)
20. 115/230 Line Power Switch
21. Oscillator Module (A1A2)
22. Summation Amplifier Module (A1A4)
23. Detector Amplifier Module (A1A6)
24. Temperature Compensation Module (A1A7)
25. Overflow Tube
26. Pump
27. Pump Drive Motor

Figure 92.— Front and Rear Views of Instrument With Cover Removed.

between the sample and the standard, compensation is fully automatic over the range of 0° to 40° C.

## FUNCTIONAL DESCRIPTION

The salinometer is completely contained in a molded fiberglass case which has a carrying handle at the top and feet at the bottom (figure 91). Remove the front of the case when operating the instrument. All operating controls are conveniently located on the front panel. The instrument is equipped with two motors: a pump drive that provides a vacuum for filling the sample cell, and a stirrer which agitates the sample to maintain temperature uniformity during measurements. Overflow from the sample cell during filling is drained into a water trap. A switch at the rear of the instrument selects either 115 or 230 VAC line power.

The sample cell (figure 92) is formed of molded lexan. It is fitted with a stopcock that has three positions: fill, drain, and closed. Contained within the sample cell are a toroidal transformer that forms an inductive coupling with the sea water, a platinum-resistance thermometer, a thermistor, and the stirrer. Plastic hoses lead from the cell to the sample bottle and to the overflow jar.

The overflow water trap (figure 92) is a reservoir which catches surplus water from the sample cell. The trap has screw threads at the top and is easily removed for emptying.

Filling the sample cell is accomplished by a vacuum pump located at the rear of the instrument (figure 92). During sample cell-filling, the operator places a finger over the FILL CONTROL opening on the front panel, which is above the sample cell. A vacuum control needle valve (figure 92) located near the overflow water trap is adjustable to regulate the vacuum. This allows precise control over filling. A three-position switch located on the front of the instrument actuates the pump in the PUMP position, and the stirrer in the STIR position.

A motor-driven stirrer in the sample cell agitates the sea water being measured to assure that the temperature throughout the sample remains uniform. The stirrer is actuated by the PUMP-OFF-STIR switch.

All operating controls for the instrument are located on the front panel (figures 91 and 92). They consist of a POWER ON-POWER OFF switch, a TEMPERATURE-SALINITY switch, a NULL/TEMPERATURE INDICATOR meter, CONDUCTIVITY RATIO dials, STANDARDIZE dials, a FILL CONTROL, and a PUMP-OFF-STIR switch. These are described in detail in the following paragraphs.

The POWER ON-POWER OFF switch is a two-position switch that applies line power to the instrument. A lamp in the switch illuminates when power is on.

The TEMPERATURE-SALINITY switch is a two-position switch, normally in the SALINITY position, which is a spring-loaded momentary switch in the TEMPERATURE position. In the SALINITY position, the circuitry of the instrument is applied to salinity measurements. In the momentary TEMPERATURE position, the temperature of the sample is shown on the NULL/TEMPERATURE INDICATOR.

The NULL/TEMPERATURE INDICATOR meter is a dual-purpose meter that indicates the null condition when conductivity ratios of samples are being established during salinity measurements and that displays the temperature in degrees Celsius during temperature measurements. The readout obtained at the meter is dependent on the position of the TEMPERATURE-SALINITY switch. Directly below the meter is a slotted zero-adjust screw, which is used to adjust the NULL INDICATOR pointer.

The CONDUCTIVITY RATIO dials (figure 92), when adjusted to null the NULL/TEMPERATURE INDICATOR, give a direct reading of the ratio of the conductivity of the unknown sample to that of the standard sea water used to standardize the instrument. These dials are initially set by comparing the indicated chlorinity of a sample of Copenhagen Standard Sea Water with the STANDARDIZING RATIO TABLE on the front of the instrument and by determining the conductivity ratio. With an unknown sample in the instrument, these dials are adjusted until the meter nulls. The dial readings obtained are converted to salinity units of measure by reference to a set of tables used for that purpose.

The STANDARDIZE dials are used during initial standardization of the instrument. After the CONDUCTIVITY RATIO dials have been set as described, the STANDARDIZE dials are set to precisely null the NULL/TEMPERATURE INDICATOR. Thereafter, the setting is not changed, except for each new salinity run.

The FILL CONTROL is a small opening that controls the vacuum to the sample cell. During all filling, the FILL CONTROL is sealed with the finger. An adjustable needle valve (figure 92) provides control over filling rate.

The three-position PUMP-OFF-STIR switch controls both the vacuum pump and the stirrer. In the PUMP position, the vacuum pump operates to fill the sample cell. In the OFF position, the motors are inoperative. In the STIR position, the stirrer is actuated to maintain a uniform temperature in the water sample while measurements are being made.

Set up the salinometer on a work table or other suitable surface with drain facilities close by. If a sink is not available, use a bucket or large bottle resting on the floor. To permanently secure the instrument to a desk or other work surface, remove the screws which attach the rubber feet and install bolts in the tapped holes from the underside of the table. If it is desirable to attach the salinometer to a table from the top side, fasten a secondary bar with suitable holes to the rubber feet and secure the unit by bolting the bar to the table. In any case, secure the instrument well enough to prevent damage from ship's movement and insulate it from major vibrations. Remove the front of the base by opening the latches on the sides of the unit and lifting the front off. Connect the power cord to a standard source of 60 Hz 115 or 230 VAC power. Note that a three-wire cord (with ground plug) is used.

OPERATION

No preliminary adjustments are required to operate the Model 6220. However, (with power off) set the NULL/TEMPERATURE INDICATOR needle to 20° C (centered), using the zero-adjust screw below the needle, before operating the instrument. In addition, (with power on) adjust the CONDUCTIVITY RATIO dials to 0.00010, 0.00020, etc., to observe meter sensitivity. Meter deflection should be perceptible for the smallest change and should be reasonably linear for the first few steps of deflection (approximately 1° C deflection on NULL/TEMPERATURE INDICATOR for the initial steps and then diminishing). The instrument is now ready to operate.

The Model 6220 Laboratory Salinometer is quite simple to operate, and personnel completely unfamiliar with the instrument can learn to use it and make precise measurement in a short period of time. The first operational step is to standardize the instrument using Copenhagen Standard Sea Water. Standardization is necessary to allow for small drifts in precision components and in the geometry of the conductivity cell and to compensate for physical changes due to ambient temperature conditions and aging. After standardization, the instrument will indicate a conductivity ratio of 1.00000 for sea water having a salinity of 35 ppt. However, since Copenhagen Standard Sea Water does not always have a salinity of 35 ppt, the conductivity ratio will vary from unity, depending upon the salinity of the standard.

The second step in operating the instrument after it has been standardized is to determine the conductivity ratio of the unknown sample. This is accomplished by filling the sample cell with the unknown sample and adjusting the CONDUCTIVITY RATIO dials until a null is obtained on the NULL/TEMPERATURE INDICATOR. The CONDUCTIVITY RATIO dial reading is the ratio-of-conductivity of the unknown sample to the conductivity of a standard having a salinity of exactly 35 ppt. Use this conductivity ratio in conjunction with a set of tables to arrive at the salinity of the unknown sample.

During the process of making salinity measurements, the standard sea water, the unknown samples, the instruments, and the room in which measurements are performed should be at a temperature of within ±2.5° C of each other. To accomplish this, store the samples and instrument in the room where measurements are to be made.

Inasmuch as the purpose of the salinometer is to perform highly precise measurements of sea water to determine its salinity, it is important that the sample being measured in the sample cell is truly representative of the unknown specimen. For this reason, the cell must be clean, free from bubbles, and uncontaminated by previous samples.

The filling controls are comprised of the FILL CONTROL opening on the front panel, the vacuum control needle valve behind the sample cell, the sample cell stopcock, and the various tubes used for filling and draining.

The FILL CONTROL is a small air inlet that taps into the suction line between the sample cell and the overflow trap to preclude accidental drawing of liquid into the cell. Restrict the opening with your finger to fill the cell.

The vacuum control needle valve, which is located adjacent to the sample cell, controls the amount of suction to the sample cell and, consequently, the vacuum at the FILL CONTROL opening. To obtain a satisfactory filling rate, adjust the needle valve.

The stopcock is a three-position valve that is used for filling and draining the sample cell. The stopcock, which has two ports through which liquid flows, is placed in a mid-position between the ports for retaining the sample.

The plumbing in the instrument is comprised of tubing for air suction and for sample draining and filling. The two tubes attached to the stopcock are for sample draining and filling. Air suction and overflow drainage are provided by the tube connecting the overflow jar to the sample cell and fill control opening. The other hose from the overflow jar connects to the needle valve, which is in series with the vacuum line. From the needle valve, a hose returns to the pump. If the overflow jar is not emptied when full, excess fluid flows from the pump through a hose that hangs loose beside the overflow jar.

In order to ensure that the sea water in the sample cell is representative of the collected sample being measured, remove all residual traces of the previous sample tested from the cell by rinsing the cell with a sample of the specimen to be measured.

Vigorous shaking of the sample is highly recommended prior to each measurement to ensure thorough mixing of the sample to be run. Shaking also helps to eliminate bubbles resulting from a rapid change in sample temperature. Introduce the sample, which should be at the temperature at which the measurements will be made, into the cell and drain it at least twice prior to the actual measurement.

Slow filling is essential to prevent bubble formation, particularly on the bottom surface of the toroid assembly. If bubbles are present after the stirrer has been started, drain the liquid back into the sample bottle and then refill the cell (Do not drain the sample back into the bottle on the first rinse filling of the cell). Any bubbles in the sampled liquid will decrease the apparent conductivity and will result in erroneous salinity values.

Leave the three-way valve open following each draining to ensure thorough emptying of the cell and fill tube. A visual check of the cell is recommended to ensure cell and tube drainage prior to inserting the fill tube in a new sample.

When large droplets of water cling to the inside surface of the cell, the cell requires cleaning. Fill the cell with a wetting agent solution such as Tergitol or Cutscum. In the Coast Guard, a 10% Tergitol solution is used for this purpose. Shake the mixture to hasten solution; then add the solution to the cell, stir it for 5 minutes, drain the solution, and rinse the cell several times with fresh or distilled water.

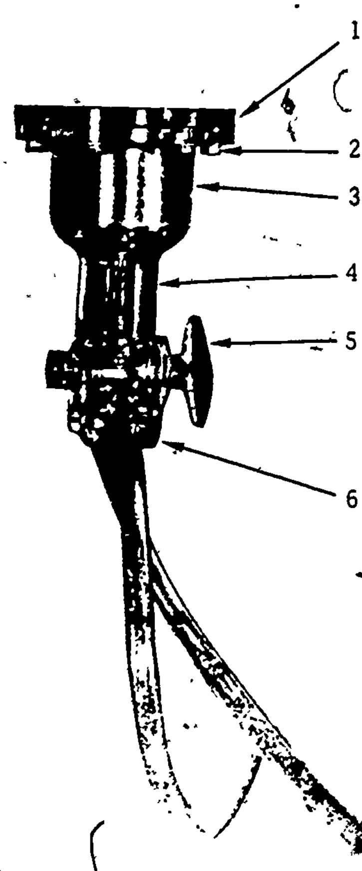
After each day's run, fill the cell with fresh or distilled water, allowing the water to run into the overflow jar. Shut the stopcock to retain the sample and run the stirrer for approximately fifteen seconds; then remove and dry the overflow jar. About every other day of operation, remove and wipe clean the stopcock and the internal portion of the cell where the stopcock fits. Coat both portions lightly with a silicone lubricant and reassemble. When securing the salinometer for storage or transport, rinse the cell with fresh water in the same manner as you do for daily cleanup. Also clean and lubricate the stopcock as directed.

A routine check to assure that power cables are not frayed or broken, that all components are securely mounted, that all water connections are secure, and that pump and stirrer drive belts are not worn is recommended upon receipt, transportation, or shipment of the salinometer.

Table 8 describes the specifications of the Model 6220 salinometer, while figures 93, 94, and 95 give a detailed close-up of some of the more common working components of this instrument.

Table 8.— Model 6220 Specifications.

| | |
|---|---|
| SALINITY MEASUREMENT | |
| Range | 0 to 51 ppt |
| Least Count | 0.0004 ppt |
| Accuracy | ±0.003 ppt |
| Temperature Compensation | ±0.002 ppt for variation of ±3°C between sample and standard |
| TEMPERATURE MEASUREMENT | |
| Range | 0°C to 40°C |
| Accuracy | ±0.5°C |
| GENERAL | |
| Dimensions | 9 x 15 x 20 inches |
| Sample Cell Capacity | 50 cc |
| Weight | 36 lbs. |
| Power Required | 115 or 230 VAC, 50-60 Hz, 1 ph |




1. Cap
2. Cap Screw (6)
3. Cell
4. Stopper
5. Stopcock
6. Clamp

Figure 93.— Sample Cell Details.

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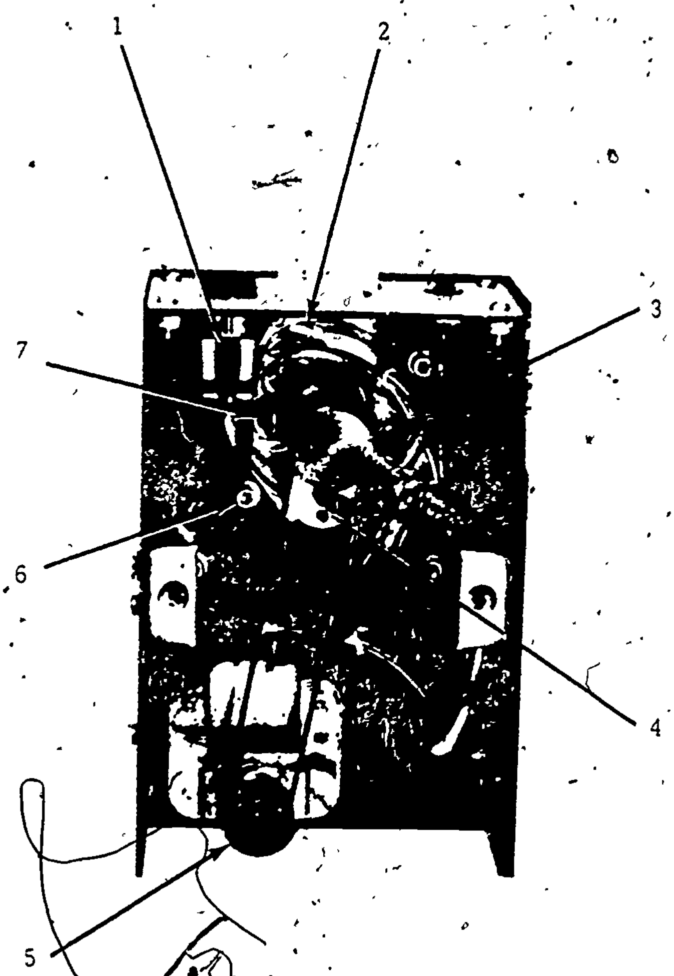


1. Pump/Off/Stir Switch
2. Thermistor
3. Stirrer Pulley
4. Platinum Thermometer
5. Stirrer Motor Pulley
6. Sample Cell Cap Screw (4)
7. Salinity Sensor (Toroid)

Figure 94.— Top View of Stirrer Drive and Sample Cell.

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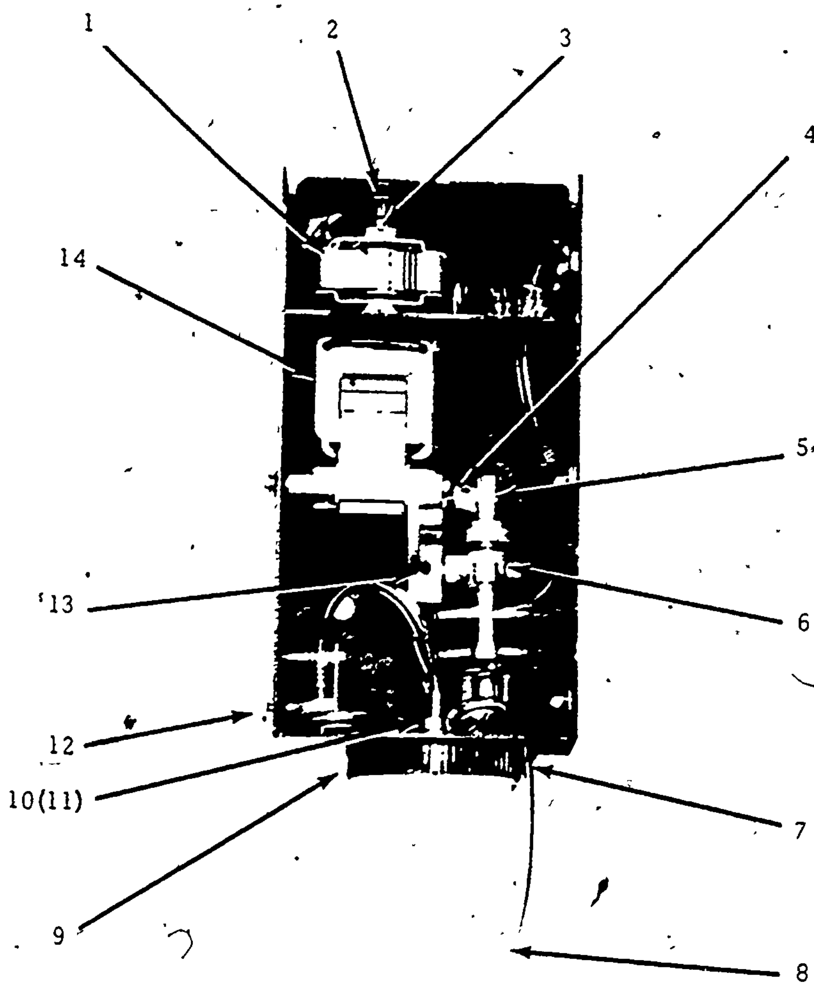


1. Stirrer Drive Motor
2. Stirrer Motor Pulley
3. Collar
4. Cam
5. Bearing
6. Pump
7. Overflow Tube
8. Overflow Jar
9. Overflow Jar Cap
10. Hollow Screws (2)
11. Nuts and Washers (2)
12. Vacuum Control Valve
13. Set Screw
14. Pump Drive Motor

Figure 95.— Overflow Bowl and Pump Details.

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## PROCESSING LABORATORY AREAS AND ASSOCIATED EQUIPMENT

### LABORATORY SPACES

Shipboard laboratory space is generally divided into two areas: the wet-lab and the dry-lab. The equipment required in the wet-lab is generally limited to storage racks for the various pieces of equipment that are used over the side, such as the STD underwater unit, water samplers, BT's, Rosette Multi-Sampler, nets, corers, or almost any other piece of oceanographic gear that may be used on a particular oceanographic cruise.

The dry-lab is used to process the data collected. The STD deck terminal equipment is normally located in the dry lab. A portion of the dry lab is often adapted for use as a chemistry lab. Whatever the situation is on your particular vessel, the following paragraphs are concerned with general features and equipment associated with laboratory spaces on a vessel that has a broad capability for oceanographic work.

An arrangement for racking the Nansen bottles or other water samplers is essential for proper conduct of operations. The rack should be fabricated to hold the necessary number of samplers normally required so that the samplers are side by side. It must be constructed so that the samplers are held securely in a vertical position and yet can be removed easily. Below each water sampler, the rack should have compartments to hold several water sample bottles (figure 96). The rack should be near the platform working area and protected from the weather. The rack should be constructed so that the reversing thermometers may be easily read while they are mounted on the water sampler (figure 97). A drainage system should be near the mounting rack so that sample bottles as well as the water samplers themselves may conveniently be drained.

Other suitable racks or storage areas should be constructed for other necessary equipment, such as the oceanographic weight, meter wheel, block, and safety equipment.

Sea racks for glassware, chemicals, samples, and other apparatus should be available in the dry-lab area. Laboratory space is generally limited and must be used to the utmost; therefore, efficient arrangement of equipment will reduce unnecessary work and is vital to the personnel working in teams to keep ahead of a backlog of samples.

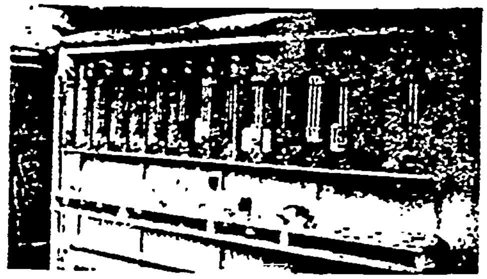

Figure 96.— Nansen bottle rack.

Figure 97.— Reading the reversing thermometer with viewer.

### LABORATORY EQUIPMENT

A properly equipped laboratory requires workbenches, storage cabinets, drawers, racks, shelves, tables, sinks, adequate lighting, and a ventilation and temperature control system. Workbenches should be of the proper height for laboratory work. The bench tops must be of acidproof composition; the tops may be made of commercial laboratory bench topping or of heavy wood top coated with black acid-resistant paint.



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TABLE 9 — APPARATUS AND GLASSWARE

| ITEM AND SPECIFICATIONS | | | QUANTITY |
|---|---|---|---|
| Bottles, dropping | -with glass dropper and rubber bulb | -30 ml capacity | 2 |
| Bottles, glass | -narrow mouth, ground glass stopper | -125 ml capacity | 124 |
| Bottle, polyethylene | -screw cap, narrow mouth | -1 gallon capacity | 1 |
| Bottle, polyethylene | -screw cap, narrow mouth | -16 ounce capacity | 12 |
| Burette, Automatic | -3 way stopcock teflon plug smallest scale division 0.05 ml | -10 ml capacity | 2 |
| Clamp, burette | -double holder | - | 1 |
| Cylinder, graduated | -glass | -100 ml capacity | 2 |
| Cylinder, graduated | -glass | -10 ml capacity | 2 |
| Flask, Erlenmeyer | -pyrex | -125 ml capacity | 12 |
| Flask, filtering | -with side arm pyrex | -500 ml capacity | 2 |
| Flask, volumetric | -Ray Sorb, with ground glass stopper | -250 ml capacity | 2 |
| Flask, volumetric | -with ground glass stopper | -100 ml capacity | 2 |
| Flask, volumetric | -with ground glass stopper | -1000 ml capacity | 2 |
| Magnetic stirrer | -115 V variable speed approximate size 5'' x 5'' x 5'' | - | 1 |
| Magnetic stirring bar | -teflon coated-approximately 5/16'' x 7/8'' | - | 3 |
| Pipet, automatic Lowy | -ground glass vent stopcocks | -50 ml capacity | 2 |
| Pipet, volumetric | - | -100 ml capacity | 2 |
| Pipet, volumetric | - | -5 ml capacity | 2 |
| Pipet, automatic plunger type | - | -2 ml capacity | 5 |
| Pipet spare barrel | -for automatic plunger type | -2 ml capacity | 6 |
| Rubber bulb | -heavy duty | -4 ounces | 1 |
| Rubber bulb | -pressure | -3 ounces | 1 |
| Stoppers, rubber | -2 holes | -number 7 | 1 lb |
| Stoppers, rubber | -one hole | -number 1 | 1 lb |
| Stopper ties, rubber | - | - | 200 |
| Support stand, for burette | -approx. size of base 7'' x 12'', height of rod 20'' | - | 1 |
| Tubing, Standard wall | -flint glass 8mm O. D. | - | 1 lb |
| Tubing, tygon | -3/8'' O. D., 1/4'' I. D. | - | 50 ft |
| Tubing, tygon | -heavy wall 5/8'' O. D., 1/4'' I. D. | - | 20 ft |
| Glassware brushes | -assorted sizes | - | 6 |
| Laboratory detergent | - | - | 2 lbs |

Table 10.— Chemical Reagents.

| Item and Specifications | Quantity |
|---|---|
| Alkaline iodide reagent | 2 quarts |
| Concentrated Hydrochloric Acid (6# bottles) or Sulfuric Acid (9# bottles) | 2 bottles |
| Distilled water | 5 gallons |
| Manganous sulfate (or chloride solution) | 2 quarts |
| Potassium bi-iodate standard 0.01 N or 0.10N | 2 quarts |
| Sodium thiosulfate solution, 0.1 N or 1 N | 1 gallon |
| Starch indicator solution, saturated | 1 quart |
| Chloroform, reagent grade | 1/2 pint |
| Sodium carbonate, dry powder | 1 pound |

Storage cabinets and drawers should be compartmented to prevent excess motion of stored materials. The cabinets and drawers should also be equipped with adequate retaining devices to prevent them from flying open during heavy seas.

A table or a table-height portion of the workbench is necessary for titrations and other analyses that the analyst must run while seated. Shelves, which are necessary over the workbenches and tables where chemical titrations are run, should be fitted with sea racks to hold the large bottles or carboys of standard solutions to which the titration burettes are connected.

The laboratory's sinks must be big enough to wash large pieces of glassware and small oceanographic instruments. The sinks should be stainless steel and must have acidproof drainboards, drains, traps, pipes, seacocks, and overboard discharge outlets. They should be furnished with hot and cold fresh-water taps and a salt-water tap.

It is recommended that the laboratory deck be covered with acidproof paint or an acid-resistant plastic (vinyl) tile and be provided with drainage facilities. The laboratory should be equipped with numerous regulated voltage electrical outlets. Compressed air and vacuum lines also are desirable.

A shipboard laboratory should be furnished with a large variety of miscellaneous laboratory equipment. Table 9 is a recommended list of apparatus and glassware required to perform a program of oxygen analysis. Table 10 lists the recommended chemicals and chemical reagents to support such a program. Keep in mind that requirements vary considerably for different projects and/or surveys.

## MAINTENANCE AND SAFETY PRECAUTIONS

Two things that are very important in operating a shipboard laboratory are neatness and cleanliness. A sloppy laboratory can quickly become chaos. As soon as you have used a piece of equipment, clean it and return it to its proper place of stowage. Considerable time can be lost searching for a particular flask or graduate only to find it broken or too dirty to use. Chipped glassware is dangerous; avoid using it. Clothing can be ruined and skin burned if spilled acids are not cleaned up immediately.

Although each method of analysis has detailed instructions for handling and cleaning its particular equipment, the seagoing technician must familiarize himself with basic laboratory precautions. At times, you will have to handle chemicals that are corrosive and toxic. Because of the dangers involved, exercise extreme care at all times when handling these chemicals.

Most laboratory equipment is delicate, and some is specially made and is difficult to obtain. Costly damage and personal injury can result if such material is handled carelessly. It is obvious, therefore, that the shipboard laboratory is a space in which only qualified personnel should be authorized. The laboratory should never, under any circumstances, be used as a general passageway or lounge.

The laboratory must be well ventilated to remove any toxic vapors created by chemicals. Since several types of equipment for sea water analysis are calibrated at 20° to 25° C, it is desirable that the laboratory be kept in this temperature range.

Several types of titration analyses utilize color-change end points. For this reason, it is important that the lighting of the laboratory be of high quality. Fluorescent lights of the daylight type are recommended. Smoking is not recommended in the area for many reasons. In an area of analysis involving refraction of light, the light-blue cigarette smoke will cause erroneous readings.

A large portion of the laboratory equipment used at sea consists of delicate glassware. Although these beakers, graduates, burettes, pipettes, flasks, etc., are each designed for particular functions, they unfortunately are of very awkward shapes and sizes for stowage. (See figure 98.) It is recommended that only those pieces of equipment in fairly frequent use be arranged in sea racks. The remaining spares and seldom-used pieces should be wrapped liberally with soft packing material and stowed in drawers or bins so they will be unaffected by motion of the ship in rough weather. Do not crowd glassware in drawers.

Stow chemicals in bottles or jars with screw caps or stoppers and pack the bottles or jars in cabinets or drawers with dependable latches or locks. Wrap fragile bottles with soft packing material to prevent contact with one another and to keep them from moving about with the motion of the ship. Stow liquids upright in tightly capped bottles in sea racks or compartmented bins.

Stow strong acids and bases in racks or bins that are well ventilated and equipped with a drain to dispose of spilled solution in the event of breakage. The drain should lead to an overboard discharge. One method is to construct a rack at the back of one of the laboratory sinks that will drain into the sink. Remember that it is far better to discard a reagent than to permit unsafe stowage.

When handling chemicals, wear a laboratroy apron or coat. While you are handling strong chemicals, wear rubber gloves and safety goggles if there is a possibility of injury from violent chemical reaction or splashing. The safest method, to mix acid solutions is to place a container of water in a cold water bath, stir the water constantly with a stirring rod, and pour the acid slowly into the water. NEVER POUR WATER INTO ACID. Keep acid away from combustible material at all times.

The most serious accidents that occur in a laboratory usually result from contact with strong chemicals. It is important that safety and first aid equipment be readily available. In addition to a first aid kit, an overhead quick-pull, safety shower or some similar apparatus should be provided. If a corrosive chemical is spilled on any part of the body, flush the contaminated area immediately with large quantities of water. Vinegar is effective in neutralizing the area after large amounts of water have been used. In the event of contact between the skin and acid, rinse the area with large quantities of tap water and then apply sodium carbonate to neutralize the area.

Keeping laboratory glassware and other equipment clean is of extreme importance. Contamination of samples will result in invalid analyses if dirty glassware is used. Always clean and dry the workbench tops and tables after completing analysis of samples or after making up chemical solutions.

Before setting up titration apparatus (figure 99), clean meticulously the burettes and pipettes to be used. Inspect them frequently during analyses and reclean them at the first signs of adherence of solutions or samples to the inner sides of the glass. The results of an analysis can be distorted greatly by the presence of a SINGLE droplet of solution or particle of grease adhering to the inside of the pipette or burette. For example, a one-drop error in delivery of the Knudsen pipette can cause an error of 0.16 parts per thousand of salinity.

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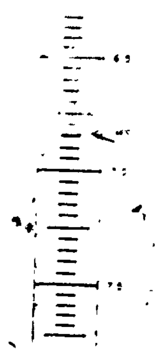
Volumetric flask

Volumetric pipet.



Burette reading.

Automatic plunger type pipet.

Figure 98.



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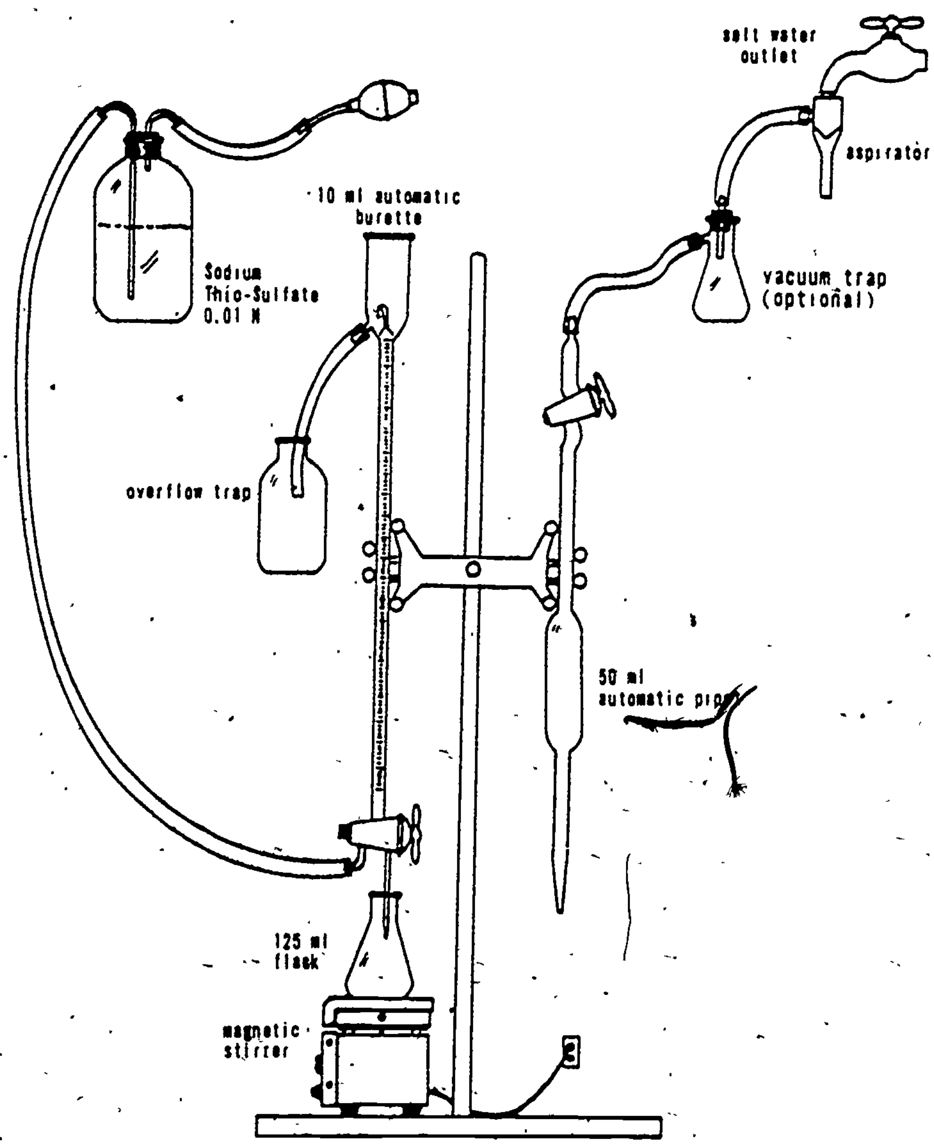


Figure 99.— Complete laboratory setup.

The following method is recommended for cleaning glassware. Rinse the instruments inside and out with fresh water and fill them with a special acid-dichromate cleaning solution. Because this solution is very concentrated, wear safety goggles and rubber gloves when handling this solution. Do not let the solution come in contact with the graduations or other markings on a burette, as it will remove the color from the lines and figures. Leave the solution in the instruments for at least 12 hours. Drain the acid-dichromate solution carefully from the instrument and return the solution to its container for reuse. Rinse the instrument for about 5 minutes in tap water and then make a final rinse with distilled water. If there is any sign of water adhering to the inside of the instrument, fill the instrument again with the cleaning solution and let it stand for at least 2 hours.

If the instrument is clean, remove the stopcocks and allow them to dry; then lubricate and reassemble them. The pipette or burette is now ready to be set up for titrations. When running the titrations, keep a close watch on the condition of these instruments. At the first evidence of droplets adhering to the inside, clean the instruments again.

The acid-dichromate solution is prepared from concentrated sulfuric acid and a commercially available solution called Chromerge. To prepare the solution, proceed as follows:

1. Slowly add a small bottle of Chromerge concentrate into a 9-pound bottle of concentrated sulfuric acid.

2. Recap the 9-pound bottle tightly and mix well.

3. Allow the slightly warmed mixture to cool to room temperature before using.

(Wear rubber gloves and goggles during preparation of the solution.) A crystalline precipitate will form at the bottom of the bottle. The precipitate indicates that the solution is saturated and may be used over again as long as the precipitate remains. When the dark brown color of the solution begins to show a greenish hue, it is an indication that too many impurities are present. The solution should be disposed of and a new solution made up.

## SAMPLING NETS

Biological sampling nets are designed for various purposes. Some nets can be used only when a ship is stopped or at anchor, and other nets are designed to take samples while a ship is drifting or underway. Certain nets can be used to obtain samples only at the surface, and still others can be used to collect samples from any depth desired. Net mesh sizes vary. The selection of the mesh size depends on the organisms sought. Qualitative samplers sieve organisms from the water, but they do not measure the volume of water that passes through the net. On the other hand, quantitative samplers not only sieve organisms but also measure the volume of water filtered. (See figure 100.)

A qualitative plankton sampling net is shown in figure 101. The net is cone shaped, and its opening at the large end is fitted with reinforced eyes and is lashed to a metal ring. The small, or cod, end of the net is attached to the sample bucket. The qualitative plankton sampling nets most commonly used have one-meter, half-meter, and 30-centimeter metal rings, and are approximately 5 meters, 3 meters, and one meter long, respectively.

The qualitative plankton sampling net is simple to operate; the only tool required is a medium size screwdriver. The qualitative plankton net may be towed either vertically, obliquely, or horizontally. After an operation is completed, rinse the net and bucket in fresh water to remove any plankton that may have adhered to the sampler; then, dry the net in the shade. (Keep oil and grease off the net.)

### CLARKE-BUMPUS QUANTITATIVE PLANKTON SAMPLER

A Clarke-Bumpus quantitative plankton sampler is shown in figures 102 and 103. It is designed to be opened and closed at a desired depth, and it is equipped with a flow meter that measures the volume of water passing through the net. Thus, a quantitative plankton sample can be taken at a desired depth by means of this sampler without contamination from plankton in overlying water strata.

After an operation is completed, rinse the sampler in fresh water, dry it, and lubricate all metal parts with a light coating of oil.

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Figure 100.— Securing Sampling Net to Oceanographic Wire.

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Figure 101.— The half-meter qualitative plankton net.

Figure 102.— Clarke-Bumpus quantitative plankton sampler.

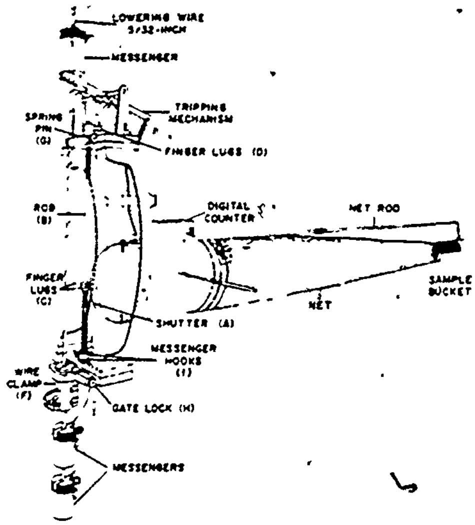


Figure 103.— Side view of Clarke-Bumpus plankton sampler.

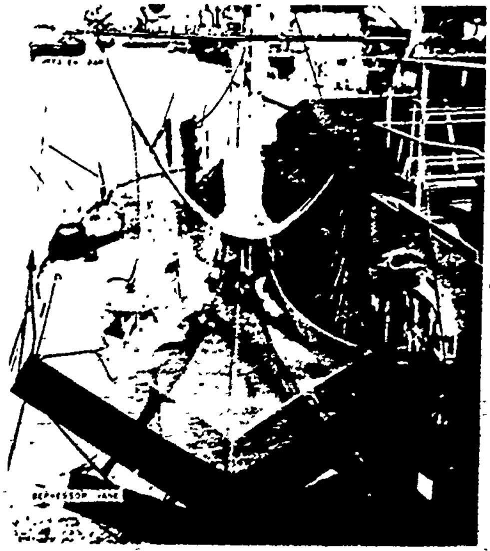

Figure 104.— The midwater trawl.

Remove the net and dry it in a shaded area before storing the net. (Keep oil off the net.)

ISACCS-KIDD MIDWATER TRAWL

The Isaccs-Kidd midwater trawl shown in figure 104 was developed at the University of California, Scripps Institution of Oceanography. It is capable of collecting some of the large and more active nekton forms found in the ocean. As implied by its name, the trawl was designed primarily for use in midwater, that is, ocean

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water below the surface layers. An ordinary net will surface behind the towing vessel unless hauled at extremely slow speeds. To counteract this tendency, the midwater trawl has an inclined plane surface rigged in front of the net entrance. This surface or vane acts as a depressor in a manner opposite to the elevating action of a kite surface.

The midwater trawl is essentially an asymmetrical cone of 2 1/2-inch stretch mesh. It has a 10- or 15-foot pentagonal mouth, it is 31- or 72-feet long, and it has a round opening at the cod end. From a point 3 feet from the end, an additional netting of 1/2-inch stretch mesh is attached as a lining, and a perforated sample container is fastened to the cod end of the trawl by draw strings.

Placing a trawl in the water is dependent upon the characteristics of the towing ship and upon the number of men and equipment available for handling. Generally speaking, however, the cod end is put over the side with bare way on. As soon as the cod end is streamed and the net is flowing freely, the depressor should be lowered just below the surface. If the trawl is lowered over the side rather than the stern, fouling in the ship's screws can be avoided by making a gradual inside turn until the trawl is streaming well aft.

If properly streamed, the V-shaped depressor will not only cause the net to dive but will also funnel additional water into the mouth of the net, keeping the net billowed out. As soon as this occurs and the net is well clear of the ship, the ship's speed should be increased to the speed that will produce the desired towing speed, with consideration for the relative motion lost due to the pay-out speed of the towing cable from the winch. A continuous watch on a dynamometer should be maintained, especially during lowering and retrieving, or during changes in weather conditions, to avoid straining or parting the towing cable or trawl.

An alternate and perhaps better way of streaming the net is to pay out cable with the ship having just enough way on to prevent the trawl from fouling itself. This method allows a trawl to sink more rapidly to the desired trawling depth. When it is estimated that this depth has been reached, the ship's speed should be increased to the desired trawling speed. A trawl will then stabilize itself at a depth dependent upon the trawling speed, cable diameter, etc.

When it is estimated that enough cable has been payed out to place a trawl at a desired trawling depth, the ship's speed should be slowed to the intended trawling speed simultaneously as the winch is stopped. Reasonable maneuvering can be accomplished by the ship during trawling. The length of the trawling period should be at least several hours. At an early point in operations, a trial series of tows should be run so that a graph can be drawn to show the necessary amount of cable to be payed out for a certain depth when hauled at a certain speed.

After a trawling period is over, the ship should be slowed to a desired trawling speed, less the speed of cable recovery by the winch. The slowing of the ship as the winch begins to retrieve the wire must be a smooth operation so that the actual net speed always remains the same. Any time the retrieving action is stopped, the ship's speed should be increased again to the desired trawling speed. Caution should be taken at all times to see that the actual trawling speed of a net is kept constant to avoid excessive strain from an increase in speed and to avoid allowing entrapped animals to escape with a decrease in speed. Any increase in trawling speed may cause the trawl to dive more steeply. This additional deepening must be taken into consideration if tows are being made close to the bottom.

Because of the additional strains due to the surging of the towing ship during heavy swell, the trawl normally will be used in fair weather. Special emphasis should be placed on trawling when a pronounced deep scattering layer is indicated on the echo sounder.

The depth of towing is of prime importance, and any depth gage available and suitable should be used if possible. Experimentation such as the use of explosives or fish poison (a seepage container of rotenone) in front of the net entrance; the use of a half-meter plankton net of coarse mesh in place of the cod-end can, or the installation of several truncated cones of netting within the cod end (similar to a fish weir) to prevent fish from escaping the net may be desired.

After using the net, it is not necessary to rinse it in fresh water, but spread it out, thoroughly dry it, and then store it. NEVER store the net in a damp condition.

## CURRENT MEASURING INSTRUMENTS

Probably more types of instruments are used for measuring currents than for measuring any other single element of oceanography. Devices range from the simple drift bottle to sophisticated electronic instruments.

Types of current-measuring instruments may be divided into four broad and general categories: free-floating, fixed, tethered, and shipboard. Those in the first category include dye marks and floats, or drogues, that can be observed from ship, shore, or aircraft. Those in the second category include instruments that are attached to piers, towers, or beacons, or are placed on the bottom of rivers, bays, estuaries, and other near-shore areas. Those of the third category include buoys in either deep or shallow water, and those of the fourth category include instruments that can be operated when the ship is underway or anchored.

## DYE MARKS

Dye marks are used to determine current patterns in coastal waters. This technique involves releasing quantities of dye at a given point and checking the dispersion of the dye by means of visual observation, color photography, or fluorometric measurement. In some applications, divers carry containers of dye to a predetermined depth and release it, and in other projects, the dye may be dumped over the side of a vessel.

## PARACHUTE DROGUES

The parachute-drogue method of measuring current speed and direction has become increasingly more important during recent years. In making these observations, an improvised array consisting of a parachute, a length of wire rope, and a lighted, radar reflector equipped buoy is launched from a ship and is tracked. Since the parachute sinks to a predetermined depth, opens, and moves with the prevailing currents, tracking the surface buoy and recording the time and position results in a record of current speed and direction. This method is very satisfactory for measuring surface and shallow water current velocity, but because of a drag force and depth uncertainty, drogues are less accurate for deeper observations.

The technique of launching a series of drogues with parachutes at various depths is especially effective where counter currents exist or where topography may have an influence on currents. The path followed by the drogue will be that of the general water mass, and internal waves or minor current fluctuations generally will not be reflected; however, by recording positions at more frequent intervals, rotary tidal currents and changing current patterns can be detected.

The parachute-drogue array used by NAVOCEANO is shown in figure 105. The parachutes usually are surplus material; and the aluminum TV antenna poles, styrofoam block, radar reflector and light, chains, connectors, cables, and weights are relatively inexpensive. The entire array can be considered expendable if it does eventually sink or becomes lost. Concrete blocks often are used for weights.

## EKMAN CURRENT METER

The Ekman current meter was developed by Dr. V. Walfred Ekman, a Swedish scientist.

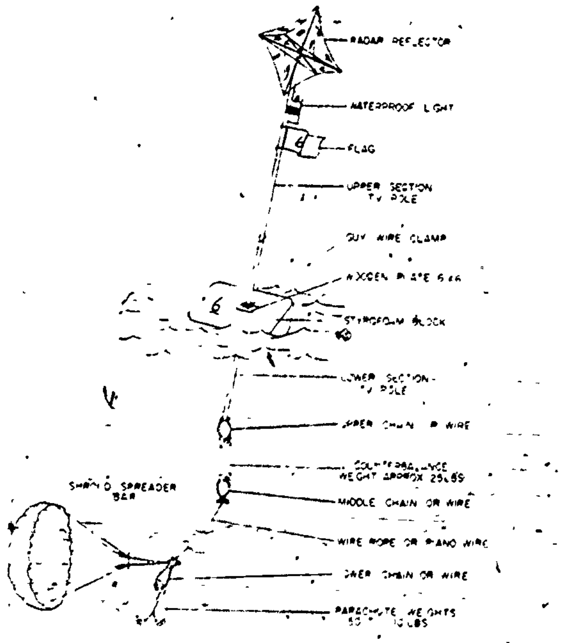


Figure 105.— Parachute drogue array.

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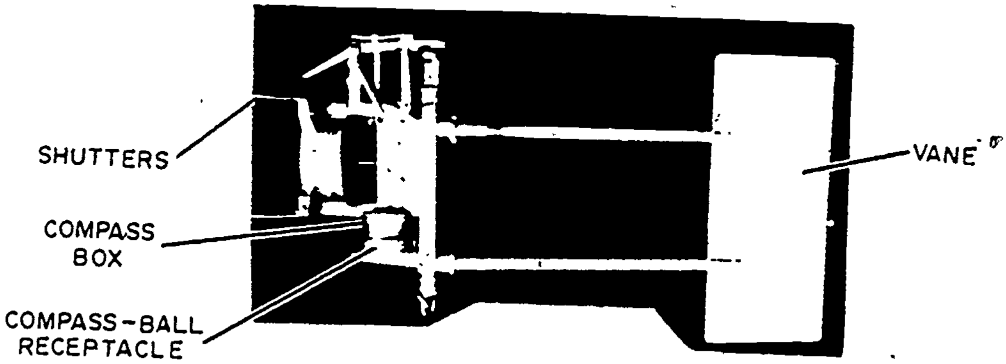


Figure 106.— Ekman current meter.

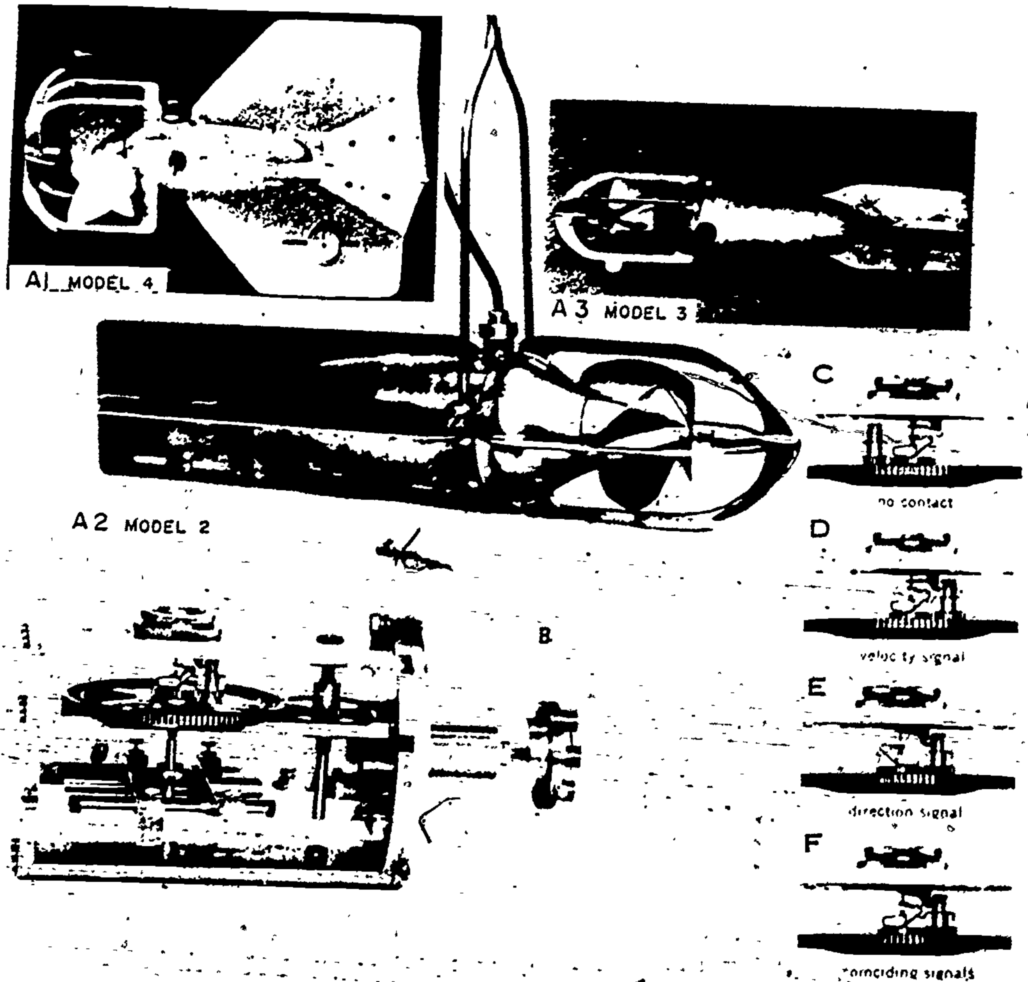


Figure 107.— Roberts radio current meters.

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The meter (figure 106) is designed to give current speed and direction at any depth. The speed-measuring mechanism consists of an impeller, or screw, and a shaft connected to a set of dials which indicate impeller revolutions. The direction device consists of a magnetic compass and compass-ball receptacle. The receptacle is divided into 36 chambers, each representing 10° of azimuth. As the impeller rotates, bronze balls fall, one at a time, from their reservoir onto the top of the compass needle and, depending on the heading of the meter, are guided to one of the 10° direction chambers. This gives the direction toward which the current is flowing.

The current meter is lowered by either the oceanographic or bathythermograph winch, using 3/32-, 5/32-, or 3/16-inch wire. The impeller is locked during lowering and hoisting. One messenger is sent down the wire to unlock the impeller and to set the meter in operation. A second messenger is sent down to lock the impeller before hoisting. The platform from which the Eckman current meter is suspended should be anchored to obtain valid measurements.

The Ekman current meter is a delicate instrument, and it requires careful handling. After each current-measurement operation, rinse the meter with fresh water and lightly oil all moving parts.

## ROBERTS RADIO CURRENT METER

The Roberts radio current meter is an instrument designed to measure current speed and direction. As the word "radio" in its name description implies, this meter was designed to be used as a part of a current-measuring system that transmits current data to the observer by radio. When the meter and the system of radio transmission and remote monitoring of the current data were developed by Captain Elliot B. Roberts of the Coast and Geodetic Survey, they were a marked improvement over the other methods of current measurements in use at that time. The Roberts radio current meter has been used successfully on numerous surveys for over 10 years. Recently, however, more sophisticated current meters have replaced the Roberts radio current meter in most applications, but because the Roberts meter has been used so extensively in the past and is still being used in some operations, a brief discussion of the meter is presented.

Three models of the Roberts radio current meter, along with the internal mechanism of a meter, are shown in figure 107. The gear mechanism (cut B) is enclosed in a watertight main body of the meter, and the rotation of the impeller is transferred to the gears through the bulkhead by magnetic drive. As the impeller turns, two devices in the mechanism make and break (cut C) an electrical circuit to produce the speed and direction signals (cuts D and E). One device is fixed relative to the meter; the other is connected with a built-in magnetic compass. The fixed device makes contact at each fifth turn of the impeller; the other, at every 10th turn. The frequency of the contacts serves as a measure of current speed, and the time relationship of the contacts serves as a measure of current direction.

Speed and direction signals are relayed via watertight cable either to a buoy or to a ship. If the current meters are suspended from an anchored ship, the cable can be brought aboard and the meters can be monitored directly. If the current meters are suspended from a buoy, the signals are transmitted by radio and received at a remote-monitoring base station. (See figure 108.)

During current measurement operations, inspect the meter periodically. Remove any rope fibers, grass, or biological growth from the impeller and impeller bearing. Check swivels, electrical and suspension cables, and ground tackle. After completing an operation, rinse the meters with fresh water. Extensive repairs in the field to the interior mechanism and impeller mount of the meter must be undertaken with caution, because calibration data for meters are determined by preset impeller response and magnetic linkage.

## GEODYNE MODEL A-101 CURRENT METER

The operation of the Geodyne Woods Hole Oceanographic Institute (WHOI) (Richardson) current meter is described in this section. Model A-101 of this current meter is used by NAVOCEANO at the present time(figure 109).

This self-contained digital-film-recording current meter measures current speed from 0.05 to 5.0 knots and current direction within ± 10°. The data are recorded photographically at sampling intervals controlled by an internal mechanism, and as many as 4,500 sets of observations can

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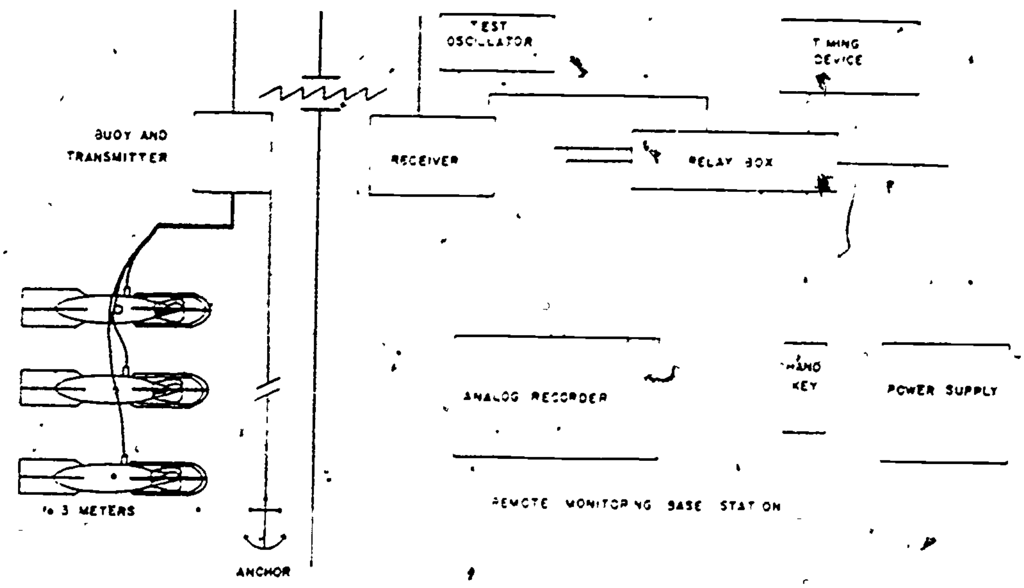


Figure 108.— Telemetering system for Roberts radio current meters.

be recorded on a 100-foot roll of film. The current meter may be programmed to operate for a period of several days or several months, depending on the frequency of the observations. The recording mechanism is battery-powered, and the meter is constructed to withstand pressures encountered at water depths of 5,000 meters.

Figure 110 shows the location of the main components of the current meter. The intelligence from the sensing devices (rotor, vane, inclinometer, compass, and timing devices) is transmitted as light through optical fibers to the field of view of the camera. These light pipes are referred to as channels. A timing device activates the light circuits, causing the various channels in the field of view to flash and be photographed as a row of dots. The meter can be programmed to operate continuously or at predetermined intervals. When operating on INTERVAL, the meter is activated one to 12 times per hour for a 50-second recording period, depending on the cam installed on the time mechanism.

This current meter requires relatively little maintenance. After retrieving the meter and removing the data-record film, close the meter, wash the exterior with fresh water and dry, tape the rotor and vane to prevent turning, and replace the meter in the shipping case.

If flooding has occurred while the meter was submerged, the data record will usually be ruined, depending on the extent of the flooding. Nevertheless, to salvage the current meter components, remove the components (camera, clock, etc.) from the instrument assembly, rinse them with alcohol, and dry them. Then rinse the instrument frame with fresh water, dry and reassemble the components, close the meter, and place the meter in the shipping case for return to NAVOCEANO or the unit that supplied the meter.

Figure 111 shows a common display used with the model A-101 current meter. Figure 112 shows divers actually working with a current meter display.

## GEOMAGNETIC ELECTROKINETOGRAPH

The Geomagnetic Electrokinetograph (GEK) is a shipboard current measuring device designed to record the electrical potential developed by the movement of an electrical cable and electrolyte (sea water) through the earth's magnetic field (figure 113). The GEK measures the



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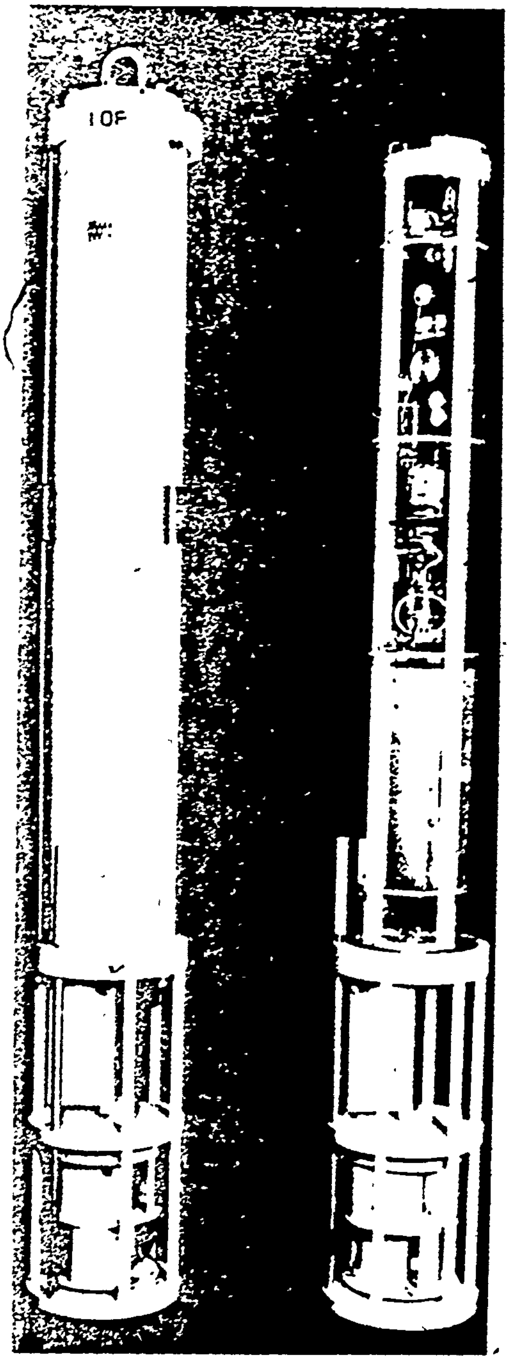

Figure 109.— Geodyne model A-101 current meter.

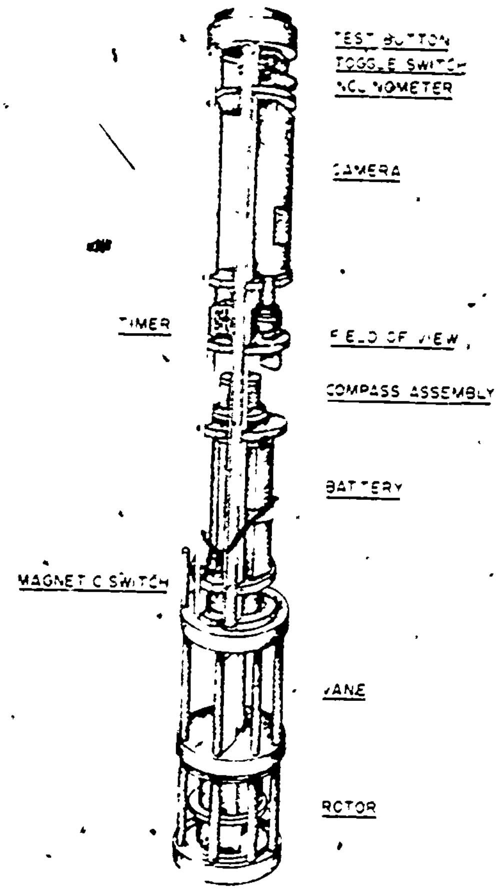


Figure 110.— Main components of the Geodyne current meter.

net current, i.e., the surface current minus the average currents to the bottom.

The essential physical equipment constituting the instrument is:

1. A matched pair of electrodes mounted 200 meters apart on a two-conductor cable long enough (ordinarily two or three times the length of the ship) to stream them astern, away from the magnetic and electrochemical influences of the ship.

2. A recording potentiometer assembly to which the cable is connected.

3. A gyrocompass repeater mounted above or close to the recorder assembly.

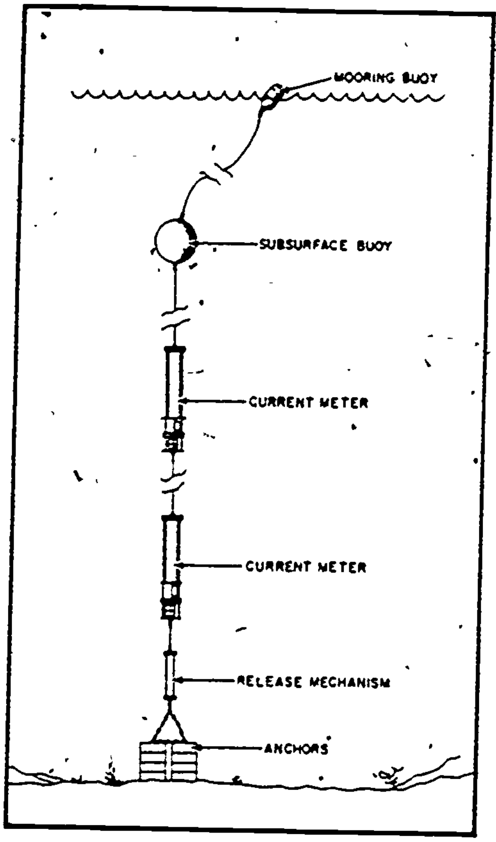


Figure 111.— Geodyne current meter array.

With the above equipment, observations of the potential difference developed in the cable are made when the ship is underway. These potential differences result from the athwartship motion both of the cable and of the water through the earth's magnetic field. They are rigidly related to the set and drift of the ship and thus of the trailing cable. The potential difference changes sign when currents set the ship to port or starboard. The magnitude of the potential difference depends on the rate of drift normal to the course, on the length of cable between electrodes, on the local strength of the vertical component of the earth's magnetic field, and on the vertical distribution of water velocities at the location. Through measurements of the potential differences on two courses nearly at right angles, the drift or component velocities in these two directions are determined. The vector sum, or resultant of these velocities, is the net current vector for that locality.

## SONAR PINGER

The sonar pinger is a battery-powered, automatic cycling, submersible sound generator unit. It is used for positioning oceanographic equipment within measured distances of the ocean floor. The sonar pinger has been used successfully in underwater photography and Nansen

Figure 112.— Divers planting Geodyne current meter on tripod.

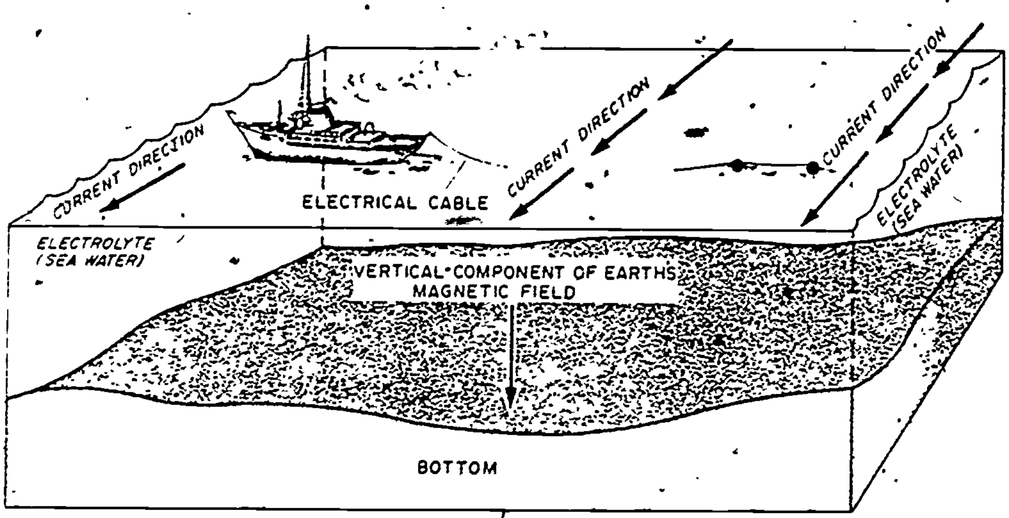


Figure 113.— Measuring currents with the GEK.

cast operations (figure 114). The pinger transmits sonar pulses at precisely timed intervals. As the pinger is lowered toward the bottom (figure 115), the transmitted pings are received on a sonar receiver and displayed on a monitor to produce a continuous visual record of the pinger-to-bottom distance. Since each sound pulse is transmitted directly to the ship and also is reflected by the bottom back to the ship, the interval between the time the direct and the reflected pings are received is:

$$T_{dif} = \frac{2D}{V} \text{ and/or } D = \frac{V\,T_{dif}}{2}$$

where D = pinger-to-bottom distance (feet)
V = velocity of sound in water (feet/second)
$T_{dif}$ = time interval between direct and reflected signals (seconds)

For example, if the pinger is 1,250 feet above the bottom and the velocity of sound in water is assumed to be approximately 5,000 feet per second, the reflected ping will be received one-half second after the direct ping;

$$T_{dif} = \frac{2 \times 1{,}250}{5{,}000} = 0.5 \text{ seconds.}$$

Likewise, a 2 millisecond difference would indicate a distance of 5 feet above the bottom;

$$D = \frac{5{,}000 \times 0.002}{2} = 5 \text{ feet.}$$

Figure 114.— Sonar pinger replaces weight on Nansen cast.

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Figure 115.— Sonar pinger bottom positioning technique for Nansen cast bottom temperature measurements.

DESCRIPTION

The sonar pinger described here is the Edgerton, Germeshausen, and Grier (EG&G), Mark 1, Sonar Pinger. The sonar pinger is composed of three main subassemblies: driver, pulse transformer, and transducer. The driver generates an electrical pulse once every second, the pulse transformer steps up the voltage of the pulse, and the transducer converts the high-voltage electrical pulse into a high intensity 12 kHz sound. The pinger driver disassembled is shown in figure 116. It consists of main driver circuitry, battery, end caps, and driver housing. The pulse transformer is shown in figure 117. It consists of two windings housed in a rubber-stoppered clear plastic tube filled with transformer oil. The transducer is shown in figure 118; it contains ADP (Ammonium di-hydrogen phosphate) crystals mounted in parallel on a backing plate. To achieve good acoustic coupling with the water, the aluminum transducer housing is filled with dehydrated castor oil and is closed with a special rubber diaphragm. In addition to the pinger, a hydrophone and its amplifiers (or echo sounding equipment used in the passive manner), paper chart recorders, and a triggered sweep oscilloscope are required in the sonar pinger operation to receive and visually or graphically display the pinger signal.

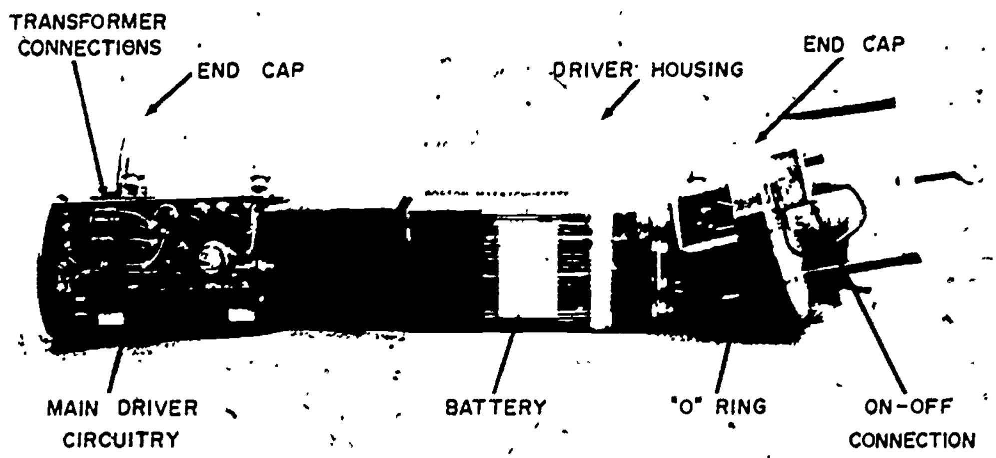


Figure 116.— The pinger driver disassembled.

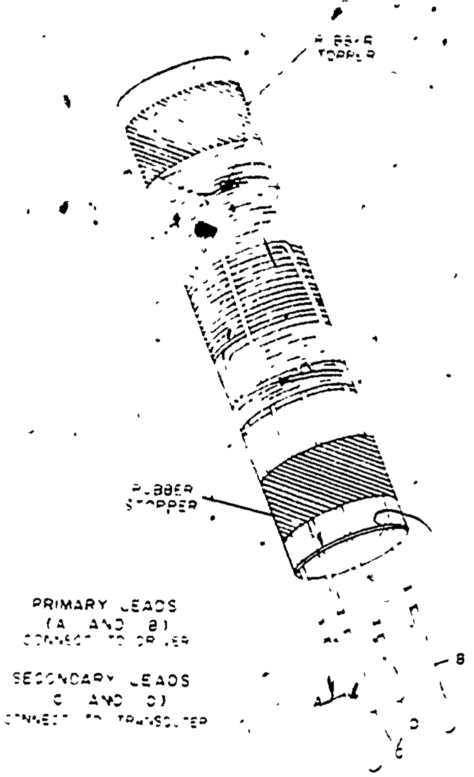


Figure 117.— Sonar pinger pulse transformer.

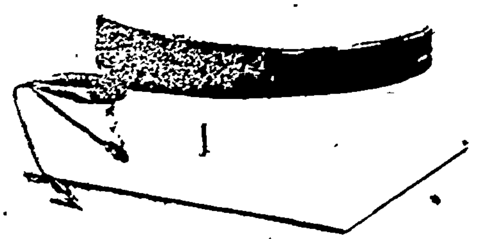

Figure 118.— Sonar pinger transducer.

THEORY OF OPERATION

Operation of the sonar pinger is automatic. Once the pinger is activated, the unit will generate a sound pulse once per second until the battery is discharged or until the unit is turned off. Every 10th pulse is blanked so that the direct and indirect ping can be matched.

When activated, 6 volts from the battery are applied to the precision-interval timing-switch motor and to the two transformer coupled transistors. They oscillate at approximately 2 kHz, creating a 6-volt alternating current, which is raised to about 420 volts in the toroidal power transformer. The 420-volt alternating current is rectified to 840 volts direct current, which charges a capacitor. When the capacitor discharges into the pulse transformer, an 8,000-volt pulse is generated and transmitted to the transducer. The secondary of the transformer and the crystals of the transducer form a tuned circuit which oscillates at about 12 kHz for approximately 0.5 millisecond (about 6 cycles) every second. The sound energy created by the oscillation of crystals is transmitted through oil to the rubber diaphragm and into the water.

NANSEN CAST BOTTOM POSITIONING TECHNIQUE

Figure 119 presents a standard supporting arrangement for a sonar pinger on a Nansen cast. The pinger assembly, which weighs about 150 pounds, replaces the 100-pound lead weight normally used. Two or three Nansen bottles (2 meters apart) are placed on the wire, with the bottom bottle as near as practical to the

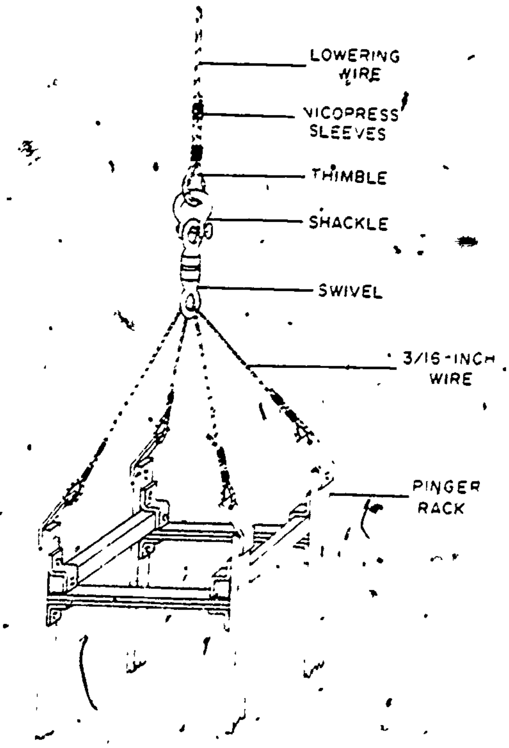


Figure 119.— Standard supporting arrangement for Sonar pinger used on Nansen cast.

pinger. During the lowering of the cast and while the messenger is sliding down the wire, the pinger-to-bottom distance is monitored so that the Nansen bottles with the reversing thermometers will be tripped when they are very near the ocean floor.

## BOTTOM POSITIONING TECHNIQUE

After a pinger is activated and over the side, the lowering should be monitored with the ship's echo-sounding equipment, a Precision Depth Recorder (PDR), and an oscilloscope (figures 120, 121, and 122).

With the ship's echo-sounding system, determine the approximate depth of water in fathoms and compute the largest multiple of 400 representing this depth (400, 800, 1,200, etc.). For example, 2,603 contains 2,400 as the largest multiple of 400. Set the ship's echo sounding system to the listening mode, and the PDR to the 0- to 400-fathom scale. As the pinger is lowered, the signal traces on the strip chart will either diverge or converge, will automatically shift when they reach the edge of the chart, and will cross when the pinger-to-bottom distance is equal to the largest multiple determined for depth. The traces will continue to diverge and converge as bottom is approached, and at each crossing the pinger-to-bottom distance will be less by 400 fathoms (figure 122).

Continue lowering until the pinger is approximately 100 fathoms off the bottom (when traces are separated by about one-fourth the full scale of the PDR); then, reduce the winch speed and lower the pinger with caution. When the pinger is approximately 20 fathoms off the bottom, stop the winch. From this point, rely mainly on an oscilloscope.

Begin to lower the cast slowly. Turn the Time/Division dial to 5 milliseconds; the unit now is set up to measure pinger-to-bottom distance from 37.5 meters down to 3.8 meters (see table 11). When the pinger-to-bottom distance decreases to 15 meters, turn the Time/Division dial to 2 milliseconds; the unit then is set up to measure between 15 and 1.5 meters. Continue to monitor the pinger-to-bottom distance, paying out and taking up wire as required for the desired depth until the operation is completed. You are now ready to retrieve the cast.

If for any reason the pinger should cease to function during an operation, raise the cast immediately. The pinger may be flooded, the leads may have fouled, or one of the components may have failed. If flooding is suspected, hoist

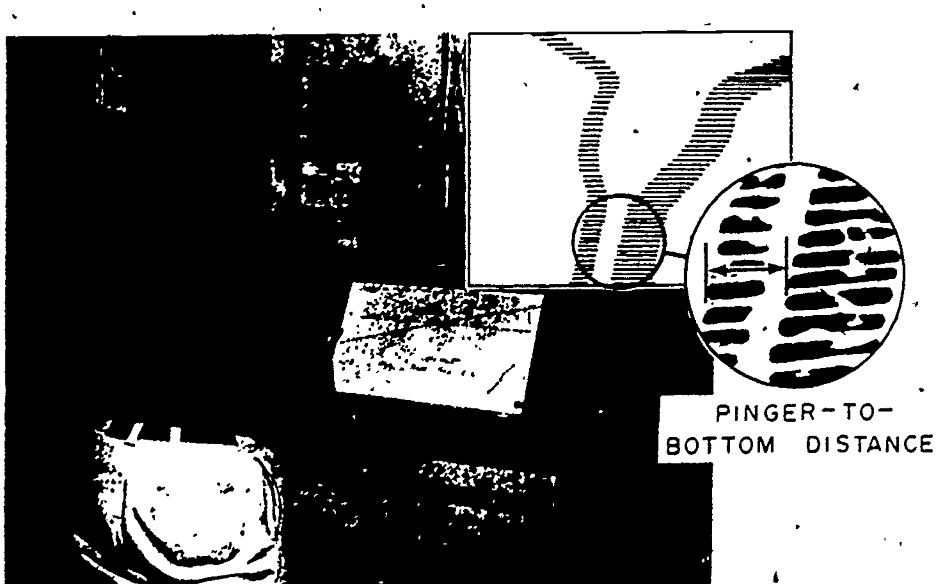


Figure 120.— NAVOCEANO scientist using the Mark 15A Precision Depth Recorder to determine pinger-to-bottom distance.

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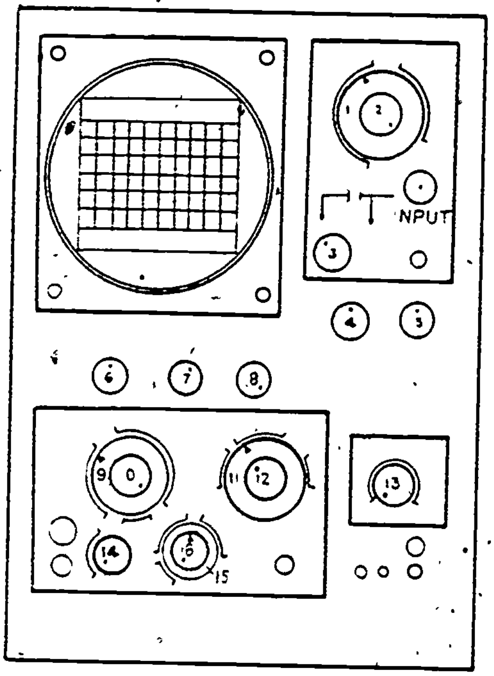
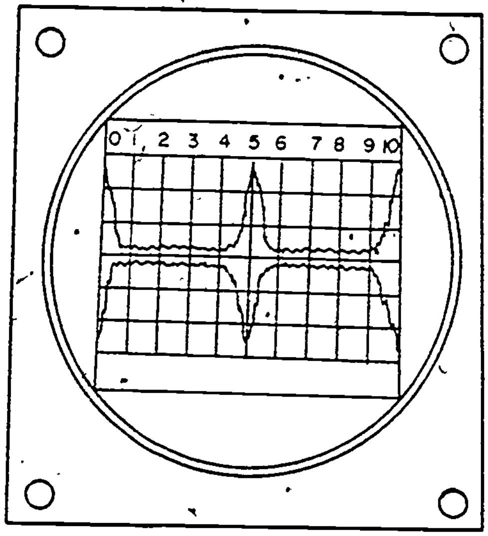
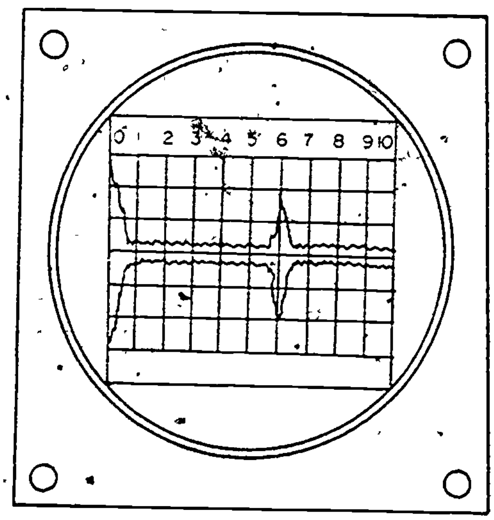



(a) Diagram of oscilloscope panel




(b) Oscilloscope grid showing direct ping at 0, 5, and 10.




(c) Oscilloscope grid, showing direct ping at 0 and reflected ping at 6. (With dial (9) set at 5 milliseconds, pinger-to-bottom distance is 23 meters. With dial (9) set at 2 milliseconds, distance is 9 meters.)

Figure 121.— Oscilloscope monitoring of pinger-to-bottom distance.

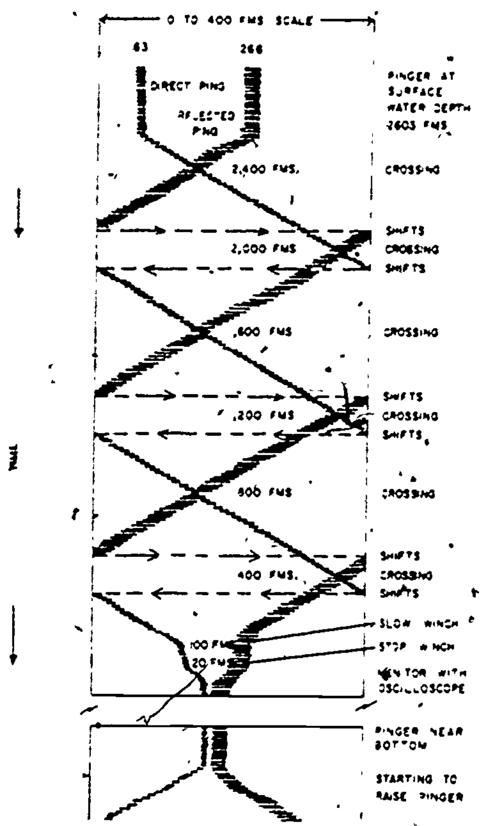



Figure 122.— PDR strip chart of Sonar pinger signals.

Table 11.— Sonar pinger-to-bottom distance.

Table based on sound velocity of 1,500 meters per second (820 fathoms per second)

| Secondary time/division dial 9 settings (milliseconds) | Oscilloscope grid divisions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 0.75m | 1.5m | 2.25m | 3.0m | 3.75m | 4.5m | 5.25m | 6.0m | 6 75m | 7 5m |
| 2 | 1.5m | 3.0m | 4 5m | 6.0m | 7 5m | 9 0m | 10 5m | 12.0m | 13 5m | 15 0m |
| 5 | 3.8m | 7 5m | 11.2m | 15.0m | 18.8m | 22.5m | 26.2m | 30.0m | 33.8m | 37.5m |
| 10 | 7.5m | 15.0m | 22.5m | 30.0m | 38m<br>20fms | 45m<br>25fms | 52m<br>29fms | 60m<br>33fms | 68m<br>37fms | 75m<br>41fms |
| 20 | 15m | 30m | 45m<br>25fms | 60m<br>33fms | 75m<br>41fms | 90m<br>49fms | 105m<br>57fms | 120m<br>66fms | 135m<br>74fms | 150m<br>82fms |
| 50 | 38m<br>20fms | 75m<br>41fms | 112m<br>61fms | 150m<br>82fms | 188m<br>102fms | 225m<br>123fms | 262m<br>143fms | 300m<br>164fms | 338m<br>184fms | 375m<br>205fms |
| 100 | 75m<br>41fms | 150m<br>82fms | 225m<br>123fms | 300m<br>164fms | 375m<br>205fms | 450m<br>264fms | 525m<br>287fms | 600m<br>348fms | 675m<br>369fms | 750m<br>410fms |



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the unit inboard and drain it by loosening the driver lower end cap. Check the O-rings for nicks or cuts. If flooding has taken place, wash the parts with fresh water and dry them before reassembling. Refer to the instruction manual in the event that a component malfunction has caused the trouble. If a lead was fouled and disconnected, cover the connection with electrical tape and lower the cast again. Check the battery voltage after each lowering.

## UNDERWATER CAMERAS

Underwater cameras may be classified under two categories: those operated in shallow water by divers and those automatic deep sea systems that are lowered from ships. Both groups use either color or black and white film.

The deep sea underwater camera systems are automatic systems that are lowered from ships or are installed on deep sea submersible vehicles. The Edgerton, Germeshausen, and Grier (EG&G) deep-sea underwater camera systems (figure 123) used by NAVOCEANO to produce stereo, double-camera, or single-camera photography make use of the following components: (1) an electrically-driven, 35-mm still camera, (2) light source, (3) battery pack, (4) mounting rack, and (5) sonar pinger.

The camera is encased in a watertight steel housing tube. (See figure 124.) The housing tube is designed to operate to a maximum pressure depth of 17,500 psi. The camera takes about 500 separate exposures on a standard 100-foot roll of film. The lens, an f/4.5 Hopkins, is specially designed to correct for the distortion introduced when light passes from the water through the housing window to the air inside the camera housing. The lens is prefocused to give a depth of field in water of about 3 1/2 to 20 feet. The maximum distance above bottom at which photographs of the bottom are possible is determined by the film speed, light intensity, and lens aperture.

Illumination for underwater photography is provided each camera by an accompanying 200-watt-second, electronic flash (strobe) unit (figure 125). The unit is enclosed in a water-tight steel housing tube and utilizes a Xenon flashtube which is fired by a bank of capacitors. These strobe units are designed to work in synchronization with the camera advance motor. Approximately every 15 seconds, the capacitors discharge and fire the strobe light; then, during the next 6 seconds, the film advance motor moves the film to the next frame; meanwhile, the capacitors are being charged to repeat the cycle.

Power for the light source and the camera motor is supplied by two battery packs (figure 126). The packs are contained in steel tubes similar to those of the camera and the light source. Each battery pack contains two series connected six-volt, silver zinc wet-cell batteries (figure 127). Model 280 contains a clock-driven mechanical time-delay switch, and Model 281 contains a 15-second cycling device. Batteries usually must be recharged after each lowering.

Many ships use an adjustable mounting rack for underwater photography. The racks are designed to accommodate a variety of camera arrangements. The rack is constructed of galvanized or stainless steel channel members, brackets, spring loaded nuts, bolts, and instrument holders. The spring loaded nuts slide to any position in the channel members so that cameras, light sources, battery packs, and the pinger can be mounted to suit the project at hand.

A sonar pinger, which has already been discussed, rounds out the basic equipment used in underwater photography. The positioning technique used for a Nansen cast is also used for the desired camera location.

## TRANSPARENCY MEASUREMENT DEVICES

The Secchi disc and Forel scale are used to measure water transparency and water color, respectively. The Secchi disc is a circular plate, having a standard diameter of 30 centimeters. One side is white and the other is black. A ring attached at the center of the disc allows a graduated line to be secured. A 5- to 7 1/2-pound lead weight is attached to the disc so the device will sink rapidly and vertically. The line attached to the Secchi disc should be marked off in 1-meter intervals to at least 50 meters. It is recommended that 1/4-inch tiller line with a phosphor bronze core, which minimizes stretching, be used.

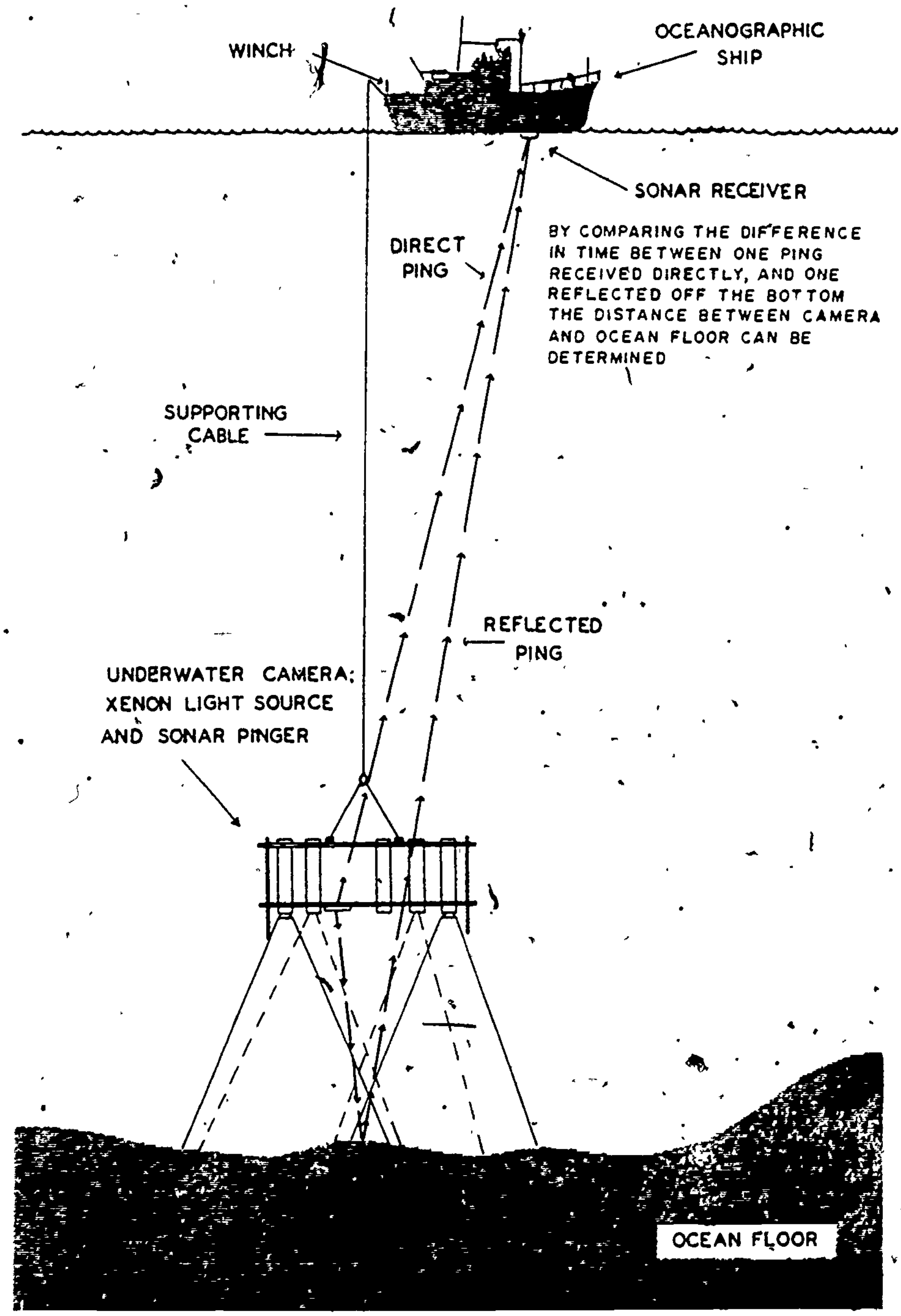


Figure 123.— Deep sea underwater camera system.

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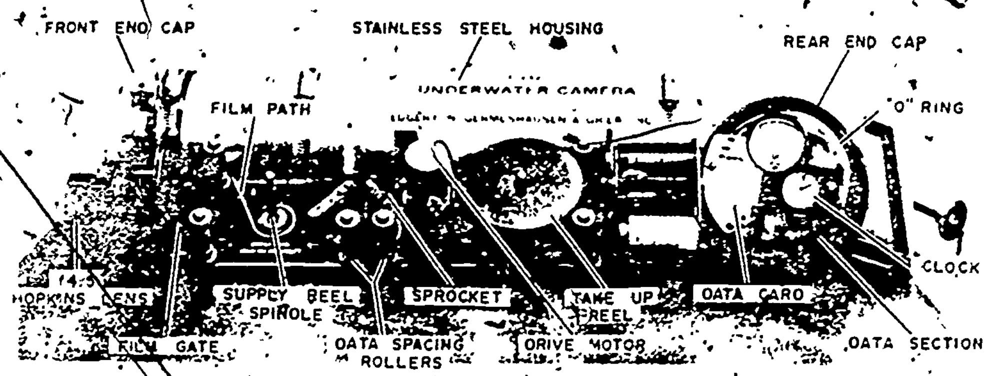


Figure 124.— Underwater cameras (EG&G Model 204).

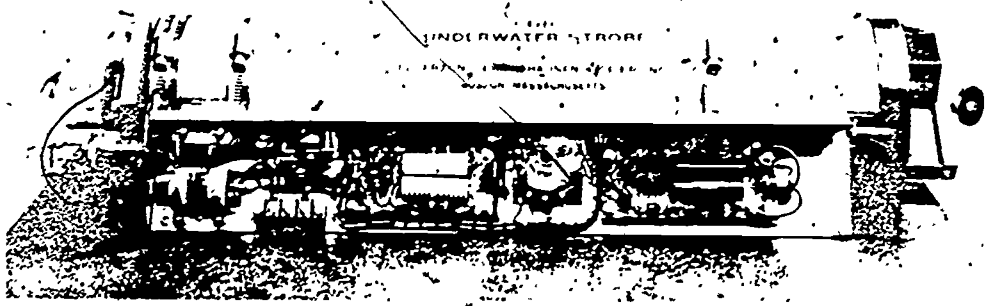


Figure 125.— Underwater light source (EG&G Model 214).

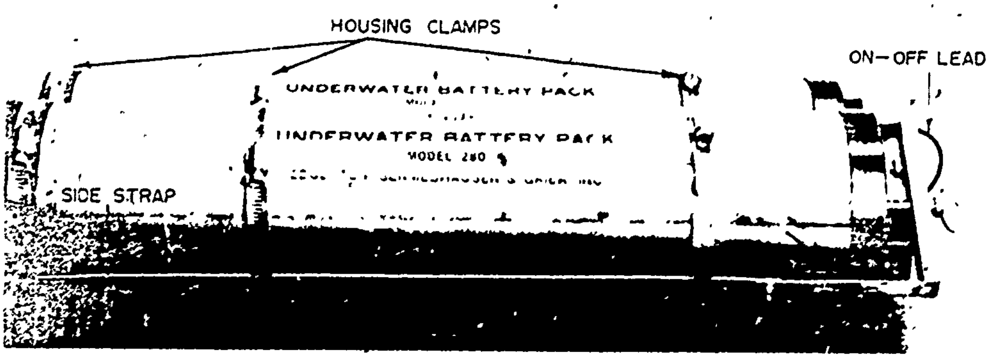


Figure 126.— Underwater battery packs (Model 280 contains time delay unit and Model 281 contains 15 second cycling device).



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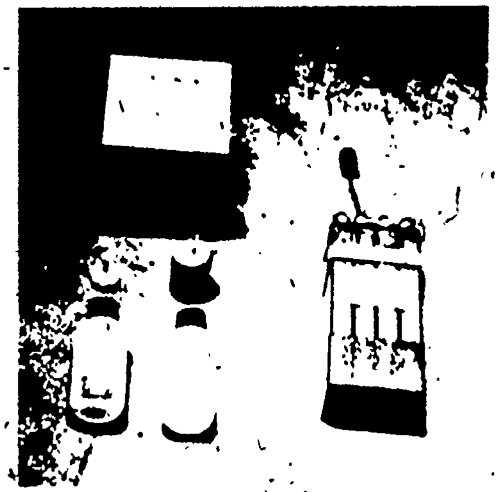

Figure 127.— Silver zinc wet cell battery and filling kit.

Water color is most easily determined in conjunction with the Secchi disc (figure 128). A standard Forel scale is used. This scale consists of a series of 11 small vials containing ammoniacal copper sulphate and neutral potassium chromate in such proportions that a different graduation of color is imparted to each vial. These vials are numerically designated and are compared directly with the water.

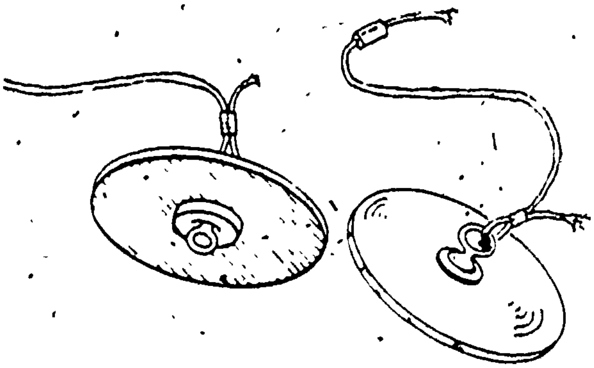

Figure 128.— The Secchi disc.

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# UPPER-AIR EQUIPMENT

In this section you will be introduced to some of the equipment generally associated with upper air observational programs. As a Marine Science Technician, you may be required to assist others in such programs, or in the case of icebreaker duty, an upper air program will constitute a large percentage of your work load. In either situation, a minimum working knowledge of equipment associated with upper air observations will benefit you in performing your assigned duties.

## BALLOONS

Sounding balloons used for upper air observations are divided into three major groups: ceiling balloons, pilot (winds aloft sounding) balloons, and radiosonde sounding balloons. Because there are differences between the types of balloons, the topics of the storage, handling, conditioning, and inflation of these balloons are treated individually in the following sections.

### CEILING BALLOONS

The standard balloon specifically designed to measure the height of clouds (ceiling) is the 10-gram, black or dark blue ceiling balloon. The ceiling balloon is normally used to determine the height of the ceiling when the broken or overcast layer of clouds is 2,500 feet or less. Sometimes, it is desirable to obtain a more rapid ascent than can be obtained with a 10-gram balloon, for instance, when taking a balloon ceiling under adverse wind conditions. Under adverse conditions, or when it is necessary to save time, it is permissible to use either a 30-gram balloon or a 100-gram balloon, depending on the desired ascension rate. When using either of these two balloons, choose the appropriate color of balloon; use red balloons for thin clouds and black balloons under other conditions.

The Universal Balloon Balance (ML-575/UM) is used to inflate the 10-gram ceiling balloon for use. The nozzle lift should be so adjusted that it weighs EXACTLY 43 grams when inflating the balloon with helium.

Since the ceiling balloon is not used to reach altitudes much beyond 2,500 feet, the rapidity of inflation is not highly important; however, an attempt should be made to inflate it in about 3/4 to 1 minute.

Ceiling balloons should be stored in a dry, warm environment. The temperature should be as high as possible, but should not exceed 120° F. When the balloons have been exposed to temperatures below freezing, they should be stored at a temperature of 65° F or higher for at least 12 hours prior to removal from their container. They should not be placed immediately adjacent to large electric generators or motors. Motors and generators emit ozone, which is detrimental to neoprene. Balloons lose their strength with age; therefore, they should be used in the order of their production dates to avoid excessive aging. Ceiling balloons need not be conditioned prior to use.

### PILOT BALLOONS

The balloons used to obtain pibals (pilot balloon observations) are of two types: the 30-gram balloons and the 100-gram balloons. Both sizes are issued in red, in black, and in white. They are manufactured in such a manner that they are without seams and are nearly spherical in shape when inflated. An extension of the lower axis, about 2 inches in length, forms

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the neck or appendix through which inflation is accomplished. Two types of balloons are now issued—balloons with a thin neck, or appendix, that fits over the cup-shaped nozzle of the standard pilot balloon balances, and those with a thickened, tubular neck, or appendix, that requires a rounded nozzle on the inflation balance.

The numerous pilot balloons used in winds aloft observations were designed for various weather conditions. If weather conditions indicate that the balloon sounding will reach 7 km or higher, a 100-gram balloon is normally used. For all other pibals, the 30-gram balloon is used, except that a 100-gram balloon may be used whenever strong winds in the lower levels make it probable that a 30-gram balloon would be blown out of sight before reaching the cloud layer. Normally, an uncolored balloon is used with a clear sky, a black balloon with a low or middle overcast, and a red balloon with high overcast or with a white or grey background.

The conditions of storage for pilot balloons are the same as those described for the ceiling balloons. The handling and conditioning of pilot balloons are the same as for radiosonde balloons.

Inflation of pilot balloons should be accomplished in accordance with the instructions given in Circular O.

RADIOSONDE AND
RAWINSONDE BALLOONS

Different sizes of balloons are used for upper air soundings, depending on the altitude required. Most of these balloons are made of neoprene and must be handled with the utmost care. Their construction is similar to that of pilot balloons, except that they are uncolored, larger, thinner, and more flexible than the pilot balloons. No particular size balloon is considered standard issue.

Balloons used for radiosonde and rawinsonde soundings should be stored in their original sealed containers and in a room isolated from large electric motors or generators. Ideal temperatures for storage are in the range 35° to 85° F. Temperatures below 32° F and above 110° F should be avoided during storage. If, by necessity, balloons are stored at temperatures below 50° F, they should be removed to an area having a temperature of 70° F or higher for at least 48 hours prior to use.

BALLOON CONDITIONING

Most of the balloons used for upper air soundings are made of neoprene rubber. Balloons made of this material lose part of their elasticity as a result of long storage and exposure to relatively low temperatures. If they are released in this state, they normally burst before maximum altitude is reached. Therefore, before the balloons can be used, they must be conditioned to restore their elasticity. The two methods used to condition them are accomplished through use of hot water and dry heat.

Hot Water Method

The hot water method provides the most satisfactory result of the two conditioning methods. The equipment needed is a container for hot water and a wooden plug. A piece of twine or a rubberband can be substituted for the wooden plug.

The hot water container should be of smooth procelain or noncorrosive metal with a rolled top rim and inner surface free of projections or roughness which would scratch or chafe the balloon. Additional protection can be provided by fitting a cheesecloth bag in the container as a lining. If the cheesecloth lining is not used, a false bottom should be placed in the conditioning container to prevent the balloon from coming in contact with the bottom adjacent to the heat source. The container should be large enough and contain sufficient water to permit the balloon, except for the neck, to be submerged without crowding.

To condition the balloon, fill the container with water, bring the water to a boil, and turn off the heat. Exhaust the air from the balloon and insert the wooden plug in the neck. If a wooden plug is not available, use a piece of twine or a rubberband to close the neck of the balloon. Then immerse the entire balloon, with exception of its neck, and slowly move it around in the water. After 5 minutes, remove the balloon from the water. Do not open the neck until the inflation nozzle is to be inserted.

Hot tap water may be used to condition neoprene balloons, but the conditioning period must be increased proportionately. The period ranges from 5 minutes at 212° F to 4 hours at 120° F. Temperatures below 120° F do not satisfactorily condition neoprene balloons.

If the outside air temperature is above 40° F, the balloon can be removed from the conditioning container, drained free of excess water, and inflated without delay. If the outside air temperature is below 40° F, the balloon should be dried completely before launching.

Dry Heat Method

The dry heat method requires a conditioning chamber in which to suspend the balloon. The chamber must be constructed so that the balloon can be uniformly heated, since uneven heating causes uneven expansion of the rubber, with resulting stress lines that cause premature bursting. Uniform heating of the balloon for 30 minutes at a temperature of 212° F produces satisfactory results. The conditioning period must be extended proportionately longer for lower temperatures. By the time a temperature of 120° F is reached, a conditioning period of 8 hours is required.

If neither of these methods can be used, neoprene balloons may be conditioned by placing them over a heater, radiator, or electric lamp, care being taken to shield the balloons from direct contact with these heat sources. Temperatures as near as possible to the boiling point of water should be used. The conditioning temperature, however, must not exceed 230° F. (If latex balloons are used, no conditioning period is required.)

The balloons are extremely delicate, especially when in a softened condition after the heat treatment. No part of the balloon except the neck should be touched with the bare hands. Soft rubber gloves, soft cloth gloves, or some other nonabrasive material should be used to protect the balloon when it is necessary to handle any portion other than the neck of the balloon. If gloves are not worn, make certain that hands are clean, fingernails are clipped, and rings are removed, particularly rings with high crowns, sharp edges, or prominent, raised figures. Dust hands with talc.

## UPPER AIR ACCESSORY EQUIPMENT

The following descriptions of mechanical upper air accessory equipments provide a résumé of some of the technical and operational characteristics of expendable and accessory items used in a sounding program.

### INFLATION KITS

Universal Balloon Balance (ML-575UM)

The universal balloon balance is used to determine buoyancy and to control the inflation of 10-, 30-, and 100-gram balloons. The set contains two aluminum adapters, two brass adapters, an aluminum valve body, a brass hook adapter, and a weight pan. These items are packed in a small wooden box.

Balloon Inflation Nozzle Weight Kit (MK-216/GM)

This inflation kit is used to determine the buoyancy and to control the inflation of a radiosonde balloon. The set contains two nozzle assemblies of different size for large- and small-necked balloons, a brass weight with mounting post, and a weight stack of assorted weights.

### BALLOON SHROUDS

Balloon shrouds are fabric canopies used to handle and release inflated radiosonde balloons in high or gusty winds. The shrouds consist of nylon parachutelike hemispheres, 6 feet in diameter, with four flaps that fold almost completely around the inflated balloon, but which have sufficient spacing between the flaps or handles to allow the neck of the balloon to protrude. (Each flap has a handle.) On the top of the shroud is an eyepiece to which a string can be tied. The string may be tied to some fixed object or held by another person during the release.

### HELIUM AND ACCESSORIES

Helium

Helium is available in two types; oil-free and oil-pumped. There are four different grades;

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grades A, B, and C are oil-free and grade D is oil-pumped. The grade and type of helium recommended for balloon inflation is grade D, oil-pumped. The other grades and type of helium may be used if necessary.

Compressed gas cylinders are color coded for proper identification. Helium cylinders have a gray body; grade D helium also has a gray cap and an orange stripe around the upper portion of the body, while the cylinders of oil-free grades of helium are identified by the buff colored cap and upper or top part of the body. The title "HELIUM" should also be painted in white on the body of the cylinder.

Helium cylinders contain 200 cu. ft. of compressed gas at working pressures near 2,000 psig. when full. A helium cylinder is 51 inches long, is 9 inches in diameter, and weighs approximately 110 pounds. A cylinder should be considered empty when the gas pressure equals 25 psig. Since cylingers containing oil-pumped gas are normally equipped with left-hand threads on the valve outlet, check the thread direction on the type of valve you are using to prevent damage to the cylinder valve.

When you handle compressed gas cylinders, the following precautions are recommended:

1. Make every effort not to drop cylinders or to strike them against another cylinder or object.

2. Do not bump or strike the discharge valve during handling operations.

3. Ensure that the cylinder outlet cap and cylinder valve protecting cap are in place when you are handling the cylinders.

4. Remove the regulators and replace the caps before moving cylinders to another location.

5. When loading or transferring cylinders, especially when using a crane or derrick, secure the cylinders in a cradle, suitable platform, or rack. Never use electromagnets to move cylinders.

6. When moving a cylinder by hand, tilt it slightly and roll it on its bottom edge, without dragging or sliding.

7. Never use hooks or lines through the valve protection cap for hoisting cylinders.

8. Do not pry loose with crowbars or similar tools cylinders frozen to the deck or otherwise fixed.

Stowage of helium cylinders should include the following considerations:

1. Stow cylinders in approved stowage areas or compartments for your vessel.

2. Maximum temperature of the stowage compartment should NOT exceed 130° F.

3. Ventilate compartments containing compressed gases a MINIMUM of 15 minutes prior to entering a compartment if the ventilation has been closed down to that compartment.

## Regulator

The helium regulator is used to provide a low-pressure helium source for balloon inflation. When connected to a helium cylinder, the regulator provides an indication of cylinder pressure, a regulated hel[illegible]outlet pressure suitable for balloon infl[illegible] an indication of the number of cubic fe[illegible]maining in the cylinder. The complete regulator is furnished with adapter couplings for attachment to either a right- or left-hand female thread on the helium flask and with a hose coupling on the outlet. Outlet connection may also be made to a right-hand threaded female coupling on a tube or pipe.

When inflating balloons using the helium regulator, try to use a pressure of abou[illegible] psi.

## PLOTTING BOARDS

Meteorological plotting boards are used to determine winds aloft, ballistic winds, true wind direction and speed at sea, fallout vectors and the principle of triangulation in meteorological work. (See figure 129.)

Plotting boards have been issued in two sizes: approximately 24 inches square and 36 inches square.



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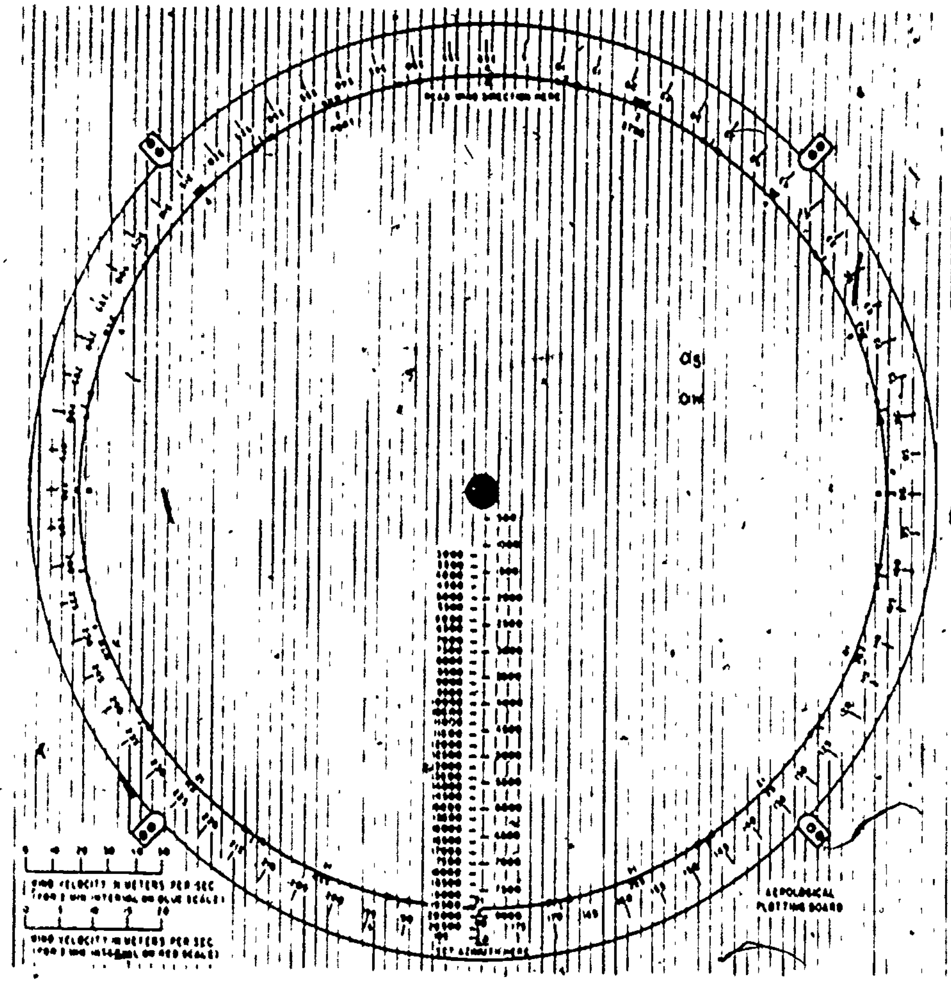

Figure 129.— Meteorological plotting board.

The base of the plotting board in the newer models is made of an aluminum casting or heavy plyboard covered by plastic. In the older models, the base consists of a square wooden board. At the center of the base, a brass bearing and a pin secure the protractor to the base and yet allow it to rotate in azimuth.

The protractor is a transparent celluloid or cellulose disk. The upper surface is frosted in order that plottings may be entered in soft pencil or washable ink. The outer edge of the protractor is graduated from 1° to 360°. The base of the plotting board beneath the protractor is ruled off in heavy vertical, orange-red lines 1 centimeter apart and in lighter lines at intervals of one-half centimeter. From the center of the board, or from the pin, two distance scales are ruled off vertically downward to the bottom of the board, the red scale to the right and the blue scale to the left of the heavy vertical index, or centerline.

These scales are graduated so that on the red scale, 1 centimeter equals 200 meters; on the blue scale, 1 centimeter equals 500 meters. Wind scales are found in the lower left-hand corner of the plotting board. There are a red and a blue scale for 2-minute periods. The red scale is used for measuring wind plots on the red scale, and the blue scale is for measuring wind plots on the blue scale. Never use the red scale to measure the blue scale or vice versa. To simplify the measuring of the wind plots, a small plastic ruler is provided, which is an exact duplicate of these scales.

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The plotting board requires very little maintenance. It should be cleaned after each observation with an eraser or an approved cleaning fluid. When cleaning the plotting board, do not use any fluid that is harmful to you or the plastic protractor.

PARACHUTE

The parachute is a lightweight, expendable, paper device used to slow the descent of a balloon-borne radiosonde after the balloon has burst. It minimizes the danger to personnel and reduces or minimizes property damage from the falling radiosonde. The parachute should be used for ALL upper air soundings unless there are specific instructions to the contrary.

TRAIN REGULATOR

The radiosonde/rawinsonde train regulator consists of a frame, reel, and braking mechanism. The regulator is furnished with approximately 60 feet of nylon cord wound on the reel. The braking mechanism permits the weight of the radiosonde to unwind the cord at the nominal rate of 12 feet per minute. The train regulator is attached between the parachute and the radiosonde and facilitates releases during strong or gusty winds.

CALCULATORS AND COMPUTERS

The important points in regard to calculators, computers, and evaluators are the cleaning and storing of them. The pointers listed in this section apply to all the computers in use, such as the psychrometric computer, true wind computer, mixing ratio calculator, and the like.

To remove accumulations of dirt, dust, and lint from the spaces between the plates and under the cursor, draw a piece of paper through the space while applying a slight pressure to the disks or cursor. If grease or gummy deposits are present, moisten a blotter with soap and water and proceed as above. Exposed surfaces may be cleaned with a soft cloth, soap, and water. Rinse thoroughly and dry. DO NOT USE SOLVENTS.

Plastic calculators, computers, and evaluators should be returned to their original packaging prior to storage or shipment. If the original packaging is no longer available, an equivalent method will suffice. The items should not be stored in any atmosphere in which the temperature exceeds 140° F.

THEODOLITES

SHORE TYPE THEODOLITE (ML-474)

The shore type theodolite, AERO-1928-USN or ML-474, is a small right-angled telescope, mounted in such a manner that it may turn in a vertical direction to determine elevation and in a horizontal direction to determine azimuth. It is designed to be used with Tripod ML-78 or with a suitable permanently fixed substitute for the tripod (figure 130).

The telescope is bent through an angle of 90°. The eyepiece acts through the angle of bend as the horizontal (azimuth) axis of the telescope, while the object end turns freely in a vertical (elevation) plane about the axis. A 45° prism, located in a cubical chamber at the right-angle bend of the telescope, serves to turn the optical line of sight through 90°, corresponding to the bend in the telescope.

The eyepiece is provided with crosshairs stretched over a reticle for centering the objective.

The telescope is provided with two sets of front and rear sights, similar to gunsights, which are in line with the optical axis through the objective end of the telescope. They facilitate picking up the balloon in the field of view of the telescope when it is first released or when it is accidentally lost from view.

An elevation circle is provided for reading the angle of elevation in degrees and tenths of a degree. This is the angular height of the balloon measured from the horizontal reference plane. This plane is an imaginary flat surface between the observation point and the horizon.

The instrument is provided with a 360° azimuth circle. (Azimuth is an arc of the horizon represented by the horizontal projection of the angle between a fixed point (direction), usually true north, and the object being observed.)

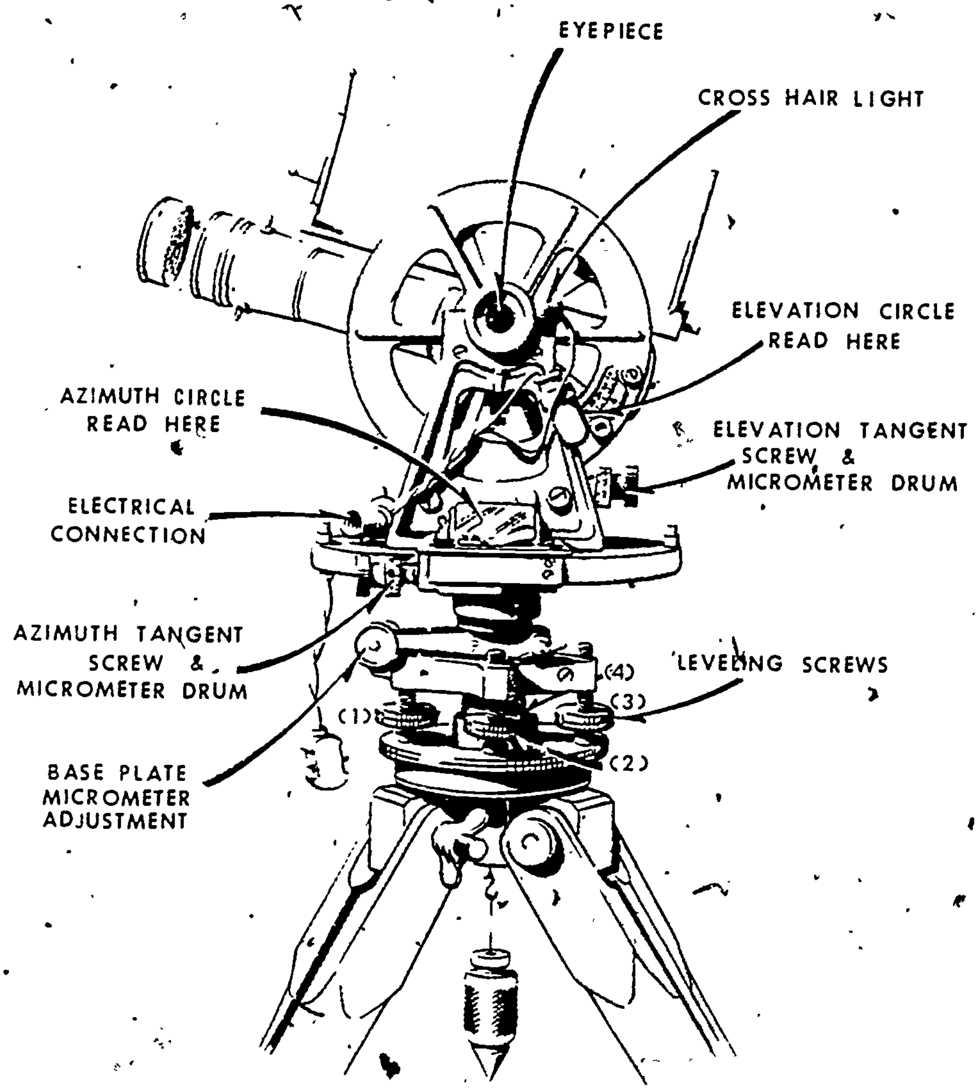


Figure 130.— Shore type theodolite (ML-474).

The telescope is turned in azimuth by engaging the worm-driven tangent screw or friction disk type of tangent screw, which is provided with a drum type of vernier graduated to read tenths of a degree.

The telescope and attachments revolve on a bearing which is a sleeve and spindle at the center of the azimuth circle. The aximuth circle is pivoted to the base plate and is provided with a clamp, which can be loosened to permit free rotation of the azimuth circle about the base plate center. The outside cone bearing of the base plate is fitted into the leveling head, which is provided with four leveling screws.

Tangent screws provide for a controllable, slow-motion rotation of the telescope about both of its axes.

In the pilot balloon observation, reliable measurement is possible only when the instrument is in proper adjustment. A theodolite must be absolutely level, and its base plate must be oriented with reference to true north. To aid in leveling the theodolite, two small spirit (plate) levels are mounted on the top plate at right angles to each other.

The theodolite has three electric lamp assemblies, one to illuminate the crosshairs to

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make them faintly visible at night, one to illuminate the elevation scale and the drum scale of the adjacent tangent screw, and one to illuminate the azimuth scale and its adjacent tangent screw drum scale. The lamps are of the miniature, screw base type and are hooded to prevent direct light from reaching the observer's eyes. Electric current is supplied by two ordinary flashlight batteries, enclosed in a battery box mounted on the base plate of the instrument. The battery box is constructed so that the batteries inserted in it are automatically connected in series in the circuit. A rheostat is mounted on one of the telescope standards and is connected only in the crosshairs lamp circuit, to control the amount of illumination of the crosshairs under various conditions. Rotating the control knob to the extreme counterclockwise position opens the circuit to the crosshairs lamp. A toggle switch, mounted on the base plate, controls the circuit of both scale lamps.

SHIPBOARD THEODOLITE

The shipboard theodolite (figure 131) differs quite radically in design from the shore type theodolite, although it performs the same functions. The essential features of construction follow.

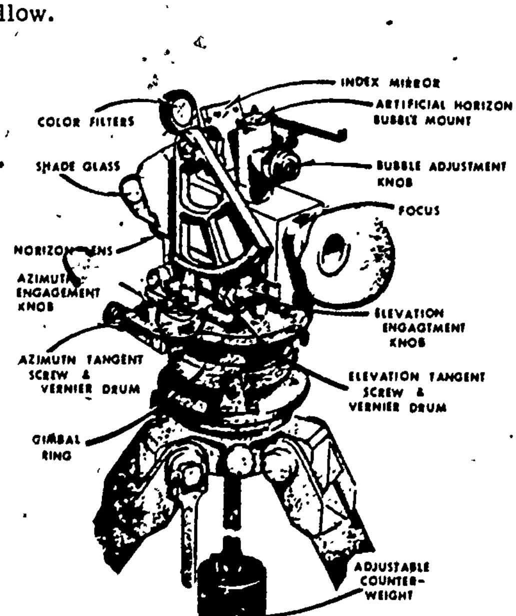


Figure 131.— Shipboard theodolite.

A small spirit level is provided on the base plate, but the theodolite cannot be leveled satisfactorily with it. The theodolite is designed for mounting in the gimbal head of a tripod with a counterbalance designed to keep the instrument as nearly in a true vertical position as possible. Since friction in the gimbals and the pendulum effect of the counterweight affect the level of the theodolite, either the true ocean horizon or an artificial bubble horizon must be used to obtain the zero level of the horizontal reference plane.

The vertical, or elevation, angle between the line of sight to the balloon and the horizontal plane (true horizon and bubble horizon) is measured by means of a movable mirror and quadrant arm operating in the same manner as a navigator's sextant. The quadrant arm is graduated to read true vertical angle when the image of the balloon is brought in line with the true horizon (or bubble horizon) as a horizontal reference plane.

The azimuth circle is provided with a clamp adjustment that permits ready orientation. Usually, it is set with the 360° azimuth (horizontal circle) on the bow of the ship, or parallel to the fore-and-aft line of the ship and oriented forward.

## ELECTRICAL UPPER AIR EQUIPMENT

### HUMIDITY CHAMBER ML-428/UM

Humidity Chamber ML-428/UM (figure 132) is provided to secure a stable environment of temperature and relative humidity for conditioning AN/AMT-11( ) radiosondes prior to release. The chamber consists of a wooden box equipped with a motor blower, evaporation tray, test leads, psychrometer cup assembly, stand, and control box. (On some units there is also a heater assembly.)

The humidity chamber is equipped with an automatic switching device located within the control box. This switching device consists of a synchronous timer unit which automatically connects the three elements of the radiosonde individually in a predetermined sequence. Located on top of the control box are switches for the automatic timer unit and motor blower unit. Below the control box is a toggle switch



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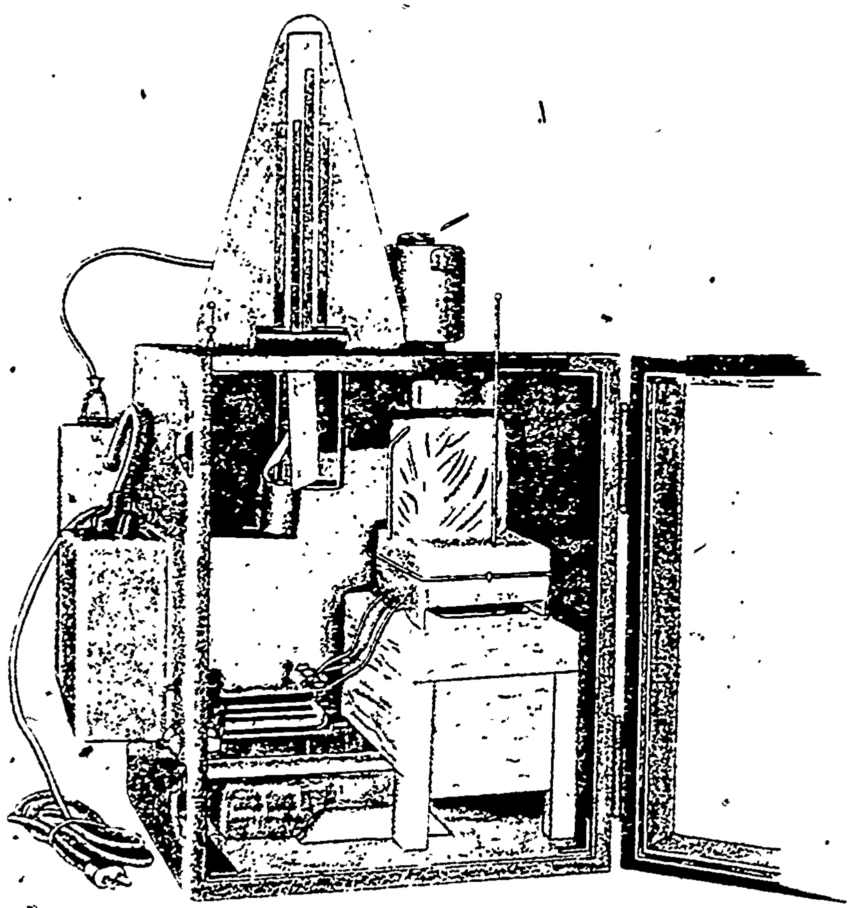

Figure 132.— Humidity Chamber ML-428/UM.

which controls the battery power. On units having a heater assembly, there is a toggle switch located on the right side of the chamber to control power to the heater assembly.

The humidity chamber should be located as close to the radiosonde receiving equipment as possible, consistent with good signal reception, and preferably in a position near the recorder where the observer can obtain psychrometric readings while the humidity chamber values are being recorded. This arrangement also enables the observer to correlate any variations in temperature or relative humidity with the values indicated by the psychrometer. The observer should stand away from the box during the check due to the effect of body capacities.

The psychrometer is mounted to its support outside the chamber and the dry and wet bulbs extend downward through the top of the box into the chamber. This enables the observer to obtain readings of chamber conditions without opening the humidity chamber.

The water in the psychrometer cup must be sufficient in amount to reach above the top of the bulb of the wet-bulb thermometer when the cup is raised. The cup can be filled conveniently with a medicine dropper or small syringe. Care should be exercised to avoid striking the thermometer bulb with the cup as well as keeping the psychrometer tube free from touching the baffle plate and the psychrometer guard.

Before placing a salt solution in the evaporation tray, coat the inside walls of the tray with a very thin film of pure petroleum jelly to reduce the tendency of the salt crystals to creep over the edge. Place one-half pound of sodium chloride (ordinary table salt) in the tray. Do not use any other salt. Add sufficient water to make a saturated solution and to cover all undissolved salt. This is important, since blowing salt particles deposited in the radiosonde might give rise to erroneous lock-in values. Place the tray containing the salt solution in the box at least 6 hours before making a humidity check to provide time for the box to reach equilibrium prior to the succeeding humidity check.

The salt solution provides a uniform value of relative humidity when the chamber is properly sealed. The recommended relative humidity value should be between 60 and 90 percent. When the salt begins to cake, stir it, and add sufficient water to restore the original consistency of the solution. If the relative humidity in the closed chamber does not meet the recommended value during the humidity check, inspect the condition of the salt solution at the conclusion of the humidity check. Clean the tray and replace the salt solution whenever the solution becomes discolored due to foreign material.

Operation

Before placing the instrument in the humidity chamber, make certain that the contact arm is off the commutator bar of the radiosonde. Then invert the instrument and place it on the stand for which it is adapted in such a manner that the humidity element is directly below the humidity chamber's blower intake. During this installation, exercise care to insure that the temperature element is not broken. Connect the test leads of the radiosonde to the corresponding terminal posts of the humidity chamber. Make sure that the radiosonde antenna properly engages the rubber gasket on the door jamb as the door is being closed.

The radiosonde is normally conditioned in the humidity chamber for at least 1 hour preceding the observation. However, do not install the humidity element until 15 minutes prior to the baseline check. After installation of the humidity element, close the box and wait 10 minutes before turning on the blower motor. After the blower motor has been operating for not less than 5 minutes, turn on the test switch motor and carry out the baseline check as outlined in the Manual of Radiosonde Observations, Federal Meteorological Handbook No. 3, (FMH #3).

If the air in the testing room is extremely dry (in winter months), store the radiosonde for the next observation in the humidity chamber for the entire period between observations in order to assure complete acclimatization.

Maintenance

Prior to each baseline check, insure that there is sufficient water in the psychrometer cup. At times it is necessary to clean the cup. This is accomplished by removing the restraining nut on the lifting rod and removing the assembly. Take care to avoid bending the lifting rod when removing or installing the psychrometer cup.

Weekly cleaning of the psychrometer assembly to remove salt deposits and monthly replacement of the wet-bulb wick are recommended.

Daily cleaning of the inside of the chamber to remove dust and salt deposits and the application of paste wax or furniture polish (inside and outside) at monthly intervals maintains the smart material appearance of the humidity chamber for a long time.

Inspect the gaskets and seals frequently to make certain that the chamber is reasonably airtight and, if not, replace them as necessary.

Oil the motor-blower at both bearing points after each 4 hours of continuous operation, or weekly. If the motor becomes excessively overheated, check the shaft clearance to insure freedom of movement. The test switch motor does not need to be oiled.

Keep the box closed when it is not in use; otherwise, unstable values of humidity may result during subsequent humidity checks.

BATTERY TEST SETS

In order to ensure a high percentage of successful radiosonde flights, perform a thorough preflight check of the radiosonde and associated battery pack. The standard battery tester is a twin-voltmeter instrument used to measure A and B battery voltages of radiosonde batteries. Read both A and B voltages directly on separate

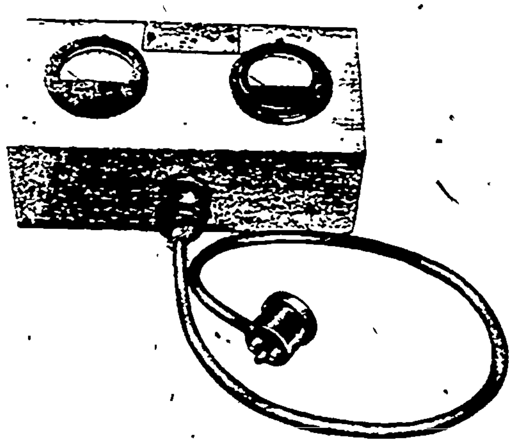

Figure 133.— Battery Tester and Battery Loading Plug.

voltmeter dials simultaneously. (See figure 133.) This equipment tests either battery BA 353/AM or BA 259/AM, but a special test plug and cable is required for each.

There is another battery test set in use. This test set, the AN/AMM-1, was designed for testing batteries BA-259/AM and BA-353/AM. and radiosonde transmitters AN/AMT-4, AMT-11, and AMQ-9.

By means of a simple switching action, the voltage and current outputs of an activated battery can be checked prior to mounting the battery on the radiosonde. The test set can also be connected to the battery and the radiosonde as shown in figure 134 for preflight testing. The internal power supply of the test set may be used to furnish voltages to the radiosonde that are normally supplied by a battery. The batteries may thus be conserved for operational flights.

BATTERIES

The batteries under consideration here are the water-activated batteries used by meteorological personnel to provide power for either lighting units or radiosonde transmitters. All of the batteries used operate on the same general principle.

Activate all batteries in strict accordance with the instructions printed on them. The

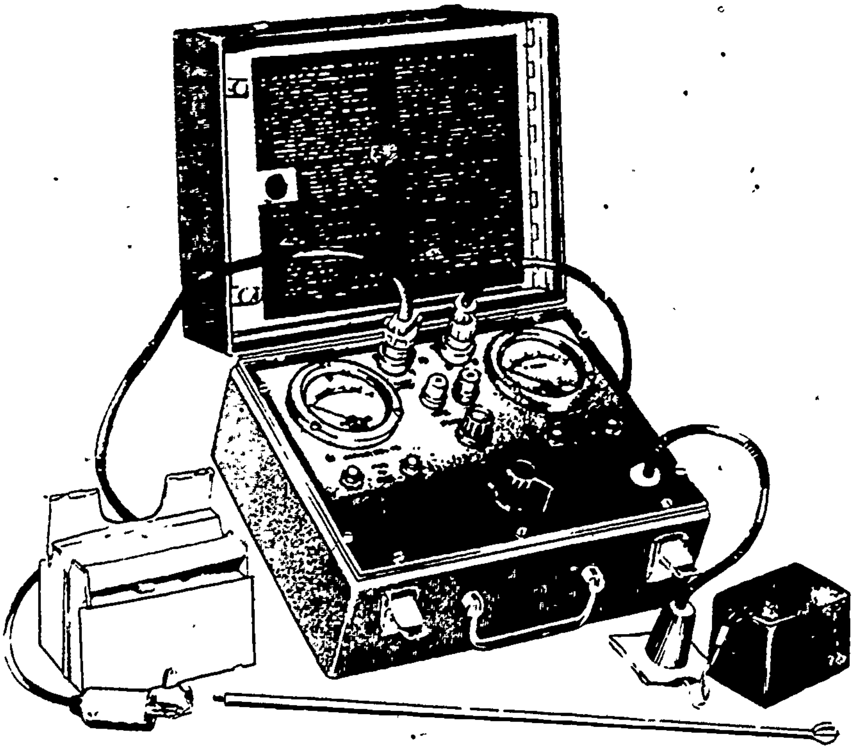

Figure 134.— Battery Test Set AN/AMM-1 connected to Battery BA-353/AM and Radiosonde AN/AMT-11( ).

instructions for activation of batteries vary from manufacturer to manufacturer; therefore, we will not cover them here.

A battery should remain in its original waterproof container until time to activate or test it. To ensure good operation of a battery, activate it before its shelf life expires. If a battery has been stored where the temperatures were very cold, bring it to a warm (room) temperature before using it.

Test the batteries in accordance with instructions contained in FMH #3 and with those of the battery tester available.

The batteries and their uses are as follows:

1. BA-292/AM is the lighting unit used for night pibals or night rabals.

2. BA-353/AM is the power unit for Radiosonde AN/AMT-11( ) for AN/SMQ-1( ) soundings.

3. BA-259/AM is the power supply unit for Radiosonde AN/AMT-4( ) for AN/GMD-1( ) soundings.

4. BA-380/AM is the power supply unit for Radiosonde AN/AMQ-9( ) for AN/GMD-2 soundings.

## ELECTRONIC UPPER AIR EQUIPMENT

### RADIOSONDE AN/AMT-11( )

Radiosonde AN/AMT-11( ), described in this section, is an expendable scientific instrument designed to be carried aloft by a sounding balloon. During its flight, the radiosonde transmits radio signals. When properly interpreted, these signals give an essentially continuous record of the pressure, temperature, and humidity of the atmosphere through which it passes. The nominal range of the meteorological sensing elements is as follows: barometric pressure from 1,060 to 5 millibars, temperature from +50° C to -90° C, and relative humidity from 15 percent to 95 percent. The frequency of the UHF (ultra-high frequency) transmitter is externally adjustable from 400 to 406 mHz.

The entire radiosonde (including the enclosing case, the radio transmitter, the barometric-pressure switch, and the temperature and humidity sensing elements, but exclusive of the battery) weighs approximately 330 grams. The temperature and humidity elements are located on the outside of the case for best exposure. All parts which may need checking or adjusting before flight are readily accessible. The power is supplied by a compact water-activated battery (Type BA-353/AM), which weighs approximately 260 grams and has three sections: 3, 7.5, and 120 volts DC.

Theory of Operation

The telemetering system of the radiosonde measures the quantity and transmits this quantity to the receiving station and there records the quantity measured. It uses a UHF signal emitted by the radiosonde as a communicating link. This signal is pulsed at a varying rate established by an oscillator whose rate of relaxation (10 to 200 Hz) is controlled by a resistance capacitance network connected in its grid circuit. The resistance in this network is varied by the change in the resistance of the meteorological sensing elements. These changes of resistance are brought about by, and are proportional to, meteorological changes encountered in the atmosphere. The resistance-capacitance network is a circuit composed of one or more resistors and capacitors.

Transmitter.— The function of the transmitter section is to relay the data from the sensing elements by means of radio waves to the radiosonde receptor. A detailed discussion of the circuitry is not given in this course; however, an explanation of the handling precautions that must be exercised is given.

The output of the UHF oscillator is coupled directly to the end of a vertical antenna extending earthward in flight and attached by means of a small threaded hole in the end of the plate line. Under no circumstances should the radiosonde be operated without the antenna, as excessive battery current may result when the antenna is removed. The transmitter frequency is normally set at the factory for 403-mHz operation; however, means have been incorporated for adjusting the frequency over a range of 395.5 to 410.5 mHz to overcome operational interference and to compensate for changes

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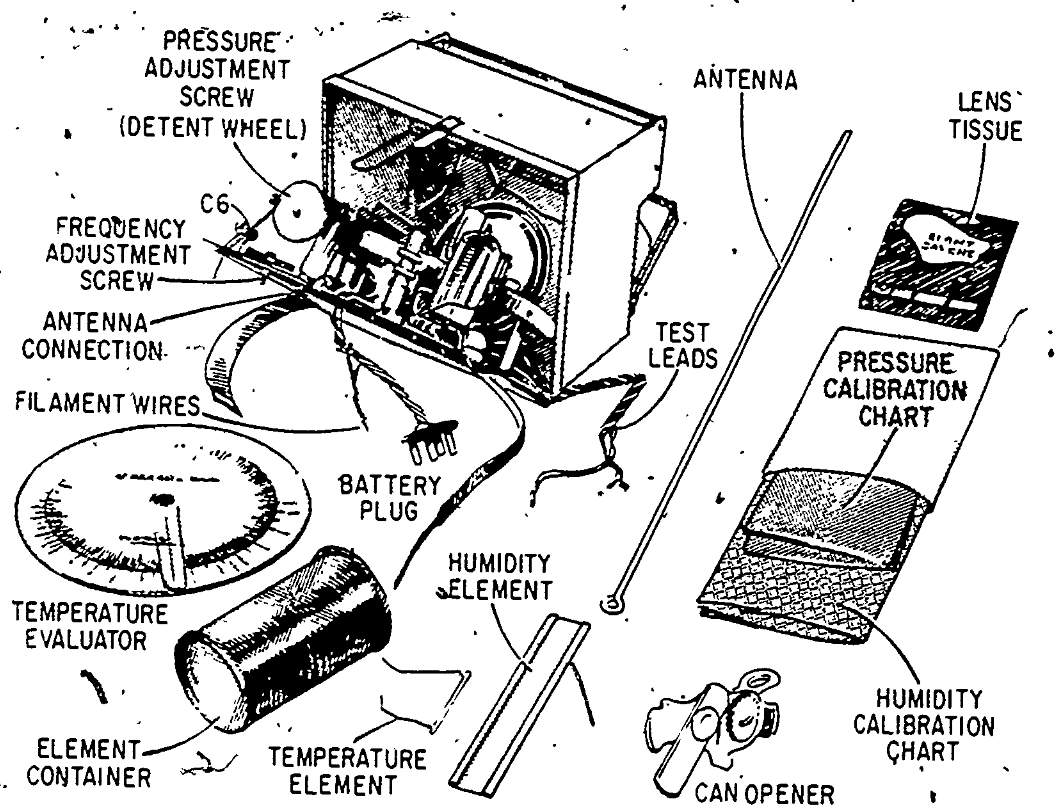


Figure 135.— Radiosonde AN/AMT-11( ).

resulting from abnormal handling in shipment. The frequency adjustment screw, which changes the capacity between the quarter-wave tuned lines, and the tuning capacitor have been provided for this purpose.

The radio signal of the AN/AMT-11( ) is normally received with Radiosonde Receptor AN/SMQ-1( ).

Visual Inspection

It is mandatory that all 24 radiosondes in a carton be visually inspected before use. Figure 135 shows a complete radiosonde.

Each carton should contain:

1. Twenty-four radiosonde sets, each with its correct calibration chart and a can containing a humidity element and a temperature element.

2. Twenty-four antennas.

3. One temperature evaluator.

4. One pad of 24 humidity-calibration charts.

5. One can opener, one pack of lens tissues, one roll of sealing tape, and one adjusting tool.

The visual inspection of the radiosonde includes checks of the temperature, humidity, and baroswitch sections; inspection of the relay and transmitter units; and comparison of the serial numbers on the calibration chart and the instrument itself. Figure 136 shows the transmitter and baroswitch in detail.

The relay is not sealed in an individual case; consequently, the modulator should be returned to its packing case until it is to be used. If the relay contacts are corroded, polish them

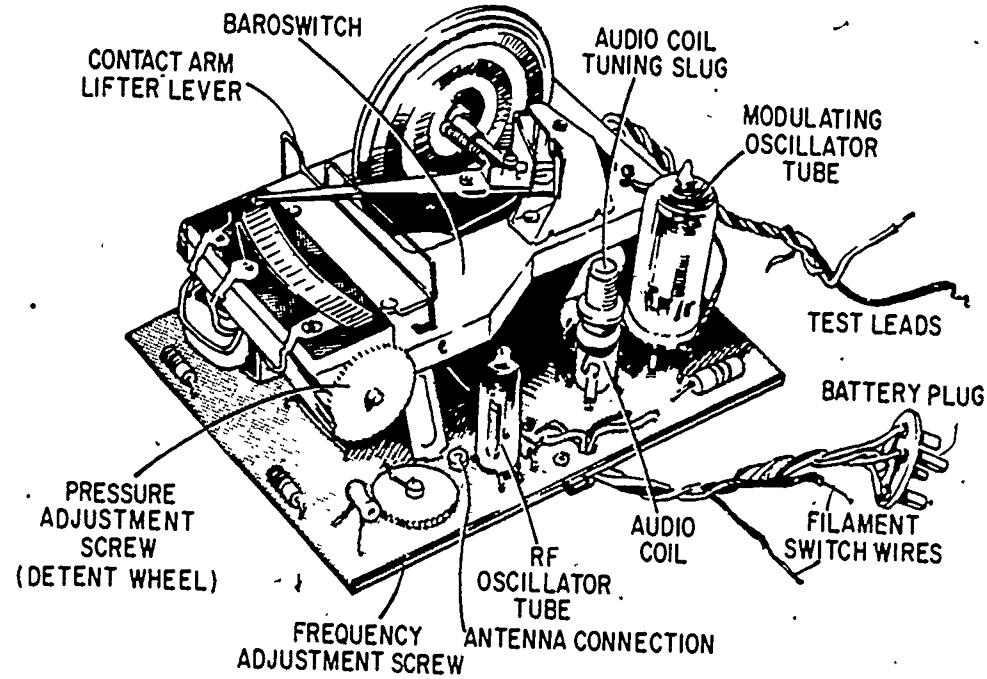


Figure 136.— Transmitter and baroswitch details.

lightly with the polishing cloth provided in the accessory kit, using only sufficient pressure to remove the corrosion. A clean camel's-hair brush should be used to remove all dust particles.

RADIOSONDE AN/AMT-11DX

The transistorized Radiosonde AN/AMT-11DX is similar in appearance to the all-vacuum-tube radiosonde presently used. One vacuum tube was retained to achieve optimum performance on the ultra-high frequency (UHF) meteorological band. The power output is approximately six times that of the earlier type of radiosonde.

The performance improvements attained in Radiosonde AN/AMT-11DX are expected to provide an increase in duration and quality of shipboard meteorological soundings. By design, only a low voltage water-activated battery is required. The fact that the activation time is consistent among the battery sections makes possible a maximum usable life. The increased power output will improve the reception range by providing a better signal-to-noise ratio in an inherently "noisy" environment.

RADIOSONDE RECEPTOR AN/SMQ-1( )

Radiosonde Receptor AN/SMQ-1( ) (figure 137) is an electronic meteorological device which receives, amplifies, demodulates, and graphically records signals emitted from a balloon-borne Radiosonde AN/AMT-11( ). The receptor covers a frequency range of 390 to 410 mHz. The radiosonde transmits data in the form of pulsed RF (radiofrequency) signals which are modulated at an audio rate controlled by the temperature, pressure, and relative humidity of the atmosphere through which the balloon-borne radiosonde passes. Radiosonde Receptor AN/SMQ-1( ) is designed for shipboard use.

Operating Principles

The radiosonde signal received by the receptor consists of pulses of 403-mHz RF energy. The frequency of repetition of these pulses is dependent on meteorological conditions. Each pulse is 150 to 250 microseconds in duration, and the pulse repetition frequency may vary from 10 to 200 pulses per second. The received signal pulses will generally be a series of pulses

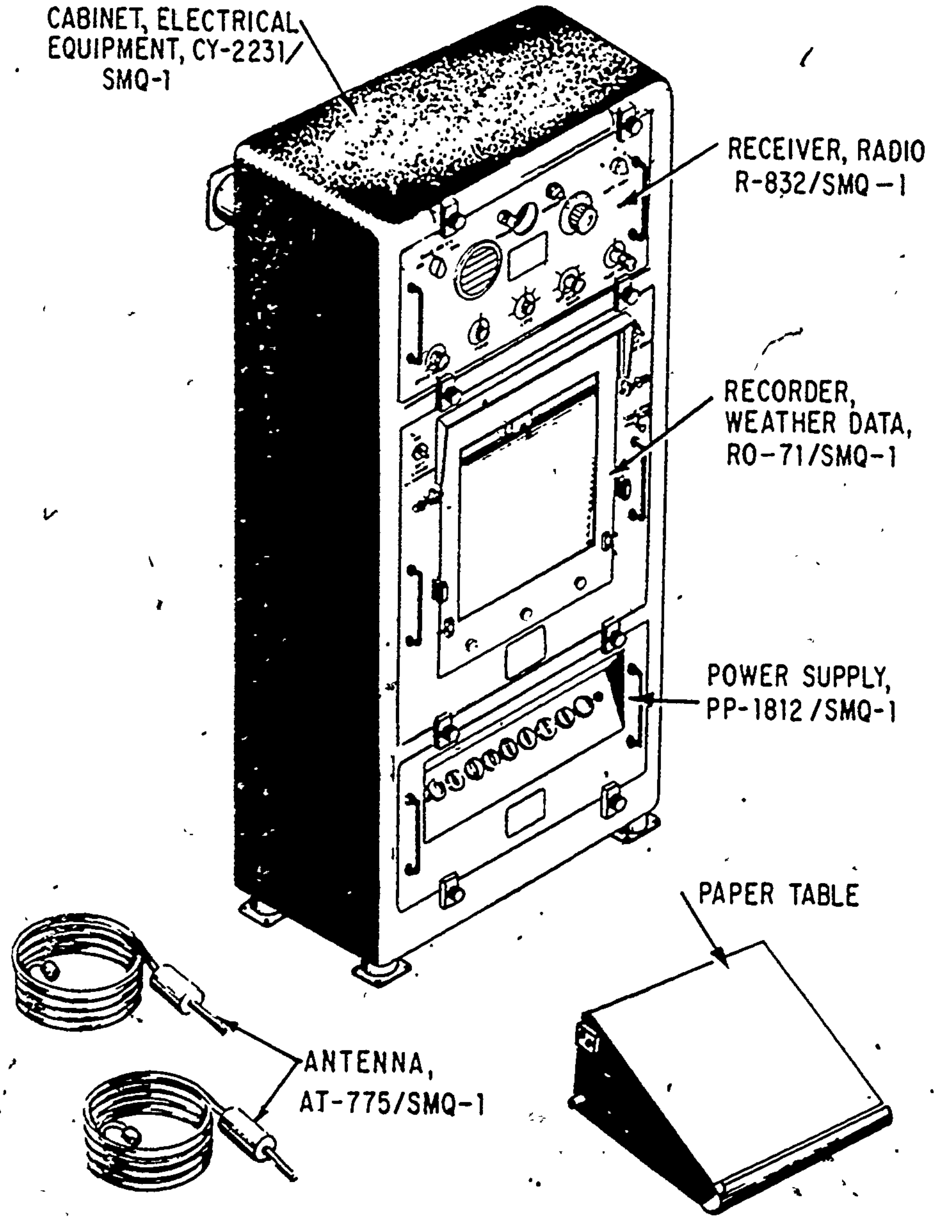


Figure 137.— Radiosonde Receptor AN/SMQ-1( ).

at one audio rate, followed by a series at a different audio rate. Each series of pulses will cause the receptor to print on the chart in a position determined by the audio rate of that particular series of pulses. The radiosonde transmits series of pulses representing humidity, a series of pulses representing temperature, and a series of pulses used as a reference. The order in which these different series are transmitted is known and is common to all radiosondes of a particular type. This order makes interpretation and evaluation of the receptor record possible.

Location

Radiosonde Receptor AN/SMQ-1( ) must be located in a dry, sheltered area. Since tuning of the receiver depends to some extent on aural (sound wave) reception, the location selected

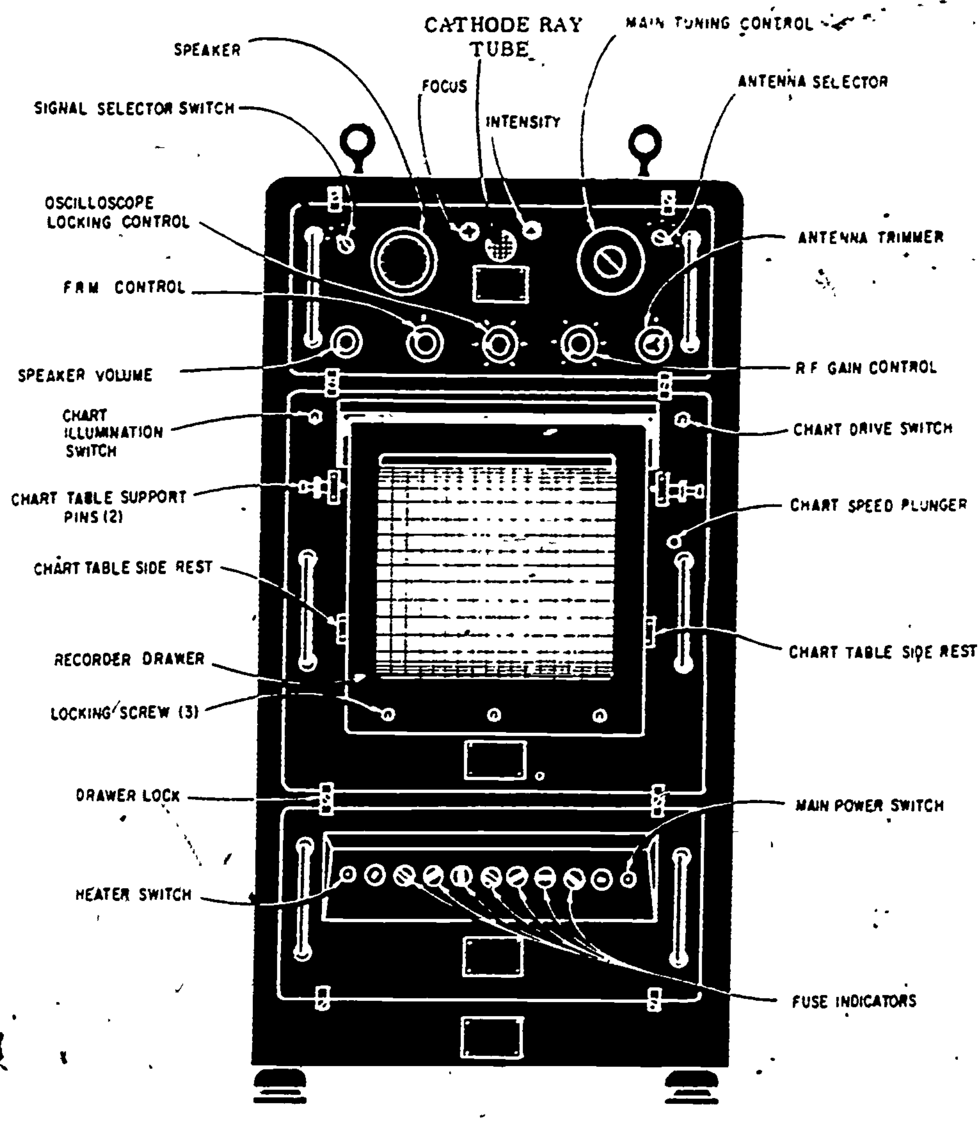


Figure 138.— Radiosonde Receptor AN/SMQ-1( ).

should have a low aural-noise level. The location should be as free from shock and vibration as possible. When determining the location of the receptor, allow a minimum access space of 18 inches at the sides, 14 inches at the back, and 6 feet in the front. This spacing will provide adequate space for operation, servicing, and ventilation. Before locating the receptor, consider the convenience of connecting incoming power and antenna cables. Avoid installation sites near sources of electrical interference, such as electrical machinery.

Functions of Components

Overall Controls.— Listed below are functional descriptions of all controls used during the operation of Radiosonde Receptor AN/SMQ-1( ). (See figure 138.)

1. The main power switch is located at the right side of the recessed panel in the upper front of the power supply panel. This switch controls all 115-volt, 60 Hz, AC input power

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to the power supply, recorder, and the thermostatically controlled cabinet heaters. An indicator light to the left of the switch provides a visual signal when the main power switch is in the ON position; this indicator light is marked I4001 above the light and IND below.

2. The heater power switch is located at the left side of the recessed panel in the upper front of the power supply. This switch controls 115-volt, 60-Hz, AC power to the thermostatically controlled cabinet heaters when the main power switch is in the OFF position. An indicator light marked I4002 above and IND below is located to the right of the switch and provides a visual signal when the heater power circuit is energized.

3. Seven blown fuse indicators are centrally located on the recessed panel in the upper front of the power supply. These indicators provide visual signals to detect blown fuses.

4. The chart speed change plunger is located at the upper right side of the front of the recorder unit adjacent to the drawer handle. Spring loading of the chart speed change plunger holds it in the OUT or NORMAL position, producing a chart speed of one-half inch per minute. When this plunger is held in the depressed position, a chart speed of 10 inches per minute is produced.

5. The chart illumination switch is located on the upper left front panel of the recorder unit.

6. The chart drive switch is located at the upper right side of the front of the recorder unit. The chart drive switch controls the 115-volt, AC power to the chart drive motor.

7. The RF gain control, marked RF GAIN, is located on the right center of the receiver panel. This control combines a LO gain control, which is adjusted and locked at the optimum preflight test position by means of a screwdriver, and a HI gain control, which is adjusted by the control knob on the panel. Turning the control knob clockwise from this position closes the switch and permits the gain to be adjusted by the control knob.

8. The ANT TRMS (antenna trimmer) control is located on the receiver front panel. It provides means for turning the RF input circuit of the receiver to obtain maximum signal transfer.

9. The main tuning dial is for tuning the receiver to a specific frequency within the range of 390 to 410 mHz. The tuning dial is calibrated in mHz. Frequency increases with clockwise rotation.

10. The antenna selector switch is marked ANT SEL and is located at the upper right of the receiver front panel for the purpose of selecting the antenna to be used, if more than one antenna is available. The switch accommodates four antenna inputs numbered 1 through 4. Position No. 5 provides means for grounding the receiver input when required.

11. The intensity control is for adjusting beam brilliance in the cathode-ray tube. It is centrally located to the right of the oscilloscope tube.

12. The focus control is provided to bring the oscilloscope pattern into proper focus. This control is centrally located at the left of the oscilloscope tube.

13. The locking control is marked LKG. This control varies the oscilloscope synchronizing frequency range from 8 to 250 Hz.

14. The cathode-ray tube is centrally located on the upper front of the receiver panel. It provides a visual presentation of the received signals.

15. The four-position signal selector switch is located at the upper left corner of the receiver front panel and is marked SIG SEL. Its four positions are marked as follows:

a. RS position permits normal reception of radiosonde signals by the receiver.

b. GND, 120 CY, and CAL positions are for test and calibration purposes.

16. The speaker volume control is marked SPKR VOL and is located near the lower left corner of the receiver front panel. It provides a means for adjusting the speaker volume.

17. The frequency meter control is located below and to the right of the speaker. This control is marked FRM. It provides a means for regulating the output of the frequency meter section.

Antenna.— This unit is a vertical half-wave dipole which operates over a frequency range of 390 to 410 mHz and has a characteristic impedance of 52 ohms. It intercepts the signals from the radiosonde transmitter and transfers them to the receiver. The antenna consists of two insulated quarter-wave sections mounted in line and separated by an insulator. The upper section is a metal rod, and the lower section is a metal tube, or skirt. The antenna has a doughnut shaped directional pattern with a null region directly above and below. The intercepted signal is conveyed to the receiver by 100 feet of coaxial cable. The cable has an impedance of 52 ohms and attenuates the signal approximately 6 db (decibels) per 100 feet at 400 mHz.

Receiver.— The function of the receiver section of Radiosonde Receptor AN/SMQ-1( ) is to intercept the transmitted signals from Radiosonde AN/AMT-11( ) and relay these signals to the recorder where they are printed for evaluation.

The receiver consists of seven sections, each of which is an integral part of the receiver. A discussion of these sections would be in the language of an electronics technician; and since it is not the purpose of this course to train you to be electronics technicians, they will be listed only by name. These sections are as follows: RF, IF, detector, discriminator, audio, frequency meter, and monitoring.

Recorder.— The recorder is an electromechanical device which measures the varying DC output voltage of the receiver and records this information on chart paper. The recorded data is a continuously changing record of the pulsed signal repetition rate as received from a balloon-borne radiosonde. The recorder contains a comparator section; a 60-Hz servoamplifier; a pen-drive servo system to which a potentiometer is connected, feeding back a reference signal to the comparator.

A chart drive motor controlled by a chart drive switch on the front panel functions to move the chart continuously at a controlled speed. Two speed selections are provided: a recording speed of one-half inch per minute and a rapid speed of 10 inches per minute. The rapid speed is obtained by depressing a plunger mounted on the front panel.

Maintenance

At the present time, the only maintenance requirements to be performed by Marine Science Technicians are testing the recorder accuracy and routine maintenance including exterior cabinet cleaning, changing recorder paper, and checking the ink supply in the ballpoint pen.

Changing Recorder Paper.— To install a roll of chart paper, release the jam locks holding the front panel of the recorder against the front of the cabinet. Slide the recorder chassis out to its fully extended position (figure 139). Release the locknut on the right-hand roll support adjusting screw, turn the screw out to withdraw the support, and remove the roll of chart paper. With the new supply roll positioned so that the paper will unroll from the top of the roll, its left end on the fixed support, and its right end in line with the retractable support, turn the adjusting screw inward until the roll is firmly held between the supports. The adjustment should be such that a slight drag is felt when the paper is pulled from the roll. Thread the paper around the guide bars and over the feed roll, as shown in figure 140. Make sure that the paper lies flat on the feed roll and that the sprocket holes enmesh with the

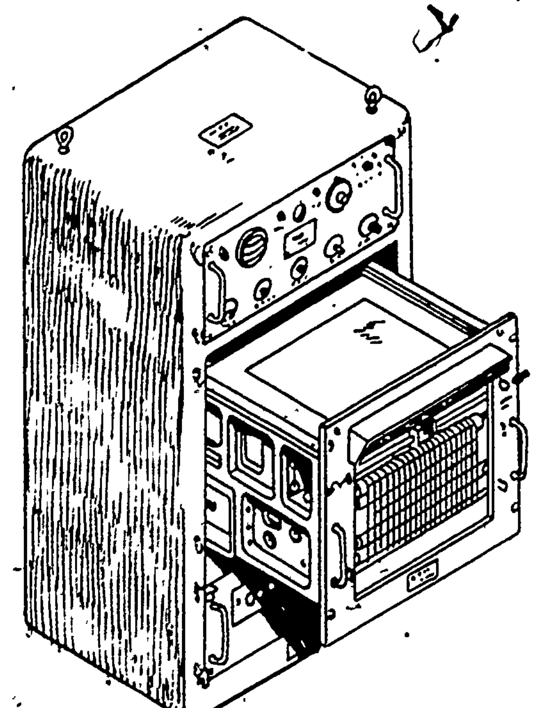

Figure 139.— Recorder drawer extended.

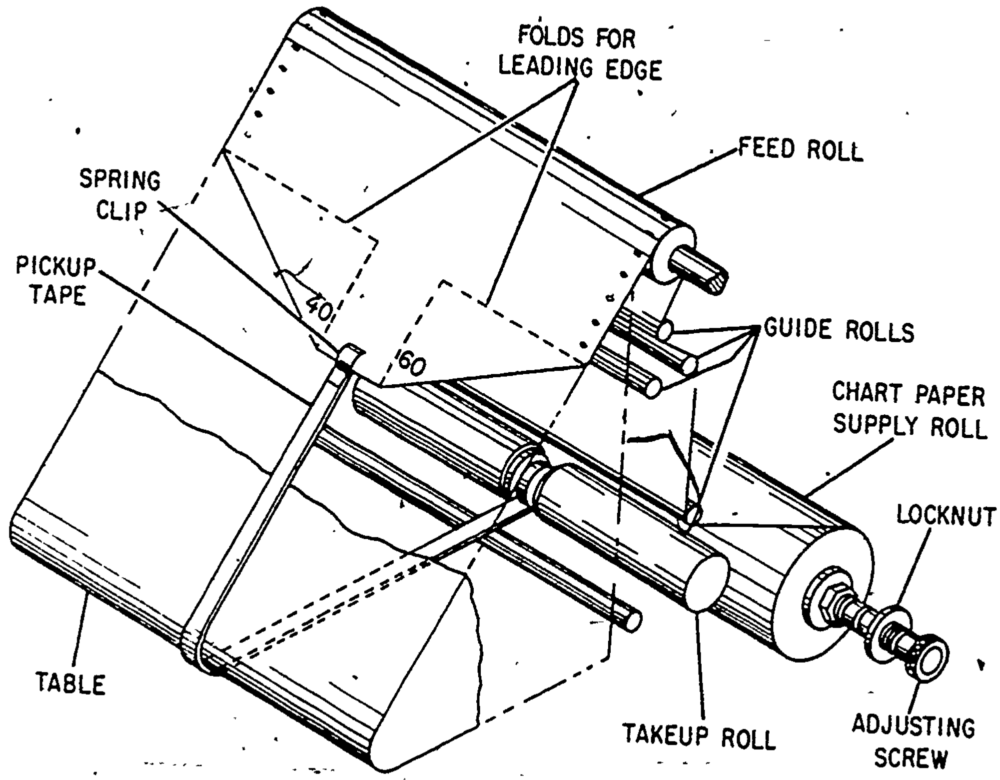


Figure 140.— Paper threading diagram.

sprocket teeth at each end of the feed roll in alinement. Check the paper feed by turning the chart drive motor to the ON position.

If the normal speed paper travel is satisfactory, push the chart high-speed plunger in and observe the high speed travel. Correct adjustment of the right-hand supply roll support will permit the paper to be drawn tightly from the supply roll without tearing at the sprocket holes. If no further adjustment of the feed roll is required, hold the high-speed plunger in until approximately 6 inches of chart paper are fed over the feed roll. Move the chart drive motor to the OFF position.

Fold a suitable leader edge on the forward edge of the paper, as shown in figure 140. Pull the pickup tape from the takeup roll, pass it around the end of the table, and attach the spring clip at its end to the end of the chart paper. Turn the top of the takeup roll forward with the fingers to tighten the pickup tape.

Cable tension should be such that a light finger pressure on the cable midway between the fixed pulleys on the left side will deflect the cable between one-sixteenth and three-sixteenths inch. To check or adjust, pull the recorder drawer to the full-out stop. Tension may be increased by turning SCR DRIVER ADJ clockwise.

Calibration.— Calibration of the AN/SMQ-1( ) is performed in accordance with the basic manual for the AN/SMQ-1( ) and Signal Generator SG-21B/U, or Linearity Calibrator LCU-705.

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# COMMUNICATIONS EQUIPMENT

## THE TELETYPEWRITER

The teletypewriter is little more than an electrically operated typewriter. The prefix "tele" means "at a distance," Coupled with the word "typewriter" it forms a word meaning "typewriting at a distance." When the keyboard, which is similar to that of a typewriter is operated, the signals produced print characters in page form, called a hard copy.

The characters appear at both sending and receiving stations. In this way, one teletypewriter will actuate as many machines as may be connected together. An operator transmitting from New York to Boston will have his message repeated in Boston, letter by letter, virtually as soon as it is formed in New York. The same will apply at all receiving stations that tie into the network. One commonly used machine is the model 28 page teletypewriter, also called the model 28 printer, a machine widely used by both military and commercial communication systems.

## MODEL 28 TELETYPEWRITERS

Model 28 is a manufacturer's designation applied to a complete line of teletypewriter equipments. Compared with some of the older models, the components of the model 28 series feature smaller size, lighter weight, increased speeds, quieter operation, and less maintenance. They are also better suited for shipboard use under severe conditions of roll, vibration, and shock.

One component of the model 28 line (designated TT-48/UG) is the keyboard-sending and page-sending and page-receiving teletypewriter shown in figure 141. Let us look at some of the external features of this machine. The numbers following correspond to those shown in figure 141.

1. POWER SWITCH—When turned ON, this switch starts the motor in the teletypewriter and makes the machine operative. To secure the machine, turn the power switch OFF.

2. KEYBOARD—Described in next paragraph.

3. BULLETIN HOLDERS—There are two on the machine. Used as necessary for recording any information an operator needs to have at his fingertips.

4. COVER RELEASE PUSHBUTTON—Releases cover of machine for raising.

5. COVER—Raised for access to typing unit. It is hinged at the rear and is counter-balanced by a mechanism that aids in lifting and holding it open.

6. COPYHOLDER AND LINE GUIDE—The copyholder holds the message to be typed. The line guide helps the operator follow the lines as he types.

7. END-OF-LINE INDICATOR LIGHT—A red lamp that lights at about six characters from the end of the line. The machine is adjusted to type 69 characters to the line, including spaces between words or groups.

8. PAPER RELEASE LEVER—Located under the cover. When pushed back, this control frees the paper for adjustment. When pulled forward, it holds the paper tight.

9. LID RELEASE PUSHBUTTON—When pushed, it releases lid of machine for raising.

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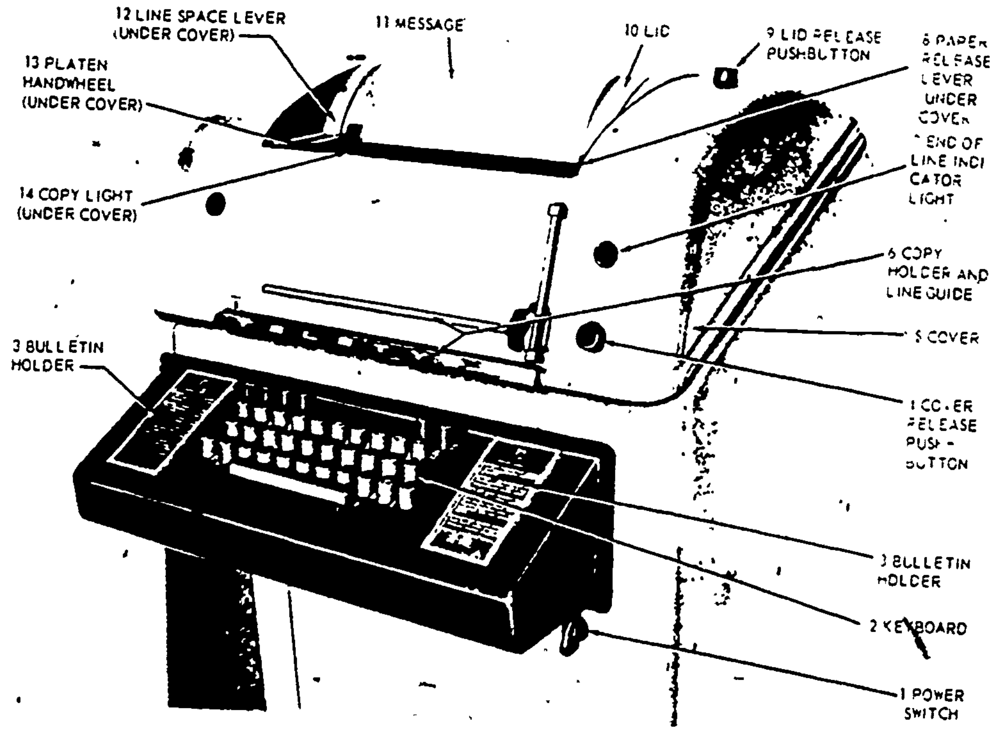


Figure 141.— Model 28 teletypewriter (TT-48/UG).

10. LID—When raised, it provides access to the paper, paper release lever, and line space lever.

11. MESSAGE—In the form of hard copy.

12. LINE SPACER LEVER—Located under the cover. Pull forward to single space; push back to double space.

13. PLATEN HANDWHEEL—Located under the cover. When depressed and turned, it feeds paper in direction in which it is turned—up or down.

14. COPY LIGHT—A clear lamp that is lit while the teletypewriter is on. It illuminates the copy.

Keyboards

The model 28 printer is equipped with either of two types of keyboards: communication or weather. The first contains letters and punctuation marks common to the standard typewriter, and the weather keyboard provides necessary symbols for transmission of weather data. Similarities and differences in the two keyboards are illustrated in figure 142. Observe that the lowercase characters are the same and that letters of the alphabet appear in the same positions. The difference lies in the uppercase of the bottom two rows. A trained operator can use either the communication or weather keyboard without loss of speed or efficiency.

Figure 143 is another illustration of the communication keyboard, with emphasis placed on the function keys. The action performed by the function keys is described as follows:

1. SPACE BAR—The space bar, located at the front of the keyboard, is used to send spaces (as between words).

2. CAR RET (carriage return)—The carriage return key is used to return both the type box carriage and the printing carriage to the left to start a new line of typing.

3. LINE FEED—When depressed, this key causes the paper to feed upward one or two



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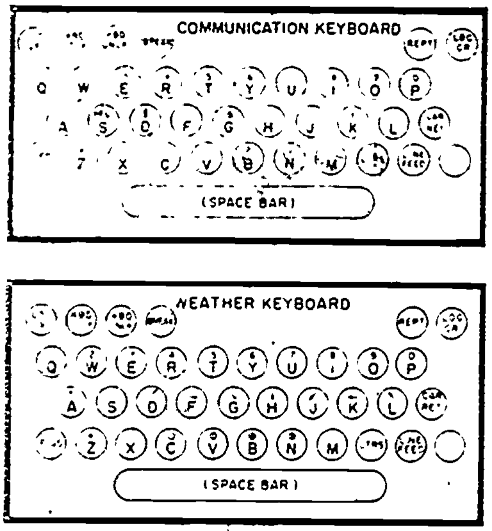


Figure 142.— Two types of teletypewriter keyboards.

spaces depending upon the position of the single-double line feed lever located on the typing unit.

4. FIGS (figures)—The figures key is pressed to condition the machine for printing figures, punctuation marks, or other uppercase characters.

5. LTRS (letters)—The letters key is used to condition the machine for printing the letters (lowercase) characters.

6. BELL—Operation of the BELL key (which is uppercase action of the S key) causes a signal bell to ring locally and at distant stations.

7. BLANK (unlabeled key in bottom row)—Depressing the blank key twice (effective in either uppercase or lowercase) locks all keyboards in the circuit and renders them inoperative by setting up the receive condition. Restoration to the send condition is accomplished, under individual circumstances, through operation of the KBD UNLK key by the operator desiring to send from his keyboard.

8. BREAK—To stop (break) another station's sending, depress the BREAK key for about 3 seconds. This causes the KBD LOCK key to drop and lock keyboards on both sending and receiving machines. After a break it is necessary to operate the KBD UNLK key to free the keyboard for sending.

9. REPT (repeat)—To repeat a character, depress the character key and the REPT key. The character will be repeated automatically at line speed as long as both keys are held down.

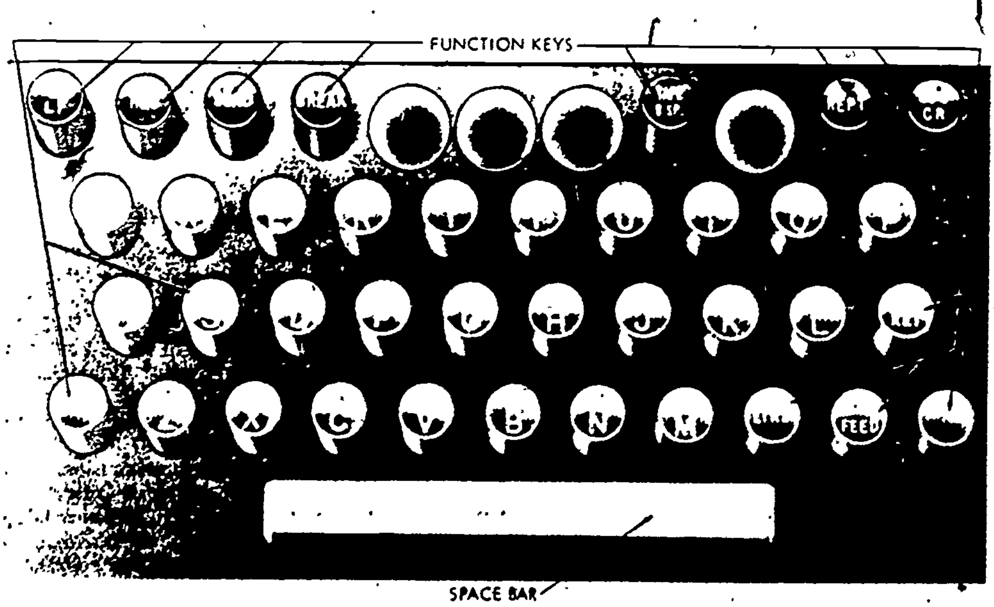


Figure 143.— Model 28 keyboard with emphasis on function keys.



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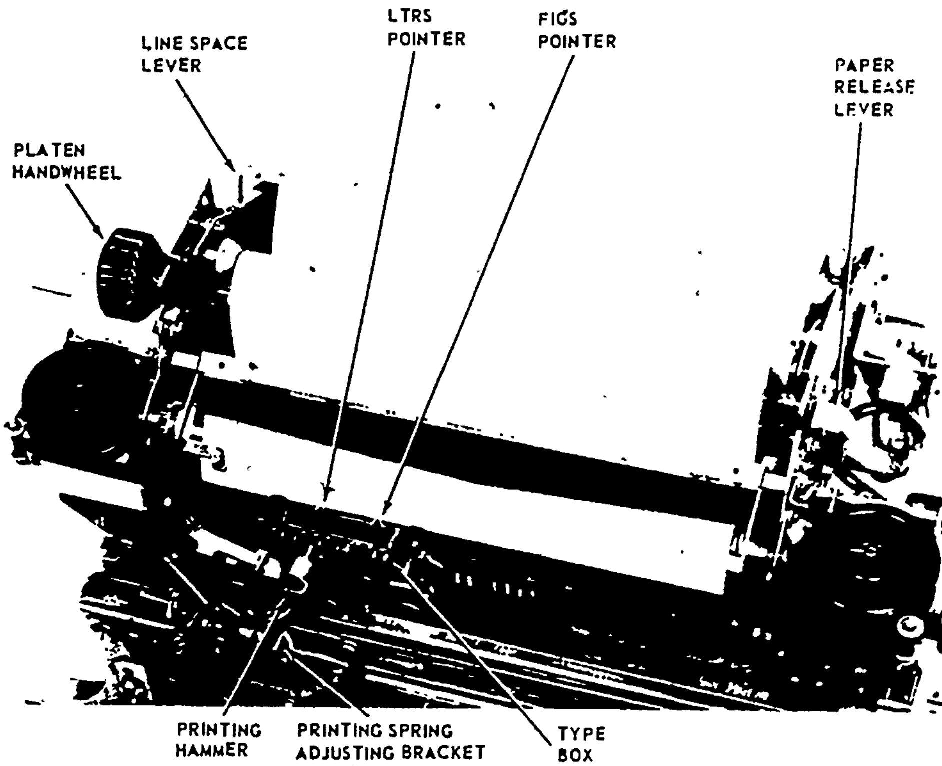


Figure 144.— Model 28 typing unit.

The four keys described next perform their functions only on the machine on which the key is operated (referred to as "local machine"), without affecting any other machine on the line.

10. LOC LF (local line feed)—To feed the paper up in the local machine, depress the LOC LF key, which feeds the paper up automatically and rapidly as long as it is held down. This key is for use in locally feeding up paper to tear off a message not fed up far enough by the transmitting station. It also is used when a new supply of paper is inserted into the machine.

11. KBD LOCK (keyboard lock)—To lock the keyboard on the local machine, depress the KBD LOCK key. The keyboard is now inoperative until released by the KBD UNLK (keyboard unlock) key. The KBD LOCK key also drops automatically when the power switch is turned OFF, when the BREAK key is operated, or when a break is received.

12. KBD UNLK (keyboard unlock)—To unlock the keyboard on the local machine, depress the KBD UNLK key. This action raises the KBD LOCK key, making the keyboard operative. Operate this key after turning on the power switch and after sending or receiving a BREAK.

13. LOC CR (local carriage return)—To return the type box to the left margin on the local machine, depress the LOC CR key. This key is for use in omission of carriage return at the end of a transmission from another station.

Typing Unit

The model 28 typing unit is shown in figure 144. Printing is produced by the type box, which contains the characters and symbols shown on the key tops. Operation of keys and the space bar moves the type box across the platen from left to right. On each key stroke, the type box is moved into position for the printing hammer to strike the proper type pallet, printing the character on the paper. Operation of the CAR RET key returns the type box to the left margin, and operation of the LINE FEED key moves the paper up to the next line.

The force of the printing blow is controlled by the printing spring adjusting bracket, which is set for the individual service requirement according to the number of carbon copies required. Notch 1 is for one to three copies, and notch 2 for four or five copies. If copies are either too light or too dark, the force of the printing blow can be adjusted by moving the printing spring adjusting bracket, taking care not to make the printing blow any heavier than necessary to produce satisfactory copies.

Type pallets are arranged in four rows. The type box moves up and down in selecting the row in which each character to be printed is located. Lowercase characters are in the left half of the box, and uppercase characters are in the right half. The type box moves left and right on shifting and unshifting operations, rather than in the familiar up-and-down motion of carriage shifting on the typewriter and older teletypewriters. This combined vertical and horizontal motion brings the character to be printed into line with the printing hammer. There are two pointers on the type box: the LTRS pointer on the left and the FIGS pointer on the right. When typing stops, the pointer at which the printing hammer is aimed indicates where the next character will be printed. If the printing hammer is aimed at the LTRS pointer, the type box is in lowercase. If the printing hammer is aimed at the FIGS pointer, the type box is in uppercase. An operation shifting the type box to uppercase or lowercase moves the corresponding pointer to the typing location.

## OPERATING THE MODEL 28 TTY

The controls and parts used to operate the model 28 printer are illustrated in figures 141 and 143. You will find frequent reference to these illustrations helpful in comprehending the instructions for operating this equipment.

Assuming that the printer is functioning properly and is connected to an incoming signal, the only action necessary to commence receiving traffic is to apply power to the equipment. This is accomplished by rotating the power switch (located slightly below and to the right of the keyboard) upward to the ON position. Do not be alarmed if the first few characters are garbled, because the printer's driving motor requires several seconds to attain running speed.

Conditioning the machine for transmitting is a simple process. After applying power and allowing the motor to attain running speed, depress the BREAK key and hold it down for at least 2 seconds. This locks the keyboards of all stations on the circuit. Additionally, depressing the BREAK key starts the motors of those machines in which the motor shutoff mechanism is utilized. (Model 28 printers have a mechanism that shuts off the motor when no signal is received for approximately 2 minutes, but the mechanism often is disabled by stations not desiring this feature.) After releasing the BREAK key, press the KBD UNLK key to unlock your keyboard. The machine now is ready for transmitting to other stations.

Transmission begins at the keyboard. With the touch system, use the CAR RET key as a guide for the right hand and the A key for the left hand. The little finger of each hand is used on the guide key. It is important that you use a light, quick, even touch on the keys. Force is unnecessary because the machine is operated electrically. Operation of the teletypewriter requires accuracy, rhythm, confidence, and speed, in their proper relation. Although a light touch is essential to speed, each key must be pressed in a positive manner. Otherwise you may be writing the word FOR and have FR appear on the page simply because the letter O was pressed without allowing sufficient time for printing the letter F. To become a skillful teletypist, proficiency in the touch system of typing is, of course, a "must."

The function keys represent "functional operations," or nontyping selections; that is, when pressed, they do not print anything on the page. Each function key was described in our discussion of the keyboard, but let us review the ones used most commonly in transmitting messages. These are the figures (FIGS) key, the letters (LTRS) key, space bar, carriage return (CAR RET) key, and LINE FEED key.

To shift the machine to the uppercase for typing numerals, punctuation marks, and special characters indicated on the upper part of the keys, press FIGS. To UNSHIFT the machine, press LTRS, and type the letters of the alphabet.

The space bar is used to space between either words or characters. On our printers the space

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bar functions the same whether uppercase or lowercase characters are transmitted. Some commercial machines, however, have a feature called "unshift on space," which means the printer returns to lowercase after each space. In fact, all printers have this feature, but on our machines it is purposely disabled. The operating procedure explained in this section requires that you press the FIGS key before each group of uppercase characters so that the distant machine will print characters in the proper case whether it is adjusted to unshift on space or to remain in uppercase.

The CAR RET key is used to return the carriage to the beginning of the line. Usually the machine is adjusted to print a line 69 characters in length. This includes the spaces between the typed words. The end-of-line indicator lamp lights about six characters before the end of the line.

The LINE FEED key feeds the paper up, one to two lines at a time, thus preventing overlining.

The latter two functions—carriage return and line feed—also are performed automatically by the printer upon printing the 69th character on each line. This prevents characters piling up at the end of a line when the normal carriage return and line feed functions are not received.

## MISCELLANEOUS OPERATING FEATURES

To raise the cover for access to the typing unit to change paper and ribbon or to clean type, press the cover release pushbutton and lift the cover. To raise the lid for access to the paper, press the lid release pushbutton and lift the lid. To turn the paper up or down, raise the cover, and press and hold down the platen handwheel (so that it engages the platen ratchet wheel) while turning it in the desired direction. Do not attempt to hold down or operate the platen handwheel while the teletypewriter is operating. To adjust the paper, raise the lid, push back the paper release lever to free the paper, straighten the paper, and pull the lever forward to its normal position. To set the line spacing for single or double space, raise the lid, press the line-space lever to the left, and pull it forward for single space or push it back for double space. To space to a desired location for typing, space the type box over until the LTRS pointer is at the desired typing location. Then, if uppercase is desired, operate the FIGS key.

### Changing Paper

To insert a new roll of paper in the model 28, first shut off the power. Press the cover release pushbutton and lift the cover. (Refer as necessary to figures 145 and 146.) Push back paper release lever, lift paper fingers, and pull paper from platen.

Lift the used roll from machine and remove spindle from core of used roll. Insert spindle in new roll. Replace spindle in spindle grooves with paper feeding from underneath roll toward you. Feed paper over paper-straightener rod, down under platen, and up between platen and paper fingers. Pull paper up a few inches beyond top of platen, and straighten it as you would straighten paper in a typewriter. Then lower paper fingers onto paper and pull paper release lever forward.

While inserting paper, take care not to disturb the ribbon on the type box latch. After paper is in place, check to see that the ribbon is still properly threaded through the ribbon guides. Also check to make certain the type box latch has not been disengaged. The latch should be in a position holding the type box firmly in place. Close cover. Open lid by pressing lid release pushbutton, bring up the end of the paper, and close lid with paper feeding out on top of it.

### Changing Ribbon

To replace a worn ribbon, press cover release pushbutton and lift cover. (Refer as necessary to figures 147 and 148.) Lift ribbon spool locks to a vertical position and remove both spools from ribbon spool shafts.

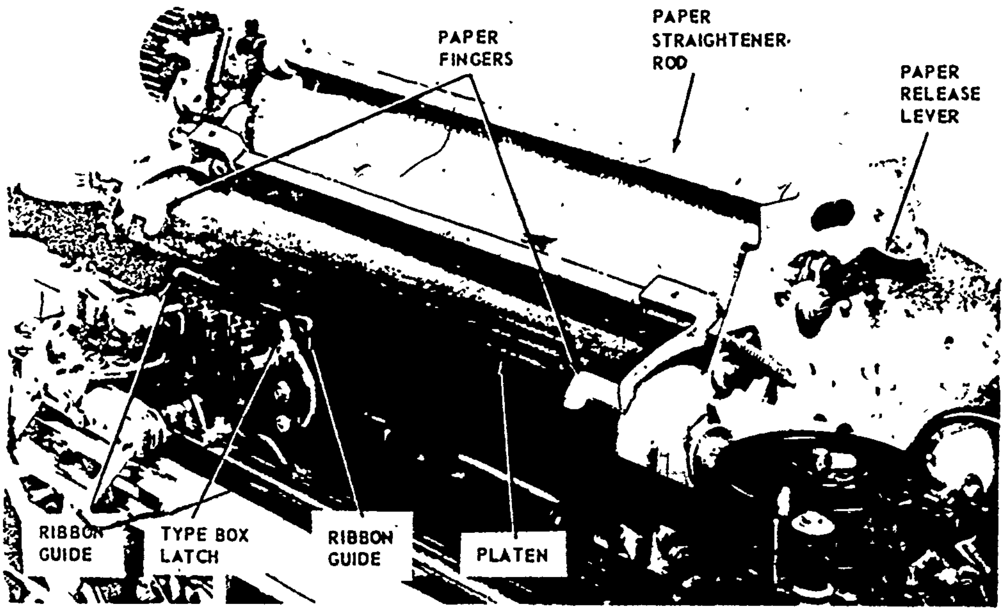



Figure 145.— Paper roll removed.

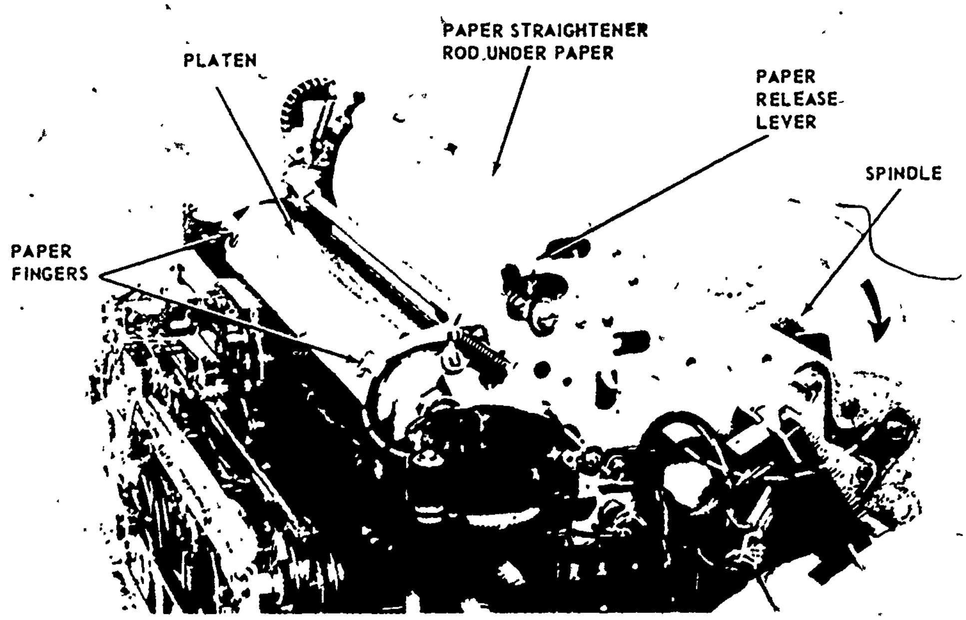



Figure 146.— Paper roll inserted.

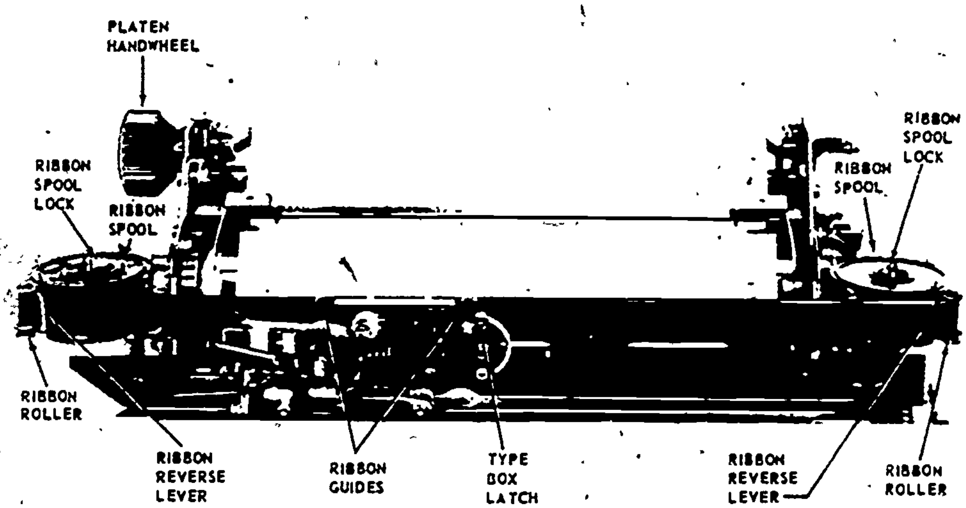



Figure 147.— Ribbon inserted.

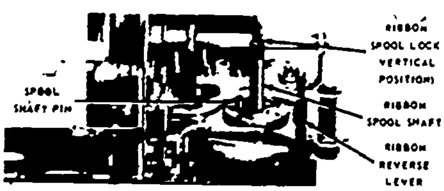



Figure 148.— Ribbon spool mechanism.

Remove ribbon from ribbon rollers, ribbon reverse levers, and ribbon guides. Unwind and remove old ribbon from one of the spools. Hook end of new ribbon to hub of empty spool and wind until reversing eyelet is on the spool. If the ribbon has no hook at the end, the spool will have a barb that should be used to pierce the ribbon near its end.

Replace spools on ribbon spool shafts, making sure they go down on spool shaft pins, and that the ribbon feeds from the outside of the spools. Turn down ribbon spool locks to a horizontal position, locking spools in place. Thread ribbon forward around both ribbon rollers and through the slots in the ribbon levers and ribbon guides. Take up slack by turning free spool. After slack has been taken up, check to make certain that ribbon is still properly threaded through ribbon guides and that the reversing eyelet is between the spool and the reverse lever. Also see that the type box latch has not been disengaged. The latch should be in position, holding the type box firmly in place.

Turn the paper up a few inches by pressing down and turning platen handwheel. Close cover. Open lid, bring up the end of the paper, and close lid, with paper feeding out on top of it.

### Cleaning Type

When printing is smudged, the type should be cleaned. You must remove the type box from the machine. Open cover and unlock type box latch by moving it to the right (see figure 149). Grasp handle on right side of type box and raise that side up and to the left until the type box unhooks on the left side and can be freed from type box carriage. Turn type box over to side with type (figure 150) and clean with a dry, hard-bristle brush. DO NOT use type cleaning solution.

To replace type box, hold it with type toward platen and the large hook on the left. Slip this hook under stub in front of left type box roller and push smaller hook on the right side down into place on stud in front of right type box roller. Hold type box latch in horizontal position and move to left over latching notch as far as it will go. Raise latch to vertical and press to left

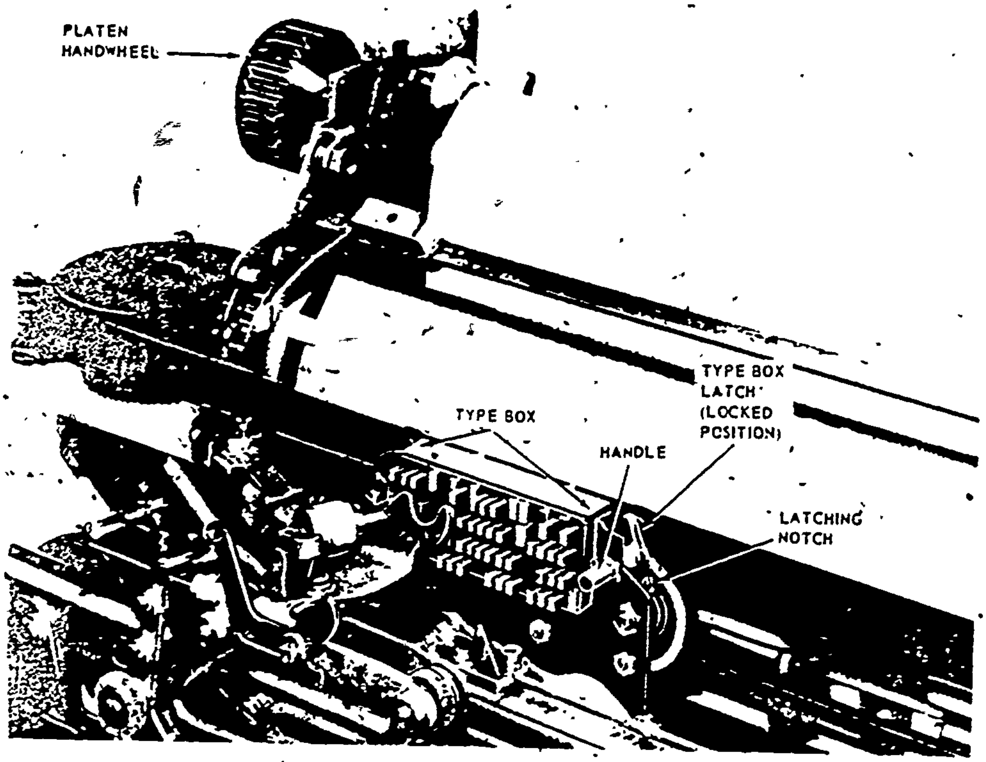



Figure 149.— Type box in place.

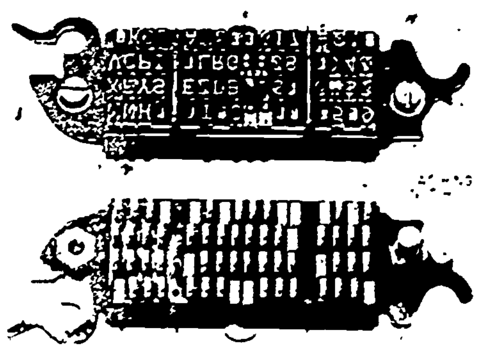


Figure 150.— Type box, front and back.

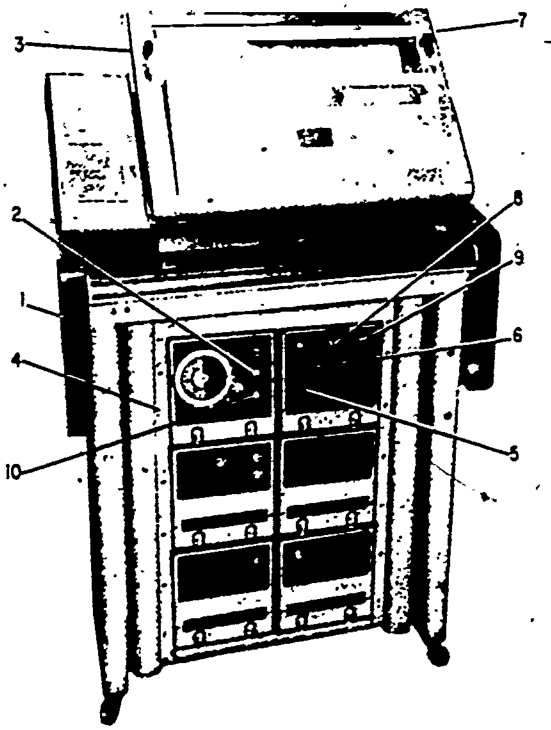
until it locks into latching notch. Check to see that the ribbon is still threaded properly.

## THE FACSIMILE

Some weather offices are equipped with facsimile equipment which is used to receive and record maps. Facsimile transmission may be accomplished either by wire (landline) or by radio. In the United States the method of transmission is principally by wire. Shipboard and overseas stations receive facsimile weather charts by radio on certain designated broadcast frequencies.

## ALDEN FACSIMILE

The Alden Weather Map Receiver is a fully automatic continuous weather map receiver which uses the simple electromechanical principle of the Alden recording technique and Alfax electrosensitive paper on which electricity acts as ink. (See figure 151.) The receiver is 34 inches wide, 24 inches deep, and 56 inches high, and stands on casters. Paper used in the recorder is white and comes in 170-foot rolls. A crisp sepia map on a clean white background is produced. The paper is thin and suitable for reproduction directly by the Bruning or Ozalid process. It is packaged in a polyethylene film and can be stored indefinitely without dating.




1. Master AC power switch.
2. Automatic fast feed.
3. "No paper" indicator.
4. Program clock.
5. Signal level.
6. White level.
7. Manual fast paper advance.
8. Marking signal test switch.
9. Signal monitor switch.
10. Manual start switch.

Figure 151.— Alden Facsimile Recorder.

The chemically treated paper has a moisture content of about 40 percent and is maintained in storage by the sealed package and in the recorder by the cover which encloses the paper from its supply to the feedout path. With the front cover open, the roll of paper is easily snapped into place. After the cover is closed, the seal is completed and the recorder is ready for use.

Special features of the receiver are that an automatic programing time clock is included and that the change in scan rate is easily accomplished by a simple hand operation by station personnel. The recorder is designed to operate on either 60 or 120 scans per minute.

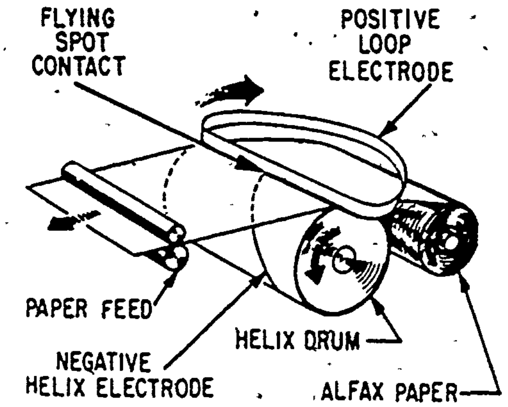



Figure 152.— Recorder operation of the Alden Facsimile.

Principles of Operation

The recorder has a helix drum which rotates synchronously with a scanner at the sending point. The paper passes between two electrodes; one is a continuously moving blade in the cover above the paper, and the other is a resilient helix wire-mounting on a rotating drum underneath the paper. (See figure 152.)

As the scanner sees the maps as an ON-OFF signal, it causes current or no current at any instant between the helix and the loop electrode. The helix wire then contacts the loop electrode of one point from left to right. The point of contact performs the work. When the paper passes between contacts at this point, there is an electrochemical action which causes ions to leave the loop electrode and plate the surface of the paper with the markings. This spot, multiplied by ON-OFF pulses, then produces the exact facsimile of the map scanned in the scanner.

Operating Instructions

The operating instructions are as follows:

1. Turning Recorder ON-OFF. Turn the recorder ON or OFF, using the power switch located on the left-hand side of the cabinet. Trigger the manual start switch on the autorephase chassis to start recording during map signals. Observe "no paper" indication light (OFF OK). Recorder shuts off at the end of the paper.

2. Setting the Program Clock. Set start to occur prior to first map required, placing start pin inside circle. Set stop to occur during last required map, placing stop pins in outside circle. Put pin in day dial for the day the recorder is to be OFF.

3. Marking Amplifier Adjustment. To adjust for best recording, turn signal level control clockwise from zero to point where signal indicator begins flashing; turn white level control counterclockwise to point where lightest map signal is still printing. Once set, the automatic gain control compensates for all normal line level variations. NOTE: Signal level set higher than necessary reduces map sharpness. White level overcontrol removes light signal. Setting for normal line conditions are 4 and 4.

4. Automatic Paper Advance. AUTOMATIC FAST FEED switch in ON position will advance paper 6 inches at the end of each map. The MANUAL FAST PAPER ADVANCE switch is located on the upper right-hand side of the recorder case. NOTE: MARKING SIGNAL TEST AND SIGNAL MONITOR switches on marking amplifier should be to the left when recording. See operating manual for line level tests.

To change recorder speed while recorder is running, proceed as follows:

1. Drum Motor. Set selector switch to either 60 or 120 rpm.

2. Paper Feed. Press manual start switch on the auto rephase chassis and hold while pressing the 60 or 120 rpm feed button (upper right side of the recorder head).

To get the best results from this machine, it is imperative that the recorder be kept clean and that the expendable parts be replaced before they have worn so far that a good copy cannot be obtained.

MISCELLANEOUS FACSIMILE EQUIPMENT

There are several other facsimile recorders still in use aboard ship and at overseas stations. These include the RD-92/UX, which has a scan capability of 30-60 lines per minute; the RO-160/UX, 60-120 lines per minute; and the RO-172/UX, 90-120 lines per minute. Many weather units utilize this equipment as "backup" for the more modern facsimile recorders.

These recorders, like the AN/UXH-2, require a radio receiver and the proper converter for facsimile weather chart reception. The RD-92/UX utilizes the CV-172/UX converter, and the RO-160/UX and RO-172/UX utilize the CV-1066/UX converter.

All of these recorders have the same basic working principle. For the purpose of brevity, only the theory of operation of the RD-92/UX is discussed now.

The RD-92/UX is used for direct stylus (electrical arcing) recording only. When receiving the copy, the recorder drum rotates at a speed of 60 rpm. As the drum rotates, a mechanical mechanism holding a stylus needle is moved across the drum to the right. The stylus needle records on a single sheet of paper fastened on a drum at the rate of one scanning line for each revolution of the drum. When the paper is covered completely, from left to right, the stylus is returned automatically to the left side of the drum.

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# SPECIAL INSTRUMENTATION

## METEOROLOGICAL SATELLITES

The world's first successful meteorological satellite, the TIROS I, was launched by the United States in 1960. Since then many other meteorological satellites have been launched. The earlier satellites had restricted capabilities due to their limited power supply, limited picture storage capacity, low latitude orbit, and satellite attitude characteristics. Most of these problems have been solved, so that now meteorological satellites are capable of presenting a complete global weather picture on a daily basis.

## TECHNICAL SPECIFICATIONS

The TIROS satellite is a relatively small instrument that is about 3 1/2 feet in diameter and about 1 1/2 feet high. It weighs about 300 pounds. Most weather satellites have two TV cameras installed, but the camera placement differs in the various satellites. Other equipment contained in these satellites include a transmitter, tape recorder, electronic timers, batteries, and infrared temperature-sensing devices.

TIROS satellites have been launched with the THOR-Able and THOR-Delta rockets. The earlier satellites were inclined about 48°, meaning that their orbits range from about 48° north latitude to 48° south latitude and required about 100 minutes to complete their orbit at an average altitude of 400 nautical miles.

The latest satellites are called ESSA (environmental survey satellites) and are part of the TOS (TIROS Operational System). They are sun synchronous (cross the Equator at the same time each day), earth oriented, and in a 750-nautical-mile circular polar orbit. (See figure 153.)

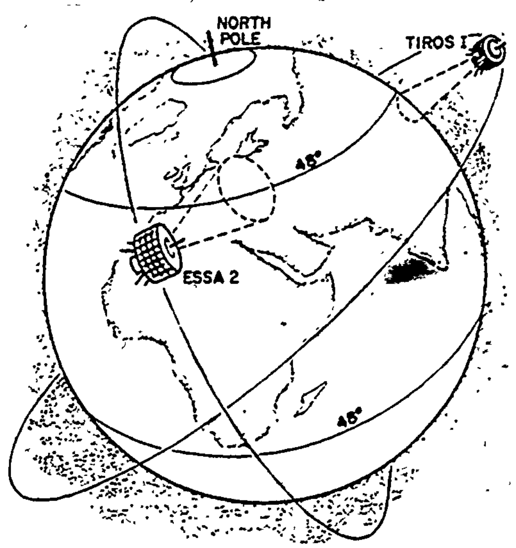


Figure 153.— Various weather satellites' orbits.

A recent operational development is the APT (Automatic Picture Transmission) system. This device is flown with the satellite and provides photographs directly to properly equipped land or shipboard stations. These stations have the capability of either "read-out" from their own antenna or "remoted" from a distant antenna. By this method, a facsimile picture of weather conditions over a large area is produced in a little over five minutes.

TIROS nephanalyses charts are transmitted over the National Weather Facsimile Network.

## AUTOMATIC WEATHER STATIONS

For many years, the National Weather Service has been hampered by the paucity or total lack of weather observations from remote oceanic and sparsely populated regions of the world. A solution to this problem was the installation of automatic weather stations. The automatic weather station's purpose is to collect weather reports and transmit these reports by radio to monitoring stations. There are two basic types of automatic weather stations—the land-based and the marine types. The most successful AWS have been the NOMAD AN/SMT-1( ), Transobuoy AN/WMT-1, and the Polar AWS, AN/GMT-4( ).

NOMAD AN/SMT-1( )

Marine Automatic Meteorological Station (NOMAD) AN/SMT-1( ) (figure 154) is a moored, boat-type automatic weather station. It is constructed of aluminum alloy and other nonmagnetic materials and is 20 feet long with a 10-foot beam. It houses a complete meteorological station, in addition to other instrumentation which is used for oceanographic research. The NOMAD is moored in deep water (as much as 1,875 fathoms).

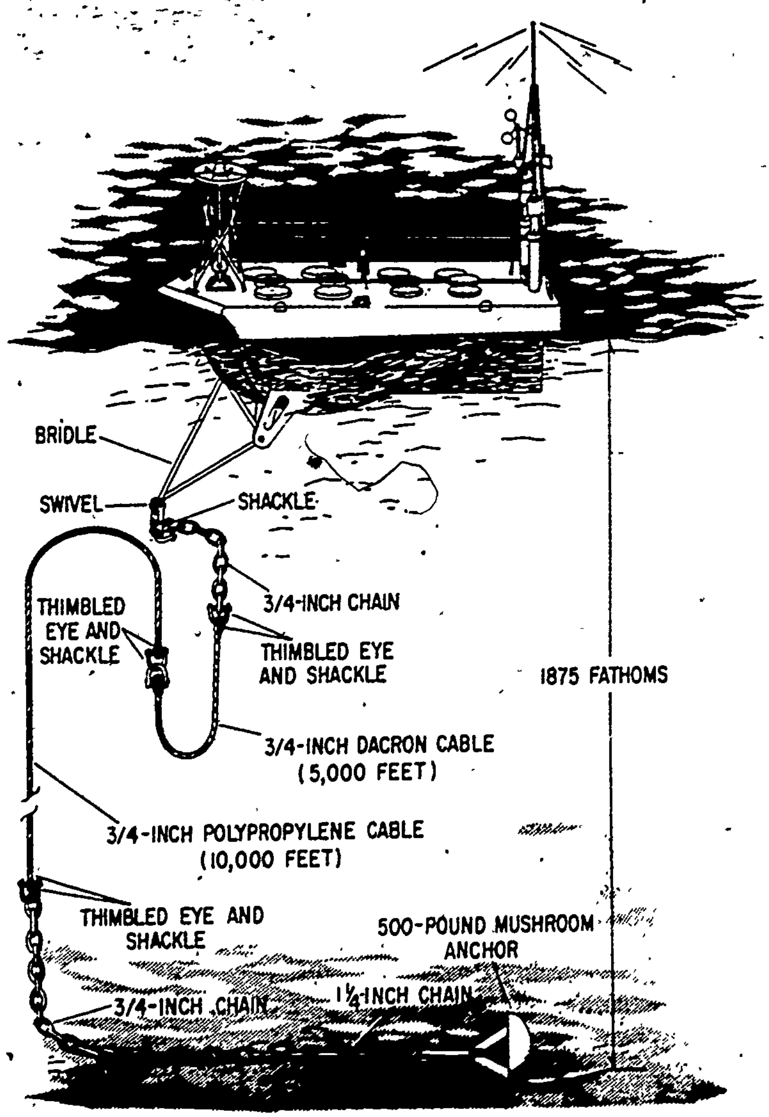


Figure 154.— NOMAD, AN/SMT-1( ).

NOMAD measures air temperature, water temperature, barometric pressure, wind speed, wind direction, and the direction of the ocean's surface currents. When the wind speed is low, observed data is transmitted once each 6 hours. During periods of high winds, the broadcasts are at hourly intervals. NOMAD transmits its weather reports on a preassigned frequency. The reports are monitored by specified stations, but have been monitored for quite some distance by other stations as well. Power is supplied to the NOMAD by batteries; however, atomic batteries are under development and may soon be used.

The first NOMAD made was moored in the Gulf of Mexico and, with its success, other NOMAD's were positioned off Norfolk, San Diego, and Charleston, S. C.

TRANSOBUOY AN/WMT-1( )

TRANSOBUOY AN/WMT-1( ) (figure 155) is a free-floating or moored automatic weather station developed for the purpose of providing weather reports from the open oceans. The TRANSOBUOY is about 10 feet in length and 30 inches in diameter and weighs about 750 pounds total. It has a 20-foot whip antenna through which it transmits on one of two different frequencies for programed ranges of between 1,000 to 2,000 miles. It has been monitored for distances of 4,000 miles.

The TRANSOBUOY transmits barometric pressure, air temperature, sea water temperature, wind speed, and wind direction every 6 hours. The powering batteries last about 6 months, and then the TRANSOBUOY needs servicing and replacement of batteries. When the TRANSOBUOY is a free-floating buoy, it has to be tracked to be located. When moored, the TRANSOBUOY's position is known. It can be moored in water 700 fathoms or more in depth.

POLAR AUTOMATIC WEATHER STATION AN/GMT-4( )

The Polar Automatic Weather Station (PAWS) AN/GMT-4( ), (figure 156) is a completely automatic weather station which measures meteorological elements and transmits them by radio. The PAWS is designed to function primarily in frigid or polar climates in order to fill the need for weather reports from inaccessible regions where manned stations are not practicable. Since the equipment is designed to operate on ice or slush, the main structure is in the form of a sled with external pontoons for added stability.

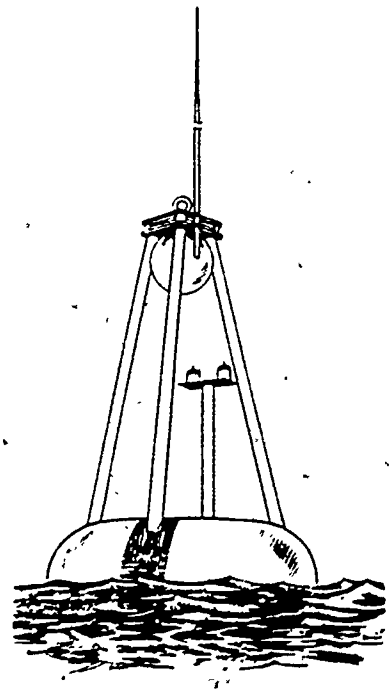

Figure 155.— Transobuoy AN/WMT-1( ).

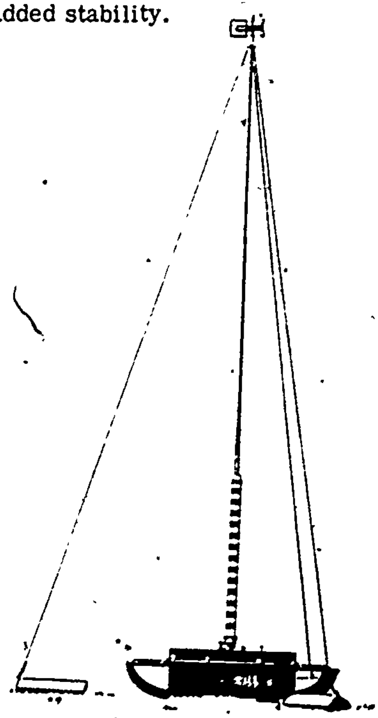

Figure 156.— Polar AWS, AN/GMT-4( ).

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The equipment is designed to be brought to a designated place by helicopter. Once there, it can be set up by one or two persons in a matter of a few minutes. Once placed in operation, it automatically measures and transmits at preselected intervals the following data: station barometric pressure, air temperature, water-air interface temperature, station magnetic orientation, wind direction, wind speed, and a station call signal. The radio transmitter is so designed that it may be called. The PAWS is powered by a battery. The battery must be recharged periodically; however, a recent development has provided an atomic recharger for the battery, making the unit more self-sufficient for longer periods.

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# APPENDIX I

# AN NOMENCLATURE SYSTEM

Part 1.—Equipment indicator letters.

| Installation | Type of equipment | Purpose |
|---|---|---|
| A—Airborne | A—Invisible light, heat radiation. | A—Auxiliary assemblies (not complete operating sets). |
| B—Underwater mobile, submarine. | C—Carrier. | B—Bombing. |
| D—Pilotless carrier. | D—Radiac. | C—Communications (receiving and transmitting). |
| F—Fixed. | E—Nupac (nuclear protection and control). | D—Direction finder, reconnaissance and/or surveillance. |
| G—Ground, general ground use (includes two or more ground installations). | F—Photographic | E—Ejection and/or release. |
| K—Amphibious. | G—Telegraph or teletype. | G—Fire control or search-light directing. |
| M—Ground, mobile (installed as operating unit in a vehicle which has no functions other than transporting the equipment). | I—Interphone and public address. | H—Recording and/or reproducing (graphic meteorological and sound.) |
| P—Pack or portable (animal or man). | J—Electromechanical (not otherwise covered). | K—Computing. |
| S—Water surface craft. | K—Telemetering. | M—Maintenance and test assemblies (including tools). |
| T—Ground, transportable | L—Countermeasure. | N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach, and landing). |
| U—General utility (includes two or more general installation classes, airborne, shipboard, and ground) | M—Meteorological. | Q—Special or combination of purposes. |
| | N—Sound in air. | R—Receiving, passive detecting. |
| | P—Radar. | S—Detecting and/or range and bearing, search. |
| | Q—Sonar and underwater sound. | |
| | R—Radio. | |

Part 1.—Equipment indicator letters—Continued

| Installation | Type of equipment | Purpose |
|---|---|---|
| V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).<br><br>W—Water, surface and undersurface. | S—Special types (magnetic, etc.) or combination of types.<br><br>T—Telephone (wire).<br><br>V—Visual and visible lights.<br><br>W—Armament (peculiar to armament, not otherwise covered).<br><br>X—Facsimile or television. | T—Transmitting.<br><br>W—Automatic flight or remote control.<br><br>X—Identification and recognition. |

Part 2—Component indicators.

| Component indicator | Family name | Definition of example (not to be construed as limiting the application of the component indicator) |
|---|---|---|
| AM | Amplifiers | Power, audio, interphone, radiofrequency, video, etc. |
| AT | Antenna | Simple: ship or telescopic, loop, dipole, reflector, also transducer, etc. |
| BA | Battery, primary type | Batteries, battery packs, etc. |
| BB | Battery, secondary type | Storage batteries, battery packs, etc. |
| C | Controls | Control box, remote tuning control, etc. |
| CP | Computers | A mechanical and/or electronic mathematical calculating device. |
| CV | Converters (electronic) | Electronic apparatus for changing phase or frequency, or from one medium to another. |
| FR | Frequency measuring devices | Frequency meters, echo boxes, etc. |
| G | Generators | Electrical power generators without prime movers. |

Part 2—Component indicators—Continued

| Component indicator | Family name | Definition of example (not to be construed as limiting the application of the component indicator) |
|---|---|---|
| ID | Indicating devices | Calibrated dials and meters, indicating lights, etc. (See IP.) |
| IP | Indicators, cathode ray tube | Azimuth elevation, PPI panoramic, etc. |
| M | Microphones | Radio telephone, throat, hand, etc. |
| MD | Modulators | Device for varying amplitude, frequency, or both. |
| ME | Meters, portable | Multimeters, volt-ohm milliammeters, vacuum tube voltmeters, power meters, etc. |
| MK | Miscellaneous kits | Maintenance, modification, etc., except tool and crystal. |
| ML | Meteorological device | Barometer, hygrometer, thermometer, scales, etc. |
| MT | Mountings | Mountings, racks, frames, stands, etc. |
| PH | Photographic articles | Camera, projector, sensitometer, etc. |
| PT | Plotting equipments | Except meteorological boards, maps, plotting table, etc. |
| R | Receivers | Receivers, all types except telephone. |
| RD | Recorders-reproducers | Sound, graphic, tape, wire, film, disk facsimile, magnetic, mechanical, etc. |
| RF | Radiofrequency component | Composite component of RF circuits. (Do not use if better indicator is available.) |
| RG | Cables and transmissions line, bulk RF | RF cable, waveguide, etc., without terminal. |
| RO | Recorders | Sound, graphic, tape, wire, film, disk facsimile, magnetic, mechanical, etc. |
| RR | Reflectors | Target confusion, etc. Except antenna reflectors. (See AT.) |
| RT | Receiver and transmitter | Radio and radar transceivers, composite transmitters and receivers, etc. |

Part 2—Component indicators—Continued

| Component indicator | Family name | Definition of example (not to be construed as limiting the application of the component indicator) |
|---|---|---|
| S | Shelters | House, tent, protective shelter, etc. |
| SB | Switchboards | Telephone, fire control, power panel, etc. |
| SG | Signal generators | Includes test oscillators and noise generators. |
| SM | Simulators | Flight, aircraft, target, signal, etc. |
| SN | Synchronizers | Equipment to coordinate two or more functions. |
| T | Transmitters | Transmitters, all types except telephone. |
| TA | Telephone apparatus | Miscellaneous telephone equipment. |
| TD | Timing device | Mechanical and electronic timing devices, range devices, etc. |
| TF | Transformers | Transformers when used as separate items. |
| TS | Test equipment | Test and measuring equipment. |
| TT | Teletypewriter and facsimile apparatus | Miscellaneous tape, teletype, facsimile. |

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# OBSERVATIONS

# AND CODES

A correspondence course pamphlet consisting of excerpts from:

| | |
|---|---|
| Aerographer's Mate 3 & 2 | NAVPERS 10363-C |
| Instruction Manual for Obtaining Oceanographic Data | N.O. Pub. 607 |
| Manual for Oceanographic Observations | CG 410 |
| Manual of Ice Observations | N.O. Pub. 606-d |
| Manual of Marine Observations | WBOH-1 |
| Manual of Surface Observations | FMH-1 |
| Manual of Synoptic Code | FMH-2 |
| Radio Weather Aids | N.O. Pub. 118 |


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## WARNING

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# SURFACE WEATHER OBSERVATIONS

Taking surface weather observations is one of the primary duties of the Coast Guard's Marine Science Technician. Since life, property, and successful Coast Guard operations depend greatly on reliable forecasts, it is essential that the observations upon which forecasts are based be as accurate as humanly possible.

The purpose of this section is to explain how to take surface weather observations and how to enter these data on the Surface Weather Observation Form (Ship), Form MF1-11. For complete and detailed instructions of the various observations and codes, consult the appropriate manuals.

## GENERAL TERMS, DEFINITIONS, AND PROCEDURES

In order to take surface weather observations, you must understand the meteorological variables you are observing and how to observe these variables. You have already considered many of these variables in this course, but to refresh you memory of them, we will discuss their meanings and their significance to surface weather observations. In addition, we will consider how to take these observations. The observational procedures are applicable at sea or ashore, unless we state otherwise.

### TEMPERATURE OBSERVATIONS

Temperature, the measure of molecular motion or the degree of heat of a substance, is measured on an arbitrary scale from absolute zero, where the molecules theoretically stop moving. "Temperature," as used in surface weather observations, refers primarily to the free air temperature, which is the ambient temperature close to the surface of the earth. Other temperatures also observed during the course of an observation are maximum and minimum free air temperatures (observed for shore stations only) and sea water temperature.

### Definitions

In order to understand how to obtain temperature readings and to determine the dew point temperature and relative humidity, you should review the following terms and their definitions:

1. Dew point — The dew point is defined as the temperature to which a sample of air must be cooled, while the mixing ratio and the barometric pressure remain constant, in order to attain saturation with respect to water. The dew point can never exceed the dry-bulb temperature in any given observation. When the air is saturated, the dew point and the temperature are the same and the relative humidity is 100 percent.

2. Dry-bulb temperature — The dry-bulb temperature is the natural temperature of the ambient atmosphere at the point and time of observation and is synonymous with the surface temperature.

3. Wet-bulb temperature — The wet-bulb temperature is the lowest temperature to be secured in the ambient atmosphere in its natural state by evaporating water from the wick-covered bulb of a thermometer at a specified rate of ventilation. It differs from the dry-bulb temperature in an amount dependent on the temperature and humidity of the air. This difference is termed the wet-bulb depression.

4. Psychrometer — A psychrometer is an instrument used for measuring water vapor content of the atmosphere; it is a type of hygrometer. It consists of two thermometers, one of which (dry-bulb) is an ordinary glass thermometer, while the other (wet-bulb) has its bulb covered with a jacket of clean muslin which is saturated with distilled water prior to an observation. When the bulbs are suitably ventilated, they indicate the thermodynamic wet-bulb and dry-bulb temperatures of the atmosphere. In this pamphlet the sling psychrometer and the hand electric psychrometer are covered.

Using the Sling Psychrometer

When using the sling psychrometer as the station standard or standby system, observe the following steps to determine psychrometric values:

1. Remove the sling psychrometer from the instrument shelter. Wet the bulb of the wet-bulb thermometer, which is covered with a muslin wick, at the time of the observation. Do this in a special manner when certain temperatures and humidity conditions exist as follows:

a. At wet-bulb temperatures below 32° F., if the wick is not frozen, touch it with clean ice, snow, or another cold object to induce freezing.

b. At dry-bulb temperatures of 37° F. or below, use water that has been kept at room temperature in order to melt completely any accumulation of ice on the wet bulb. Moisten the bulb thoroughly at least 15 minutes before ventilating the psychrometer and longer if necessary to permit the latent heat, released if the water freezes, to be dissipated before you ventilate the psychrometer. Do not allow excess water to remain on the wet-bulb, since a thin, thoroughly cooled coating is necessary for accurate data.

c. In areas where the temperature is high and the humidity is low, use precooled water for moistening the wet bulb to avert premature drying of the wick. Water can be precooled for this purpose by storing it in a porous jug.

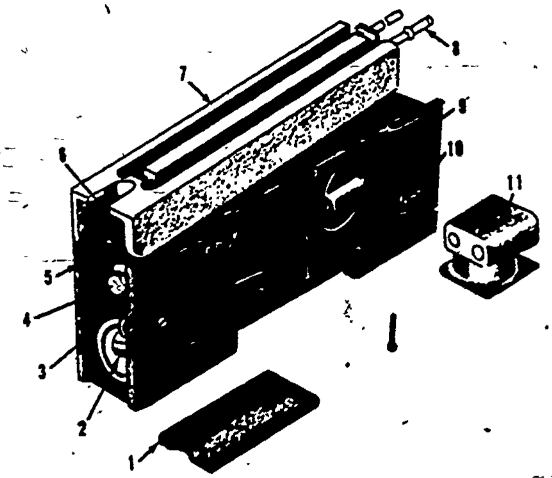
2. Take the psychrometer to a clear and open space, preferably exposed to the wind. Never touch the bulb or stem in handling or expose it to the direct rays of the sun while making an observation. Whirl the psychrometer as far in front of the body as possible.

3. Ventilate the psychrometer for about 10 seconds. For the best results, whirling should produce air flow of not less than 15 feet per second (2 rotations per second). Bring the psychrometer to a stop without any sharp jar and then bring it to the eye level and read both thermometers to the nearest tenth of a degree, reading the wet-bulb thermometer first. Repeat the whirling and make other readings until the wet-bulb temperature fails to show further decline.

4. After observing the wet- and dry-bulb temperatures, calculate the difference between the dry-bulb and the wet-bulb temperature readings. After you obtain the difference, or wet-bulb depression, the next step is to compute the dew point and the relative humidity by use of the psychrometric computer (CP-165/UM). The instructions for use of the computer are printed on the computer. When using the psychrometric computer, utilize the scale closest to the NORMAL station pressure. For shipboard operations, always use the 30-inch scale. For further instructions, see the appropriate chapter of the Federal Meteorological Handbook No. 1 (FMH #1).

Using the Hand
Electric Psychrometer (ML-450A/UM)

Another instrument used to obtain the free air temperature and the wet-bulb temperature is the hand electric psychrometer (ML-450A/UM) (figure 1). Although the psychrometer is constructed primarily of noncorrodible materials, prolonged exposure to weather, salt air, stack gases, and other corrosive elements shorten the useful life of this instrument. Therefore, shelter the instrument when it is not in actual use.




1. Sliding door.
2. Spring contact.
3. Battery compartment.
4. Water bottle.
5. Bottle compartment.
6. Hinge pin.
7. Thermometer holder.
8. Wet-bulb wick.
9. Knob.
10. Exhaust ports.
11. Sliding air intake.

Figure 1.— Hand Electric Psychrometer ML-450A/UM.

In order to operate the psychrometer when the temperature is above 50° F., expose the psychrometer to the free air for at least 5 mintues before using it for readings. Open the sliding door halfway, remove the water bottle, and then close the sliding door. Saturate the wet-bulb wick with distilled water by using one of the following methods:

1. Remove the sliding air intake and thoroughly saturate the wet-bulb wick, taking every precaution to prevent water from contacting either the thermometer tube or the dry bulb. Remove any moisture which may have contacted the dry bulb.

2. Without removing the sliding air intake, hold the psychrometer so that the thermometer bulbs point upward. Carefully apply water, a drop at a time, to the wet-bulb wick so as not to cause the thermometer tube to become wet from an overly saturated wick. Remove any moisture which may have contacted the dry bulb.

If you have followed method 1, replace the air intake, being sure that the small circular holes in the air intake are positioned against the thermometer holder. Replace the water bottle.

Either of the following positions may be used during operation:

1. Place the instrument on a flat surface with the graduations of the thermometer facing upward and the air intake positioned into the wind and to the left of the operator, or

2. Grasp the instrument in the left hand with the fingers fitting the curved portion of the case, the graduations of the thermometers facing the operator, and the air intake pointing to the left and into the wind.

CAUTION

In either position, the air intake and both exhaust ports must be entirely free of obstructions and far enough away from your body or any other source of moist air or temperature that may cause a false reading.

Turn the switch knob clockwise to start aspiration. If illumination is desired, continue turning the knob clockwise until you obtain sufficient light intensity.

When the wet-bulb temperature stabilizes at a minimum value, note the readings of both thermometers and turn off the switch by turning the knob counterclockwise. Evaluate the readings, using the psychrometric computer.

In order to operate the psychrometer when the temperature is below 50° F., observe the following precautionary measures to ensure accurate instrument performance:

1. Store the instrument in its case in an instrument shelter or other suitable location to keep it approximately at the ambient temperature. To prevent the distilled water from being frozen when you are ready to use it, store it indoors and then carry it out of doors to the instrument when ready to saturate the wick.

2. If brought from a warm room to an outside temperature below 50°F., take special care to point the instrument into the wind and to ensure that an equilibrium temperature is reached, letting the fan run for 5 to 10 minutes.

3. If you bring the psychrometer from a cold temperature to a warm temperature for a reading, ensure that condensation on the dry bulb does not give an erroneous reading due to the wet-bulb effect.

The remaining steps in the operation of the hand electric psychrometer are identical with those already mentioned for operation of the hand electric psychrometer at temperatures above 50° F.

WIND OBSERVATIONS

Wind is air in motion. As such, wind has four important properties of vital interest to you when you make wind observations. These qualities are direction, speed, character, and shift. Definitions of these qualities and instructions for determining these qualities are contained in the following paragraphs.

Wind direction is the direction from which the wind is blowing. Wind direction is observed for a one-minute interval with reference to true north and is expressed in 10° increments in a clockwise direction from true north. When the

Table 1.— Determination of true wind speed by sea condition.

| Speed (knots) | Descriptive terms | Sea conditions |
|---|---|---|
| Less than 1 | Calm | Sea smooth and mirrorlike. |
| 1-3 | Light air | Scalelike ripples without foam crests. |
| 4-6 | Light breeze | Small, short wavelets; crests have a glassy appearance and do not break. |
| 7-10 | Gentle breeze | Large wavelets; some crests begin to break; foam of glassy appearance. Occasional white foam crests. |
| 11-16 | Moderate breeze | Small waves, becoming longer; fairly frequent white foam crests. |
| 17-21 | Fresh breeze | Moderate waves, taking a more pronounced long form; many white foam crests; there may be some spray. |
| 22-27 | Strong breeze | Large waves begin to form; white foam crests are more extensive everywhere; there may be some spray. |
| 28-33 | Near gale | Sea heaps up and white foam from breaking waves begin to be blown in streaks along the direction of the wind; spindrift begins. |
| 34-40 | Gale | Moderately high waves of greater length; edges of crests break into spindrift; foam is blown in well-marked streaks along the direction of the wind. |
| 41-47 | Strong gale | High waves; dense streaks of foam along the direction of the wind; sea begins to roll; spray may reduce visibility. |
| 48-55 | Storm | Very high waves with long overhanging crests. The resulting foam in great patches is blown in dense white streaks along the direction of the wind. On the whole; the surface of the sea is white in appearance. The rolling of the sea becomes heavy and shocklike. Visibility is reduced. |
| 56-63 | Violent storm | Exceptionally high waves that may obscure small- and medium-sized ships. The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility reduced. |
| 64-71 | Hurricane | The air is filled with foam and spray. Sea completely white with driving spray; visibility very much reduced. |

air is not in motion, the wind is said to be CALM. When instruments for measuring wind direction are not available or are inoperative, estimate the direction by observing a wind cone or tee, movement of trees, or smoke, or by facing into the wind in an unsheltered area.

Wind speed is the rate of motion of the air in a unit of time. Wind speed is determined to the nearest knot. In general, observed wind speeds are a one-minute average. So far as possible, an average wind speed observation should not be made during a peak or lull in gusty winds or squalls. When wind speed instruments are temporarily unrepresentative or not available, estimate speed (including gustiness and squall data) by means of table 1.

The character of the wind refers to its gustiness and the like. A gust is a rapid fluctuation in wind speed with a variation of 10 knots or more between peaks and lulls. A squall, however, is a sudden increase in wind speed of at least 15 knots which is sustained at 20 knots or more for at least 1 minute.

A wind shift is a change in wind direction of 45 degrees or more which takes place in less than 15 minutes. "Wind shift," as used in this course, is associated with some or all of the phenomena characteristics of a cold-front passage. The phenomena are as follows:

1. Gusty winds shifting in a clockwise manner in the Northern Hemisphere and counterclockwise in the Southern Hemisphere.

2. Rapid drop in dew point.

3. Rapid drop in temperature.

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4. Rapid rise in pressure.

5. In summer: lightning, thunder, heavy rain, and possibly hail.

6. In winter: frequent rain or snow squalls with cloud heights changing rapidly.

Changes of wind direction may also result from other causes, such as katabatic or foehn winds, sea breezes, and thunderstorms. In such cases, the change of direction may be gradual or abrupt and may or may not be accompanied by significant changes of other weather elements. Report a wind shift when you believe it is associated with a frontal movement, regardless of the magnitude of the shift, and when a change of wind speed and direction is so abrupt as to be considered important to aircraft operations.

## PRESSURE OBSERVATIONS

### Definitions

Several important terms related to pressure observations are defined as follows:

1. Atmospheric pressure — Atmospheric pressure is the pressure exerted by the atmosphere as a result of the gravitational attraction exerted upon the column of air lying directly above the point in question.

2. Station pressure — Station pressure is the pressure computed for the level of the station elevation.

3. Sea level pressure — Sea level pressure is the station pressure reduced to sea level in accordance with established procedures. Sea level pressures are computed so that all stations give a value of pressure with reference to a STANDARD level.

4. Altimeter setting — The altimeter setting is a pressure, in inches, used to set the altimeter in the cockpit of an aircraft so that the altimeter indicates station elevation in feet above mean sea level when the aircraft is sitting on the runway. The altimeter in an aircraft is essentially a small aneroid barometer calibrated in feet instead of inches or millibars.

5. Barometric pressure tendency — The barometric pressure tendency consists of two elements. The first is the net barometric change within a specified time. The second is the characteristic of the change during the specified time, based on the appearance of the barogram and on the direction of the change, if any (e. g., higher, lower, or no change).

### Determining Pressures

Weather observations require observations of the station pressure, sea level pressure, and the altimeter setting, also required at certain standard times are the pressure tendency and the net three-hour change.

When properly calibrated and compared, the precision aneroid barometer at both shore stations and aboard ship is used for airways and synoptic observations. The microbarograph will be used only for "tendency." The mercurial barometer is used mainly for comparison of the readings from the aneroid barometer. Ship stations compare their aneroid barometers with a mercurial barometer before getting underway.

Sea level pressure is obtained by several methods, depending on the elevation of the station. Aboard ship obtain sea level pressure by ADDING a constant pressure reduction factor to the station pressure. Obtain this constant by multiplying the height (in feet) of the precision aneroid barometer above the loadline by either 0.001 inch or 0.037 mb., depending on the markings on the barometer.

The barometric pressure tendency comprises the net change within a specified time and the characteristic of the change during that time. Pressure tendencies are determined only at stations equipped with a microbarograph. The pressure tendency is determined for the full three-hour period ending at the actual time of the observation. Classify the characteristic of the barograph trace for the three-hour period, using the code figure prescribed in FMH #1, corresponding to the same general pattern. When the tendency of the observed trace is incompatible with the sign of the net change, select the tendency that is most nearly representative and still compatible with this sign.

## PRECIPITATION OBSERVATIONS

Precipitation is measured on the basis of the vertical depth of water, or water equivalent,

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which would accumulate within a specified time on a level surface. The inch is the unit of measurement for precipitation. The vertical depth of water, or water equivalent, is expressed to the nearest 0.01 inch; less than 0.005 inch is called a trace. Precipitation measurements are made from samples caught in gages, or from samples taken from representative areas when the catch of solid forms in the gage is not representative.

Most weather units use the 4-inch rain gage. The tube of the 4-inch rain gage holds 1 inch of water. In the event that more than 1 inch falls, the excess drains into the overflow container.

The depth measurement of the water equivalent of the solid forms of precipitation, such as snow, sleet, hail, and freezing rain, is more difficult to obtain. You can use the rain gage if you remove the collector ring and measuring tube. Collect the solid forms in the overflow container. At the time of the observation, add a measured amount of warm water to the contents of the container to melt the solid forms. Once melted, make the measurement as for rainfall. You must, of course, deduct the added amount of water in computing the total water equivalent.

In measuring snow, another method is to obtain a definite volume of the snow from a representative area by removing the overflow container and using it like a doughnut cutter to remove a snow section. Melt and measure the snow as described above. When the water equivalent of snow cannot be accurately measured by melting, you may use one-tenth of the average snow depth as the water equivalent; that is, 10 inches of snow correspond to 1 inch of melted snow.

## OBSERVATIONS OF CEILING AND SKY CONDITIONS

Of all the weather conditions adversely affecting aircraft operations, low ceilings and low visibilities are by far the most common. They are the cause of most of the flight delays and cancellations due to weather. This subsection describes the methods for observing ceilings and sky conditions.

### Definitions

Ceiling and sky condition definitions are as follows:

1. Layer — Clouds or obscuring phenomena whose bases are at approximately the same level are regarded as a layer. The layer may be continuous, or it may be composed of detached elements. The term "layer" does not imply that a clear space exists vertically between layers or that clouds or obscuring phenomena composing them are of the same type. The only requirement of composition is that all the elements of the layer are based at approximately the same level.

2. Obscuration — The term "obscuration" is used to denote that an observer at the surface is unable to evaluate the sky condition aloft in the usual manner because surface-based obscuring phenomena (fog, smoke, etc.) hide more that 9/10 of the sky, as determined to the nearest tenth. (See figure 2-A.)

3. Partial obscuration — Term "partial obscuration" is used to denote that 1/10 or more of the sky (to nearest tenth), but not all of the sky, is hidden by surface-based obscuring phenomena. Normally the phenomena is uniformly distributed. (See figure 2-B.)

4. Transparency and opacity — As used in this training course, "transparency" and "opacity," as related to cloud layers or obscuring phenomena, are defined as follows:

a. Transparent sky cover — A transparent sky cover is made up of those portions of cloud layers, or obscurations which do not hide the sky. A blue sky or higher clouds can be discerned through these portions during daylight, and the moon and brighter stars may be discerned at night.

b. Opaque sky cover— An opaque sky cover is made up of those portions of cloud layers or obscurations which hide the sky and/or higher clouds. A translucent sky cover which hides the sky but through which the sun and moon (not stars) may be dimly visible will be considered as opaque.

5. Thin sky cover — This term is applied to a layer when the ratio (of summation amounts at and below the level of the layer) of transparent sky cover to total sky cover is 1/2 or more.

6. Surface — For height determinations, the term "surface" means the horizontal plane

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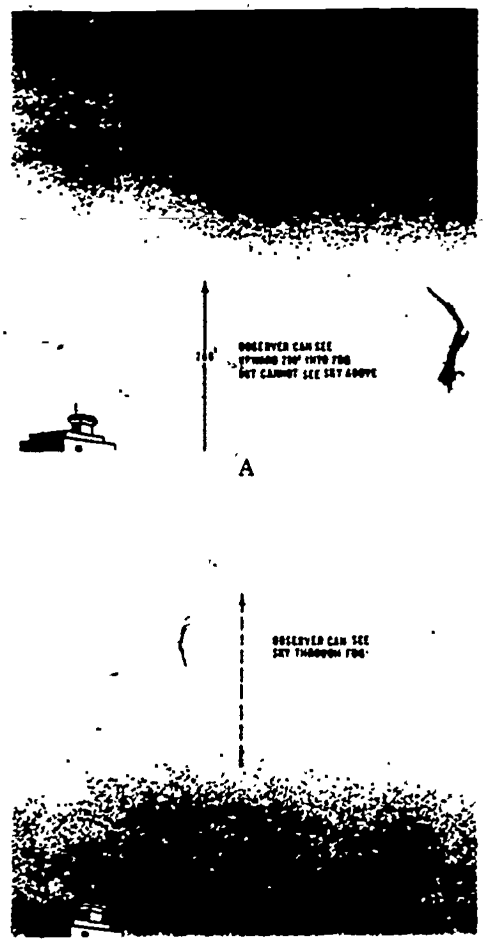


Figure 2.— (A) Sky completely hidden by fog; (B) sky partially obscured by fog.

whose elevation above sea level equals field elevation. At a station where the field elevation has not been established, the term "surface" refers to ground elevation at the point of observation.

7. Ceiling — The ceiling is the height ascribed to the lowest layer of clouds or obscuring phenomena aloft that is reported as "broken" or "overcast" and not classified as "thin," or it is surface-based obscuring phenomena (obscuration) not classified as "partial."

For an obscuration, a ceiling value represents vertical visibility into obscuring phenomena rather than the height of the base.

The ceiling is termed "unlimited" when the foregoing conditions are not satisfied.

8. Vertical visibility — Vertical visibility is a ceiling value used to express the distance that an observer at the ground in an obscuring medium can see vertically upward into the medium, or the maximum ~~vertical~~ height above the ground at which a pilot in surfaced-based obscuring medium can recognize the ground.

9. Variable ceiling — "Variable ceiling" describes a condition in which the ceiling rapidly increases and decreases by one or more reportable values while the ceiling observation is being taken. It is reported only for ceilings less than 3,000 feet. The average of all observed values is used as the ceiling.

Evaluation of Sky Cover

You should take several factors into consideration when evaluating sky cover (clouds and obscuring phenomena): determination of the sky cover's stratification, amount of sky cover, direction of movement of the clouds, height of the bases of the clouds, and the effect of obscuring phenomena on the vertical visibility. Observe these elements from as many points as necessary to view the entire sky.

Determination of Stratification— You should first determine how many layers of clouds or obscuring phenomena are present at the time of the observation.

Frequent observation is necessary to evaluate stratification. A series of observations often show the existence of upper layers above a lower layer. Through thin lower layers it may be possible to observe higher layers. Differences in the directions of cloud movements are often a valuable aid in observing and differentiating cloud stratification, particularly when haze, smoke, etc., render depth perception difficult.

Cumulo type clouds developing below other clouds may reach or penetrate them. Also, by horizontal extension, swelling cumulus or cumulonimbus may form stratocumulus, altocumulus, or dense cirrus. When clouds formed in this manner are attached to a parent cloud, they are regarded as a separate layer only if their bases appear horizontal and at a different level from the parent cloud. Otherwise, the entire cloud system is regarded as a single layer at a height corresponding to that of the base of the cumulonimbus.



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Sky Cover Amounts.— Sky cover amounts are evaluated in terms of the entire sky above the local (apparent), rather than the celestial, horizon in tenths for aviation observations and in eights (oktas) for synoptic observations; in terms of the amount of sky covered, or hidden, depending on the aspect of sky cover being determined; and with reference to an observer on the earth's surface.

Evaluations are made of the following:

1. Amount of sky hidden by surface-based atmospheric obscuring phenomena, such as fog, smoke, haze, precipitation, etc.

2. The amount of sky covered by cloud and/or obscuring phenomena in each layer aloft, i.e., an integrated evaluation based on several recent and successive evaluations, if necessary and possible, where a significant portion of the layer is hidden at the time of observation by lower layers.

3. Layers reportable as being thin.

4. Amount of sky hidden by surface-based atmospheric phenomena, and for level of each layer aloft, the amount of sky hidden by surface-based sky cover, if any, and additionally covered by sky cover aloft at and below each level aloft.

There are various methods of estimating the amount of sky cover. The procedure is simplifed if the sky cover consists of an advancing or receding layer, or a continuous layer surrounding the station.

To estimate the amount of an advancing (or receding) layer, determine the angular elevation above the horizon of the forward or rear edge of the layer as seen against the sky. Use a theodolite or clinometer until you have gained experience in estimating vertical angles. Convert the angle to tenths of sky cover. (See table 2.)

When the layer does not extend to the horizon, determine the angular elevation of the forward and rear edges and the tenths of sky cover corresponding to each elevation. The difference equals the sky cover. For example: forward edge 78° = 0.4 sky cover; rear edge 53° = 0.2 sky cover. Total sky cover is the difference between the two, or 0.2 sky cover.

Table 2.— Sky cover with advancing or receding layers.

| Angles subtended by sky cover | Tenths of sky cover |
|---|---|
| Less than 26° | 0.0 |
| 26° to 45° | 0.1 |
| 46° to 59° | 0.2 |
| 60° to 72° | 0.3 |
| 73° to 84° | 0.4 |
| 85° to 95° | 0.5 |
| 96° to 107° | 0.6 |
| 108° to 119° | 0.7 |
| 120° to 134° | 0.8 |
| 135° to 154° | 0.9 |
| 155° to 180° | 1.0 |

Table 3.— Sky cover with layer surrounding station.

| Angular elevation | Tenths of sky cover |
|---|---|
| Less than 3° | 0.0 |
| 3° to 8° | 0.1 |
| 9° to 14° | 0.2 |
| 15° to 20° | 0.3 |
| 21° to 26° | 0.4 |
| 27° to 33° | 0.5 |
| 34° to 40° | 0.6 |
| 41° to 48° | 0.7 |
| 49° to 58° | 0.8 |
| 59° to 71° | 0.9 |
| 72° to 90° | 1.0 |

When a continuous layer surrounds the station and extends to the horizon, determine the angular elevation of the edge, and convert to tenths of sky cover. (See table 3.) Since such a distribution is improvable, the table serves only as a guide in estimating amounts in situations that approach such a configuration in degree.

After you have determined the amount of sky cover and have assigned a value to the various layers present, classify each layer in accordance with table 8.

NOTE: Although we mention table 8 at this point, the table does not appear until the latter part of this section. Tables 6 through 14 do not appear on the pages where we first mention them. Instead, these tables appear as a group immediately following the discussion of the airways column entries of Form MF1-11, because these tables are used to determine column entries of Form MF1-11.

Determining Cloud Heights.— There are many methods that may be used to determine the heights of cloud bases. These include the use of ballons; radar height data; known height references, such as buildings, mountains, and other landmarks; convective cloud height diagrams; pilot reports; and ceiling lights and ceilometers. (Refer to FMH #1 for guidance in selecting the most reliable method.) In the unavailability of the above methods, estimate the heights, relying on your experience and knowledge of cloud forms, and on a comparison with previous observations.

Regardless of what method you use, determine the layers and report in terms of feet above the surface of the station and round them to the reportable values in accordance with table 7.

> NOTE: Code heights that are halfway between reportable values as the smaller of the two values.

When using a ceiling balloon, choose the appropriate color of ballon; red balloons are usually preferable with thin clouds, and blue or black for other conditions. Note the length of time that elapses between the release of the balloon and entry into the base of the layer. The point of entry is considered as midway between the time the balloon first begins to fade and the time of complete disappearance. Balloon ascension tables, maintained by most weather units or found in FMH #1, are entered with this elapsed time value to determine the cloud base height.

Compute heights derived from rawin or raob balloons rather than determine them from ascensional rate tables. Visually observe the entry of the balloon into the cloud base and make a notation on the recorder record of the rawin or radiosonde recorder.

Heights ascribed to sky cover layers, including vertical visibility, may be based on landmarks, including mountains, trees, buildings, etc., where the heights of the objects above the surrounding terrain and observation point are known. Normally, each weather unit maintains a chart (or a list) showing objects suitable for reference heights.

Heights of cloud layers may also be based on RHI (range height indicators) radarscope data. The radar operator normally supplies this information.

Use the Convective Cloud Height Diagram, which is found in FMH #1, to determine the height of convective-type clouds. It is not suitable for stations situated in mountainous or hilly terrain. Use the observed dew-point and dry-bulb temperatures as coordinates when entering the diagram, and read the base height of convective type clouds adjacent to the intersection of these two elements.

## OBSERVATIONS OF VISIBILITY

"Ceiling" and "visibility" are two fundamental terms in aviation terminology and are probably used more than any others in describing flying weather. Seldom does a pilot check on the flying weather without paying particular attention to the visibility conditions, since visibility, together with ceiling, holds the answer to many flight problems. "Visibility" is a term that denotes the greatest horizontal distance at which selected objects can be seen and identified under specified conditions.

There are three categories of visibility: prevailing, sector, and runway visibility. This pamphlet will discuss in detail only prevailing visibility; consult FMH #1 for details about runway and sector visibility.

### Guidance in Determining Visibility

Transparency of the atmosphere in the open country (except in polar regions), removed from sources of atmospheric pollutants and at relative humidities less than 90%, changes very little from daylight to darkness and vice versa. Visibility between day and night under these conditions may change significantly due to the difference in brightness contrast between lights at night on the one hand and the brightness contrast between an object and the horizon sky in the daytime on the other hand. In areas subject to pollution (as smoke from domestic heating or cooking, and industrial exhausts) there may be systematic variations in transparency of the atmosphere during the transition periods between sunrise and sunset, which further complicate visibility patterns. In such areas a decrease in visibility often occurs near dawn, particularly when a steep temperature inversion exists in the layer of atmosphere near the surface.

Before taking a visibility observation at night, spend as much time as necessary to permit your eyes to adapt to the darkness.

When you are ashore, take visibility observations from as many points as necessary to view all appropriate markers. Take the observation with reference to a plane 6 feet above the ground or, if the station facilities preclude an observation at this level, as close as practicable to it. When the visibility is greater than the distance to the farthest visible marker, note the sharpness with which the marker stands out. Sharp outlines in relief, with little or no blurring of color, indicate that the visibility is much greater than the distance to the reference object. On the other hand, blurred or indistinct (yet identifiable) objects indicate the presence of some obscurant that has reduced the visibility to not less than the distance of the objects.

When aboard ship, determine visibility from as many points as possible, using the horizon, ships in company, radar, and stadimeter ranges. Base your estimates upon the apparent size of the ship (or other object) and the portion visible. Use table 4 as a guide in determining distances (e. g., in accordance with line 7 of table 4, when you view the horizon from a bridge 40 feet above the sea, the horizon is 7.6 nautical miles away).

Prevailing Visibility

Prevailing visibility is the greatest visibility which is attained or surpassed throughout at least half of the horizon circle not necessarily continuous. This term is synonymous with the term "horizontal visibility" as used in the synoptic code. If the visibility is variable (i.e., the prevailing visibility rapidly increases and decreases by one or more reportable values during the period of the observation), the average of all observed values is the prevailing visibility.

In uniform conditions the determination is relatively simple because the prevailing visibility will be the same as the visibility in any direction.

In nonuniform conditions one aid for determining prevailing visibility is to divide the horizon circle into several sectors, each of which has substantially uniform visibility. Then determine the visibility value that equals or surpasses at least one-half of the horizon circle. (See figure 3 for various examples.)

Reportable Values

Visibility is reported at land stations in statute miles, and at ocean stations in nautical miles, to the nearest value given in table 10.

## OBSERVATIONS OF ATMOSPHERIC PHENOMENA

Atmospheric phenomena considered as weather elements of an observation are tornadoes, waterspouts, funnel clouds, thunderstorms, squalls, and precipitation in any form. Hydrometeors

Table 4.— Distance to Objects on the Horizon at Sea (Nautical Miles).

| Height of observer's eyes above sea level (feet) | Height of object above sea level (feet) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0[1] | 10 | 20 | 30 | 40 | 60 | 80 | 100 | 150 | 200 | 300 | 400 | 600 | 800 | 1,000 |
| 10 | 3.8 | 7.2 | 8.7 | 9.9 | 10.8 | 12.5 | 13.9 | 15.1 | 17.7 | 19.8 | 23.5 | 26.5 | 31.6 | 36.0 | 39.8 |
| 15 | 4.6 | 8.0 | 9.5 | 10.7 | 11.6 | 13.3 | 14.7 | 15.9 | 18.5 | 20.6 | 24.3 | 27.3 | 32.4 | 36.8 | 40.6 |
| 20 | 5.4 | 8.7 | 10.2 | 11.4 | 12.3 | 14.0 | 15.4 | 16.6 | 19.2 | 21.3 | 25.0 | 28.0 | 33.1 | 37.5 | 41.3 |
| 25 | 6.0 | 9.3 | 10.8 | 12.0 | 12.9 | 14.6 | 16.0 | 17.2 | 19.8 | 21.9 | 25.6 | 28.6 | 33.7 | 38.1 | 41.9 |
| 30 | 6.6 | 9.9 | 11.4 | 12.6 | 13.5 | 15.2 | 16.6 | 17.8 | 20.4 | 22.5 | 26.2 | 29.2 | 34.3 | 38.7 | 42.5 |
| 35 | 7.1 | 10.4 | 11.9 | 13.1 | 14.0 | 15.7 | 17.1 | 18.3 | 20.9 | 23.0 | 26.7 | 29.7 | 34.8 | 39.2 | 43.0 |
| 40 | 7.6 | 10.8 | 12.3 | 13.5 | 14.4 | 16.1 | 17.5 | 18.7 | 21.3 | 23.4 | 27.1 | 30.1 | 35.2 | 39.6 | 43.4 |
| 45 | 8.0 | 11.2 | 12.8 | 14.0 | 14.9 | 16.6 | 18.0 | 19.2 | 21.8 | 23.9 | 27.6 | 30.6 | 35.7 | 40.1 | 43.9 |
| 50 | 8.5 | 11.7 | 13.2 | 14.4 | 15.3 | 17.0 | 18.4 | 19.6 | 22.2 | 24.3 | 28.0 | 31.0 | 36.1 | 40.5 | 44.3 |
| 60 | 9.3 | 12.5 | 14.0 | 15.2 | 16.1 | 17.8 | 19.2 | 20.4 | 23.0 | 25.1 | 28.8 | 31.8 | 36.9 | 41.3 | 45.1 |
| 70 | 10.0 | 13.2 | 14.7 | 15.9 | 16.8 | 18.5 | 19.9 | 21.1 | 23.7 | 25.8 | 29.5 | 32.5 | 37.6 | 42.0 | 45.8 |
| 80 | 10.7 | 13.9 | 15.4 | 16.6 | 17.5 | 19.2 | 20.6 | 21.8 | 24.4 | 26.5 | 30.2 | 33.2 | 38.3 | 42.7 | 46.5 |
| 90 | 11.4 | 14.5 | 16.0 | 17.2 | 18.1 | 19.8 | 21.2 | 22.4 | 25.0 | 27.1 | 30.8 | 33.8 | 38.9 | 43.3 | 47.1 |
| 100 | 12.0 | 15.1 | 16.6 | 17.8 | 18.7 | 20.4 | 21.8 | 23.0 | 25.6 | 27.7 | 31.4 | 34.4 | 39.5 | 43.9 | 47.7 |

[1] Horizon.

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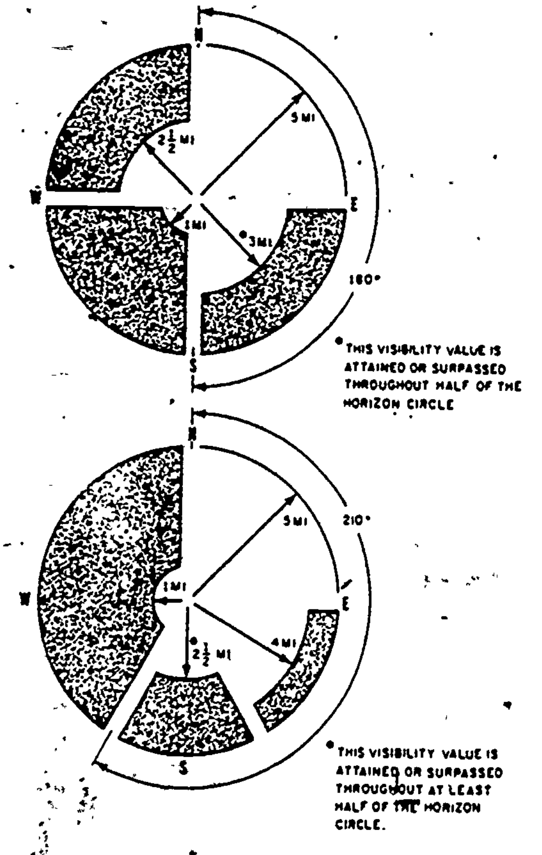


Figure 3.— Illustrative examples of determining prevailing visibility.

(other than precipitation) and lithometeors are termed obstructions to vision. Igneous and luminous meteors, such as lightning, rainbows, halos, coronas, and auroras, are also observed. Observations of these phenomena, except freezing rain and the determination of precipitation, are taken without the use of instruments and from as many points as necessary to view the entire horizon.

The symbols for weather and obstruction to vision entries on MF1-11 are shown in tables 11 and 12 of this pamphlet. For a detailed explanation of the entries and how they are obtained, see FMH #1.

### Intensity of Precipitation

Intensities of precipitation are determined by one of two methods. One method is the rate of accumulation. The other method is the degree to which the precipitation affects visibility.

Intensities of all forms of precipitation except snow and drizzle are determined by the rate of accumulation. Intensities of all forms of snow (snow, snow grains, and snow pellets) and drizzle, when they occur alone, are determined by their effect on visibility. When any form of snow or drizzle occurs in combination with one or more hydrometeors or lithometeors, the intensity of the precipitation is determined on the basis of the rate of accumulation. The term "hydrometeors" includes all atmospheric phenomena composed of liquid or solid forms of water. A lithometeor, on the other hand, is composed of solid dust or sand particles, or the ashy products of combustion.

At stations not having recording gages, determine the intensity of rain from the guides indicated in table 13-A. Determine the intensity of drizzle or snow when neither is occurring simultaneously with other atmospheric obstruction to vision (smoke, fog, etc.) on the basis of table 13-B. When either drizzle or snow is occurring simultaneously with other atmospheric obstructions to vision (except precipitation), estimate the intensity of drizzle on the basis of criteria in table 13-C and estimate the intensity of snow on the basis of experience with the relative apparent rate-of-fall or accumulation on a surface recently free of precipitation.

It is well to remember that when precipitation equals or exceeds 0.04 inch per hour, there is a strong presumption that the precipitation is rain.

When more than one form of precipitation is occurring simultaneously, the individual intensities are estimated on the basis of experience; the use of tables 13-A through 13-C and table 13-D, which gives the basis for estimating the intensity of precipitation (other than drizzle) on the rate of fall; and the apparent relative proportion of the precipitation forms, as observed during their fall, or upon impact upon surfaces recently free from precipitation.

### Association of Precipitation with Clouds and Temperature

RAIN is associated with cumulonimbus, altostratus, stratocumulus, stratus, nimbostratus, and cumulus clouds. Rain showers are associated with cumuliform clouds; persistent rain, with stratiform clouds. The temperature may



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be above, at, or below freezing where the condensation occurs, which results in rain. Thus, rain may originate in a liquid or solid form, or a combination, but it must reach the earth's surface as water droplets to be classified as rain. If supercooled droplets turn to ice on contact with cold surfaces, the precipitation is called a freezing rain.

DRIZZLE is associated with stratiform clouds. It is usually persistent. Like rain, it may originate in a liquid or solid form, and it must reach the earth's surface as minute water droplets to be classified as drizzle. If the water droplets freeze on falling to surfaces, it is called freezing drizzle.

SNOW GRAINS, or granular snow, occur under meteorological conditions similar to those of drizzle, except that the temperature is lower.

SNOW occurs under meteorological conditions similar, with the exception of the accompanying temperatures, to those with which corresponding forms of rain are associated. Snow is formed when water vapor condenses at temperatures at or below freezing. A snowflake consists of several (sometimes hundreds) geometrically designed ice crystals.

HAIL is a special type of frozen precipitation associated exclusively with thunderstorms. It is characterized by extreme sizes much in excess of those of any other precipitation elements.

SOFT RIME consists of white layers of ice crystals deposited chiefly on vertical surfaces—especially on points and edges of objects—generally in supercooled fog or light fog. HARD RIME is opague, granular masses of ice deposited chiefly on vertical surfaces in wet fog at temperatures below 32° F.

SLEET is associated with stratiform clouds. It is formed when water droplets of rain fall through a layer of air at or below the freezing point and freeze before they reach the earth's surface.

## MARINE OBSERVATIONS

Specific observation procedures applicable only at sea are described in the following paragraphs.

Table 5.— Apparent Wind Speed.

| Speed (knots) | Indication |
|---|---|
| Less than 1-- | Calm; smoke rises vertically |
| 1-3-------- | Smoke drifts from funnel |
| 4-6-------- | Wind felt on face |
| 7-10------- | Wind extends light flag |
| 11-16------ | Wind raises dust and loose paper on deck |
| 17-21------ | Wind waves and snaps flag briskly |
| 22-27------ | Whistling in rigging |
| 28-33------ | Inconvenience felt walking against wind |
| 34-40------ | Walking becomes difficult |

### Wind

When the ship is moving, the wind experienced on the ship and the ship's anemometer is the apparent wind, a combination of the wind vector and the ship's vector. Apparent wind must be converted to true wind.

Obtain apparent wind from the ship's anemometer when the anemometer is available and is adequately exposed. Otherwise, estimate the apparent wind direction to the nearest 10 degrees measured clockwise off the bow and the apparent wind speed by noting the effect or "feel" of the wind and referring to table 5.

To compute true wind from apparent wind relative to the ship's bow, adjust a rotary protractor such as the winds aloft plotting board or a shipboard wind plotter so that 0° coincides with the index line at the edge of the protractor which is near you. Using any suitable scale, plot a point "a" at a distance from the center representing the ship's speed. Turn the protractor to the apparent wind direction relative to the ship's bow on the index. Using the same scale, plot a point "b" representing the apparent wind speed. Measure the distance between points "a" and "b." This distance on the scale used for "a" or "b" is the true wind speed. Rotate the protractor until point "a" is vertically above point "b" on a line parallel to the index line. When the two points are thus aligned, the protractor index indicates the wind direction relative to the ship's bow. Add the ship's true heading to this value to obtain the true wind direction with respect to true north. An example is shown in figure 4.

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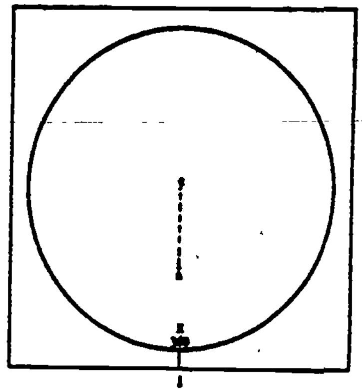
Given: 1. Ship's speed 20 knots.
2. Apparent wind relative to bow of ship, 300° at 15 knots.
3. Ship's heading 160°.

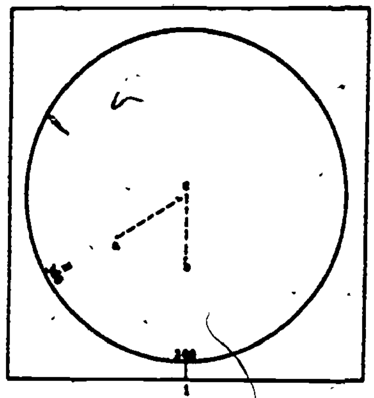
Computation:

Step 1. Rotate the protractor until 360° is at bottom of protractor on index line "ci." Using any convenient scale, locate and identify point "a" on line "ci" 20 units distant from center of protractor "c" and toward point "i." The distance "ac" now represents the ship's speed of 20 knots.



Step 2. Rotate the protractor until the apparent wind direction, i. e., 300°, coincides with index line "ci." Using the same scale as in step 1, plot "b" along the index line 15 units distant from "c" and toward "i." This distance "bc" represents the apparent wind speed.

Step 3. Using the same scale as in step 1, obtain the *true wind speed* by measuring the distance from "a" to "b."



Step 4. Turn the protractor until the line determined by points "a" and "b" is parallel to the vertical parallel lines on the plotting board (beneath the protractor), and until point "a" is above point "b." Read the computed wind direction relative to the bow, i. e., 226°, from the edge of the protractor closest to the observer on line "ci."

Step 5. Add the ship's heading, i. e., 160°, to the direction obtained in step 4, i. e., 160+226=386. Since this sum is greater than 360, subtract 360 to obtain the true wind direction, i. e., 386 minus 360=26°, which is the *true wind direction.*

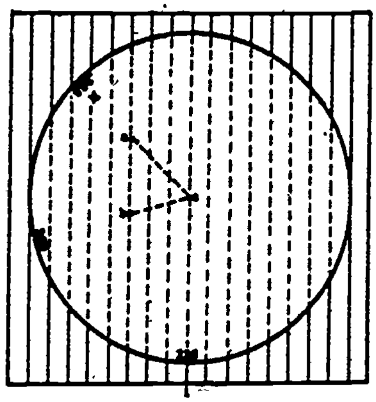


Figure 4.— Computation of True Wind.

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Use the following guidelines for a check when computing true wind at sea.

1. The true wind direction is always on the same side of the ship as the apparent wind direction, but farther from the bow.

2. When the apparent wind direction is aft of the beam, the true speed is greater than the apparent speed.

3. When the apparent wind direction is ahead of the beam, the true speed is less than the apparent speed.

Temperature

At sea, obtain free air temperatures by portable thermometers and psychrometers. When operating the portable sling psychrometer or the electric-aspirated psychrometer, use the purest available water to moisten the wet bulb. You may use cooled condenser water if distilled water is not available. When practicable, store psychrometers outside in a location protected from spray and sunlight. If the muslin on the wet-bulb thermometer is exposed to spray, change it immediately. Otherwise, change the muslin once a week. Make psychrometric readings on the windward side of the ship, holding the instrument at arm's length and upwind from you. Whirl the sling psychrometer at a rate of 4 revolutions per second (9 knots or 15 feet per second) until you obtain the lowest wet-bulb reading. When this occurs, read both thermometers. When the apparent wind is 9 knots or more, whirling is unnecessary. To operate the electric-aspirated psychrometer, be sure that the plastic shield is in place over the thermometer bulbs and turn the fan on under all wind conditions. A rheostat on the fan switch controls a light which illuminates the thermometers for night observations. When you have obtained the dry- and wet-bulb readings, proceed with computations for dew-point temperature, using the psychrometric computer.

Obtain sea water temperature by bucket observation, if feasible. If you use other sensors, make comparisons for each trip between bucket samples and the sensor used at 5-knot increments of the ship's speed, and apply the appropriate correction to the sensor reading. When using other sensors, enter a remark under "Remarks, Notes and Miscellaneous Phenomena," stating which sensors you used for which observations, e.g., "Condensor intake temperature used for hourly and 3-hourly observations. Bucket observations made for 6-hourly observation only."

1. Bucket Observation Method. Be sure a line is attached to the bucket. From as far forward as possible, heave the bucket overboard. Allow time for the bucket to come to the sea temperature. Haul in the sample rapidly and take it to a point out of sunlight and wind. Stir the water with a thermometer until the thermometer reading stabilizes. Read the thermometer to the nearest tenth of a degree with the bulb still immersed in the water.

2. Condensor Intake Temperature. Within 15 minutes of the scheduled observation time, read the intake thermometer to the nearest 0.1°, or if the thermometer is marked in 2-degree increments, estimate between scale markings to 0.2°. Add the bucket comparison correction for the ship's speed, if one has been determined.

3. Other Systems. Use the instructions provided with the sea water temperature sensing system.

Ice Accrection

When ice forms on the ship's superstructure, observe the following factors for synoptic purposes:

1. Source of ice accretion — Note whether the icing is caused by ocean spray, fog, rain or pairs of these phenomena.

2. Thickness of ice accretion — At each synoptic observation, measure the thickness of the ice on an exposed object where the ice build-up is greatest. If possible, use a centimeter stick and measure the thickness in whole cm. Otherwise, measure the thickness in tenths of an inch and use a rough conversion of 0.4 in. = 1 cm.

3. Rate of ice accretion — Note whether the ice thickness is building up slowly or rapidly, is remaining the same, or is melting or breaking up slowly or rapidly.

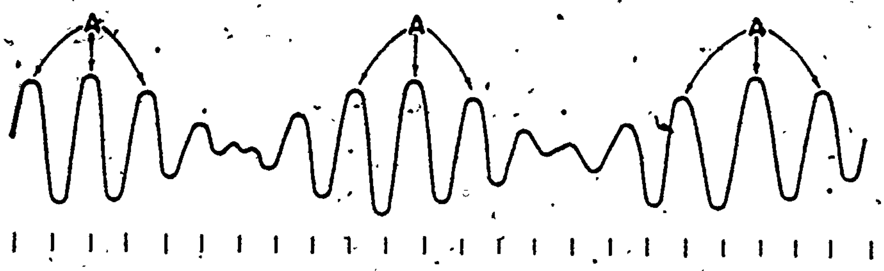



Figure 5.— Well Formed Waves (A) Shown on an Automatic Wave Recorder Trace.

Sea Condition

At each observation, determine the height and period of wind waves. Determine the direction, height, and period of each swell system if distinguishable from wind waves and if:

1. The swell direction differs from the wind direction by 30° or more or

2. The swell period differs from the wind wave period by 4 seconds or more.

Any additional swell systems must differ in direction from both the wind direction and each evaluated swell direction by 30°. In most circumstances, only one swell system can be distinguished.

Selecting Waves for Wave Data.— Waves in the same system usually occur in "sets" consisting of a sequence of a few large, well formed waves followed by an interval in which only small, poorly formed waves occur, then another set of well formed waves, etc. Determine the required data, using only the well formed waves in each set. Figure 5 shows wave sets as they appear on an automatic wave recorder trace.

Wave Direction. — Determine wave direction by turning to face the oncoming waves or by sighting parallel along the crests of the waves and adding or subtracting 90° as appropriate. Do not report the direction for wind waves. When you can neither determine swell direction nor classify it as "confused," do not evaluate the height or period of that swell system.

Wave Period.— To determine the wave period for wind waves or swell, select a distinctive patch of foam or a floating object at some distance forward of the ship. Note the elapsed time in seconds between the moments when the object is on the crest of the first and last well formed wave in the group. Also count the number of wave crests that pass under the object during the interval. Continue to evaluate the wave sets in this manner until you have timed at least 15 waves. Divide the number of waves by the elapsed time to determine the wave period. Do not count the wave crest on which you started the timing of the object.

Wave Height. — Estimates are required for the height of wind waves and swell. Whenever possible, estimate the height of waves near the side of another ship with respect to known dimensions of the ship; e.g., if the height of the other ship's bridge is 28 feet above the waterline and the wave crest reaches one-quarter of this distance, the wave height is 7 feet. When another ship is not in sight, take the observation from a point amidships near the center line when roll and pitch is at a minimum as follows:

1. When the distance between successive crests is the same as or less than the length of the ship, estimate the wave height by looking over the side of the ship and determining the relative heights of the crest and trough with respect to known heights along the ship, e.g., height of the sea ladder above the waterline, port holes, etc.

2. When the distance between crests is greater than the length of the ship, move up and down until the wave crest is aligned with the horizon when the ship is on an even keel and in a trough. The wave height is the same as eye level above the waterline. Unless the ship

is on an even keel when this estimate is made, the height will be erroneous.

In general, it has been found by comparing instrument measurements to eyeball estimates that small wave heights are underestimated while great wave heights are overestimated. Theoretically, the wave height cannot exceed 1/13 of the wave length measured from trough to trough.

Sea Ice

When you observe ice in the sea within 30 n. mi. of the ship's position at observation time, determine the kind of ice, the effect of the ice on navigation, the bearing of the ice-limit, and the orientation of the ice-limit.

GENERAL OBSERVATION PROCEDURES

Some general procedures to follow when taking surface weather observations are as follows:

1. Accuracy of time in observations. The accuracy of the actual time of observations and of the time checks on recording charts is of the utmost importance in weather observations. The actual time of observation will be the time that the last element is entered on the observation form.

2. Disposal of insignificant figures. When computations require that a number be rounded, disregard algebraic signs and observe the following procedure:

a. If the fractional part to be disposed of is one-half or greater, increase the preceding digit by one.

b. If the fractional part to be disposed of is less than one-half, the preceding digit will remain unchanged.

c. An exception to this procedure is in the reporting of cloud heights and visibility. When the actual value of a cloud height or the visibility falls midway between two reportable values, report the lower of the two.

3. Use of form MF1-11. Generally the form MF1-11 is used for shipboard observations (formerly WBAN 11). Prepare an original and at least one carbon copy of MF1-11. Start a new page for each day with the first observation for that day (Greenwich time).

4. Disposition of forms. Complete MF1-11 in full and forward the original to the appropriate agency in accordance with current instructions.

5. Observing practices. Adhere to the following practices when taking a surface weather observation:

a. Time. Take all observations with reference to the 24-hour clock; e.g., 1:48 a.m. is refered to as 0148 and 1:48 p.m. is referred to as 1348. The times 0000 and 2359 indicate the beginning and the ending of the day, respectively.

b. Time of beginning. Insofar as possible, do not observe elements more than 15 minutes prior to dissemination of the observation.

c. Order of observing. Evaluate elements having the greatest rate of change last. When conditions are relatively unchanging, evaluate the elements in the following order:

(1) Elements outdoors

(2) Elements indoors

(3) Pressure

d. When taking observations at night, allow sufficient time for your eyes to become adjusted to the darkness.

e. Normally, all observations taken by the MST will be record observations and will be indicated by the letter "R."

SURFACE WEATHER OBSERVATIONAL FORM (SHIP) - MF1-11

Form MF1-11 is the basic form for recording marine surface observations. It provides space for airways (aviation) observations, 3- and 6-hourly synoptic observations, and climatological data. Prepare a new MF1-11 in duplicate each day at midnight, GMT. Enter the ship's name and the date in the form's heading.

The airways code is columns 1 through 24 of MF1-11. The airways code for marine observations is the same as the land-station airways code except that position, course, and speed are substituted for the land-station location identifier.

Columns 25 through 40 are the synoptic code. The synoptic code used is WMO Code FM21.D, found in N. O. 118 Radio Weather Aids. For more detailed instructions of the airways observation code and the synoptic code, see FMH #1 and FMH #2.

. AIRWAYS COLUMN ENTRIES

Position (Col. 1)

Enter coded data as specified by the column heading. The symbols have the following meanings:

1. Q — Quadrant of the globe from table 6.

2. LL — Latitude to the nearest whole degree.

3. lll — Longitude to the nearest whole degree.

Course (Col. 2)

Enter true course to the nearest degree. Enter a dash if the ship is not underway.

Ship's Speed (Col. 3)

Enter ship's speed to the nearest knot. Enter a dash if the ship is not underway.

Type (Col. 4)

Enter the letter "R" for record observation unless you receive instructions to the contrary.

Time (Col. 5)

Enter the time in hours and minutes, GMT, that the last element is observed.

Sky and Ceiling (Col. 6)

Enter sky cover data in accordance with the following paragraphs. Enter data for each layer of clouds and obscuring phenomena present at and below the highest layer visible from the observation site. Make entries in ascending order of the height of the bases of the layers. Use an additional line if more space is needed, and enter data in the following format:

1. Sky cover symbol. Enter the sky cover visible from the observation site, using the appropriate symbol or combination of symbols from table 8.

2. Height of sky cover. Prefix each symbol, except clear and partly obscured conditions, with the height in hundreds of feet, using the increments shown in table 7.

3. Ceiling designator. Prefix a ceiling designator to the height of the first layer which is reported as either obscured, broken, or overcast, but not classified as thin, using the appropriate designator from table 9.

Visibility (Col. 7)

Enter the prevailing visibility in increments of nautical miles, using table 10.

Weather and Obstructions to Vision (Col. 8)

Enter the weather and obstructions to vision occurring both at the station and at the time of the observation, using the symbols from table 11 or plain language. Indicate the intensity of weather when appropriate, using the symbols for intensity from table 12. To determine the intensity of the different types of weather, use tables 13A, 13B, 13C, and 13D. Never assign intensity symbols to obstructions to vision.

Sea Level Pressure (Col. 9)

Enter the sea-level pressure in millibars, using only the tens, units, and tenths digits (without a decimal point), e.g., enter 1013.2 as 132. If you estimate the pressure, prefix the value with an "E."

Dry-Bulb Temperature (Col. 10)

Enter the dry-bulb temperature to the nearest 0.1 of a degree Fahrenheit. Temperatures below zero degrees Fahrenheit are prefixed with a minus sign.

Dew Point (Col. 11)

Enter the temperature of the dew point to the nearest whole degree Fahrenheit. Dew-point temperatures below zero degrees Fahrenheit are prefixed with a minus sign.

Wind Direction (Col. 12)

Enter the true direction from which the wind is blowing to the nearest ten degrees, as listed in table 14. When the wind is calm, enter "00" for the direction.

Wind Speed (Col. 13)

Enter the wind speed in whole knots, using the tens and units digits. When the speed is 100 knots or more, add 50 to the wind direction as entered in column 12 and enter only the tens and units digits of the wind speed in column 13. When the speed is determined to be calm (less than 1 knot) enter "00" for speed.

Wind Character (Col. 14)

If gusts or squalls are observed in the 10 minutes prior to the observation, enter "G" for gust or "Q" for squall, as appropriate, followed by the peak speed in the 10-minute period.

Whenever either the reported wind direction, speed, or speed of gusts or squalls is estimated, prefix the direction with an "E".

Altimeter Setting (Col. 15)

Enter the altimeter setting in inches of mercury, using only the units, tenths, and hundredths digits (without a decimal point). If the altimeter setting is below 29.00 inches, prefix the value with the word "low." Normally the altimeter is not entered; however, on icebreakers when helicopters are attached, it becomes necessary to enter the altimeter. The procedure for determining the altimeter is as follows: subtract 10 feet from the barometer height above the ship's mean waterline and multiply the height obtained by a factor of 0.00108 inches of mercury. Add this value to the corrected station pressure and round off to the nearest 0.01 inch to obtain the altimeter setting. This value is then entered in column 15.

Remarks (Col. 16)

Make entries in this column to record operationally significant information not reported elsewhere, to elaborate on preceding coded data, or to record for dissemination supplementary 3- and 6-hourly synoptic data. The entries that can be made in this column are long and varied; consult the appropriate chapters in FMH #1 for instructions.

Total Sky Cover (Col. 17)

Enter for each observation the tenths of sky covered (not necessarily hidden) by all clouds visible at the station. For example, enter 6 for six tenths.

Total Opaque Sky Cover (Col. 18)

Enter as a whole number the total tenths of sky that is hidden by clouds and/or obscuring phenomena. Note that this entry is similar to the entry in column 21 except that sky cover through which the sky can be seen is disregarded. The maximum amount to be entered is 10.

Wet-Bulb Temperature (Col. 19)

Enter the wet-bulb temperature to the nearest 0.1 of a degree Fahrenheit.

Sea Water Temperature (Col. 20)

Enter the sea water temperature to the nearest 0.1 of a degree Celsius.

Sea Waves (Col. 21)

Enter four digits, the first two representing the average period of the wind waves in seconds and the last two representing the average height of the wind waves in feet.

Swell Waves (Col. 22)

When you observe swell, enter six digits, the first two representing the swell direction in tens of degrees, the second two representing the average period of swell in seconds, and the last two the average height of the swell in feet. When you do not observe swell, leave this column blank.

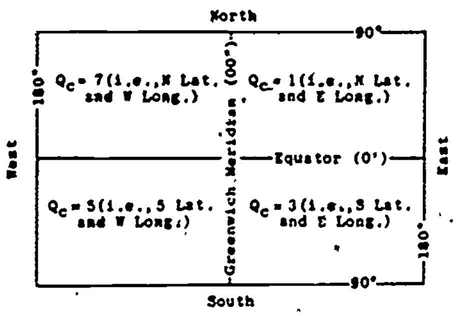
Station Pressure (Col. 23)

Enter the station pressure to the nearest 0.005 inch of mercury.

Observer's Initials (Col. 24)

Enter your initials in this column.

Table 6.— Symbol $Q_c$ — Quarter of the globe.




1. When the ship is precisely on the Greenwich Meridian (i.e., $L_oL_oL_oL_o$ = 0000) either code figure 1 or 7 (Northern Hemisphere) or code figure 3 or 5 (Southern Hemisphere) may be reported, as appropriate with respect to latitude.

2. When the ship is precisely on the Equator (i.e., $L_aL_aL_a$ = 000) either code figure 1 or 3 (Eastern Hemisphere) or code figure 5 or 7 (Western Hemisphere) may be reported, as appropriate with respect to longitude.

Table 7.— Sky cover height values.

| Feet | Reportable values (coded in hundreds of feet) | Entries |
|---|---|---|
| 5,000 or less. | To nearest 100 ft. | 1, 10, 50, etc. |
| 5,001 to 10,000. | To nearest 500 ft. | 55, 75, 100, etc. |
| Above 10,000. | To nearest 1,000 ft. | 140, 180, 200, etc. |

1. Encode height values that are halfway between reportable increments as the lower of the two increments.

2. Suffix the average of all observed values with a "V" (for "variable") whenever the ceiling height:

   a. Is less than 3,000 feet, and

   b. Rapidly increases or decreases by one or more tabular values (consecutive increments) during the period of the observation.

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| Summation Amount of Sky Cover in Tenths | Symbol | | Contraction When Symbols Not Used | Remarks |
|---|---|---|---|---|
| 1/10 to less than 10/10 surface-based obscuring phenomena | | -X | PTLY OBSCD | No height assigned this condition. Vertical visibility is not completely restricted. |
| 10/10 surface-based obscuring phenomena | | X | OBSCD | Always preceded by a "W" and a vertical visibility value. |
| Less than 1/10 | | ○ | CLR | This symbol is not used in combination with others. If considered significant include a remark in column 16 pertaining to the presence of less than 1/10 clouds, e.g., STFRA NW. |
| 1/10 thru 5/10 half or more thin | Only used to report layers aloft. | -⦶ | THN SCTD | Height values preceding these symbols are never designated as ceiling layers. |
| 1/10 thru 5/10 more than half opaque | | ⦶ | SCTD | |
| 6/10 thru 9/10 half or more thin | | -⦷ | THN BKN | |
| 6/10 thru 9/10 more than half opaque | | ⦷ | BKN | Height value preceding this symbol prefixed with a ceiling layer designator provided a lower ceiling layer is not present. |
| 10/10 half or more thin | | -⊕ | THN OVC | Height value preceding this symbol is never prefixed with a ceiling layer designator. |
| 10/10 more than half opaque | | ⊕ | OVC | This symbol is used in combination with lower overcast layers only when such layers are classified as thin. Height value preceding this symbol is prefixed with a ceiling layer designator provided a lower broken ceiling layer is not present. |

Table 8.—Sky Cover Symbols.

NOTE: The time required to take an observation should not exceed the 15 minutes prior to time of dissemination of the observation data, since the weather elements and sky conditions can vary considerably in 15 minutes. Therefore, you should memorize some of the tables that are used in recording surface weather observations. The tables that you should memorize are as follows:

1. Ceiling designators (table 9)

2. Sky cover height values (table 7)

3. ~~Sky cover~~ symbols (table 8)

4. Symbols for weather and obstructions to vision (table 11) and symbols for their intensities (table 12)

Table 9.— Sky Cover Ceiling Height Classification Designators.

| Ceiling Designator | Method Used to Determine Height |
|---|---|
| M | Measured (ceilometer, ceiling light, buildings, etc.) |
| R | Radar |
| A | Aircraft report |
| B | Balloon ascent (ceiling, pilot, raob) |
| E | Estimation |
| W | Vertical visibility into obscuration. This is the only symbol used with an X condition. |

1. In general, when more than one current height evaluation is available, base the designator and height on the method of determination, using this table as a guide, on the recency of the observation, and on the observer's nearness to the observation site. Designators are in general descending order of reliability.

2. Pilot reports of the maximum vertical height above the ground in surface-based obscuring phenomena (obscured sky) or the height of layers aloft, other than cirriform, need not be used if, in your judgment, they are not representative of conditions.

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Table 10.— Reportable Visibility Values (miles).

| Increments of Separation (Miles) | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1/16 | 1/8 | | 1/4 | 1/2 | 1 | | 5 |
| 0 | 3/8 | 1 1/4 | 2 | 2 1/2 | 3 | 10 | 15 |
| 1/16 | 1/2 | 1 3/8 | 2 1/4 | 3 | 4 | 11 | 20 |
| 1/8 | 5/8 | 1 1/2 | 2 1/2 | | 5 | 12 | 25 |
| 3/16 | 3/4 | 1 5/8 | | | 6 | 13 | 30 |
| 1/4 | 7/8 | 1 3/4 | | | 7 | 14 | 35 |
| 5/16 | 1 | 1 7/8 | | | 8 | 15 | 40 |
| 3/8 | 1 1/8 | 2 | | | 9 | | etc. |

1. Enter the visibility in statute miles at land stations and in nautical miles on ships and ocean-station vessels. When the visibility is halfway between consecutive tabular values, select the lower value.

2. When the prevailing visibility is judged to exceed 15 miles and the most distant marker is 15 miles or less, but more than 7 miles from the point of observation, code the visibility as 15+.

3. Suffix the average of all observed values with a "V" (for "variable") whenever the prevailing visibility:

   a. Is less than three miles, and

   b. Rapidly increases or decreases by one or more tabular values (consecutive increments) during the period of the observation.

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Table 11.— Symbols for Weather and Obstructions to Vision.

| Weather | | | |
|---|---|---|---|
| TORNADO, WATERSPOUT or FUNNEL CLOUD are always written out in full | | | |
| T+ | Severe Thunderstorm | IP | Ice Pellets |
| T | Thunderstorm | IPW | Ice Pellet Showers |
| R | Rain | S | Snow |
| RW | Rain Showers | SW | Snow Showers |
| L | Drizzle | SP | Snow Pellets |
| ZR | Freezing Rain | SG | Snow Grains |
| ZL | Freezing Drizzle | IC | Ice Crystals |
| | | A | Hail |
| **Obstructions to Vision** | | | |
| F | Fog | IF | Ice Fog |
| GF | Ground Fog | H | Haze |
| BS | Blowing Snow | K | Smoke |
| BN | Blowing Sand | D | Dust |
| BD | Blowing Dust | BY | Blowing Spray |

1. Combinations of these symbols are entered in the following order:
   a. Tornado, funnel cloud or waterspout
   b. Thunderstorm
   c. Liquid precipitation, in order of decreasing intensity
   d. Freezing precipitation, in order of decreasing intensity
   e. Frozen precipitation, in order of decreasing intensity
   f. Obstructions to vision; in order of decreasing predominance, if discernible.
2. Obstructions to vision are reported only when the prevailing visibility is less than 7 miles and the obstruction to vision is occurring at the station. If the visibility is reduced to less than 7 miles by obscuring phenomena not at the station, report the phenomena in remarks.

Table 12.— Symbols for Intensity.

| | | | |
|---|---|---|---|
| + | Heavy | -- | Very light |
| - | Light | | Absence of symbol indicates moderate |

No intensity is assigned to tornadoes, waterspouts, funnel clouds, hail or ice crystals; and only moderate or severe is reported for thunderstorms.

Table 13A — Guides for approximating intensity of rain.

| | |
|---|---|
| Very light . . . . . . . . . . . . | Scattered drops that do not completely wet an exposed surface, regardless of duration. |
| Light (slight)*. . . . . . . . . . | Individual drops are easily identifiable; spray observable over pavements, roofs, and the like is slight; puddles form very slowly; over 2 minutes may be required to wet pavements and similarly dry surfaces; sound on roofs ranges from slow pattering to gentle swishing; steady small streams may flow in gutters and downspouts. |
| Moderate . . . . . . . . . . | Individual drops are not clearly identifiable; spray is observable just above pavements and other hard surfaces; puddles form rapidly; downspouts on buildings run 1/4 to 1/2 full; sound on roofs ranges from swishing to gentle roar. |
| Heavy . . . . . . . . . . . . . . . | Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray to height of several inches is observable over hard surfaces; downspouts run more than 1/2 full; visibility is greatly reduced; sound on roofs resembles roll of drums or distant roar. |

* The term "slight" is used only in synoptic observations.

Table 13B — Intensity of drizzle and snow with visibility as criteria.

| | |
|---|---|
| Very light. . . . | Scattered flakes or droplets that do not completely cover or wet an exposed surface, regardless of duration. |
| Light (slight)* . | Visibility 1,100 yards or more (5/8 statute mile). |
| Moderate . . . . | Visibility less than 1,100 yards, but not less than 550 yards. |
| Heavy . . . . . . | Visibility less than 550 yards (5/16 statute mile). |

*The term "slight" is used only in synoptic observations.

Table 13C — Intensity of drizzle on rate-of-fall basis.

| | |
|---|---|
| Very light | Scattered drops that do not completely wet an exposed surface, regardless of duration. |
| Light (slight)* | Trace to 0.01 inch per hour. |
| Moderate | More than 0.01 inch to 0.02 inch per hour. |
| Heavy | More than 0.02 inch per hour. |

*The term "slight" is used only in synoptic observations.

Table 13D — Intensity of precipitation (other than drizzle) on rate-of-fall basis.

| | |
|---|---|
| Very light | Scattered drops or flakes that do not completely wet or cover an exposed surface, regardless of duration. |
| Light (slight)* | Trace to 0.10 inch per hour: maximum 0.01 inch in 6 minutes. |
| Moderate | 0.11 inch to 0.30 inch per hour: more than 0.01 inch to 0.03 inch in 6 minutes. |
| Heavy | More than 0.30 inch per hour: more than 0.03 inch in 6 minutes. |

*The term "slight" is used only in synoptic observations.

Table 14.— Wind Direction in Tens of Degrees (True).

| Degrees True | Compass Points | Tens of Degrees | Degrees True | Compass Points | Tens of Degrees |
|---|---|---|---|---|---|
| 355-004 | N | 36 | 175-184 | S | 18 |
| 005-014 | | 01 | 185-194 | | 19 |
| 015-024 | NNE | 02 | 195-204 | SSW | 20 |
| 025-034 | | 03 | 205-214 | | 21 |
| 035-044 | | 04 | 215-224 | | 22 |
| 045-054 | NE | 05 | 225-234 | SW | 23 |
| 055-064 | | 06 | 235-244 | | 24 |
| 065-074 | ENE | 07 | 245-254 | WSW | 25 |
| 075-084 | | 08 | 255-264 | | 26 |
| 085-094 | E | 09 | 265-274 | W | 27 |
| 095-104 | | 10 | 275-284 | | 28 |
| 105-114 | ESE | 11 | 285-294 | WNW | 29 |
| 115-124 | | 12 | 295-304 | | 30 |
| 125-134 | | 13 | 305-314 | | 31 |
| 135-144 | SE | 14 | 315-324 | NW | 32 |
| 145-154 | | 15 | 325-334 | | 33 |
| 155-164 | SSE | 16 | 335-344 | NNW | 34 |
| 165-174 | | 17 | 345-354 | | 35 |

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SYNOPTIC CODE COLUMN ENTRIES

Columns 25 through 40 comprise the FM 21.D form of the synoptic code. For a complete and detailed study of this code, refer to FMH #2, Synoptic Code. Since the entries here can be many and varied and are also subject to constant change, we will briefly cover only the general terms and meanings of each column.

Ship (Col. 25)

Prefix used to identify the report as a ship synoptic report.

$99L_aL_aL_a$ (Col. 26)

1. 99 — Indicator used to indicate ship report.

2. $L_aL_aL_a$ — Latitude in tens, units, and tenths of a degree.

$Q_cL_oL_oL_oL_o$ (Col. 27)

1. $Q_c$ — Code figure for the quadrant of the globe.

2. $L_oL_oL_oL_o$ — Longitude in hundreds, tens, units, and tenths of a degree.

$YYGGI_w$ (Col. 28)

1. YY — Indicates the day of the month using two figures.

2. GG — Indicates the time of the day to the nearest hour (GMT) using two figures.

3. $I_w$ — Code figure used to indicate how and in what units the wind was observed.

Nddff (Col. 29)

1. N — Amount of sky coverage.

2. dd — Wind direction in tens of degrees.

3. ff — Wind speed in the units as reported by $I_w$.

VVwwW (Col. 30)

1. VV — Code figure for the prevailing visibility.

2. ww — Code figure for present weather.

3. W — Code figure for past weather.

PPPTT (Col. 31)

1. PPP — Sea level pressure in tens, units, and tenths of millibars.

2. TT — Dry-bulb temperature in tens and units. Reported in Celsius.

$N_hC_LhC_MC_H$ (Col. 32)

1. $N_h$ — Amount of sky covered by low or middle type clouds.

2. $C_L$ — Code figure for the type of low cloud observed.

3. h — Code figure for the height of the lowest cloud reported.

4. $C_M$ — Code figure for the type of middle cloud observed.

5. $C_H$ — Code figure for the type of high cloud observed.

$D_sv_sapp$ (Col. 33)

1. $D_s$ — Code figure for the direction the ship has made good in the past three hours.

2. $v_s$ — Code figure for the speed the ship has made good in the past three hours.

3. a — Code figure used to indicate the tendency of the pressure during the past three hours.

4. pp — Amount of pressure change during the past three hours reported in units and tenths of millibars.

$0T_sT_sT_dT_d$ (Col. 34)

1. 0 — Indicator used to indicate the sea water temperature difference and the dew point group.

2. $T_sT_s$ — Sea water/air temperature difference reported in 1/2 degree Celsius.

3. $T_dT_d$ — Temperature of the dew point reported to the nearest whole degree Celsius.

$1T_wT_wT_wt_T$ (Col. 35)

1. 1 — Indicator used to indicate the sea water temperature group.

2. $T_wT_wT_w$ — Sea water temperature to the nearest 0.1 degree Celsius.

3. $t_T$ — The tenths value of the dry-bulb temperature.

$2I_sE_sE_sR_s$ (Col. 36)

1. 2 — Indicator for ice accretion group.

2. $I_s$ — Source of the ice accretion.

3. $E_sE_s$ — Thickness of the ice accretion in centimeters.

4. $R_s$ — Rate of ice accretion.

$3P_wP_wH_wH_w$ (Col. 37)

1. 3 — Indicator of the wind waves.

2. $P_wP_w$ — Period of the wind waves in seconds.

3. $H_wH_w$ — Height of the wind waves in increments of 1.5 feet.

$d_wd_wP_wH_wH_w$ (Col. 38)

1. $d_wd_w$ — Direction from which the swell is coming, in tens of degrees.

2. $P_w$ — Code figure for the period of the swell.

3. $H_wH_w$ — Height of the swell in increments of 1.5 feet.

ICE (Col. 39)

Indicator used only when ice is observed within 30 N.M. of the ship at the time of observation.

$c_2KD_ire$ (Col. 40) Ice Group

1. $c_2$ — Description of the type of ice.

2. K — Effects of the ice on navigation.

3. $D_i$ — Bearing of the ice edge from the point of observation.

4. r — The distance from the observation point to the ice edge.

5. e — Orientation of the ice edge.

CLIMATOLOGICAL DATA

Columns 41 through 57 contain information on climatological observations, miscellaneous phenomena, and additional coded synoptic data.

DRY (Col. 41)

Enter the dry-bulb temperature to the nearest 0.1 degree Celsius.

WET (Col. 42)

Enter the wet-bulb temperature to the nearest 0.1 degree Celsius.

ICE (Col. 43)

Enter a check mark if the bulb of the wet-bulb thermometer is covered with ice.

Remarks, Notes, and Miscellaneous Phenomena (Col. 44)

1. Enter the time of the sunrise and sunset (GMT).

2. Enter additional synoptic code groups. When it is necessary to encode additional groups, place the groups in this column, identified by the hour code figures (GG), in parentheses, of the observation.

3. Other pertinent data may be entered in this block, such as the method used to obtain

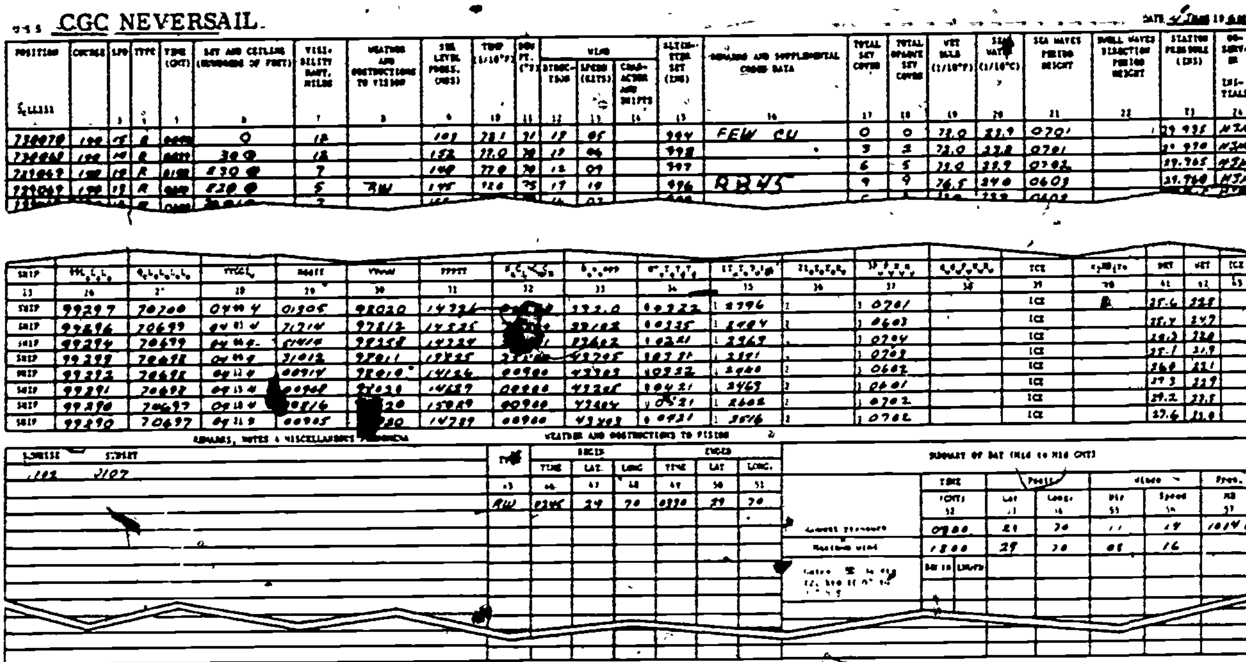


Figure 6.— Proper entries on MF1-11.

the sea water temperature, the occurrence of aurora, etc.

Weather and Obstructions to Vision (Cols. 45 through 51)

Enter the times of beginning and ending of weather and obstructions to vision to the nearest minute using the weather and obstruction to vision symbols used in column 8. Enter positions to the nearest whole degree.

Summary of the Day.
(Midnight to Midnight, GMT) (Cols. 52 through 57)

Enter the data specified below for the period midnight to midnight, GMT. Enter estimated wind data if recording equipment is not available.

1. Enter times to the nearest minute, GMT.

2. Enter positions to the nearest whole degree.

3. Enter true wind directions to the nearest ten degrees, and speed in knots.

4. Enter the lowest pressure in tenths of millibars.

# METEOROLOGICAL CODES AND PLOTTING

Codes are the lifeblood of meteorological work; without them there could not be a system of observing and disseminating weather information as it exists. Codes permit the translation of a wealth of meteorological weather information into concise and comprehensive reports consisting entirely of numbers. Moreover, codes break the language barrier and make possible international cooperation in the area of meteorology and its associated services.

Codes are also the elements with which MST's come in daily contact. A great responsibility is placed upon you when entrusted to encode or decode meteorological information. You can, and should, shoulder this responsibility by learning and knowing the meteorological codes well.

This section deals with the general form of various meteorological codes. It does not give detailed explanation of the specific elements, or instructions for encoding them and decoding them, except in a general form. For detailed knowledge, see the appropriate code manuals and Radio Weather Aids, N. O. Pub. No. 118. However, the information presented here is sufficient to give you a knowledge of the codes that enable you to encode or decode the most important and most widely used meteorological information.

## CODE SYSTEMS INFORMATION

Before launching into a discussion of specific codes, let us examine the structure of meteorological codes. First, they are numbered according to a system. Second, the symbolic letters and numbers used in the codes are also systematized. This alone makes the learning of codes easier and facilitates referencing and checking. Third, the position of the code groups is of vital importance in the code. Without a sequence, it would be impossible to decode a particular message. Fourth, the groups are arranged so that they are both easily decoded and plotted. However, they are also arranged so that it is still possible to use the report and decode the remaining groups if and when a particular group (or portions of a group) is missing from the message. For instance, a wind group in the radiosonde code has certain characteristic entries inherent to it, and it is difficult to confuse such a group with a height / temperature group. This feature becomes clearly evident as experience is gained.

## FM CODE NUMBERING SYSTEM

Each code form bears a number, preceded by the letters FM. This number is followed by a letter that identifies when the code form was modified or introduced— A, B, C, or D for the 1953, 1958, 1962, or 1966 session, respectively.

This numbering enables the code forms to be distinguished from one another and from the code tables, which are numbered with a simple 4-figure number.

Furthermore, an indicator term is used to designate the code form colloquially and is therefore called "code name." In most cases, this code name is included as a symbolic prefix in the code form, and during transmission ensures ready identification of the type of report (e.g., SHIP, TAF, etc.).

In collective messages, certain code names may be given only at the beginning of the section which contains appropriate reports, and they are not repeated for every individual report.

Shown in the following list are the appropriate "code names," along with an explanation of the contents of the code and its FM code number.

| | |
|---|---|
| ABTOP | Summary of upper air report, in abridged form (FM 38.B). |
| AERO | Aviation routine weather report (FM 12.C). |
| ARFOR | Area Forecast (FM 53.B). |
| BBBBB | Selected special weather report (sudden changes) for improvement in weather conditions from land station (FM 13.A). |
| CAVOK | Word replacing the visibility, present weather, and cloud data when the specific conditions occur (FM 15.D, FM 16.D). |
| CLIMATE | Report of monthly means from land station (FM 71.D). |
| CLIMAT SHIP | Report of monthly means from ocean weather station (FM 72.D). |
| CLIMAT TEMP | Report of monthly aerological means from land station (FM 75.D). |
| CLIMAT TEMP SHIP | Report of monthly aerological means from ocean weather station (FM 76.D). |
| CLINP | Report of monthly means for the oceanic area of the North Pacific (FM 73). |
| CLISA | Report of monthly means for the oceanic area of the South Atlantic (FM 73). |
| CODAR | Upper-air report from aircraft (other than weather reconnaissance aircraft) (FM 41.D). |
| FIFOR | Flight forecast (FM 55.D). |
| IAC | Analysis in International Analysis Code (FM 45.D). |
| IAC FLEET | Analysis in abbreviated form of the International Analysis Code, for marine use (FM 46.D). |
| ICE | Prefix of the ice group (FM 21.D, FM 22.D, FM 23.D). |
| ICING | Prefix of ice accretion on ships when reported in plain language (FM 21.D, FM 22.D, FM 23.D). |
| INCLI | Report of monthly means for the oceanic area of the Indian Ocean (FM 73). |
| JJJ | Ends an upper level temperature and wind (possibly air density) report from a land rocketsonde station or from a rocketsonde station on a ship (FM 39.C, FM 40.C). |
| MAFOR | Forecast for shipping (FM 61.D). |
| MMMMM | Selected special weather report (sudden changes) for deterioration of weather conditions from land station (FM 13.A). |
| MONT | Cloud report from land station (FM 17). |
| NACLI | Report of monthly means for the oceanic area of the North Atlantic (FM 73). |
| NEPH | Report of nephoscopic observation (FM 31). |
| NORMAL | Prefix of groups giving normal values of the elements in a CLIMAT or CLIMAT SHIP report (FM 71.D, FM 72.D). |
| PILOT | Upper wind report from land station (FM 32.D). |
| PILOT SHIP | Upper wind report from ship (FM 33.D). |
| PROAR | Area forecast for aviation (height indication in pressure units) (FM 56.D). |
| PROFI | Flight forecast for aviation (height indication in pressure units) (FM 58.D). |
| PRORO | Route forecast for aviation (height indication in pressure units) (FM 57.D). |
| ROCOB | Upper level temperature and wind (possibly air density) report from rocketsonde station (FM 39.C). |
| ROCOB SHIP | Upper level temperature and wind (possibly air density) report from rocketsonde station on ship (FM 40.C). |
| ROFOR | Route forecast for aviation (FM 54.D). |
| SFAZI | Synoptic report of atmospherics bearings (FM 81.A). |
| SFAZU | Detailed report of the distribution of atmospherics by bearings of the preceding 24 hours (FM 83.A). |

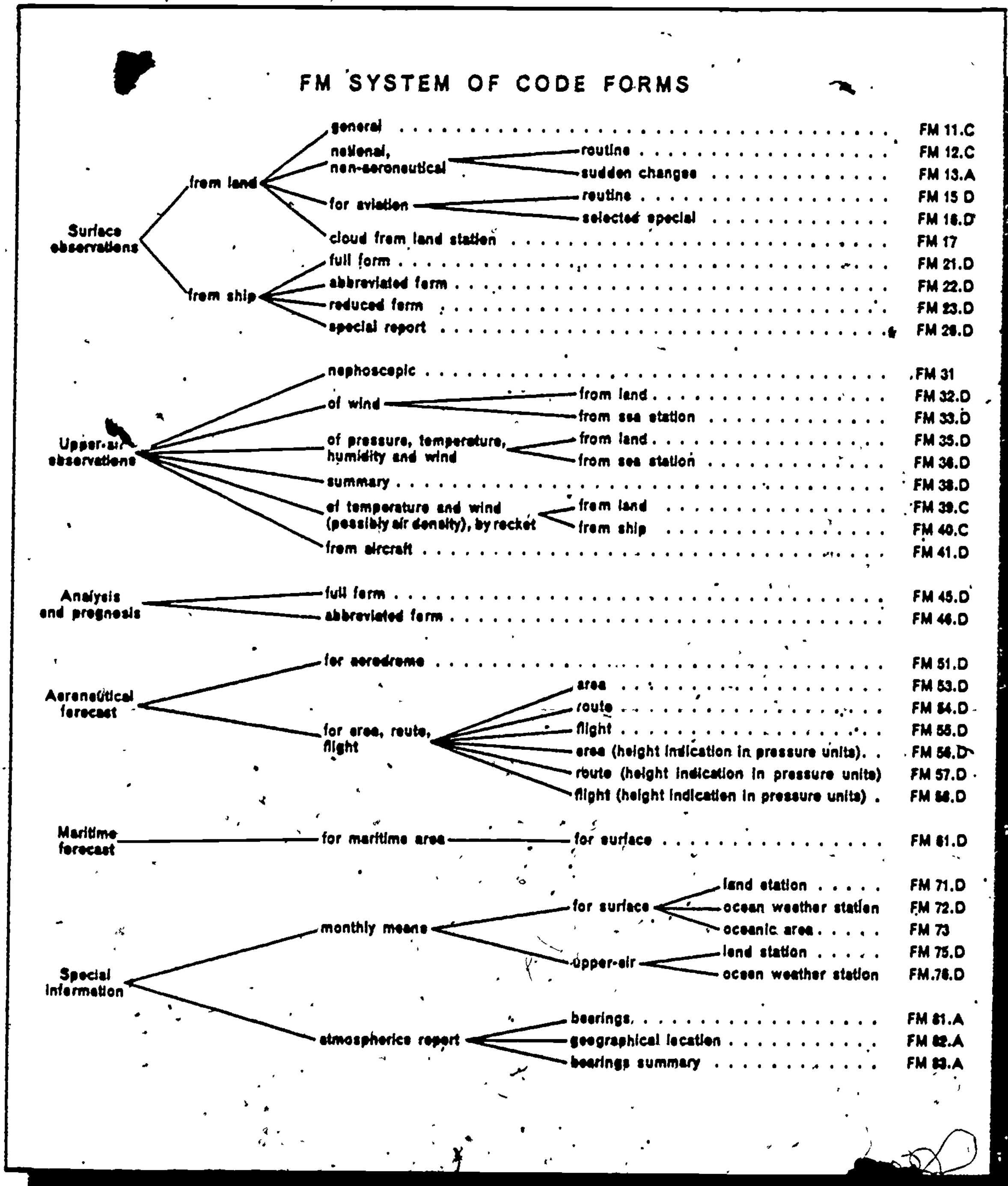


Figure 7. —FM system of code forms.

SFLOC — Synoptic report of atmospherics geographical location. (FM 82.A).

SHIP — Surface report from ship (FM 21.D, FM 22.D).

SHRED — Surface report from ship in reduced form (FM 23.D).

SPCLI — Report of monthly means for the oceanic area of the South Pacific (FM 73).

SPESH — Special weather report from ship (FM 26.D).

SYNOP — Surface report from land station (FM 11.C).

TAF — Aerodrome forecast (FM 51.D).

TEMP — Upper level pressure, temperature, humidity, and wind report from land station (FM 35.D).

TEMP SHIP — Upper level pressure, temperature, humidity, and wind report from ship (FM 36.D).

WATEN — Prefix of waves group, when tendency is reported (FM 11.C, FM 13.A).

Figure 7 graphically illustrates the FM system of code forms, showing the various observations, forecasts, analyses, and special information code forms available.

## SYMBOLIC FIGURE GROUPS

Symbolic figure groups serve essentially the same purpose as the symbolic word and letter groups. They identify certain information at the beginning of a code form, within a code form, or at the end of a code form.

10001 Analysis message follows (FM 45.D, FM 46.D).

11111 Data on the position of the jet core and the wind to be encountered in the jet core (FM 53.D, FM 54.D, FM 55.D, FM 56.D, FM 57.D, FM 58.D).

11133 Correction message to an analysis or prognosis message follows (FM 45.D, FM 46.D).

19191 Ends an analysis or prognosis message or a correction to an analysis or prognosis message (FM 45.D, FM 46.D).

21212 Indicates that data for significant levels with respect to wind follow (FM 32.D, FM 33.D, FM 35.D, FM 36.D).

22222 Indicates that forecast maximum wind data and/or forecast vertical wind shear follow (FM 53.D, FM 54.D, FM 55.D, FM 56.D, FM 57.D, FM 58.D).

31313 Indicates that data for 250 mb surface follow (FM 35.D, FM 36.D).

33300
33311
33322 Indicate that position groups are given in the form $L_aL_aL_oL_ok$ instead of the form $QL_aL_aL_oL_o$ indicated in the code form (any one of these symbolic groups being inserted instead of the group 33388) (FM 46.D).

41414 Indicates that cloud information follows (FM 35.D, FM 36.D).

44777 Ends the vocabulary section (FM 45.D, FM 46.D).

51515 Indicates that additional data in regional code follow (FM 35.D, FM 36.D).

65556 Prognosis message follows (FM 45.D, FM 46.D).

66600 Indicates that atmospherics are located by means of cathode-ray direction finder (CRDF) (FM 82.A).

66655 Indicates that atmospherics are located by means of narrow-sector direction finder (FM 82.A).

77744 Vocabulary section follows (FM 45.D, FM 46.D).

77999 Specifies that maximum wind was not observed or was not transmitted (FM 32.D, FM 33.D, FM 35.D, FM 36.D).

88800 Wave or sea temperature follows (FM 45.D, FM 46.D).

88822 Vertical wind shear follows (FM 45.D).

99900 Analysis or prognosis* of pressure systems or topography systems follows (FM 45.D, FM 46.D).

99911 Analysis or prognosis* of frontal systems follows (FM 45.D, FM 46.D).

| | |
|---|---|
| 99922 | Analysis or prognosis* of isopleths follows (FM 45.D, FM 46.D). |
| 99933 | Analysis or prognosis* of air mass follows (FM 45.D, FM 46.D). |
| 99944 | Analysis or prognosis* of weather area follows (FM 45.D, FM 46.D). |
| 99955 | Analysis or prognosis* of the tropical section of the message follows (FM 45.D, FM 46.D). |
| 99966 | Analysis or prognosis* of the cloud follows (FM 45.D). |
| 99977 | Analysis or prognosis* of the upper wind follows (FM 45.D). |
| 99988 | Analysis or prognosis* of the jet-stream follows (FM 45.D). |
| 99999 | Analysis or prognosis* of the tropopause follows (FM 45.D). |

*Preceding group 10001 or 65556 specifies whether an analysis or prognosis follows.

## SYMBOLIC LETTERS SPECIFICATIONS

Meteorological codes are composed of groups of symbolic letters arranged in a specific sequence. Each letter (or group of letters) has a meaning within the group, and each group has a meaning within the code. For the most part, coding and decoding are a matter of substituting the correct values for the symbolic letters. This is usually done with the meteorological code tables.

The symbolic letters are not arbitrarily chosen; they have a pattern. This helps in studying them, and aids in using the codes correctly. For instance, the letters TT always stand for temperature. Then, too, the TT may be combined with other letters in subscripts and thus form new meanings, but these meanings still are based on temperature. For instance, $T_dT_d$ stands for the dew-point temperature, and $T_tT_t$ represents the air temperature, in whole degrees Celsius, at the tropopause level. There are occasional exceptions to this generalization, but these exceptions do not invalidate the general rule. Similarly, PPP stands for pressure; hhh stands for height; GG stands for time; etc. It remains therefore only for you to learn the specifics of each symbolic letter. When you encounter a symbolic form of a code that is new, you will not be puzzled as to the general meaning of the symbols used.

A few excerpts from the specifications of symbolic letters or groups of letters as they are used in the international meteorological codes are shown in figure 8. For the complete listing, see N.O. Pub. No. 118 or the appropriate code manual.

## WMO REGIONS

Meteorological codes are international in scope and use. Basically, all the codes are the same the world over. They have been devised and agreed upon by the World Meteorological Organization (WMO). This organization is an affiliate of the United Nations, and its function is primarily to coordinate meteorological matters between the members.

Much standardization in meteorological matters—including meteorological codes—has been achieved. However, there are some regional or national exceptions to the general rules. For this reason, meteorological codes are defined in terms of the WMO regions. Within the six WMO regions there are, in addition, national differences. The WMO regions are as follows:

WMO Region I—Africa.
WMO Region II—Asia.
WMO Region III—South America.
WMO Region IV—North and Centeral America.
WMO Region V—Southwest Pacific.
WMO Region VI—Europe.

## PRIMARY METEOROLOGICAL CODES

There is only one way to learn meteorological codes, and that is to sit down with the symbolic form and the specifications for the symbols and STUDY THEM. Several different approaches could be used to learn the codes as well as to teach them. This training course cannot teach all the details of all the codes; that would be an undertaking too large for the purpose of this training course. Further, the codes are subject to change, and this puts a limitation on what this training course can offer. Therefore, a suggested method of study is offered here. First, write down on a separate sheet of paper the symbolic form of the code being studied. This helps because writing something out helps to remember it. Then, refer to the symbolic letters specifications in the applicable code manual or in N.O. Pub. No. 118 and jot down the specifications for all the symbols appearing in the symbolic form of the code being

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k — Indicator used to specify the half-degrees, if any, to be added to $L_aL_a$ and $L_oL_o$ as given in the group $L_aL_aL_oL_ok$. (Code 2200)
(FM 45.D, FM 46.D, FM 82.A)

$L_a$ — Tenths of a degree of latitude.
(FM 45.D, FM 46.D)

(1) See Note (6) under FM 45.D, Note (9) under FM 46.D and Note (3) under $x_1x_1$.

$L_o$ — Tenths of a degree of longitude.
(FM 45.D, FM 46.D)

(1) See Note (6) under FM 45.D, Note (9) under FM 46.D and Note (3) under $x_1x_1$.

$L_aL_a$ — Latitude in whole degrees.
(FM 45.D, FM 46.D, FM 53.D, FM 54.D, FM 55.D, FM 56.D, FM 57.D, FM 58.D, FM 82.A)

$L_oL_o$ — Longitude in whole degrees.
(FM 45.D, FM 46.D, FM 53.D, FM 54.D, FM 55.D, FM 56.D, FM 57.D, FM 58.D, FM 82.A)

(1) The hundreds digit is omitted for longitudes 100° to 180°.

$L_aL_a$, $L'_aL'_a$, $L''_aL''_a$, ... — Latitude parallel, in whole degrees, along which pressure values are given.
(FM 73)

(1) See notes under $\overline{P_1P_1}$, $\overline{P_2P_2}$, ..., $\overline{P'_1P'_1}$, $\overline{P'_2P'_2}$, ...

$L_oL_o$, $L'_oL'_o$, $L''_oL''_o$, ... — Meridian, in whole degrees, to which the first given pressure ($\overline{P_1P_1}$, $\overline{P'_1P'_1}$, $\overline{P''_1P''_1}$, ...) refers.
(FM 73)

(1) See notes under $\overline{P_1P_1}$, $\overline{P_2P_2}$, ..., $\overline{P'_1P'_1}$, $\overline{P'_2P'_2}$, ...

$L_aL_aL_a$ — Latitude in tenths of a degree.
(FM 21.D, FM 22.D, FM 23.D, FM 26.D, FM 33.D, FM 36.D, FM 39.D, FM 40.C, FM 41.D, FM 72.D, FM 76.D)

(1) Tenths are obtained by dividing the number of minutes by 6, disregarding the remainder.

$L_oL_oL_o$ — Longitude in tenths of a degree.
(FM 40.C)

(1) The hundreds digit is omitted for longitudes 100° to 180°.

(2) See Note (1) under $L_aL_aL_a$.

Figure 8.

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studied. Again, writing these specifications out will help you remember them better. Now you are ready to drill a few times on the code and the specifications.

You have already seen the pattern of the codes, and have also seen that most of the code forms using identical symbolic letters or groups of letters have identical criteria for them. Thus, when dd is used in FM 11.C, 21.D, or 51.D, it always means the same thing. This makes it easier to use and to learn the codes, as you will discover during your progress of study of meteorological codes.

The following coverage on codes is limited to the symbolic code form, significant differences between the various codes, and a necessarily brief description of a few of the symbolic letters and figures. For a complete listing of the specifications for these letters and figures, refer to the applicable code manual or N.O. Pub. 118.

LAND SYNOPTIC CODE
(FM 11.C)

The word "synoptic" means, in general, pertaining to or affording an overall view. Synoptic observations are periodic (3-hourly or 6-hourly) observations which describe the overall weather conditions existing at the observing stations. The implication here is that they are complete weather observations. The synoptic code, therefore, is a code by which synoptic weather observations are communicated. Synoptic weather observations are, in turn, plotted on synoptic charts and then analyzed. The result is that a synoptic analysis or an overall view of the weather is obtained.

Synoptic observations are taken at periodic intervals worldwide. Since the intervals coincide—that is, since they are taken at the same time all over the world—the plotted and analyzed synoptic charts afford a "snapshot" of the weather situation at that time worldwide.

The symbolic form of message used by land stations for synoptic reports (SYNOP, FM 11.C) is as follows:

(SYNOP)

(II)iii Nddff VVwwW PPPTT

$N_h C_L h C_M C_H$ $T_d T_d j_a j_p j_p$ (99ppp)

(7RRjj) ($8N_s C h_s h_s$) ($9S_p S_p s_p s_p$)

The first six (occasionally seven under specified conditions) groups of the form of the message are mandatory or universal groups, as they are invariably included in the report. If datum is not available for an element in these groups, the appropriate missing datum indicator is included in lieu of the coded datum. Synoptic reports included in collectives used for international exchange purposes normally contain as a minimum these first six (or seven) groups.

The code name SYNOP may prefix the report, indicating that it is a surface report from a land station; but in the case of a group of such reports, it may be used only in the heading of the collective.

Elements or groups enclosed in parentheses are dropout items and may or may not be included in the report, depending on the following specified conditions:

1. (II)iii—When individual reports are identified by the station number iii and all reports in a collective message have the same block number II, a group 999II is added immediately before the group iii of the first report of the message. When any following report or group of reports originates from station (s) with block number not identical with the preceding block number, a new group 999II is given immediately before such a report or group of reports. The group 999II is not repeated at the end of the group of reports to which it pertains in collectives for ground-to-air transmissions; and while it may be repeated at the end of groups of reports for ground-to-ground transmissions, care should be taken to ensure that such repetition does not lead to confusion. However, when the individual reports are identified by the index number IIiii, it is not necessary to use the 999II group in collective messages.

2. (7RRjj)—The use of this group is fixed regionally.

3. ($8N_sCh_sh_s$)—The inclusion of this group is fixed, regionally or nationally. The $8N_sCh_sh_s$ group may be repeated to report a number of layers of clouds. The order of reporting the groups is always from low to high levels. The selection of layers to be reported is made in the following manner:

a. Regardless of amount, the lowest individual layer or mass is reported. This is one group.

b. The next 8-group to be reported is the next higher layer of clouds covering 0.4 of the sky.

c. The next 8-group to be reported is the next higher layer of clouds covering 0.6 of the sky.

d. The next 8-group to be reported is a group for cumulonimbus only. This group is reported when the cumulonimbus amounts do not meet the specifications laid down for the first three groups.

The normal number of 8-groups does not exceed three. It may, however, be four in cases in which cumulonimbus clouds are reported. When the sky is clear, the 8-group is omitted; when the sky is obscured, the 8-group should read $9/h_sh_s$, where $h_sh_s$ is the vertical visibility.

4. ($9S_pS_ps_ps_p$) — The use of this group is fixed regionally.

The following additional groups, comprising an indicator figure and/or the following information, may be added to the SYNOP form:

1. Coastal stations and light vessels may add in their reports the wave groups $3P_wP_wH_wH_w$ ($d_wd_wP_wH_wH_w$), in accordance with national or regional instructions. Coastal stations desiring to report tendency of the waves replace the above wave groups with WATEN $O_wP_wP_wH_wH_w$.

2. Additional or supplementary groups with the indicator figures 1, 2, 4, and 5 may be added to the SYNOP form. The form and the use of these groups are fixed regionally.

3. High-level stations may use the group $6a_3hhh$ to indicate the geopotential of an agreed standard "constant pressure level."

4. Under special pressure tendency conditions, a group of the form 99ppp is inserted in the report after the $T_dT_dj_aj_pj_p$ group.

5. One or more of the following words should be added at the end of the report when the weather conditions specified for each of them justify their inclusion:

a. HAIL.—When a shower or a thunderstorm, accompanied by hail, occurs in the period covered by ww.

b. PAST HAIL.—When a shower or a thunderstorm, accompanied by hail, occurred in the period covered by W.

c. SNOW or SLEET.—When a snow shower or a shower of rain and snow mixed, with a temperature above 0° C, has been observed during the period covered by W.

d. SANDSTORM.—When a sandstorm, with a temperature below 0° C, has been observed during the period covered by W.

e. COTRA.—When the cloud reported consists in whole or in part of condensation trails.

6. In reports from aeronautical stations using FM 11.C instead of FM 12.C, appropriate Q signals or plain language may be added at the end of the report when the horizontal visibility differs in different directions and when it is desired to report this.

SHIP SYNOPTIC CODE (FM 21.D)

The ship synoptic code, FM 21.D, full form is the basic ship synoptic code in use by U.S. ships. The contents of the code are very similar to those of the land station synoptic code; the only differences are those in reporting position, time, and certain information relating to the sea. The symbolic form of the ship synoptic code, full form, is as follows:

SHIP $99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$ $YYGGi_w$

Nddff VVwwW PPPTT

$N_hC_LhC_MC_H$ $D_sv_sapp$

(7RRjj) ($8N_sCh_sh_s$)

$(9S_pS_ps_ps_p)$ $(0T_sT_sT_dT_d)$

$(1T_wT_wT_wt_T)$ $(2I_sE_sE_sR_s)$

$(3P_wP_wH_wH_w)$ $(d_wd_wP_wH_wH_w)$

ICE followed by plain language or by

$(c_2KD_ire)$

The code name SHIP is used as a prefix to the report, indicating that it is a surface report from a ship; but in the case of a group of such reports, it should be used only in the heading of the collective.

The form FM 21.D is considered suitable not only for selected ships, but also for ocean weather stations.

If the group $D_sv_s$app is not reported, 30 is added to the time of observation in whole hours GMT (example: actual time of observation 0550 GMT; GG = 06 + 30 = 36). If the groups $N_hC_LhC_MC_H$ and $D_sv_s$app are not reported, 60 is added to the time of observation in whole hours GMT (example: actual time of observation 1145 GMT; GG = 12 + 60 = 72). However, in accordance with instructions or because of failure of instruments, ships which do not report the group $D_sv_s$app include a group $D_sv_s$/// in the ship report when in an area where the ship report collecting center (in order to meet a requirement of a search and rescue center) has requested this inclusion as a routine procedure.

Groups in parentheses are dropout items, and they may or may not be included in the report, depending on specified conditions. These groups, being provided with an indicator figure, may be repeated as necessary in the following manner:

7RRjj—For lightships reporting in the SHIP code form and for ocean weather stations, the use of this group is fixed regionally or nationally. In the case of mobile ship stations, which make precipitation observations, the group 7RRjj is added to each SHIP report under the form $7RRt_Rt_R$.

$8N_sCh_sh_s$—This cloud group is optional for merchant ships but mandatory for ocean weather stations. When the 8-group is included in a SHIP report, the rules for the use of the 8-group in SYNOP code FM 11.C apply.

$9S_pS_ps_ps_p$—This group is normally not reported in ship reports, other than ocean weather stations. Cases may occur in which reports of special phenomena would justify inclusion in SHIP reports of ships other than ocean weather stations. As these cases are very rare, these reports should be sent in plain language.

$0T_sT_sT_dT_d$—This group may or may not be included in the report in accordance with national instructions.

$1T_wT_wT_wt_T$—This group is optional for merchant ships but mandatory for Navy ships.

$3P_wP_wH_wH_w(d_wd_wP_wH_wH_w)$—These groups should be included in the report. They are mandatory for Navy ships. The group $3P_wP_wH_wH_w$ is to be used to report wind waves. When swell can be distinguished from wind waves, the swell should be reported by the group $d_wd_wP_wH_wH_w$, and this group should be repeated to report a second swell system, if such can be distinguished. If there is a swell with no wind waves, the first group is to be reported as 30000.

ICE $c_2KD_ire$— Reporting ships, from which ice other than icebergs is visible or has been observed at a point within a distance of 30 nautical miles from the ship's position at the synoptic hour, should add to the SHIP report the word ICE followed by the group $(c_2KD_ire)$ or by plain language. Ice information for other special purposes may be given by means of the special ice codes in the codes section. Reporting of sea ice in SHIP reports is not to supersede the reporting of sea ice and icebergs in accordance with the International Convention for the Safety of Life at Sea.

When the ice accretion on ships is reported in plain language, it is preceded by the word ICING.

Under special conditions, a group of the form 99ppp is inserted in the report after the $D_sv_s$app group.

Reporting ships from which icebergs are visible should add, in plain language, to their report the number of icebergs seen at the actual time of observation (e.g., "3 BERGS"), unless these bergs have been reported with the group (ICE $c_2KD_ire$).

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In addition to the previous plain language additions described, HAIL, PAST HAIL, SNOW or SLEET, SANDSTORM, and COTRA may be added when the weather conditions specified for each of them justify their inclusion. These criteria are the same as for the land synoptic code.

SHIP (FM 22.D)

The abbreviated form of the ship synoptic code, FM 22.D, is as follows:

SHIP $99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$ $YYGGi_w$ Nddff

$VVwwW$ PPPTT $N_hC_LhC_MC_H$

$(D_sv_s///)$ $(2I_sE_sE_sR_s)$

ICE followed by plain language

or by $(c_2KD_ire)$

The abbreviated form of the ship synoptic code is not normally used, but you should be familiar with this form because many of the merchant ships or foreign ships use this form. As a plotter, you will need to know this special form.

SHRED (FM 23.D)

Coast Guard ships do not use this short ship synoptic form; however, you should know the code because you will encounter this type of report in your plotting work. It supplies wind, weather, pressure and temperature, and ice information primarily. For the symbolic form of this code, see N.O. Pub. No. 118.

SPESH (FM 26.D)

This code is the marine counterpart of the land station code, FM 13.A. The two significant differences are the prefix SPESH and the replacement of the station number group with the ship's position groups. In addition, when extra groups are used, they ordinarily relate to the state of the sea; that is, they contain sea-swell or ICE information.

LAND UPPER WIND CODE (FM 32.D)

The upper wind code for land stations, FM 32.D, is designed to allow the reporting of wind conditions in the upper air. It is a relatively easy code to learn, but there are many technicalities and variations to the code that you will have to study carefully. Since MST's will be using (that is, plotting) upper wind reports from other WMO Regions, the Region IV symbolic form and the general symbolic form are given here.

The symbolic form of the message for upper wind reports used in most of North and Central America, including the United States, is divided into two portions—all data up to and including 100 mb being in the first portion, and all data above 100 mb in the second portion. The symbolic form for the first and second portions is as follows:

FIRST PORTION

PART A

SECTION 1 PP $YYGGa_4$ IIiii

SECTION 2 $\left.\begin{matrix}44nP_1P_1\\ \text{or}\\ 55nP_1P_1\end{matrix}\right\}$ ddfff ddfff

. . . . . . . . . . .

$\left.\begin{matrix}44nP_1P_1\\ \text{or}\\ 44nP_1P_1\end{matrix}\right\}$ ddfff ddfff ddfff

SECTION 3 $\left.\begin{matrix}77P_mP_mP_m\\ \text{or}\\ 66P_mP_mP_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

$\left.\begin{matrix}7H_mH_mH_mH_m\\ \text{or}\\ 6H_mH_mH_mH_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$ ①

PART B

SECTION 1 QQ $YYGGa_4$ IIiii

SECTION 4 $9t_nu_1u_2u_3$ ddfff ddfff

. . . . . . . . . . .

$9t_nu_1u_2u_3$ ddfff ddfff ①

SECOND PORTION

PART C

SECTION 1 MM $YYGGa_4$ IIiii

SECTION 2 $\left.\begin{matrix}44nP_1P_1\\ \text{or}\\ 55nP_1P_1\end{matrix}\right\}$ ddfff ddfff ddfff

. . . . . . . . . . .

$\left.\begin{matrix}44nP_1P_1\\ \text{or}\\ 55nP_1P_1\end{matrix}\right\}$ ddfff ddfff ddfff

562

SECTION 3 $\left.\begin{matrix}77P_mP_mP_m \\ \text{or} \\ 66P_mP_mP_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

$\left.\begin{matrix}7H_mH_mH_mH_m \\ \text{or} \\ 6H_mH_mH_mH_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$ ①

PART D

SECTION 1 LL YYGGa$_4$ IIiii

SECTION 4 $\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff

. . . . . . . . . . . .

$\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff ①

The WMO symbolic form of the upper wind code, FM 32.D, is divided into four parts—A, B, C, and D. Parts A and B are confined to data up to and including the 100-mb level, and parts C and D contain data above this level. The symbolic form is as follows:

PILOT

PART A

SECTION 1 $M_1M_1$ YYGGa$_4$ IIiii

SECTION 2 $\left.\begin{matrix}44nP_1P_1 \\ \text{or} \\ 55nP_1P_1\end{matrix}\right\}$ ddfff ddfff . . . . etc.

SECTION 3 $\left.\begin{matrix}77P_mP_mP_m \\ \text{or} \\ 66P_mP_mP_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

$\left.\begin{matrix}7H_mH_mH_mH_m \\ \text{or} \\ 6H_mH_mH_mH_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

77999

PART B

SECTION 1 $M_1M_1$ YYGGa$_4$ IIiii

SECTION 4 $\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff

$\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff

and/or

21212 $n_on_oP_oP_oP_o$ $d_od_of_of_of_o$

$n_1n_1P_1P_1P_1$ $d_1d_1f_1f_1f_1$

. . . .  . . . .

$n_nn_nP_nP_nP_n$ $d_nd_nf_nf_nf_n$

PART C

SECTION 1 $M_1M_1$ YYGGa$_4$ IIiii

SECTION 2 $\left.\begin{matrix}44nP_1P_1 \\ \text{or} \\ 55nP_1P_1\end{matrix}\right\}$ ddfff ddfff . . . etc.

SECTION 3 $\left.\begin{matrix}77P_mP_mP_m \\ \text{or} \\ 66P_mP_mP_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

$\left.\begin{matrix}7H_mH_mH_mH_m \\ \text{or} \\ 6H_mH_mH_mH_m\end{matrix}\right\}$ $d_md_mf_mf_mf_m$

or

77999

PART D

SECTION 1 $M_1M_1$ YYGGa$_4$ IIiii

SECTION 4 $\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff

$\left.\begin{matrix}9 \\ \text{or} \\ 8\end{matrix}\right\}$ $t_nu_1u_2u_3$ ddfff ddfff ddfff

and/or

21212 $n_1n_1P_1P_1$ $d_1d_1f_1f_1f_1$

. . . .  . . . .

$n_nn_nP_nP_nP_n$ $d_nd_nf_nf_nf_n$

Section 1 of all four parts of the code contains the identification and position data. Section 2 of Part A contains data for the standard isobaric surfaces of 850, 700, 500, 400, 300, 200, 150, and 100 mb, and Section 2 of Part C contains data for the standard isobaric surfaces of 70, 50, 30, 20, and 10 mb when pressure measurements and wind data are obtained simultaneously from the sounding. Section 3 of Parts A and C contain data for the level(s) of the maximum wind(s), with altitudes given in pressure in units of 1/10 mb or in units of geopotential decameters. Section 4 of Parts B and D contain data for fixed regional and/or significant levels, with altitudes given in units of 300 or 500 meters or significant levels with altitudes given in pressure to a whole millibar when pressure measurements and wind data are obtained simultaneously from the sounding.



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SHIP UPPER WIND CODE (FM 33.D)

The WMO symbolic code form of the shipboard upper wind code, FM 33.D, is similar to the WMO land station upper wind code. The significant differences are the replacement of the station identifiers with the ship's position groups and the inclusion of the Marsden Square Number group, $MMMU_{La}U_{Lo}$ (used to verify the ship's position), following the position data in Section 1 of all parts.

PILOT SHIP

PART A

SECTION 1 $M_1M_1$ $YYGGa_4$ $99L_aL_aL_a$
$Q_cL_oL_oL_oL_o$ $MMMU_{La}U_{Lo}$

SECTION 2 $44nP_1P_1$ or $55nP_1P_1$ ddfff ddfff .... etc.

SECTION 3 $77P_mP_mP_m$ or $66P_mP_mP_m$ $d_md_mf_mf_mf_m$
or
$7H_mH_mH_mH_m$ or $6H_mH_mH_mH_m$ $d_md_mf_mf_mf_m$
or
77999

PART B

SECTION 1 $M_1M_1$ $YYGGa_4$ $99L_aL_aL_a$
$Q_cL_oL_oL_oL_o$ $MMMU_{La}U_{Lo}$

SECTION 4 9 or 8 $t_nu_1u_2u_3$ ddfff ddfff ddfff
9 or 8 $t_nu_1u_2u_3$ ddfff ddfff ddfff

and/or

21212 $n_on_oP_oP_oP_o$ $d_od_of_of_of_o$
$n_1n_1P_1P_1P_1$ $d_1d_1f_1f_1f_1$
.... ....
$n_nn_nP_nP_nP_n$ $d_nd_nf_nf_nf_n$

PART C

SECTION 1 $M_1M_1$ $YYGGa_4$ $99L_aL_aL_a$
$Q_cL_oL_oL_oL_o$ $MMMU_{La}U_{Lo}$

SECTION 2 $44nP_1P_1$ or $55nP_1P_1$ ddfff ddfff .... etc.

SECTION 3 $77P_mP_mP_m$ or $66P_mP_mP_m$ $d_md_mf_mf_mf_m$
or
$7H_mH_mH_mH_m$ or $6H_mH_mH_mH_m$ $d_md_mf_mf_mf_m$
or
77999

PART D

SECTION 1 $M_1M_1$ $YYGGa_4$ $99L_aL_aL_a$
$Q_cL_oL_oL_oL_o$ $MMMU_{La}U_{Lo}$

SECTION 4 9 or 8 $t_nu_1u_2u_3$ ddfff ddfff ddfff
9 or 8 $t_nu_1u_2u_3$ ddfff ddfff ddfff

and/or

21212 $n_1n_1P_1P_1P_1$ $d_1d_1f_1f_1f_1$
.... ....
$n_nn_nP_nP_nP_n$ $d_nd_nf_nf_nf_n$

LAND STATION RADIOSONDE CODE (FM 35.D)

The complete radiosonde report is divided into four parts —A, B, C, and D— each of which is an individual message complete with position groups and ending indicator (Ⓘ). Parts A and C are specified for worldwide distribution and Parts B and D for areas of continental or WMO regional size. The United States (WMO Region IV) collects Parts A and B (data up to and including the 100-mb level) in a single message which is referred to as the first transmission and Parts C and D (data above 100 mb) as the second transmission.

First Transmission

Both parts of the first transmission are divided further into four sections—1, 2, 3, and 4 for Part A and 1, 5, 7, and 9 for Part B. The symbolic form of the first transmission with a brief explanation of the various sections follows:

PART A

SECTION 1 TT YYGGI$_d$ IIiii

SECTION 2 $99P_oP_oP_o$ $T_oT_oT_{ao}D_oD_o$
$d_od_of_of_of_o$

00hhh $TTT_aDD$ ddfff

564

85hhh $TTT_aDD$ ddfff

70hhh $TTT_aDD$ ddfff

50hhh $TTT_aDD$ ddfff

40hhh $TTT_aDD$ ddfff

30hhh $TTT_aDD$ ddfff

20hhh $TTT_aDD$ ddfff

15hhh $TTT_aDD$ ddfff

10hhh $TTT_aDD$ ddfff

SECTION 3 $88P_tP_tP_t\ T_tT_tT_{at}D_tD_t\ d_td_tf_tf_tf_t$

SECTION 4 77 or 66 $P_mP_mP_m\ d_md_mf_mf_mf_m$①

PART B

SECTION 1 VV YYGG/ IIiii

SECTION 5 $00P_oP_oP_o\ T_oT_oT_{ao}D_oD_o$

11PPP $TTT_aDD$

22PPP $TTT_aDD$

33PPP $TTT_aDD$

44PPP $TTT_aDD$

..... ..... etc.

SECTION 7 31313 25hhh $TTT_aDD$ ddfff

SECTION 9 51515 $101A_{df}A_{df}$①

SECTION 1.—This section of both Part A and B serves the same function — to identify the data. A brief definition of the symbolic letters is as follows:

TT or VV—TT specifies that Part A of a radiosonde report follows. VV specifies that Part B of a radiosonde report follows.

YY— specifies the day of the month (GMT) i.e., 01 means the first day of the month, 02 the second, etc; and, if the unit of wind speed is in knots, 50 is added to the day of the month value.

GG— actual time of observation to the nearest whole hour in GMT.

$I_d$— indicator of the last standard isobaric surface for which the wind group is included in Parts A and C.

IIiii— block and station number.

SECTION 2.— This section normally includes upper air and wind data from the surface up to and including the 100-mb level. The symbolic letters are defined as follows:

99—identifies the surface data groups

$P_oP_oP_o$—pressure at the surface in whole millibars

$T_oT_o$—temperature of the air in whole degrees Celsius at the surface

$T_{ao}$—approximate tenths value and plus or minus sign indicator of the surface air temperature

$D_oD_o$—depression of the dewpoint temperature (with respect to water) at the surface release point

$d_od_o$—true direction in tens of degrees (the hundreds and tens digits of the observed direction have been rounded off to the nearest 5°) from which the surface wind is blowing. If the value for the nearest 5° is 5°, 500 is added to $f_of_of_o$; otherwise, $f_of_of_o$ is the actual wind speed.

$f_of_of_o$—speed of the surface wind in knots, or in knots plus 500

00, 85, 70, etc—standard isobaric surface indicators for 1000-mb, 850-mb, 700-mb surfaces, etc.

hhh—geopotential altitude of the standard isobaric surface indicator given in geopotential meters or decameters

NOTE: The remaining symbolic letters, $TTT_aDD$ ddfff, are coded in a manner similar to the associated surface symbolic letters above except the data are applicable to the standard isobaric surface indicated.

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SECTION 3.—This section, with the indicator figures 88, provides for reporting data for the tropopause as follows: pressure, temperature, approximate tenths value and plus or minus sign indicator of the air temperature, depression of the dew-point temperature (with respect to water), and true wind direction and wind speed. These symbolic letters are similar to the letters described in Section 2.

SECTION 4.—This section has two sets of indicator figures to identify maximum wind data groups—66 or 77. The figures 66 are used to identify the groups when the maximum wind occurs at the terminating level of the sounding in Parts A and C, and the figures 77 when the maximum wind occurs within the sounding in Parts A and C.

SECTION 5.—This section provides a means of reporting significant levels with respect to temperature and/or humidity that are sufficiently important, or unusual, to warrant the attention of a forecaster, and/or are required for precise plotting of the radiosonde observation.

All significant levels are assigned a significant level indicator number; i.e., 00, 11, 22, etc. The indicator number 00 is always assigned to the surface data groups. The remainder of the significant levels are numbered in consecutive order (lowest to highest with respect to geopotential height).

The remaining symbolic letters are coded in a manner similar to those described in Section 2.

SECTION 7.—The inclusion of this section is mandatory whenever any of the data for the 250-mb surface is available. Whenever this section is reported, all four of its groups must be included in the message. When data for the 250-mb surface are not observed, this section is completely omitted from the message.

The group 31313 is the indicator group for the 250-mb surface data, and the remainder of the symbolic letter groups are coded in a manner similar to those in Section 2.

SECTION 9.—This section provides a means of reporting various types of information pertaining to the ascent that cannot be otherwise included in the message.

The indicator group, 51515, specifies that the groups that follow contain data in a regionally adopted code form and are coded utilizing code table 101 of the Manual for Radiosonde Code.

Second Transmission

Part C of the second transmission is divided into 4 sections—1, 2, 3, and 4—and Part D into 3 sections—1, 5, and 9. The symbolic form of the second transmission with a brief explanation of the various sections is as follows:

PART C

SECTION 1 WW YYGGI$_d$ IIiii

SECTION 2 70hhh TTT$_a$DD ddfff

50hhh TTT$_a$DD ddfff

30hhh TTT$_a$DD ddfff

20hhh TTT$_a$DD ddfff

10hhh TTT$_a$DD ddfff

07hhh TTT$_a$DD ddfff

05hhh TTT$_a$DD ddfff

03hhh TTT$_a$DD ddfff

02hhh TTT$_a$DD ddfff

01hhh TTT$_a$DD ddfff

SECTION 3 88$P_tP_tP_t$ $T_tT_tT_{at}D_tD_t$ $d_td_tf_tf_tf_t$

SECTION 4 77 or 66 $P_mP_mP_m$ $d_md_mf_mf_mf_m$①

PART D

SECTION 1 YY YYGG/ IIiii

SECTION 5 11PPP TTT$_a$DD

22PPP TTT$_a$DD

33PPP TTT$_a$DD

44PPP TTT$_a$DD

..... ..... etc.

SECTION 9 51515 101$A_{df}A_{df}$①



576

564

All sections of Parts C and D have a counterpart in Parts A and B and have similar coding procedures. The message identifier letters for Parts C and D are WW and YY, respectively.

As was mentioned previously, all data in Parts C and D are applicable to levels above 100 millibars. Data for a 100-mb level or below, even if not transmitted in Parts A or B, cannot be reported by Parts C or D.

Strata reported in the body of the radiosonde message as having superadiabatic lapse rates will be verified by the use of plain language. The plain language arrangements will consist of the word SUPER followed by the pressure values, in tens of millibars, of the base and top of the stratum involved; i.e., SUPER $P_BP_B$–$P_TP_T$mb stratum where $P_BP_B$ is the pressure at the base and $P_TP_T$ is the pressure at the top of the stratum. If more than one distinct stratum is involved, the pressure values for the strata will be given in ascending order with respect to altitude (e.g., SUPER $P_BP_B$–$P_TP_T$, $P_BP_B$–$P_TP_T$ mb, etc.).

SHIPBOARD RADIOSONDE CODE (FM 36.D)

The symbolic form of the radiosonde code used by ships is basically the same as the land station radiosonde code. The significant difference is the position symbolic groups used in Section 1 in all parts of the shipboard code. The shipboard symbolic code format for Part A, Section 1, with an explanation of the various groups is as follows:

TT YYGGI$_d$ 99$L_aL_aL_a$ $Q_cL_oL_oL_oL_o$
MMM$U_{La}U_{Lo}$

The groups TT and YYGGI$_d$ are coded the same as a land station report.

99—identifies ship station position groups in all parts of the code

$L_aL_aL_a$—latitude in tens, units, and tenths of degrees

$Q_c$—quadrant of the globe

$L_oL_oL_oL_o$—longitude in hundreds, tens, units, and tenths of degrees

MMM—number of Marsden Square for the ship's position at time of observation

$U_{La}U_{Lo}$—units figure in the reported latitude and longitude

Section 1 of Parts B, C, and D is identified by the message identifier letters VV, WW, and YY, respectively.

INTERNATIONAL ANALYSIS CODE (IAC FULL FORM) (FM 45.D)

This code reduces to a numerical code form a coded weather map analysis from maps plotted and analyzed at forecasting centers of meteorological services. Data included in these messages give the types, characteristics, central pressures, locations, and movements of pressure systems and position points for use in drawing the fronts and isobars. Types of fronts (whether warm, cold, occluded, or stationary) and the values for the isobars are also indicated in the messages. The message may be either a current map analysis with indications as to movement or development, or a prognostic map analysis.

For land stations with facsimile equipment, this code is normally plotted only in case of complete equipment failure or in cases in which it is desirable to compare another analysis from an analysis center whose facsimile broadcast is outside the range of the receiving equipment.

The symbolic form and an explanation of the letters specifications of this code may be found in N.O. Pub. No. 118.

IAC FLEET (FM 46.D)

The international analysis code, FM 46.D, was designed primarily for marine use. It is an abridged form of FM 45.D, and the symbolic letters and figures have the same meaning in both codes. The symbolic code form is as follows:

| | | | | |
|---|---|---|---|---|
| | 10001 | 33388 | OYY$G_cG_c$ | or |
| | 65556 | 33388 | OYY$G_cG_c$ | 000$G_pG_p$ |
| 99900 | 8$P_tP_c$PP | $QL_aL_aL_oL_o$ ($QL_aL_aL_oL_o$) $md_sd_sf_sf_s$ | | |
| or | 000$g_pg_p$ | 9$P_tP_c$PP | $QL_aL_aL_oL_o$ ($QL_aL_aL_oL_o$) $md_sd_sf_sf_s$ | |
| and | 000$g_pg_p$ | 7$P_tP_c$PP | $QL_aL_aL_oL_o$ ($QL_aL_aL_oL_o$) $md_sd_sf_sf_s$ | |

99911 $66F_tF_lF_c$ $QL_aL_aL_oL_o$ $QL_aL_aL_oL_o$ ----
$md_sd_sf_sf_s$

or $000g_pg_p$ $69F_tF_lF_c$ $QL_aL_aL_oL_o$ ----
$md_sd_sf_sf_s$

and $000g_pg_p$ $67F_tF_lF_c$ $QL_aL_aL_oL_o$ ----
$md_sd_sf_sf_s$

99922 44PPP $QL_aL_aL_oL_o$ $QL_aL_aL_oL_o$ ----

99955 $(55T_tT_lT_c)$ (555PP) $QL_aL_aL_oL_o$ $QL_aL_aL_oL_o$
---- $md_sd_sf_sf_s$

99944 $987w_sw_s$ $QL_aL_aL_oL_o$ $QL_aL_aL_oL_o$ ----

88000 $77e_2uu$ $(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$
$(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$ etc. $(00C_100)$

$000g_pg_p$ $79e_2uu$ $(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$
$(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$ etc. $(00C_100)$

and/or

$000g_pg_p$ $76e_2uu$ $(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$
$(9d_wd_wP_wP_w)$ $QL_aL_aL_oL_o$ etc. $(00C_100)$

77744 . . . Vocabulary groups . . . 44777
19191

The groups in the first two lines of the above message constitute the preambles of the message. The preamble in the first line is for the surface analysis, and the preamble in the second line is for surface prognosis.

The appropriate preamble is included each time the analysis or prognosis is made up from a different chart and for each different type. Each such analysis or prognosis ends with the group 19191.

The following groups precede the various sections of code and indicate the type of data that follows:

99900—Section of pressure systems.
99911—Section of frontal systems.
99922—Isobars section.
99944—Weather area section.
99955—Tropical section.
88800—Wave or sea temperature section.

Each analysis or prognosis section may be repeated as many times as necessary. Use of the tropical section does not preclude the use in the same general area of other sections where applicable. Movement group must be given for each pressure, frontal, or tropical system included.

Amplifying phrases from a vocabulary code can be inserted as and where desired, but must be preceded and terminated by the appropriate key groups. Other information is invariably to be given in the sequence shown in the code.

The following sequence is used for coding each section:

1. Pressure systems: to be given in the order of occurrence from west to east.

2. Frontal information: to give a general run as far as possible from west to east.

3. Tropical systems: as for pressure systems or frontal information according to whichever the tropical system more closely resembles.

4. Isobar delineation: points on an isobar encircling a LOW should be given first and in a cyclonic direction. Points on an isobar encircling a HIGH should be given last and in an anticyclonic direction.

5. Significant weather: in order of occurrence from west to east.

The position group for each pressure system may be given twice. Points on fronts, tropical systems resembling fronts, isobars, and boundaries of areas of significant weather are given only once. If a pressure or tropical system is elongated and open, two or more points (twice each if desired) are given to indicate the axis of the system; the first position and the pressure, when given, refer to the vertex of the system. The speed, direction, and rate of change or characteristic of motion of the system then refer to the axis of the system.

When used with fronts or tropical systems resembling fronts, the movement group refers to the central portion of the type concerned. When it is necessary to use two or more movement groups in reference to a given type, the type is subdivided by repetition of the group $66F_tF_lF_c$ or $55T_tT_lT_c$.

Additional groups or supplementary information may be added. In these cases the same rules as those for the IAC, full form, apply. A correction to the analysis or prognosis commences with the groups 11133 $OYYG_cG_c$. The corrections follow, preceded by the appropriate indicators (8---, 66---, 44---, etc.), and the message ends with the 19191 group.

UPPER AIR FALLOUT DATA CODE (UF)

Upper air fallout data originate for transmission at Washington, D. C., and are prepared by electronic computer at the National Meteorological Center. These reports consist of data derived from the upper wind reports transmitted by the various rawinsonde stations in the United States.

The data computed are the true bearing and distance in statute miles from the station to the points on the earth's surface where fallout from various levels would occur in 3 hours after a bomb detonation. All heights referred to in the instructions pertaining to fallout winds are in respect to rawin surface altitude.

The standard levels for which data are computed and transmitted are the 3-, 6-, 12-, 18-, and 24-km levels (10,000-, 20,000-, 40,000-, 60,000-, and 80,000-ft levels).

Sequence collections of these coded reports are made on Service C as described in that system's transmission schedules.

The sequence collection heading consists of the collection designator, the circuit of origin, and the data and time of the observation. Thus, the heading would be: UF CC YYGGggZ.

UF—Upper air fallout data.

CC—Circuit on which the collection is being made (30 through 35).

YY—Day of the month in Greenwich civil time (i.e., first day—01; second day—02; etc.).

GGgg—Time of observation in hours and minutes (GCT) upon which these computations are based.

Z—Designator for Greenwich civil time.

Form of Message

The symbolic form of the message and the definitions of the symbols are as follows:

iii 1ddss 2ddss 4ddss 6ddss 8ddss

iii—Letter identifier for the observing station.

dd—True direction, in tens of degrees (i.e., clockwise from true north on the scale 01 to 36), towards which particles would fall from the specified level. The nearest tens of degrees reported.

ss—Distance, in tens of statute miles, from the station or ground zero point, at which particles would land that take 3 hours to fall from the specified level. The nearest tens of miles are reported (i.e., code figure 00-0 to 4 miles; 01-5 to 14 miles; 02-15 to 24 miles, etc.).

1, 2, 4, 6 & 8—Level indicators of the height in tens of thousands of feet above station elevation (i.e., 1-10,000; 2-20,000; etc.).

MAP PLOTTING

Map plotting, together with observing, is one of the most important job functions to be encountered. The training you received in map plotting while at the MST "A" School should have made you entirely familiar with many of the basic and often-used codes. In the first part of this section, we have reviewed many of these codes which you have already learned, and have introduced codes with which you were not, perhaps, so familiar.

The maps and charts that you will plot are of prime importance to all concerned because from these maps and charts the forecaster is able to locate pressure areas, fronts, precipitation areas, ridges, troughs, and numerous other meteorological phenomena of great importance. Also, the maps and charts that you will plot are determined by the geographical location of your weather station, its operational requirements, and its area of responsibility.

A thorough knowledge of the codes used and the employment of good map plotting practices should make you an excellent map plotter.

The following procedures are employed for plotting most codes, and have generally been standardized so that the minimum amount of confusion will result:

1. Do not plot indicator figures for code groups.

2. Most wind directions are reported in tens of degrees. Plot the wind direction, dd, as the wind direction, in tens of degrees, from which the wind is blowing.

3. Report all wind speeds in knots.

a. A half barb (1/8 inch) represents 5 knots.

b. A full barb (1/4 inch) represents 10 knots.

c. Pennants (1/4 inch) represent 50 knots.

Employ any combination of a, b, and c to represent the correct speed. You should plot "X" at the end of the wind shaft when the speed is missing.

4. Plot the wind direction and speed so that you can show true direction and not interfere with other elements plotted.

5. Latitude is the degree of distance north or south of the Equator. Longitude is the degree of distance west or east of Greenwich, England.

6. Plot minus signs for subzero Celsius or Fahrenheit temperatures.

7. If any mandatory plotted element is garbled or partly or wholly missing, plot a dash (—) in its place.

8. Orient all elements that you plot to the adjacent meridian (latitude and longitude) lines.

9. Fill out all legends as indicated in the printed portion of the map containing the legend block. If a legend block is missing, information normally entered in the printed legend is entered in the lower left-hand corner of the map. The entries may be rubber stamp or printed block entries. Do not forget your name and rate in the legend.

10. Data plotted around a station circle should cover an area not greater than a dime, if possible.

11. Report and plot the code figures that are coded for temperature (TT) and dew point ($T_dT_d$) as either whole degrees Celsius or Fahrenheit, except plot tenths on upper air charts.

12. After completing plotting of the map, check the following items:

a. Neatness.

b. Wind direction and speed plotted correctly.

c. Size of station plots.

d. Completeness (all available data plotted).

e. Entry of late and off-time reports.

f. Plotting of additional upper air data as required.

g. In case of ships, proper location.

13. There are inks of several different colors which you can use when plotting a map to indicate the types of data plotted. Although no standard set of colors exists in the Coast Guard, and the colors used are normally determined locally, the following colors are recommended:

a. Black or blue-black—On-time data or blocks of off-time data (so indicated in the map legend).

b. Red—Gradient winds and off-time data.

c. Green—Data that are entered after the map has been plotted.

14. Quadrants of the globe are designated in the symbolic code breakdown by the letter Q. It is of the utmost importance that you plot the weather reports in the correct quadrant. Erroneously plotted data definitely give a wrong picture of the weather.

15. Be sure to plot the past positions of pressure centers and fronts on the map. Indicate

the past positions of the pressure centers by an X circumscribed by a circle with the date and time placed immediately above. Indicate the date by two numbers separated by a colon indicating the day of the month. The second two numbers indicate the time of data to the nearest whole hour GMT preceding the time of the appropriate map. Thus, enter 1230Z on the 20th day of the month as 20:12Z (or 20/12Z).

## SYNOPTIC CODE PLOTTING (LAND STATIONS)

There are many variations to the synoptic code. The difference in most cases is small, but very important. Be sure to check the WMO Region in which you are stationed or operating for the differences in the code that is employed in your area. The synoptic code breakdown in the following section is that applicable to North and Central America and the Caribbean Islands. This area is WMO Region IV.

The Manual of Synoptic Code, FMH #2, is to be used in coding the regular 6-hourly surface land station observations. As explained previously in this section, this code is composed of groups of five figures (with the exception of the first group), plus additional plain language words, as required, to report certain meteorological phenomena. Each figure in each group has significance according to its position in the group and the position of the group in the message. The order of the symbols in the group and the order of the groups in the message are always the same. Refer to N. O. Pub. No. 118 or FMH #2 for the symbolic letter specifications not included here. An example of a synoptic report giving the first seven groups is shown below. (Refer to figure 9 for the synoptic code plotting model.)

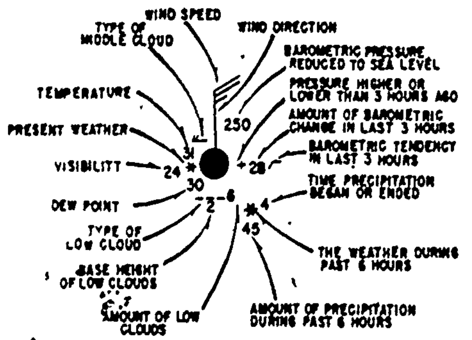


Figure 9.—Synoptic station model—land station.

| | | | |
|---|---|---|---|
| iii - | Nddff | VVwwW | PPPTT |
| 334 | 82219 | 16956 | 99776 |
| $N_hC_LhC_MC_H$ | | $T_dT_d$app | $7RRR_ts$ |
| 59402 | | 76807 | 70710 |

A definite order of decoding and entry has been established so there will be a mutual understanding between the decoder and the plotter (if two people are working on a map) as to which element of the code is next to be decoded and plotted on the chart.

The order of decoding and map entry is as follows:

| Order Decoded | Symbol and Position Around Station Circle |
|---|---|
| iii | Station number (locate station). |
| dd | Wind direction (changes depending upon direction). |
| ff | Wind speed (at the end of dd). |
| N | Fraction of sky covered by clouds (in station circle). |
| PPP | Sea level pressure (northeast quadrant). |
| TT | Temperature (northwest quadrant). |
| ww | Present weather (west of station circle). |
| VV | Visibility (to the left of ww or next to the station circle under TT if ww is absent). |
| $T_dT_d$ | Dewpoint (southwest quadrant). |
| ppa | Amount and characteristic of barometric tendency during past 3 hours (east of station circle). |
| $C_M$ | Middle cloud type (north of centerline of station between PPP and TTT. |
| $C_H$ | High cloud type (north of centerline of station above $C_M$). |
| $C_L$ | Low cloud type (south of centerline of station). |
| $N_h$ | Amount of $C_L$ or $C_M$ (to the right of $C_L$). |
| h | Height above ground of $C_L$ or $C_M$ (under $C_L$). |
| W, $R_t$, RR | Past weather, time precipitation began or ended, and amount of precipitation for past 6-hour period preceding actual time of observation (under ppa). |

## SHIPBOARD CODE PLOTTING

At sea there is a lack of the close network of land reports, and a single ship report may be the only one in a vast area. A single ship report, too, may be the only one giving an indication of a developing tropical storm which may be heading for a task force or a heavily populated area. It is especially important that the location of the ship be plotted accurately as well as complete plotting of the data around the station circle.

Surface synoptic reports from ships are identical with land synoptic reports with the exception of the position groups, the direction and velocity of the ship group, the group in which difference between sea water and air temperature is encoded, and the ice group. The ice group is omitted if there is no ice.

Figure 10 shows the grouping of entries around the U. S. ship plotting model. Refer to N.O. Pub. No. 118 for the symbolic letter specifications.

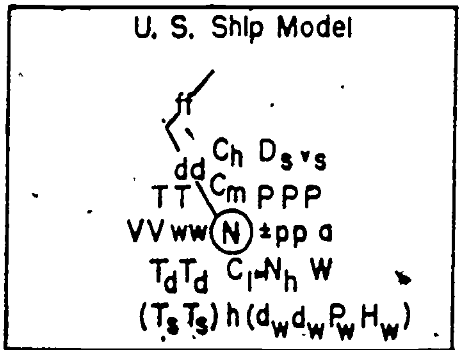


Figure 10.—U.S. ship plotting model.

The following is an example of the symbolic form of the code and numerical code values from a shipboard observation.

$99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$ $YYGGi_w$ Nddff VVwwW

PPPTT

99322 70421 01004 73515 97802 13114

$N_hC_LhC_MC_H$ $D_sv_sapp$ $OT_sT_sT_dT_d$

$3P_wP_wH_wH_w$

52472 54811 05413 30304

A definite order of decoding has been established, as in the land station code, to eliminate confusion between the decoder and plotter on the order of entries.

The first elements to be checked by the decoder are the day of the month (YY) and the time (GG), to be sure that the report is consistent with the date and time of the chart being plotted.

After the quadrant ($Q_c$) of the globe is determined, the first verbally decoded element is latitude ($L_aL_aL_a$), and this is always decoded as "North" or "South."

The second item decoded is the longitude ($L_oL_oL_oL_o$), and this is always decoded as "West" or "East."

When the plotter has located the position indicated, he should draw a 1/8-inch circle over it.

The decoder then proceeds decoding in the following manner:

| | |
|---|---|
| dd | Wind direction |
| ff | Wind velocity |
| N | Total sky coverage |
| PPP | Sea level pressure |
| TT | Temperature |
| ww | Present weather |
| VV | Visibility (from ship's visibility code table) |
| $T_dT_d$ | Dewpoint temperature |
| $T_sT_s$ | Sea water temperature |
| app | Pressure tendency (pressure change, as recorded on shipboard, is affected by the movement of the ship. Therefore, the ship's movement should be shown whenever pressure change is entered.) |
| $D_s$ | Ship's average direction. |
| $v_s$ | Ship's average speed |
| $C_m$ | Middle cloud type |
| $C_H$ | High cloud type |
| $C_L$ | Low cloud type |
| $N_h$ | Amount of low clouds |
| h | Height of lowest cloud |
| $P_wP_wH_wH_w$ | Wave period and height |

See figure 10 for an illustration of the plotting of a ship's report from the foregoing ship's code example.

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## PLOTTING ASYNOPTIC (OFF-TIME) DATA

Since a "synoptic chart" is one showing meteorological conditions observed at various places over a region at or very near the same given Greenwich time, it readily follows that "asynoptic data" are those data not normally appearing on a synoptic chart by virtue of being observed at a different time. In other words, asynoptic data may be termed "off-time" data. Although there is question as to how much difference may exist between observation time and synoptic chart time, and here again local rules have to apply, asynoptic data provide valuable supplements to synoptic data in areas where synoptic reporting stations are sparse or in case of communications failure. Frequently, asynoptic reports indicate significant weather developments not apparent at map time.

The criteria for asynoptic data are, in general, as follows: for surface data, surface observations more than 1 hour from the synoptic chart; for upper air data, those observations departing more than 2 hours from the synoptic chart time.

A color code, such as the one given in a previous part of this section, should be adopted for plotting such data. These plotted reports must be distinguished from the regular synoptic data in that sufficient changes generally occur during the time intervals to yield an inaccurate or inconsistent analysis if the off-time data were treated as synoptic.

## PLOTTING AIRWAYS CODE

When bad or hazardous weather is approaching the station, it often becomes necessary to supplement the 6-hourly synoptic map with 3-hourly airways maps. These may be either a regular synoptic type chart or a sectional chart. At times it may even be necessary to enter hourly airways maps. These charts give a detailed analysis over a limited area of the relation of pressure systems, fronts, temperature, and humidity to operationally significant weather elements. These maps also enable the forecaster to keep a "weather eye" on the situation and to note any sudden or unusual changes which are occurring.

The Airways Code is probably the most familiar of all weather codes. It is used not only when weather reports are made from MF1-10, but can be used to plot airways charts and to fill in areas of sparse or little data on synoptic charts.

Since the airways maps, when plotted, are subject to careful scrutiny, it is imperative that they be entered both rapidly and accurately. The size, type, and scale of the map, and the amount of data to be plotted are governed by local requirements.

The arrangement of data around the station circle is essentially the same as for the land synoptic code plotting model.

Figure 11 (A and B) shows a typical station model and a plotted model used for plotting the 3-hourly airways code data.

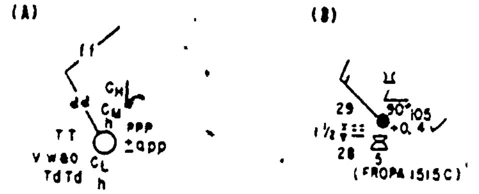


Figure 11—(A) Station model for plotting airways reports; (B) plotted airways station model.

The entries made on this chart are as follows:

| | |
|---|---|
| s | Airways symbol representing the greatest sky cover. |
| V | Actual visibility. |
| W & O | Weather and obstructions to vision. Enter, using synoptic symbols. Use combinations and intensity symbols. Intermittent precipitation is shown in remarks. |
| PPP | Enter as given. |
| TT | Enter as given. |
| $T_dT_d$ | Enter as given. |
| dd | Same as synoptic entry (G or Q may be placed at the end of the shaft to indicate gusts or squalls and the maximum wind in the gusts or squalls may also be placed at the end of the shaft). |
| ff | Same as the synoptic entry (see dd note for additional entries). |
| app | Entered the same as 6-hourly synoptic reports. |

$1C_LC_MC_H$ Enter the symbol representing the type of low, middle, and high clouds. Directly below the low and middle clouds enter the height (h) of these clouds using the standard procedure for entry of cloud heights. (Use height of lowest middle or low clouds when there is more than one layer.)

The altimeter setting is not entered. Remarks, as appropriate, should be entered.

PLOTTING WINDS ALOFT AND UPPER AIR DATA

Winds aloft reports may be plotted on separate charts or may be used to fill in stations on the constant pressure charts which do not take or transmit radiosonde data. Take extreme care when plotting the wind direction and speeds on these charts, as many areas of the world are using streamline analyses almost exclusively on upper air charts. A misplotted direction or an incorrect speed could cause an entirely erroneous analysis in a crucial area.

When wind speed and direction are critical in the analysis of an upper air chart, the following procedure is recommended:

1. Plot all wind directions with a protractor, using the latitude and longitude lines for orientation. Draw the wind shaft to the station circle. (See figure 12.)

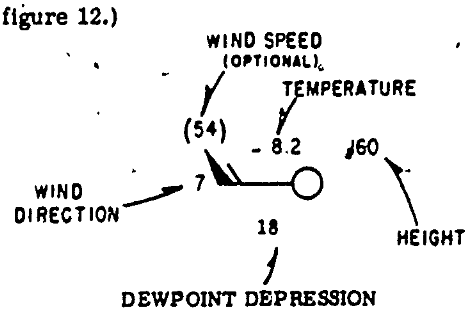


Figure 12.— Constant pressure chart plotted report.

2. Indicate the speed of the wind by the appropriate number of feathers, pennants, or combinations of both.

3. Place the tens number of the wind direction on the end of the wind barb shaft.

4. Optional entries normally governed by local procedure are:

a. To place the actual wind speed in parentheses at the tip of the wind feather or pennant indicating the speed;

b. To draw the wind shaft through the station circle with an arrowhead on the end pointed in the direction toward which the wind is blowing.

If the wind is calm, draw a circle around the station circle. If the wind is missing, do not make any entry for the wind. If the wind direction is encoded and the speed is missing, enter an X at the end of the wind shaft where the wind feather is normally located.

The height is entered as encoded to the northeast of the station circle; the temperature, to the northwest of the station circle in degrees and tenths; and the dew-point depression, to the southwest of the station circle in degrees and tenths.

If the height, temperature, or dew-point depression is missing, enter a dash in the appropriate space for each of these elements.

PREPARATION OF WEATHER MAPS FROM THE IAC (FLEET) CODE

Underway at sea, you may find that because of other duties time cannot be spared to plot all ship and coast station reports available for drawing a weather map. On such occasions, an analyzed weather map and/or prognosis showing the centers of pressure systems, the fronts, and isobars drawn from data given in the coded analysis message may meet the local requirements. Also, in cases of a communications failure which precludes the receipt of facsimile transmissions, this coded analysis or prognosis may be the only source upon which a forecast may be based.

The symbolic form of the International Analysis Code (Fleet) is given in an earlier part of this section. Assume that you have received in a western North Atlantic shipping broadcast a coded analysis message as follows:

ASNT 110000Z

NOTE: In analysis messages, the heading may read "Analysis" or "ASNT," plus the date and time group. In the 4-letter group "ASNT," the letters AS indicate that the message is a surface weather map analysis and the NT means that it is for the North Atlantic.

| | | | | | |
|---|---|---|---|---|---|
| 10001 | 33388 | 01100 | XX | | |
| 99900 | | | | | |
| 81075 | 05446 | 20408 | X | | |
| 81085 | 05479 | 50312 | X | | |
| 81098 | 13598 | 20408 | X | | |
| 85029 | 04122 | 20420 | X | | |
| [illegible]5021 | 04159 | 21025 | XX | | |
| [illegible]011 | | | | | |
| 66652 | 05437 | 04838 | 04242 | X | |
| 66411 | 04242 | 03849 | 03765 | X | |
| 66032 | 03765 | 03875 | 04178 | 04779 | |
| | 04782 | X | | | |
| 66463 | 05479 | 04782 | 14290 | | |
| | 13900 | X | | | |
| 66222 | 03535 | 03938 | 04242 | X | |
| 66222 | 05169 | 05373 | 05479 | XX | |
| 99922 | | | | | |
| 44976 | 05546 | 05348 | 05444 | 05546 | X |
| 44984 | 05648 | 05350 | 05243 | 05542 | |
| | 05648 | X | | | |
| 44992 | 05850 | 05353 | 05045 | 05137 | |
| | 05634 | 05742 | 05850 | X | |
| 44000 | 06154 | 05557 | 05055 | 04748 | |
| | 04838 | 05726 | 05941 | 06154 | X |
| 44008 | 06655 | 05583 | 04960 | 04549 | |
| | 04242 | 05720 | 06130 | 06144 | |
| | 06655 | X | | | |
| 44016 | 02218 | 01640 | 01960 | 02475 | |
| | 02980 | 03475 | 03765 | 04370 | |
| | 04665 | 04250 | 03849 | 04039 | |
| | 04830 | 05320 | 05405 | 06220 | |
| | 06340 | X | | | |
| 44020 | 02815 | 02630 | 02350 | 02568 | |
| | 03072 | 03360 | 03548 | 03938 | |
| | 05024 | 05210 | X | | |
| 44024 | 04012 | 03415 | 03225 | 03338 | |
| | 03637 | 04259 | 04920 | 04808 | |
| | 04012 | X | | | |
| 44028 | 04019 | 03925 | 04255 | 04420 | |
| | 04019 | X | | | |
| 44992 | 05476 | 05679 | 05482 | 05180 | |
| | 05476 | X | | | |
| 44000 | 05373 | 05776 | 05880 | 05686 | |
| | 04486 | 04780 | 05383 | X | |
| 44000 | 13796 | 13500 | 13497 | 13796 | X |
| 44008 | 01080 | 01678 | 02085 | 12194 | |
| | 12698 | 13690 | 04178 | 05169 | |
| | 05772 | 06090 | 15696 | 15092 | |
| | 14494 | 14000 | XX | | |
| 19191 | XX | | | | |

From the heading of the message, first enter on the chart the date and hour of the analysis given by the date and time group 110000Z as explained in the preceding part of this section. Now decode the analysis message and plot the pressure system centers, the fronts, and the isobars on the weather map. (See figure 13 for code tables.)

From your knowledge of the symbolic form of the International Analysis Code (IAC-FLEET), you know that each coded message begins with a preamble. Data for pressure systems, fronts, and the isobars then follow in order by sections.

The preamble groups are as follows: 10001 33388 01100. The first group 10001 indicates that the message is coded in IAC-FLEET, while the second, 33388, means that the positions of the pressure systems, the fronts, and the isobars are coded in the form $QL_aL_aL_oL_o$. It may be well to mention here that sometimes the key group 33388 may be replaced by one of the groups 33300, 33311, or 33322. When any of these three key groups appears in the preamble, this means that the locations of pressure systems and position points for the fronts and the isobars are encoded to the nearest half degree of latitude and longitude. In such cases, all position points in each section of the message are then encoded in the form $L_aL_aL_oL_ok$ instead of $QL_aL_aL_oL_o$; the half-degrees to be added to the $L_aL_a$ and $L_oL_o$ are indicated by the figure encoded for symbol k.

The last group in the preamble, 01100, is a date and time group; the first figure is an indicator and is always 0, the second and third figures giving the date, and the last two figures the time of observations used in making the analysis; that is, the 11th day of the month and 0000 GMT, in this case. Data included in this group should be identical to the date and time shown in the heading of the analysis message, i.e., 110000Z.

The next section of the message with the prefix 99900 contains data for pressure system centers to be plotted on the map, 81075 05446 20408 X 81085 05479 50312 X 81098 etc. Data for pressure systems are given in series of three 5-figure groups; the first group in each series commences with the figure 8 which is the indicator for pressure systems. Using the code tables, begin to plot on the weather map the data for the first pressure system, its type, character, central pressure, location, and its course and movement at observation time as

| | I - $P_t$ Type of pressure system | II - $P_c$ Pressure system characteristic | III - Q Octant of the globe | | IIIA - a Position group index figure | | |
|---|---|---|---|---|---|---|---|
| 0 | Complex low | No specification | 0° - 90°W | NORTHERN LATITUDE | $L_aL_aL_oL_o$ as sent | Long. E 0°-90° or Long. W 100°-180° | 0 |
| 1 | Low | Low filling or high weakening | 90°-180° | | 1/2° added to $L_aL_a$ | | 1 |
| 2 | Secondary | Little change | 180°-90°E | | 1/2° added to $L_oL_o$ | | 2 |
| 3 | Trough | Low deepening or high intensifying | 90°-0° | | 1/2° added to $L_aL_a$ and $L_oL_o$ | | 3 |
| 4 | Wave | Complex | | | Whole degrees | | 4 |
| 5 | High | Forming or existence suspected (cyclogenesis or anticyclogenesis) | 0°-90°W | SOUTHERN LATITUDE | $L_aL_aL_oL_o$ as sent | Long. W 0°-99° or Long. E 100°-180° | 5 |
| 6 | Area of uniform pressure | Filling or weakening but not disappearing | 90°W-180° | | 1/2° added to $L_aL_a$ | | 6 |
| 7 | Ridge | General rise of pressure | 180°-90°E | | 1/2° added to $L_oL_o$ | | 7 |
| 8 | Col, | General fall of pressure | 90°E-0° | | 1/2° added to $L_aL_a$ and $L_oL_o$ | | 8 |
| 9 | Tropical storm | Position doubtful | | | Whole degrees | | 9 |

| | IV - m Movement Indicator figure | V - $F_t$ Type of front | VI - $F_i$ and $T_i$ Frontal and tropical system intensity | $T_i$ when $T_t$ = 9 | VII - $F_c$ Character of front | |
|---|---|---|---|---|---|---|
| 0 | No specification | quasi-stationary front at surface | no specification | 10 | no specification | 0 |
| 1 | Stationary | quasi-stationary front above surface | weak, decreasing (frontolysis) | 11 | frontal activity area, decreasing | 1 |
| 2 | Little change | warm front at surface | weak, little or no change | 12 | frontal activity area, little change | 2 |
| 3 | Becoming stationary | warm front above surface | weak, increasing (frontogenesis) | 12 | frontal activity area, increasing | 3 |
| 4 | Retarding | cold front at surface | moderate, decreasing | 12 | intertropical | 4 |
| 5 | Curving to left | cold front above surface | moderate, little or no change | 5 | forming or existence suspected | 5 |
| 6 | Recurving | occlusion | moderate, increasing | 6 | quasi-stationary | 6 |
| 7 | Accelerating | instability line | strong, decreasing | 7 | with waves | 7 |
| 8 | Curving to right | intertropical front* | strong, little or no change | 8 | diffuse | 8 |
| 9 | Expected to recurve | convergence line | strong, increasing | 9 | position doubtful | 9 |

* Preferable to use Tropical section

| | VIII - $T_t$ Tropical System Type | IX - $T_c$ Tropical System characteristic | X - $W_sW_s$ Significant Weather | |
|---|---|---|---|---|
| 0 | intertropical convergence zone | no specification | area of heavy swell | 00 |
| 1 | shear line | diffuse | area of strong winds (force 6 & 7 Beaufort) | 11 |
| 2 | line or zone of convergence | sharply defined | area of medium cloud | 22 |
| 3 | axis of doldrum belt | quasi-stationary | area of low cloud | 33 |
| 4 | trough in westerlies | existence certain | area of poor visibility | 44 |
| 5 | trough in easterlies | existence uncertain | area of gales (force 8 Beaufort or more) | 55 |
| 6 | LOW area | formation suspected | area of continuous precipitation | 66 |
| 7 | surge line | position certain | area of squally weather | 77 |
| 8 | line or zone of divergence | position uncertain | area of heavy showers | 88 |
| 9 | tropical cyclonic circulation (see Note ix) | movement doubtful | area of thunderstorms | 99 |

Figure 13.—International Analysis Code (IAC-FLEET) specification tables.

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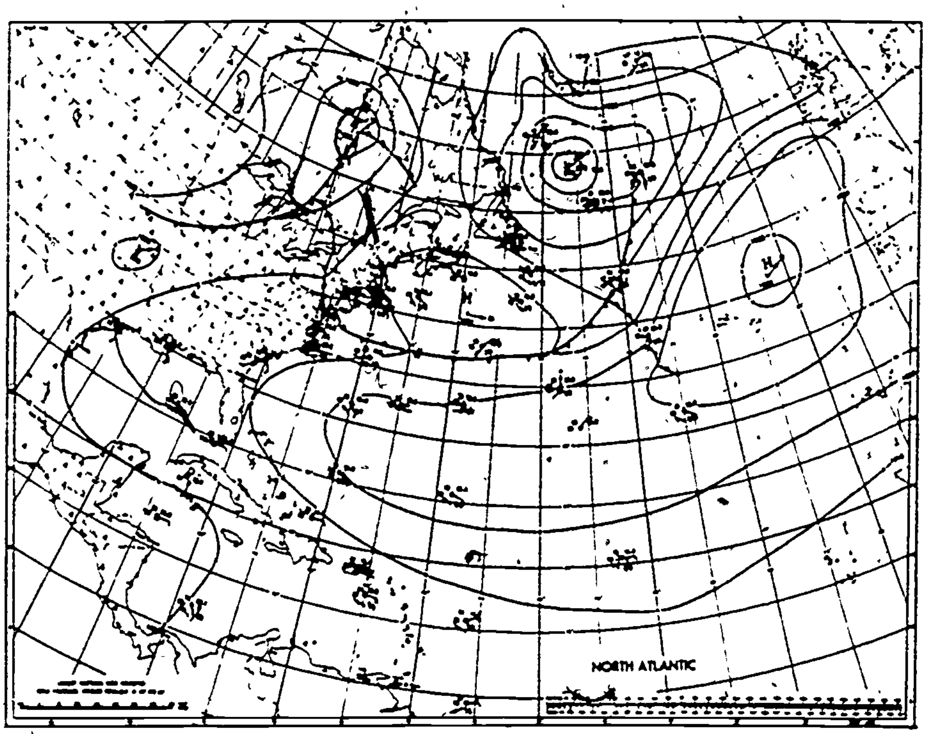


Figure 14.— Map showing plotted IAC-FLEET analysis.

given by the groups 81075 05446 20408. In the first group, the figure 8 is the indicator for the pressure system, 1 indicates that the pressure system is a LOW, 0 indicates no specification is given as to the character of the LOW, and 75 gives its central pressure as 975 millibars.

From the next group, 05446, obtain the position of the LOW. The figure 0 indicates that the LOW is in the octant between the Greenwich meridian and 90° W in the Northern Hemisphere; the figures 5446 give its location at latitude 54°N, longitude 46°W. On the weather map, place a small cross (X) at 54°N, 46°W, and enter the LOW's central pressure 975 as given in the preceding group 81075. Also mark the center of this pressure system with an L or the word LOW. The LOW's movement is given in the third group, 20408. The figure 2 indicates little change in the LOW's movement; 04 shows that it is moving on a course of 40°, and 08 gives its speed as 8 knots. A short arrow pointing toward a course of 40° and the figure 8 immediately underneath should be entered above or alongside the L on the chart.

On the chart continue to enter data for each succeeding series of pressure system groups included in the message. After you have plotted data for the groups 85021 04159 21025 X, you have entered on the map all the pressure systems given in the message. (See figure 14.)

In the next section of the message, with the prefix 99911, note that there are several series of groups and that the first group in each series begins with the figures 66. This section of the message indicates the types, intensities, and characteristics of the fronts as well as the position points needed for drawing the fronts on the map.

The first frontal system in the message is encoded in the groups 66652 05437 04838 04242 X. In the first group, 66 is the indicator for the frontal systems, 6 shows that the front is occluded, 5 means that it is of moderate intensity, and 2 indicates that its activity shows little change.

From the second group, 05437, the first position point given on this occluded front is at 54°N, 37°W, and at this point on the chart, place a small cross.

In the third group, 04838, the second point indicated on this front is at 48°N, 38°W, and at this location on the chart, mark another small cross.

For the last group, 04242, make a cross at 42°N, 42°W. All the points for this front have been plotted and you should now draw a line connecting these points. Since it is an occluded front, the line for this front may be drawn in purple.

Then plot the position points for the next frontal system given in this section of the message by the groups 66411 04242 03849 03765 X. In the group 66411, the figure 4 indicates that the system is a cold front at the surface; draw a blue line through the points. Continue to enter on the map the data for each frontal system included in the message.

When you have entered data for the groups 66222 05169 05373 05479 XX on the chart and have drawn a warm front through the points, you have completed the plotting and drawing of all of the fronts given in this section of the message.

Now you are ready to commence plotting the isobars as contained in the final section of the message. This section has the prefix 99922 and contains several series of groups, each with the first group beginning with the indicator figures 44, for example, 44976 05546 05348 05444 05546 X.

In the group 44976, 44 is the indicator for isobars; 976 indicates that the isobar is for 976 millibars. From the next group, 05546, note that the first point on this isobar is at latitude 55°N, longitude 46°W, and place a small cross at this location on the chart.

The next group is 05348 and you mark another cross at 53°N, 48°W, while the group 05444 shows that the third cross should be placed at 54°N, 44°W. Note that the last group 05546 is identical to the first position point group 05546 given for the above-mentioned isobar. This shows that the isobar encircles the LOW which is centered at 54°N, 46°W. (See figure 14.) Now draw the isobar through the three position points just plotted on the chart and mark the isobar 976. When drawing isobars, it is important for you to ensure that the isobars are drawn at the correct angles where they join the front or fronts.

Then mark the position points for the next isobar on the map as given by the groups 44984 05648 05350 etc., and draw the isobar for 984 millibars. When data for the groups 44008 01080 01678 02085 ..... ..... ..... 14000 X have been plotted and the isobar for 1,008 millibars has been drawn, the map is complete. The LOWS and HIGHS, the fronts, and the isobars should look like those shown in figure 14. The last group in the message, 19191, indicates the end of the analysis message.

Note that in analysis messages, isobars may not be given for every 4-mb interval. As a rule, where the isobars are close together, some isobars may be encoded in the message for an 8- or 12-mb interval. In such cases, the isobars for the 4-mb intervals can easily be sketched in between those with 8- or 12-mb interval spacing. Over areas on the map where the isobars are spaced at considerable distances apart (i.e., around a HIGH), isobars for each 4-mb interval are usually included in the message.

It may be well to mention again that as you mark the position points for each front on the map, you should draw the line connecting the points to complete the front before entering the position points for the next frontal system given in the message. Follow this same procedure in plotting and drawing each isobar. Otherwise, you may sometimes become confused in drawing the fronts or isobars if the points for two fronts or adjacent isobars are close by.

Sometimes analysis messages may be received in which the isobars are encoded for 3-mb intervals. In this case, the isobar group 44PPP contains the value for PPP encoded in multiples of 3 millibars; that is, 999, 002, etc.

With a little practice, you soon find that you can decode much of the data in analysis messages at sight. Thus, you will be able to plot and draw a weather map showing the pressure systems, the fronts, and the isobars in a minimum amount of time.

NAVY RADFO MESSAGES

The Fleet Numerical Weather Facility Monterey and other Naval weather units responsible for the dissemination of radioactive fallout information normally utilize the standardized Navy RADFO message. This section is designed to familiarize the MST with the symbolic format, interpretation, and illustration of the Navy fallout message.

Table 15.—Navy fallout message code table.

| GROUP | DESCRIPTION | REMARKS |
|---|---|---|
| RADFO | Radiological fallout forecast follows | --------- |
| ATLANTIC/ PACIFIC | Ocean area covered | Only one of these groups is used. |
| $YYGGG_v$ | YY = day of the month (GMT) | 01 = 1st day of month<br>02 = 2nd day of month<br>The date is defined with reference to Greenwich mean time and not local time. |
| | GG = time to the nearest whole hour (GMT) at which valid time of fallout forecast begins | |
| | $G_v$ = period of time covered by forecast | Forecast valid for<br># . . . hours<br>1 . . . 3<br>2 . . . 6<br>3 . . . 9<br>4 . . . 12<br>5 . . . 18<br>6 . . . 24<br>7 . . . 48<br>8 . . . 72 |
| $QL_aL_aL_oL_o$ | Q = octant of globe | Northern Hemisphere<br>0 . . . 0° . . . 90° W.<br>1 . . . 90° . . . 180° W.<br>2 . . . 180° . . . 90° E.<br>3 . . . 90° . . . 0° E.<br>Southern Hemisphere<br>5 . . . 0° . . . 90° W.<br>6 . . . 90° . . . 180° W.<br>7 . . . 180° . . . 90° E.<br>8 . . . 90° . . . 0° E. |
| | $L_aL_a$ = Latitude in whole degrees of point for which fallout forecast which follows is made | |
| | $L_oL_o$ = Longitude in whole degrees of point for which fallout forecast which follows is made (The hundreds digit is omitted for longitudes 100° to 180°.) | |

Table 15.—Navy fallout message code table—Continued.

| GROUP | DESCRIPTION | | REMARKS |
|---|---|---|---|
| $T_N d_L d_L s_L s_L$ | $T_N$ | = Fallout template number which applies | # Template<br>1 ............ ALFA<br>2 ............ BRAVO<br>3 ............ CHARLIE<br>4 ............ DELTA<br>5 ............ ECHO<br>6 ............ FOXTROT |
| | $d_L d_L$ | = Direction from which the low-yield effective fallout wind blows, measured in tens of degrees clockwise from north | |
| | $s_L s_L$ | = Low-yield effective fallout wind speed in knots | |
| $T_N d_H d_H s_H s_H$ | $T_N$ | = As above | |
| | $d_H d_H$ | = Direction from which the high-yield effective fallout wind blows, measure in tens of degrees clockwise from north | |
| | $s_H s_H$ | = High-yield effective fallout wind speed in knots | |

The following is the symbolic form used in transmitting Navy fallout messages: RADFO

ATLANTIC/PACIFIC $YYGGG_v$ $QL_aL_aL_oL_o$

$T_Nd_Ld_Ls_Ls_L$ $T_Nd_Hd_Hs_Hs_H$ $QL_aL_aL_oL_o$

$T_Nd_Ld_Ls_Ls_L$ $T_Nd_Hd_Hs_Hs_H$.

The various groups included in the Navy fallout message should be interpreted as shown in table 15.

The following is a sample fallout message:

RADFO ATLANTIC 09184 03070 22550 32950 03080 23230 22760 ... RADFO means a Navy radiological fallout forecast follows.

ATLANTIC means the fallout message involves the Atlantic Ocean area.

(09184) 09 means the forecast is for the 9th day of the month, 18 means the valid time for the forecast starts at 1800 GMT, and 4 means the forecast is valid for 12 hours (until 0600 GMT on the 10th day of the month).

(03070) 0 means the point for which the forecast is made is located in the Northern Hemisphere between longitude 0° and 90°W. 30 means the latitude of the point is 30°N., and 70 means the longitude of the point is 70°W.

(22550) 2 means the fallout area is delineated by the pattern of template BRAVO; 25 indicates that the low-yield effective fallout wind is from 250°—therefore, the true bearing of the fallout trajectory is 070° (figure 15); and 50 indicates that the low-yield effective fallout wind speed is 50 knots.

(32950) 3 means the fallout area is delineated by the pattern of template CHARLIE; 29 indicates that the high-yield effective fallout wind is from 290° —therefore, the true bearing of the fallout trajectory is 110°; and 50 indicates that the high-yield effective fallout wind speed is 50 knots.

(03080) means the next forecast point is in the Northern Hemisphere at 30°N. and 80°W.

(23230) indicates that the low-yield fallout area is delineated by template BRAVO, the effective fallout wind is 320° or the fallout trajectory bearing is 140°, and the speed is 30 knots.

(22760) indicates that the high-yield fallout area is delineated by template BRAVO, the effective fallout wind is 270° or the fallout trajectory bearing is 090°, and the speed is 60 knots.

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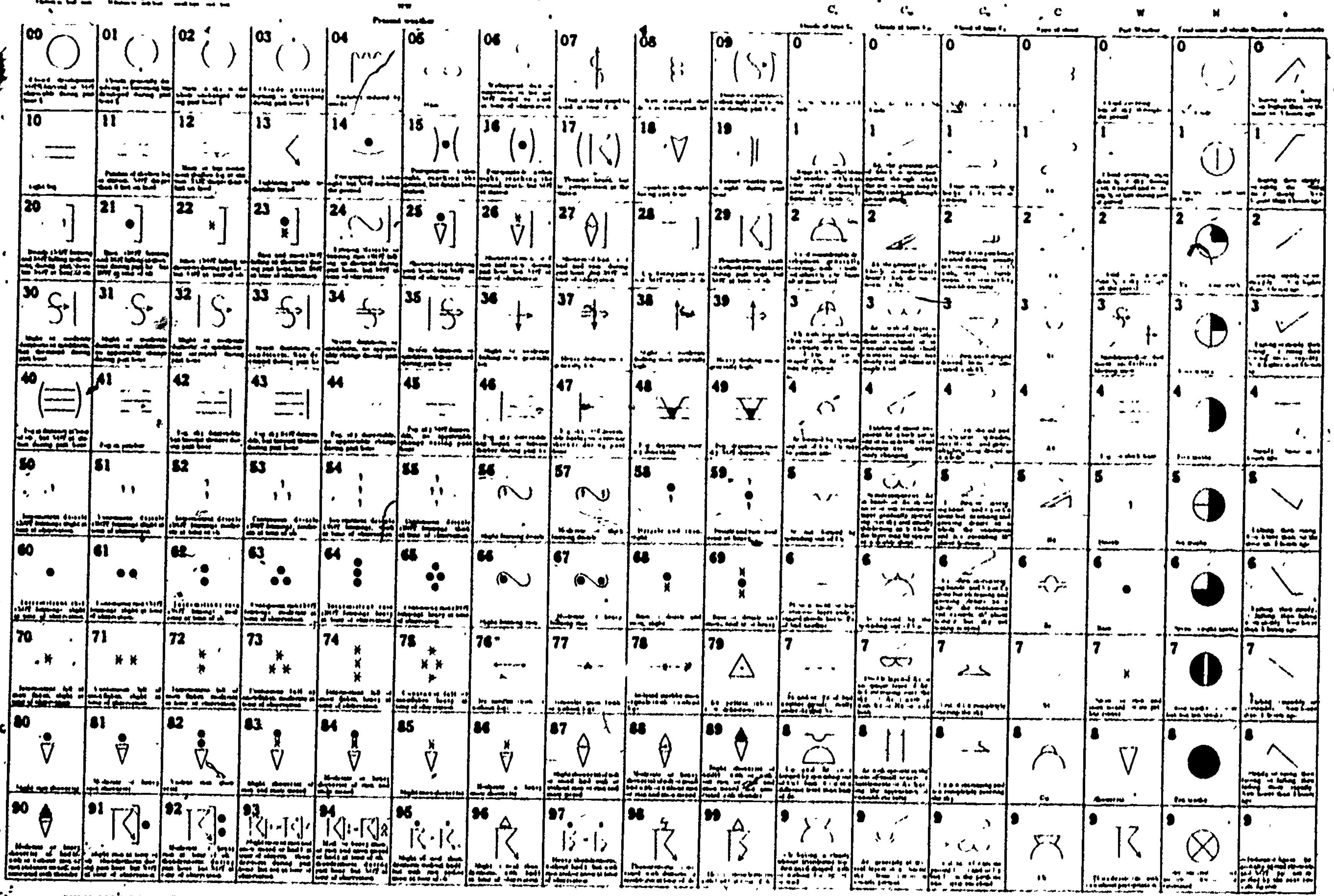
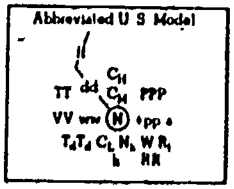
U S DEPARTMENT OF COMMERCE, WEATHER BUREAU

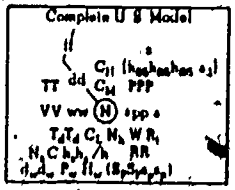
# STATION MODEL AND EXPLANATION OF WEATHER CODE FIGURES AND SYMBOLS

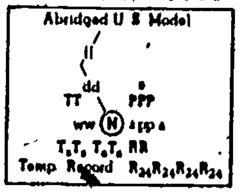



SYMBOLIC FORM OF SYNOPTIC CODE iii Nddff VVwwW PPPTT $N_hC_LhC_MC_H$ $T_dT_dapp$ $7RRR_s$ $8N_sCh_sh_s$ $9S_pS_ps_ps_p$ $Id_wd_wP_wH_w$ $2h_{es}h_{es}h_{es}e_3$ $3R_{24}R_{24}R_{24}R_{24}$ $4T_xT_xT_nT_n$ (Additional Plain Language Data)

STATION MODELS




APPENDIX A.

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6-13

5 81

# ICE OBSERVATIONS

Ice observations are made from aboard ship, from land or drifting ice stations, and from aircraft, with each type of observation offering specified information. A comprehensive description of ice conditions requires a combination of the three types of observations.

As a shipboard observer, you are in a position to examine closely the ice immediately surrounding your vessel. With this vantage you must determine accurately the texture and solidity of the ice, variations in thickness, state of deterioration, and other features requiring close contact with the ice. As a shore or ice station-based observer, you must accurately measure such features as topographic heights, thickness of ice, and depth of snow cover. Also as either a ship, shore, or aerial observer, you must be able to evaluate the observations.

Ship and shore observations are limited to small areas around the stations; therefore, the data from each observer is local in nature. The helicopter has expanded the observer's horizon, but helicopter observation is considered a tactical operation providing short-range reconnaissance.

Detailed, firsthand information provided by ship and shore observers is complemented by long-range flights of aircraft which provide information on the concentration and extent of the ice pack over great areas and of large-scale changes that may affect sea operations and shore conditions.

If possible, you should prepare sufficiently in advance of an arctic operation by obtaining pertinent publications and required training aids. A number of informative arctic exploration films issued by the U. S. Navy may be obtained on loan. Photographs illustrating various techniques used in ice observation are also available, and a number of publications containing useful information have been prepared by the Navy.

Several publications of great help in observing and reporting ice conditions include N.O. Pub. 609, "A Functional Glossary of Ice Terminology," and the World Meteorological Organization (WMO) Illustrated Ice Nomenclature soon to be published. The latter supersedes the former in most instances. However, N.O. Pub. 609 has been retained, because it contains many terms used in the U. S. which do not appear in the WMO publication. In addition, the WMO Floating Ice Nomenclature defines all terms in the Illustrated Nomenclature. The Floating Ice Nomenclature also provides foreign language equivalents for each term.

## CHARACTERISTICS OF ICE

### ICE OF LAND ORIGIN

Ice of land origin in the sea, though often spectacular, is of minor importance in arctic operations except in localized areas.

Icebergs are large masses of ice calved from the fronts of glaciers, from glacier ice tongues, or from the shelf ice of Antarctica. Smaller masses, termed bergy bits and growlers, originate, like bergs, from glaciers or are formed by the disintegration of icebergs and other masses of land-formed ice. (See figure 15.)

### ICE OF SEA ORIGIN

Certain properties of ice in the sea should be measured and recorded by ice observers. The following paragraphs describe briefly the ice characteristics that are observed and reported to the Naval Oceanographic Office.

#### Concentration

Determine the total ice concentration as well as the concentration, size, and age of various ice floes within the total ice concentration.

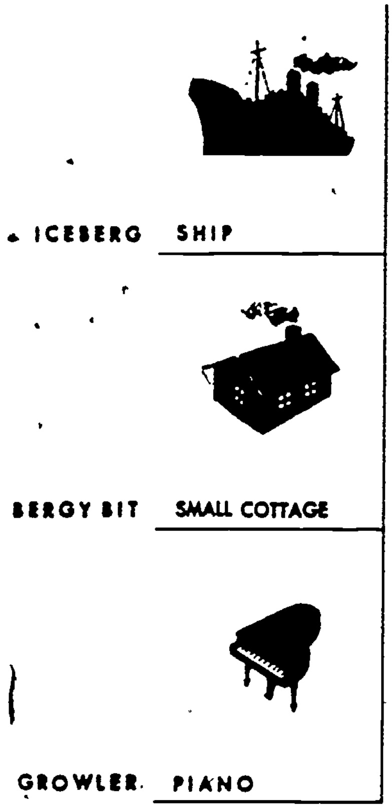


Figure 17—Relative sizes of ice masses of land origin.

(See figures 16 and 17.) All ice observers are concerned with concentration within a prescribed spot, but ship and shore observers are primarily concerned with the concentration in their immediate vicinity, and aerial observers with the concentration over large areas. Estimate concentration to the nearest eighth.

Relief and Topography

Relief is the vertical distance between the highest and lowest points on the ice. The topography, or configuration of the ice surface, is described in qualitative terms, such as rafted, flat, hummocked, etc. Heights of ice features can be estimated most accurately from the lower weather deck of a ship or from a low-flying airplane. More accurate measurements can be made by ship and shore observers on the ice.

Ice Age

Older, harder ice can be distinguished from newer, softer ice. Second-year or older ice will often appear in fields of first-year ice as a light blue island surrounded by light green or gray-blue ice. Determine all ages if more than one age is present.

Snow Cover

Ship and shore observers should estimate or measure directly the depth of the snow. Aerial observers should estimate the areal coverage of the snow.

Puddling

Puddles and frozen puddles are easily identified. Frozen puddles appear to shore and shipboard observers as greenish ground-glass patches against a lighter background. To the aerial observer, puddles beginning to freeze appear ashen gray, whereas puddles frozen solid are powder blue. To the shipboard and shore observer, puddles that have melted through the ice appear the same shade and color as open water. These puddles appear almost black to the aerial observer.

Water Features

The number, type, and orientation of water features may be determined readily for particular areas. Because ship and shore observers have a limited scope, they probably will not be able to determine the overall char[illegible]stics of distant fractures and polynyas (l[illegible]f open water other than fractures) as we[illegible]e aerial observer. Open and newly frozen features should be noted. Artificial fractures should not be considered.

Fast Ice

Any sea fresh-water ice attached to the shore by stranding or by other means is called fast ice. Glaciers fronting the sea are considered part of the land. Shore observers are best able to describe local changes in the characteristics of this ice.

Thickness of Ice

Shore and shipboard observers can accurately measure ice thickness with equipment such as

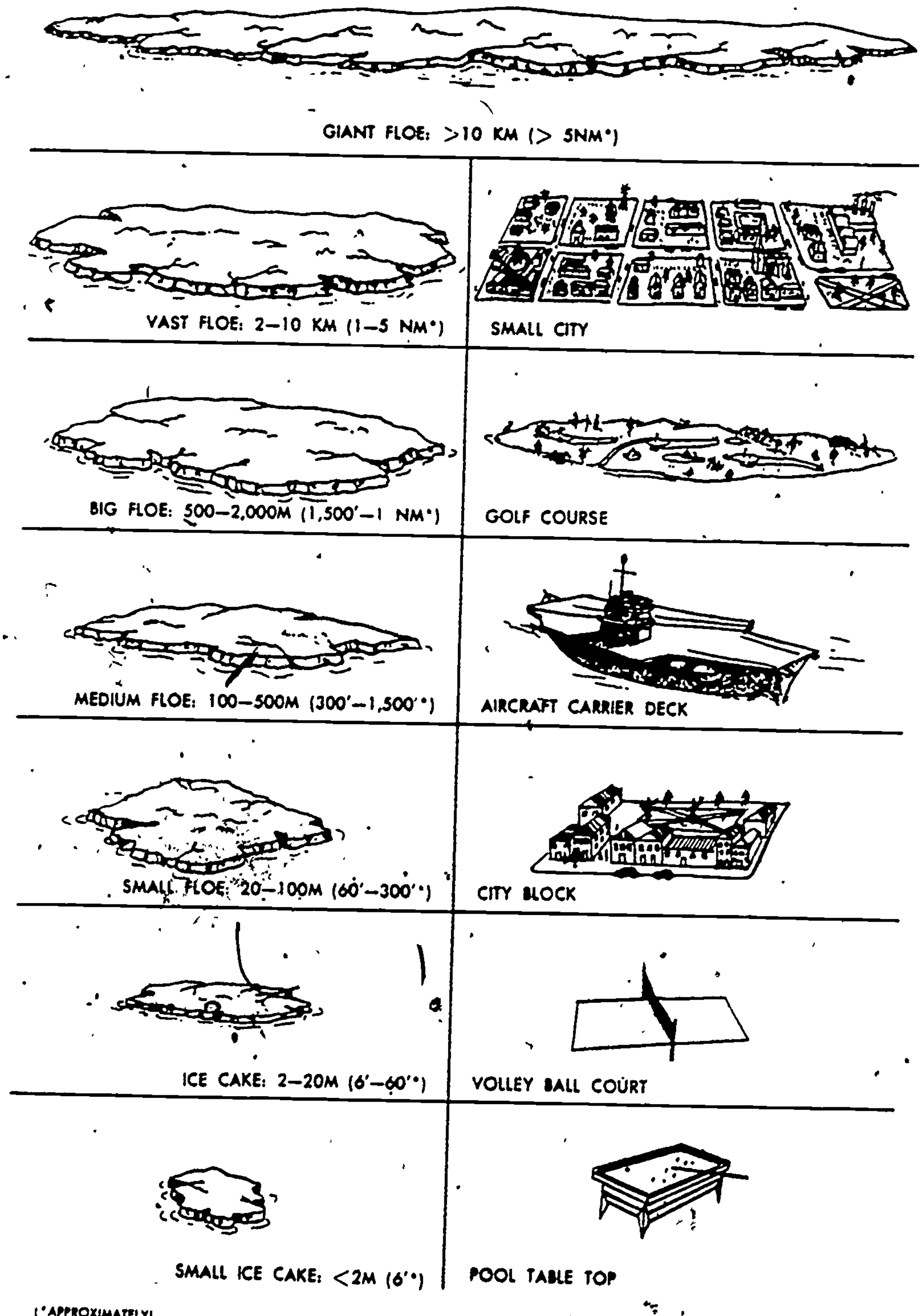


Figure 16.— Relative sizes of sea ice.

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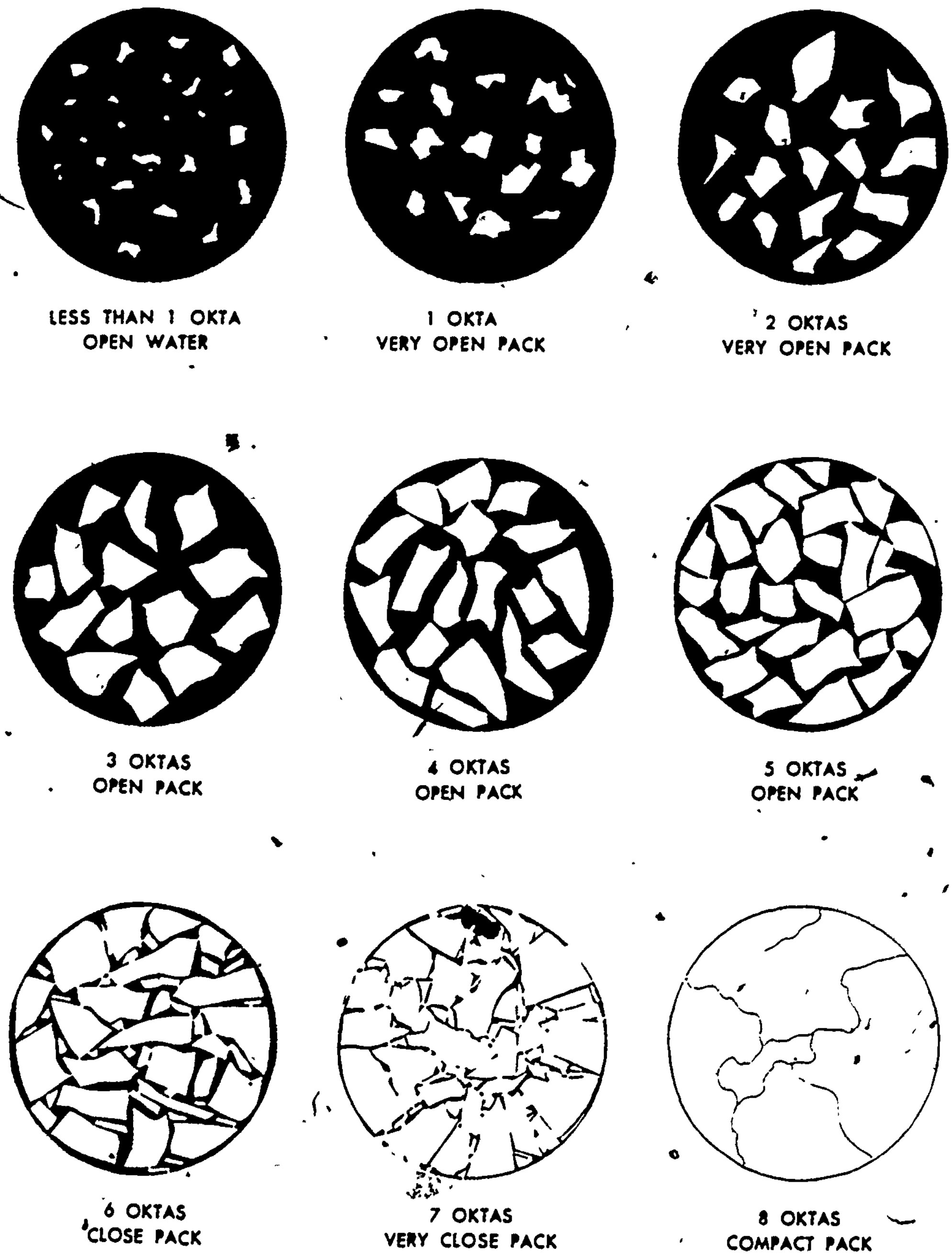


Figure 17.— Representative ice distributions for determining ice concentrations.

augers or saws. Shipboard observers can reliably estimate thickness from lower weather decks as the ice is turned on its edge by the ship. Aerial observers should not attempt to estimate ice thickness, except as it is related to age.

Ice of Land Origin

The number of bergs, bergy bits, and growlers will be determined for the given area.

ICE LOGS AND CODES

The Ship-Shore Ice Log (NAVOCEANO-EXP-3167/54) and the Aerial Observation Log (NAVOCEANO-3930/7) have been devised for coding ice information in a format tentatively adopted by the World Meteorological Organization (WMO). Since the WMO code is unified, it is usable with any observation platform when proper procedures are employed. Certain minor differences exist in the code; however, these differences are readily apparent when the proper log is used for the observation.

The WMO ice code is a numerical "spot" code (figure 18); that is, the observations depict ice conditions at a given location. A circular area of one kilometer in radius for ship and shore observation and a semicircular area two kilometers in radius for aircraft observation have been defined as the spots, and the basic observations cover ice conditions within these areas. Provision is also made for reporting ice observed outside the boundaries of the spots by use of optional groups. These optional groups are exceedingly important since they permit the observer to record large-scale features which do not fit within the spot.

The code format consists of several 5-digit information groups preceded by a message identifier group. The message-identifier groups are ICEAC, ICESH, or ICECO and are used to identify observations from aircraft, ship, or shore, respectively. Information groups consist of mandatory, supplemental, and optional groups. Mandatory groups, always reported when an observation is taken, consist of position, time, and basic ice information. Supplemental groups are always reported if the pertinent features are present. Optional groups should be reported when boundaries, water openings, and certain ice features exist outside the spot.

SHIPBOARD OBSERVATIONS AND CODES

SHIPBOARD OBSERVATIONS

Every vessel operating in the Arctic or Antarctic zones should make systematic ice observations. When you are aboard such a vessel, make observations at least every six hours when the ship is hove to or beset by ice. If overall ice conditions are changing within fairly short periods, make observations more frequently.

Study of ice from shipboard can provide reliable information concerning ice coverage within close range of the ship, such as relief, topography, age, puddling, size and orientation of water features (fractures, polynyas, etc.), and estimates of ice and snow thickness.

You can make detailed periodic observations of ice conditions regardless of the weather, whereas as an aerial observer, you must limit your study to ice areas not obscured by overcast. From the lower weather deck of a ship, you can estimate the thickness of snow and ice as the ship upends the ice. Whenever you can get onto the ice, you can make accurate measurements of ridge heights and snow and ice thickness. From the crow's-nest or the wings of the bridge, you can estimate accurately ice coverage, type of ice, and size and orientation of water features.

Ice analysts and forcasters can give better support to a ship which provides accurate ice observations. Data for arctic regions are sparse; therefore accuracy is essential. Safe and rapid passage of ships in arctic waters can be assured only if observations are taken with experience and care.

REPORTING PROCEDURES

Ice reporting codes for ship and shore-station observations are almost identical, and observing procedures are very similar. Consequently, a single log has been devised for use with both types of observations. The Ship-Shore Ice Log is a self-contained log (figure 19) complete with instructions for taking observations, encoding tables, definitions of pertinent symbols, and other required information.

Study instructional cover sheet of the Ship-Shore Ice Log carefully before commencing your observations. Preliminary preparation insures accuracy of observations and prompt receipt of information by the user.

Figure 20 illustrates a sample Ship-Shore Ice Log Instructions cover sheet; however, the two parts of the Instructions entitled "Instructions for Coding the Ice Log" and "Observation Hints" are not shown. Figure 21 shows the encoding tables of the Ship-Shore Ice Log.

# WMO SPOT ICE CODE

MANDATORY GROUPS

| | | | | | | |
|---|---|---|---|---|---|---|
| AERIAL | ICEAC | $99L_aL_aL_a$ | $Q_cL_oL_oL_oL_o$ | YYGGV | /hhhh | $CF_pC_pS_1C_1$ |
| SHIP | ICESH | $99L_aL_aL_a$ | $Q_cL_oL_oL_oL_o$ | YYGG/ | $CF_pC_pS_1C_1$ | $VI_EiD_bL_e$ |
| SHORE | ICECO | IIiii | YYGG | $T_WT_WE_tD_Ee_E$ | $CF_pC_pS_1C_1$ | $VI_EiD_bL_e$ |

SUPPLEMENTAL GROUPS

| | | | | | | |
|---|---|---|---|---|---|---|
| AERIAL / SHIP / SHORE | $2F_1C_1S_2C_2$ | $3F_eC_eS_3C_3$ | $4F_{c}C_{c}S_4C_4$ | $5F_uC_uS_5C_5$ | $6T_1T_2R_oR_h$ | $7W_fD_WE_em_s$ |

OPTIONAL GROUPS

| | | | | | |
|---|---|---|---|---|---|
| AERIAL / SHIP / SHORE | $9n_Gn_Gn_gn_g$ | 888nn | $i_zd_zd_zs_zs_z$ | $OD_zL_zL_ze_z$ | $C_zF_{pz}C_{pz}S_{1z}C_{1z}$ |

## NOTES:

1. The code names ICEAC, ICESH, and ICECO are used as a prefix to the report, indicating that it is a spot ice report from, respectively, an aircraft, a ship, or a coastal station.
2. When no ice is observed the group immediately following the date-time group in ICESH and ICECO, or the time-altitude group in ICEAC shall be coded ///// if observation was impossible due to darkness, fog, etc., and 00000 if no ice is present. If ice is observed outside the spot, report it using optional groups.
3. When ice is observed the reporting of the first five groups is mandatory. Groups with indicator figures 2 to 7 inclusive and 9 shall be included only if the related phenomena are present and observed.

Section with indicator group 888nn

This section contains information on ice conditions outside the spot. Its use is optional. Depending upon the feature which is being reported (code $i_z$), the section takes one of the following forms:

a. $i_z$ = 0, 1, or 2.

888nn $i_zd_zd_zs_zs_z$ $/d_zd_zs_zs_z$ $d_zd_zs_zs_z$ ... $C_zF_{pz}C_{pz}S_{1z}C_{1z}$

b. The group $/d_zd_zs_zs_z$ indicating the bearing and distance of the observed feature may be repeated as often as is necessary to delineate an edge or a boundary.

$i_z$ = 3 to 7 inclusive

888nn $i_zd_zd_zs_zs_z$ $OD_zL_zL_ze_z$ $C_zF_{pz}C_{pz}S_{1z}C_{1z}$

$i_z$ = 8, 9

888nn $i_zd_zd_zs_zs_z$ $OD_zL_zL_ze_z$

c. It may be necessary to report several ice or water features outside the spot. In this case the entire set of groups related to each of the respective features should be reported, the first feature being indicated by the group 88811, the second by 88822, etc.

Figure 18.— WMO Spot Ice Code.

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SHIP OBSERVATIONS — ICESH
VESSEL NAME ____
HULL TYPE AND NUMBER ____
VOYAGE FROM ____
TO ____

## U. S. NAVAL OCEANOGRAPHIC OFFICE
## SHIP-SHORE ICE LOG

SHEET NO ____
MONTH ____
YEAR ____

SHORE OBSERVATIONS — ICECO
STATION NAME ____
INTERNATIONAL INDEX NUMBER ____
SITE NUMBER ____
LOCATION ____

| Column | Table No. | Heading |
|---|---|---|
| 1 | | Message identifier: ICESH ship, ICECO shore station |
| 2 | | Ship: Indicator for moving platform |
| 3 | | Ship: Latitude in degrees and tenths |
| 4 | | Quadrant of the globe |
| 5 | | Ship: Longitude in degrees and tenths |
| 6 | | Shore: International block number |
| 7 | | Shore: International index number |
| 8 | | Date and hour in GMT (Ship / Shore) |
| 9 | | Water temperature in whole degrees Celsius |
| 10 | 19 | Type of fast ice |
| 11 | 20 | Ice drift near shore |
| 12 | 21 | Trend in behavior of ice near shore |
| | | Total concentration |
| 14 | 4 | Predominant form of ice |
| 15 | | Concentration of predominant form |
| | 5 | Predominant stage of development |
| | 3 | Concentration of the predominant stage |
| | | [illegible] |
| | 16 | Thickness of ice |
| | 17 | Depth of snow cover on the ice |
| | 14 | Water sky or ice blink |
| | 11 | Width of shore lead |
| | | Group identifier |
| | 4 | Secondary form of ice |
| | 3 | Concentration of secondary form |
| | 5 | Secondary stage of development |
| | 3 | Concentration of the secondary stage |
| | | Group identifier |
| | 4 | Tertiary form of ice |
| | 3 | Concentration of tertiary form |
| | 5 | Tertiary stage of development |
| | 3 | Concentration of the tertiary stage |
| | | Group identifier |
| | 4 | Quaternary form of ice |
| | 3 | Concentration of the quaternary form |
| | 5 | Quaternary stage of development |
| | 3 | Concentration of the quaternary stage |
| | | Group identifier |
| | 4 | Quintary form of ice |
| | 3 | Concentration of the quintary form |
| | | Quintary stage of development |
| | | Concentration of the quintary stage |
| | | Group identifier |
| | 6 | Primary type of topography |
| | 6 | Secondary type of topography |
| | 7 | Extent of [illegible] |
| | 2 | Maximum [illegible] |
| | | Group identifier |
| | 9 | Type of opening in the ice |
| | 10 | Orientation of water feature reported in $W_r$ |
| | 11 | Extent of fast ice |
| | 12 | Stage of melting |
| | | Group identifier |
| 54 | 13 | Number of growlers and bergy bits |
| 55 | 13 | Number of icebergs |
| 56 | | Identifier for optional groups |
| 57 | | (Used to differentiate several features) First is 88811, second 88522, etc. |
| | 14 | Indicator for ice or water features outside the spot |
| 59 | | True bearing to ice or water feature in tens of degrees |
| 60 | | Distance to the ice or water feature in kilometres |
| | | Group identifier |
| 62 | 10 | Orientation of the ice or water feature indicated by |
| 63 | | Length of the ice or water feature in kilometers |
| | 15 | Width of the ice or water feature |
| | | Total concentration in feature described in |
| | 4 | Predominant form of ice in feature described by |
| | 3 | Concentration of predominant form described by |
| | 5 | Predominant stage of development described by |
| | 3 | Concentration of predominant stage of development |
| 70 | | Date time group of message in GMT |

NAVOCEANO EXP 3167 54 (REV 2 69)

Figure 19.— Ship-Shore Ice Log.

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# SHIP-SHORE ICE LOG INSTRUCTIONS

## GENERAL

The Ship-Shore Ice Log is designed to serve both as a basic data recording sheet for ice observers and as a guide for the transmission of coded ice messages. The completed form is essential to the data control program of the U.S. Naval Oceanographic Office. Be sure to fill in all pertinent items on this form. Instructions for filling in this form and for transmittal of messages can be found below. Other pertinent information is found in The WMO Floating Ice Nomenclature and the WMO Illustrated Ice Nomenclature, soon to be published.

## DISPOSITION OF RECORDS

1. Shore Station. Mail the completed log sheets monthly to the National Oceanographic Data Center, Washington, D.C. 20390.

2. Ship Station. Completed log sheets will be mailed, after entering port, to the National Oceanographic Data Center, Washington, D.C. 20390.

## RADIO MESSAGE REPORTS

1. Shore Station. Following the observation, the ice message will be transmitted to NAVOCEANO, WASH., D.C.

2. Ship Station. Following the observation, the ice message will be transmitted to the appropriate Fleet Weather Central or Fleet Weather Facility, and to NAVOCEANO, WASH., D.C.

3. Ship Helicopter Reports. The observation will be transmitted when the helicopter arrives back at the ship. It will be considered a special observation and will be followed by the letters HLCPTR in the radio message.

4. Column 70 of the log will not be transmitted.

5. Columns 1 through 17 of the log are mandatory and will always be transmitted.

6. Columns 18 through 52 of the log are supplemental and will always be transmitted when the feature is observed.

7. Columns 53 through 69 are optional groups and are transmitted only if indicated phenomena outside the spot can be observed. As many of these groups should be sent as are necessary to describe the ice conditions.

## REQUISITION OF FORMS

Ship-Shore Ice Log forms may be requisitioned as follows:

1. Naval activities in the Atlantic Area (including the Gulf of Mexico, Panama Canal Zone, European and Mediterranean Area) should submit orders on Form DD-1149 to the Oceanographic Distribution Office, U.S. Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.

2. Naval activities in the Pacific Area (including the Alaskan and Antarctic Areas) should submit orders on Form DD-1149 to the Officer in Charge, U.S. Naval Oceanographic Distribution Office, Clearfield, Utah 84015.

3. Other agencies may obtain ship-shore ice log forms from the National Oceanographic Data Center, Washington, D.C. 20390.

## INSTRUCTIONS

1. General

The observer should become fully acquainted with the WMO Ice Nomenclature, which can be found in Pub. No. 606d. Since each observation can make a valuable contribution to the present knowledge of ice, it should be made carefully and thoroughly. Only those conditions present at the time of the observation will be reported. Mandatory and supplemental ice groups will be reported within a one-kilometer radius of the observer. See figure A.

### LIMITS FOR REPORTING THE VARIOUS GROUPS ON THE ICE LOG

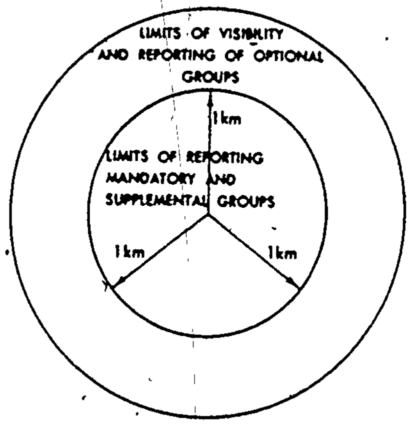
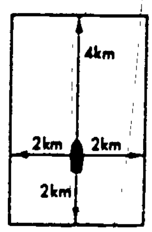



FIGURE A

The observer will report any optional group seen within the limits of visibility (e.g., the ice edge when surrounded by fairly open water or a polynya or pool when in close ice). See figure A. Visibility is defined as the horizontal distance at which prominent objects can be seen and positively identified by the unaided eye. See figure B.

### HOW TO REPORT VISIBILITY




AVERAGE VISIBILITY

$$= \frac{4+2+2+2}{4}$$

$= 2.5$km

or code 5 of table 2

FIGURE B

If the observer is located in a lead or polynya in which the nearest ice boundary is greater than a distance of 700m, report the total concentration (CT) of the ice within the lead or polynya. See figure C. If the nearest ice boundary is less than a distance of 700m, report the total concentration within the one-kilometer radius. See figure D. In both instances, report the polynya or lead as an optional group with bearing and distance both recorded as zero.

Figure 20 (cut apart)

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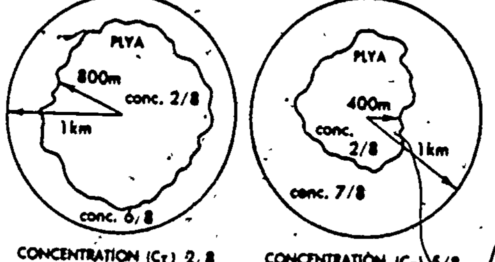
REPORTING CONCENTRATION
WHEN LOCATED WITHIN A POLYNYA




CONCENTRATION ($C_T$) 2/8
FIGURE C

CONCENTRATION ($C_T$) 5/8
FIGURE D

Follow with optional groups as required to describe all optional features present. Optional groups near the horizon cannot be accurately estimated and should be ignored. When located in ice-free water but within visible limits of an ice edge or a boundary, report several optional groups. If it is necessary to use more than one set of optional groups continue on the line directly below, using the appropriate columns.

If radar is available use radar bearings and distances to the ice edge whenever possible. Radar observations are especially valuable if darkness or visibility restrictions make visual observation difficult or impossible.

Columns 2 through 5 will be reported only by ship stations or operating locations without index numbers. Columns 6, 7, and 9 through 12 will be reported only by shore stations. Note that column 8 is reported differently for ship and shore stations.

If no ice is observed within the one-kilometer circle the indicator and location groups will be sent followed by columns 13 through 17, coded 0. Any remaining groups reported will be optional groups describing ice features outside of the one-km area. If no ice is observed because of darkness or poor visibility, columns 13 through 17 will be coded /. In both cases, if radar is available, optional groups based on radarscope interpretation can be sent.

Codes were designed to be used separately from meteorological observations. If, however, it is desired to append the ice data to a meteorological observation of any type, the appropriate indicator group, ICESH or ICECO, should follow the weather report followed immediately by the ice data, omitting the indicator and location groups.

2. Ship Station

Shipboard observers will make an ice observation at the time the ice edge is first seen; subsequently, an ice observation will be taken four times daily at 00Z, 06Z, 12Z, and 18Z while operating in the ice or in view of the ice boundary. One vessel from each convoy will make the ice observation. Additionally, any ship or group of ships separated from the convoy or any ship navigating the ice alone will initiate an observing program. While at sea, the ice observations will be made at the scheduled times regardless of the headway being made. Helicopter reports will be considered as a special shipboard observation. The latitude and longitude of a helicopter observation are particularly important.

3. Shore Station

Shore station observers will make an ice observation four times daily at 00Z, 06Z, 12Z, and 18Z. Columns 2 through 5 will not be reported by shore stations except when reporting for an operating location which has not been assigned an international index number. These stations will be treated as ships.

4. Special Observations — Ship and Shore

An additional observation will be made when any of the following changes occur:

a. Change of 2/8 in total ice concentration.

b. Change in table 3A from any one of the following five groups to any other:

| | | | |
|---|---|---|---|
| 1 | Code 0, 1, 2 | 2. | Code 3, 4, 5 |
| 3 | Code 6 | 4 | Code 7, 8 |
| 5. | Code 9 | | |

c. Change in table 4 of any one of the following four groups to any other:

| | | | |
|---|---|---|---|
| 1. | Code 0, 1, 2, 3 | 2. | Code 4, 5 |
| 3 | Code 6, 7, 8 | 4. | Code 9 |

d. Change in table 5 of any one of the following four groups to any other:

| | | | |
|---|---|---|---|
| 1 | Code 0, 1, 2 | 2. | Code 3, 4 |
| 3 | Code 5, 6, 7 | 4 | Code 8, 9 |

e. Change in table 7 of any one of the following three groups to any other:

| | | | |
|---|---|---|---|
| 1. | Code 0, 1, 2, 8 | 2. | Code 3, 4, 5, 6, 7 |
| 3. | Code 9 | | |

f. Change in table 11 of any one of the following five groups to any other:

| | | | |
|---|---|---|---|
| 1. | Code 0 | 2. | Code 1, 2 |
| 3 | Code 3, 4 | 4. | Code 5, 6 |
| 5. | Code 7, 8 | | |

Figure 20.— Ship-Shore Ice Log Instructions.



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(1)
QUADRANT OF THE GLOBE
(Qc)

| | Latitude | Longitude |
|---|---|---|
| 1) | North | East |
| 3) | South | East |
| 5) | South | West |
| 7) | North | West |

(2)
VISIBILITY
(V)

0) 50m
1) 50— 200m
2) 200— 500m
3) 500— 1,000m
4) 1— 2km
5) 2— 4km
6) 4— 10km
7) 10— 20km
8) 20— 50km
9) 50 or more km

(3)
CONCENTRATION
($C_p$, $C_1$, $C_s$, $C_2$, $C_e$, $C_3$, $C_q$, $C_4$, $C_u$, $C_5$, $C_{p2}$, $C_{1z}$)

0) ½ okta
1) 1 okta
2) 2 oktas
3) 3 oktas
4) 4 oktas
5) 5 oktas
6) 6 oktas
7) 7 oktas
8) 8 oktas with openings
9) 8 oktas without openings
/) Undetermined

(3A)
CONCENTRATION
(C, $C_2$)

0) No ice
1) 1 okta
2) 2 oktas
3) 3 oktas
4) 4 oktas
5) 5 oktas
6) 6 oktas
7) 7 oktas
8) 8 oktas with openings
9) 8 oktas without openings
/) Undetermined

(4)
FORMS OF ICE
($F_p$, $F_s$, $F_e$, $F_q$, $F_u$, $F_{p2}$).

0) No form of ice
1) New ice, nilas
2) Pancake ice
3) Brash ice, small ice cakes, ice cakes
4) Small ice floes
5) Medium ice floes
6) Big ice floes
7) Vast ice floes
8) Giant ice floes
9) Fast ice
/) Undetermined or unknown

(5)
STAGES OF DEVELOPMENT
($S_1$, $S_2$, $S_3$, $S_4$, $S_5$, $S_{1z}$)

0) No stage of development
1) Frazil ice, grease ice, slush, shuga
2) Ice rind, dark nilas, light nilas
3) Gray ice
4) Gray-white ice
5) Thin first-year ice
6) Medium first-year ice
7) Thick first-year ice
8) Second-year ice
9) Multi-year ices
/) Undetermined or unknown

(6)
TOPOGRAPHY
($T_1$, $T_2$)

0) Level ice
1) Rafted ice
2) Finger-rafted ice
3) Hummocks
4) New ridges
5) Weathered ridges
6) Very weathered ridges
7) Aged ridges
8) Consolidated ridges
9) Standing floe
/) Undetermined or unknown

(7)
EXTENT OF RIDGING
($R_e$)

0) No ridging
1) 1/10—2/10
2) 3/10
3) 4 10
4) 5 10
5) 6 10
6) 7/10
7) 8/10
8) 9/10
9) 10/10
/) Undetermined or unknown

(8)
MAXIMUM HEIGHT OF RIDGING
($R_h$)

0) 0—1 meter
1) 2 meters
2) 3 meters
3) 4 meters
4) 5 meters
5) 6 meters
6) 7 meters
7) 8 meters
8) 9 meters
9) 10 or more meters
/) Undetermined or unknown

Figure 21 (cut apart)

(9)

TYPE OF OPENING IN THE ICE

($W_t$)

0) No openings
1) Crack
2) Very small fracture (0-50m)
3) Small fracture (50-200m)
4) Medium fracture (200-500m)
5) Large fracture ( >500m)
6) Lead, flaw lead
7) Polynya, shore polynya, flaw polynya
8) Recurring polynya
9) Open water
) Undetermined or unknown

(10)

ORIENTATION

($D_W$) ($D_z$)

0) No distinct orientation
1) Major axis of feature oriented N-S
2) Oriented NE-SW
3) Oriented E-W
4) Oriented SE-NW
5) Parallels shore to N
6) Parallels shore to E
7) Parallels shore to S
8) Parallels shore to W
) Undetermined or unknown

(11)

EXTENT OF FAST ICE

($E_e$)

WIDTH OF SHORE LEAD

($L_e$)

0) Not present
1) 100m
2) 100— 1km
3) 1— 2km
4) 2— 5km
5) 5— 10km
6) 10— 30km
7) 30— 50km
8) 50— 100km
9) 100 or more km
) Undetermined or unknown

(12)

STAGE OF MELTING

($m_s$)

0) No melting
1) Few puddles
2) Many puddles
3) Many puddles with few thawing holes
4) Many puddles with many thawing holes
5) Thawing holes without puddles
6) Dried ice
7) Rotten ice
8) Flooded ice
9) Brash ice formed by melting
) Undetermined or unknown

(13)

ICE OF LAND ORIGIN GROWLERS AND BERGY BITS

($n_G n_G$)

ICE BERGS

($n_B n_B$)

| | | | |
|---|---|---|---|
| 00) | None | 13) | 13 |
| 01) | 1 | 14) | 14 |
| 02) | 2 | 15) | 15 |
| 03) | 3 | 16) | 16 |
| 04) | 4 | 17) | 17 |
| 05) | 5 | 18) | 18 |
| 06) | 6 | 19) | 19 |
| 07) | 7 | 20) | 20 |
| 08) | 8 | 21) | 21—50 |
| 09) | 9 | 22) | 51—100 |
| 10) | 10 | 23) | 101—200 |
| 11) | 11 | 24) | 201—500 |
| 12) | 12 | 25) | 500 |

(14)

INDICATOR FOR ICE WATER FEATURE

($i_z$)

0) Ice edge
1) Concentration boundary
2) Fast ice edge, fast ice boundary
3) Lead
4) Polynya
5) Belt
6) Patch
7) Field
8) Ridge zone
9) Fracture zone
/) Not reported

(15)

WIDTH

($e_z$)

0) 50m
1) 50— 100m
2) 100— 200m
3) 200— 500m
4) 500— 1,000m
5) 1— 2km
6) 2— 5km
7) 5— 10km
8) 10— 50km
9) 50 or more km
/) Undetermined or unknown

(16)

THICKNESS OF ICE

($t_E$)

0) < 5cm
1) 5—< 10cm
2) 10—< 20cm
3) 20—< 30cm
4) 30— 40cm
5) 40—< 60cm
6) 60—< 90cm
7) 90—< 150cm
8) 1.5—< 2.5 meters
9) >2.5 meters
/) Undetermined or unknown

(17)

DEPTH OF SNOW

(s)

0) Bare ice or trace
1) < 2cm
2) 2—< 5cm
3) 5—< 10cm
4) 10—< 15cm
5) 15—< 25cm
6) 25—< 50cm
7) 50—< 100cm
8) 100—< 200cm
9) 200 or more cm
/) Undetermined or unknown

(18)

WATER SKY OR ICE BLINK

($D_b$)

0) Not present
1) Ice Blink to N
2) Ice Blink to E
3) Ice Blink to S
4) Ice Blink to W
5) Water Sky to N
6) Water Sky to E
7) Water Sky to S
8) Water Sky to W
9) Frost smoke
/) Undetermined or unknown

(19)

TYPE OF FAST ICE

($E_t$)

0) No fast ice
1) Young coastal ice
2) Young fast ice
3) First-year fast ice
4) Second-year fast ice
5) Multi-year fast ice
6) Ice foot
7) Grounded ice
8) Stranded ice
9) Grounded hummock
/) Undetermined or unknown

(20)

ICE DRIFT NEAR SHORE

($D_E$)

0) No ice drift
1) Ice drift to N
2) Ice drift to NE
3) Ice drift to E
4) Ice drift to SE
5) Ice drift to S
6) Ice drift to SW
7) Ice drift to W
8) Ice drift to NW
9) All ice motionless
/) Undetermined or unknown

(21)

TREND IN BEHAVIOR OF ICE NEAR SHORE

($a_E$)

0) No change
1) Ice situation improving (for navigation)
2) Ice situation worsening (for navigation)
3) Ice breaking up
4) Ice opening or drifting away
5) Ice increasing
6) Ice freezing together
7) Ice drifting in
8) Ice under pressure
9) Ice hummocking or screwing
/) Undetermined or unknown

Figure 21.— Encoding Tables of the Ship-Shore Ice Log.

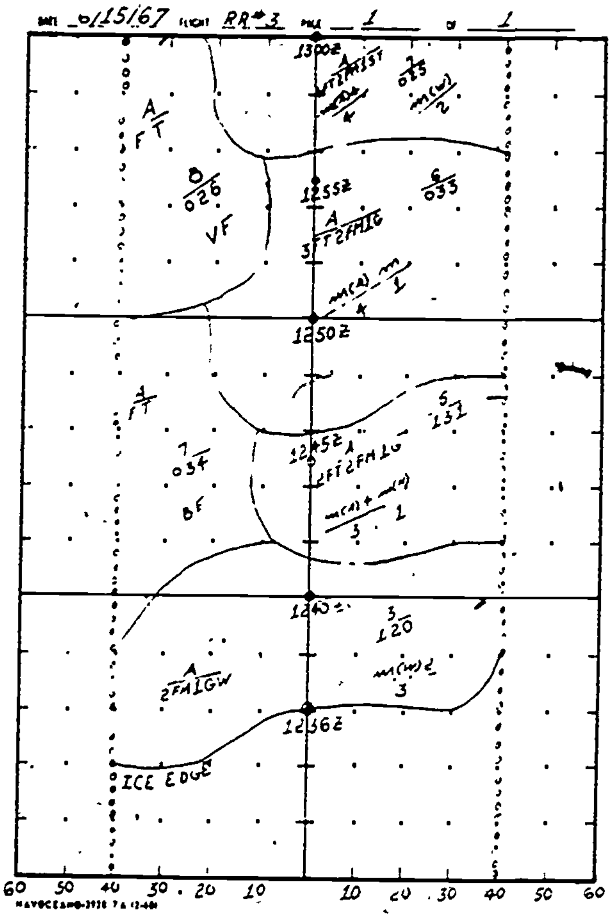
## AIRCRAFT ICE RECON PLOT AND MESSAGE

Spot observations on the flight track will be made when an aircraft first comes over the ice and at 5-minute intervals past the hour, e.g., 1235, 1240, 1245, 1250, etc. Optional groups at the end of each observation describe features such as ice edges, concentration boundaries, and fracture zones located outside the spot. The observations will be taken when the aircraft is over ice or near enough to ice to report it in some part of the code.

NAVOCEANO form 3930/7 is used for recording aerial ice observations. The observer records ice conditions numerically and graphically on an Ice Plotting Grid, NAVOCEANO form 3930/7A (2-68), and subsequently transposes these observations into the coded ICEAC format. Detail A of figure 23 illustrates a completed Ice Plotting Grid, and detail B shows how this plot has been coded into the ICEAC message format. Messages are usually terminated with track flown, total flight time, date, and observer's names.

The Ice Plotting Grid is used to maintain a constant plot of ice features which the observer deems significant. (A key to ice symbols used in plotting ice features is given in figure 24.) The plot can be used to encode optional groups in NAVOCEANO form 3930/7.

Figure 22.— Aerial view of pack ice.




FM THULE AB

TO NAVOCEANO WASH DC

BT

UNCLAS

ICEAC

99733 70600 15128 /3612 34262 23141 65021 79001 88811 02540 /2422 /0000 /0922 /0840

99736 70600 15128 /4012 34262 23141 65021 79001 88822 12540 /3317 /0213 /0743

99739 70600 15128 /4512 55272 26162 34131 43100 67433

79002 91017 88833 12122 /3113 /3224 /3339 /3148 76577 88844 13113 /0417 /0645

99742 70600 15128 /5012 66273 25262 37131 44100 67333 79001 91121

99745 70600 15128 /5512 66273 25262 37131 44100 67333 79001 91722 88855 12141 /2122 /3009 /3119 /3340 87678 88866 13009 /0619 /0840

99748 70600 15138 /0012 77374 25262 38181 46100 67553 79001 92121

FLT SONDRESTROM TO THULE 6 PT 3 15 JUNE HYYTINEN ZUEHLS

Figure 23.— (A) Ice Plotting Grid; (B) sample ICEAC message.

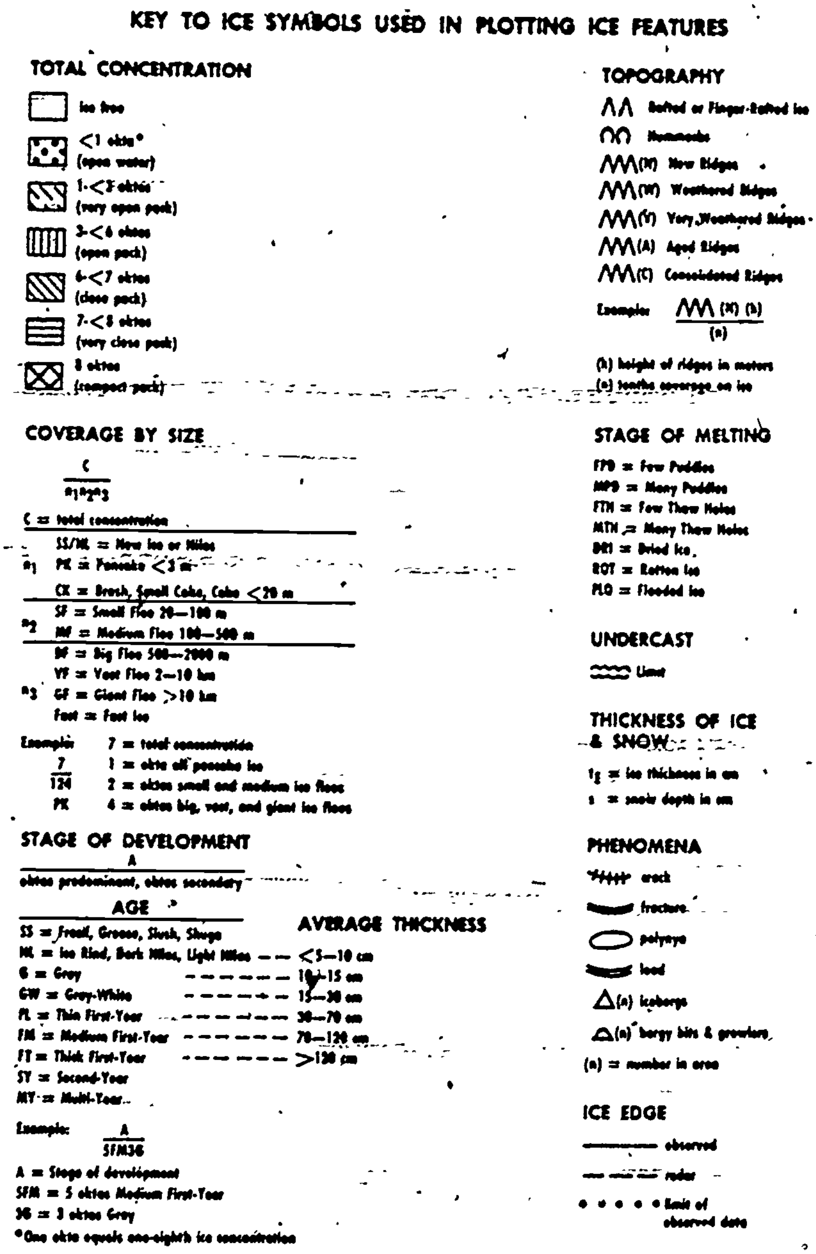



Figure 24.— Key to ice symbols in plotting ice features.

# BATHYTHERMOGRAPH OBSERVATIONS

## THE MECHANICAL BATHYTHERMOGRAPH

The mechanical bathythermograph (figure 25), which is commonly referred to as the bathythermograph or BT, is an instrument for obtaining a record of the temperature of sea water at moderate depths. The BT is lowered into the sea and retrieved by means of a wire rope. It can be operated while the ship is underway at speeds up to 18 knots. It works more satisfactorily, however, at speeds of 12 knots or less.

### Equipment Needed to Operate the BT

In addition to the BT, the following pieces of equipment are required to operate the instrument:

1. A BT winch. Examples of winches include: The E6/S Winch and the ACCO Equipment Division Winch.

2. A BT boom.

3. A BT towing block, counterbalanced.

4. Wire rope, 3/32-inch diameter, 7 x 7 stainless steel, in 3,000-foot length per reel.

5. A grid mount assembly.

6. Metallic-coated glass slides.

7. A slide viewer.

8. A thermometer for measuring surface water temperature.

9. Tools (8-inch pliers, medium screwdriver, and a 3/32-inch Nicopress).

10. Nicopress sleeves, thimbles, swivels, wire clips, and shackles.

One other tool, which is not essential but is always handy if the wire should jump the block sheave or backlash, is a cable-grip (come-along).

### Recording BT Data

BT data is recorded on the National Oceanographic Data Center Bathythermograph Log, NODC-EXP-3167/10 (Rev. 6-70). This log is designed to provide NODC with information required for BT analog and digital processing and to provide a standard message format for radio transmission of synoptic BT data for automatic data processing. Instructions for completing the items on the Bathythermograph Log are printed inside the cover of each pad of log sheets. Later in this section of the pamphlet, we will consider these instructions in greater detail.

### Taking a BT

Making a BT lowering is described by the phrase "Taking a BT." It is a relatively simple operation; nevertheless, a new operator should practice lowerings and recoveries with a dummy BT before undertaking the lowering with an actual instrument.

Certain operations are necessary to assure that good data is obtained. Taking a BT includes the following procedures:

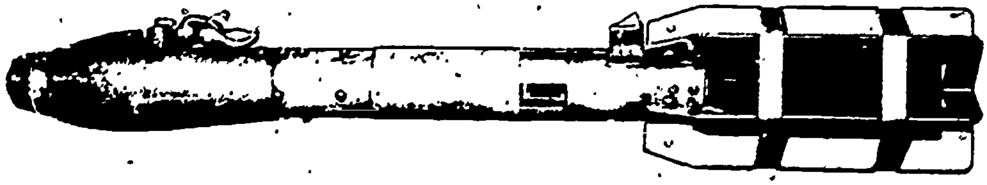


Figure 25.—The Bathythermograph (BT).

Step 1. Checking the operating instruction manual for the model winch to be used.—The hand lever on the E6/S winch serves both as a brake and clutch. It has three positions: (1) When it is vertical, the winch is in neutral and the drum can be turned in either direction; (2) When it is pushed outboard to the engaged (hoist) position, the motor turns the drum and spools on the wire; (3) When the lever is pulled inboard toward the operator, to the brake position, the drum is locked and cannot be rotated. On other models the operation is different. The operating lever and the brake are separate.

Examine the winch installation to assure that the wire comes across the top of the drum. Run the free end of the wire through the towing block at the end of the boom. This block is of a special counterbalanced design for BT use. Make certain that the winch drum and block are properly lubricated.

Step 2. Connecting the BT to the Lowering Wire.—Cut off rusted, kinked, or frayed wire and make a new connection using a thimble with three Nicopress sleeves or wire clips. Check the swivel and if the BT does not have a built-in swivel, include one in the connection. Connect the lowering wire thimble to the BT swivel with a shackle. NOTE: More BT's are lost by poor connections than from any other cause.

Another important precautionary measure is to paint the last 50 feet of the BT wire a bright color. This will signal the operator during retrieval to be on the immediate lookout for the BT, preventing accidental "two-blocking" and loss of the instrument. It is unwise to trust the counter dial on any BT winch.

Step 3. Inserting the Slide in the BT.— It is important that the slide is inserted in the BT properly.

Slide the BT sleeve forward toward the BT nose (figure 26). This will uncover the stylus assembly and slide holder. Hold the slide between the thumb and index finger with coated side up. Insert the slide into the hole on the side of the BT and push the slide into its bracket. The edge of the slide with the beveled corner goes in first, with bevel towards the nose of the BT.

Push the slide all the way in. Occasionally check the grooves of the slide holder to make sure they are clean and free of glass chips. Also, check the spring to assure that the slide is being held firmly in position.

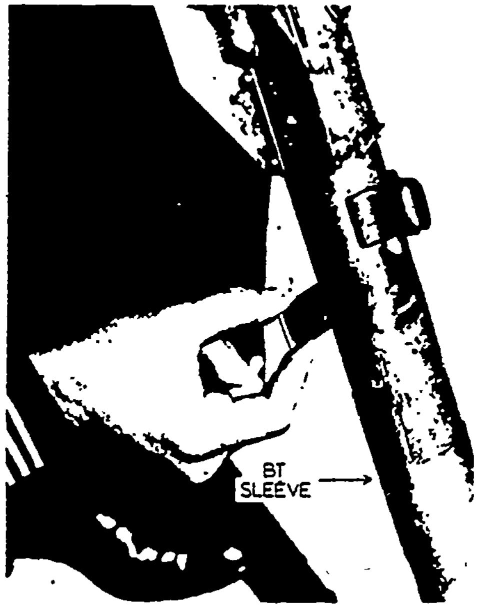


Figure 26.— Inserting glass slide into BT.

Move the sleeve back to cover the opening prior to putting the BT over the side. This will bring the stylus assembly in contact with the glass slide.

Step 4. Putting the BT Over the Side.— After obtaining permission from the bridge, you can put the BT over the side.

Hold the BT at the rail; take up the slack wire.

Lower the BT into the water to such a depth that it rides smoothly just below the surface.

Put on the brake and hold the BT at this depth for at least 30 seconds to enable the thermal element to come to the temperature of the surface water.

Turn on the motors so that power is available instantly for the rest of the operation.

Set the counter on the winch to zero.

Step 5. Taking the Sea Surface Reference Temperature.—While towing the BT at the surface, take the sea surface reference temperature.

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Use any reliable thermometer. The most common method of obtaining the temperature is to collect a bucket of surface water, immediately immerse the thermometer in the water, stir the thermometer with a circular motion, and read the thermometer with the stem still immersed in the water. Make several readings to assure a valid observation.

Record the sea surface reference temperature on the Bathythermograph Log.

Step 6. Lowering the BT.—After you have taken the sea surface reference temperature, lower the BT. Have a round stick about 15 inches long to use to control the speed of the drum.

The following instructions apply to underway lowering:

CHECK THE DEPTH OF WATER JUST BEFORE MAKING EACH LOWERING.

Release the brake, and allow the wire to pay out freely. Success in reaching the maximum desired depth depends on paying out the wire as quickly as possible.

Watch the wire and the drum carefully and gently slow the drum with the stick if excessive slack appears. Do not apply too much pressure to the drum with the stick. Once the diving motion of the BT is arrested, it will not dive deeper regardless of the amount of wire payed out.

The proper amount of wire to be payed out will depend upon the speed of the ship, the type of BT, whether or not the nose sleeve is attached, and the operator's experience. Make several lowerings to obtain the ship-speed/wire-out ratio to use for your BT.

Stop the winch when the counter indicates the proper length of wire has been payed out. Apply the brake smoothly; avoid excessive jerk, because it may part the wire. NOTE: Never pay out the last layer of wire on the drum.

Step 7. Retrieving the BT.—As soon as the brake is applied, the BT will stop diving and return to the surface far astern.

Haul in the BT at full speed. Guide the wire back and forth in even layers on the drum. If the winch does not have a level wind, use the wooden stick for proper spooling.

Decrease the winch speed when the BT is close astern. Continue to haul in until the BT begins to porpoise (breaking clear of the surface and swinging forward as the ship rolls or as wave crests pass). NOTE: This is the most critical point in the operation. To bring the BT along-side and raise it without too much swing requires practice.

Stop the winch with the BT 2 or 3 feet from the towing block. If the BT skips or swings forward of the boom, allow the BT to sink freely until it has passed clear astern, and try again.

Turn off the winch motor and commence bringing the BT aboard. The BT can be brought aboard in various ways, depending on how the boom is rigged. With the standard gate boom, the use of a retrieving line and ring is recommended. This consists of a metal ring an inch and a half in diameter through which the wire is passed between the towing block and the BT. The ring is attached to a retrieving line which is secured to the lifeline or rail. With the proper amount of slack, the ring will ride freely when the BT is being lowered and retrieved. By hauling in on the retrieving line while easing the brake, the BT can be brought to hand.

Step 8. Removing the BT Slide.—As soon as the BT is in hand, slack off the wire, set the brake, and remove the BT slide in the following manner:

Move the sleeve forward toward the BT nose to lift the stylus off the slide. Partially eject the slide by pushing against its edge with the forefinger, or a pencil, through the slide-ejecting port.

Carefully, grip the slide by the thumb and forefinger (figure 27) holding the slide only by the edges. Be careful not to obscure the trace with smudges or fingerprints.

Place the BT in its deck rack, and notify the bridge that the BT is on deck.

Step 9. Securing the Equipment.— If another lowering is to be made soon and there is no danger of overheating the BT, you may leave the BT in the deck rack connected to the wire; otherwise, unshackle it and stow it in a cool place. CAUTION: Never let the temperature of the BT exceed 105°F. (40.56°C). If this temperature is exceeded, the insturment will be damaged and the calibration will be invalid. Never leave the BT on deck without protection from hot sun. Suitable protection to the thermal element can be afforded by keeping the BT covered with wet cloths.

Figure 27.— Holding the BT slide.

Step 10. Labeling the BT Slide.—As soon as you remove the BT slide from the BT, examine it to be sure that a suitable trace has been obtained. With a sharp instrument or pencil, write the following information on the slide, being careful not to obscure or touch the temperature-depth trace (figure 28).

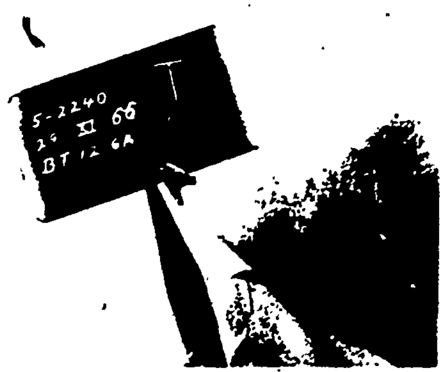


Figure 28.— Labeling the BT slide.

Slide number and time group. Number the slides consecutively. Use Greenwich Mean Time (0000 to 2359), giving the hour and minute at which the BT entered the water. Enter a dash between slide number and time. Slide number five taken at 2240 is marked: 5-2240.

Day, month, and year. Use Roman numerals for the month. 29 November 1966 is written: 29-XI-66.

BT instrument serial number. The serial number of the BT is stamped near the nose of the instrument. This number is very important, as each BT has a calibrated grid, a duplicate of which is on file at the laboratory that will process the slide. Without the proper serial number, the information on your slide is valueless. Include any letter which precedes or follows the serial numbers; e.g., BT A-1257 or BT-1216A.

Always enter the information on the slide in the order given above. Avoid the temptation to improve an apparently faint trace by enlarging or tracing over it at the time you enter the data. The processing laboratory can copy an actual trace, however faint, by the delicate photographic processes it uses, but a retouched trace will invariably be detected and rejected. After you label the slide, rinse it in fresh water, read it, and record the data on the Bathythermograph Log.

Reading the BT Slide

The BT grid (figure 29) is connected to a magnifying grid mount viewer which facilitates holding and reading the BT slide.

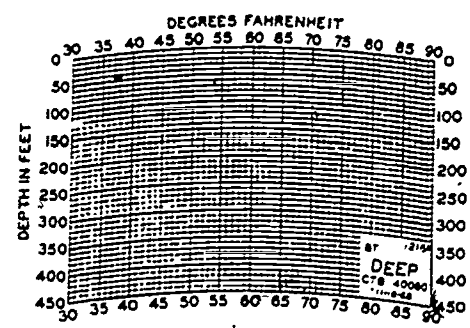


Figure 29.— BT grid.

Clean the grid with a ~~cloth or~~ tissue. Place the slide in the viewer with the coated surface toward the grid and the beveled edge toward the set screw. Gently push the slide down against the spring and into place so the coated surface lies flat against the grid and snugly against the set screw.

To remove the slide from the grid, depress the spring to loosen the slide from the grid mount.

The trace scratched by the stylus is a temperature-depth record. Each point on the trace represents a value of temperature and depth which can be read off the appropriate line of the grid. The lines on the grid are established by actual test of the instrument. Each BT has its own grid for converting the stylus trace to temperature and depth readings. These grids are not interchangeable between instruments. Serial numbers of both grid and BT must agree. Read the surface temperature from the BT slide by noting the temperature of the point at which the trace starts downward from the surface. Read temperatures to tenths of a degree and depth to within 10 feet.

Storing and Shipping BT Slides

At the end of each calendar month or at the end of a cruise, mail the log sheets along with the slides in accordance with COMDTINST 3161.1 series.

To protect your slides, proceed as follows:

1. Replace slides in issue box.

2. Put no material between slides.

3. Pad top of slides (use issue pad) before replacing cover.

4. Paste on standard mailing label NODC 3167/11* (9-61), giving ship's name, date(s) of cruise, and BT log sheet number.

5. Pad box well and pack in cardboard box.

6. Wrap securely and label clearly, repeating information in item 4.

7. Fold and staple the bathythermograph log so that the mailing format printed on the reverse side is displayed.

8. Mail BT slides and log sheets to:

National Oceanographic Data Center
Washington, D.C. 20390 U.S.A.

All grids from BT's lost during operations at sea shall be forwarded to the NODC on return to port or at the end of a survey cruise.

BT Maintenance

The BT requires very little maintenance, but careful handling is essential to maintain the accuracy of the delicate internal mechanisms.

After survey operations, rinse the BT with fresh water. Never store a BT that is being withdrawn from use without thoroughly rinsing it.

Do not disassemble the BT. It is a precision instrument with delicate internal mechanisms, and even with the greatest care possible it is difficult to avoid damage if disassembling is attempted aboard ship. If for any reason the BT fails to operate satisfactorily, turn it in for repair with a report indicating the symptoms to aid the repair facility in correcting the trouble.

Procurement and replacement instructions for the procurement and replacement of bathythermographs and associated equipment are found in paragraph 3B17045, Comptroller Manual.

Malfunctions

The BT normally is a very reliable instrument; however, you, as the operator should be alert to several common malfunctions. Shocks which occur to the instrument during the handling and lowering may cause hysteresis, temperature error, and/or depth error.

Hysteresis.—The stylus scratches its trace while the BT is diving and as it rises to the surface. Water conditions where it dives may be slightly different from where it rises. These conditions are usually negligible; however, the instrument may have hysteresis; i.e., there may be a slight lag in the movement of its thermal and depth elements. If the up and down traces are essentially similar, a slight divergence of the traces is immaterial. If the traces differ widely, change to another BT. The temperature reading at the given depth (if the water conditions are not changing) would be a point midway between the two traces. Nothing can be done aboard ship for hysteresis. NOTE: Closely spaced traces (less that 0.5°F.) and double traces in strong gradients (layers of rapid change of temperature) are not considered as hysteresis.

Temperature Error.—It is advisable to make frequent comparisons between the BT surface temperatures and the sea surface reference temperatures. These temperatures should be approximately the same. If they differ slightly, the difference should remain constant over a long period of time. If this difference changes and if the amount of the diffenence then found continues for subsequent lowerings, it is an indication that the calibration has shifted. A shift in calibration, sometimes called a "shift in the zero points," should not affect the shape of any given trace. If a shift in calibration occurs, you make a note of it on the log sheet showing the slide number and time at which you detected this shift in calibration.

If the zero shift is more than 4° F. or if it shifts from one lowering to another, the BT needs adjustment and should be turned in for repair. If you must use the instrument, use the following procedures to determine the amount of temperature correction to apply.

Load the BT with a slide and leave the brass sleeve up so the stylus does not rest on the slide. Immerse the tail fins, thermal element, and the sleeve in a bucket of water for several minutes. Then push the sleeve down to bring the stylus in contact with the slide. At that instant obtain the water temperature in the bucket with a thermometer. Then raise the sleeve and trip the automatic stylus lifter without taking the BT out of the bucket. Add hot water to raise the temperature a few degrees. Stir the water and allow time for the BT to come to this temperature and then make another mark as before and read the thermometer. Repeat the process several times to establish a series of temperature points across the slide, along the zero depth line. The values of the points are read with the viewer and may be plotted on a graph against the temperatures obtained by the thermometer.

Depth Error.—The BT, when on deck, usually has a different temperature than when in the water. The BT thermal element assembly moves the stylus assembly along the zero depth line to the surface water temperature position during the period the BT is being towed at the surface. Thus, the top of the trace is almost always a horizontal line which should be on the zero depth line of the grid when the slide is viewed. If the trace appears more than 3 feet above or below the zero line, the depth readings must be corrected by the amount of this error for accurate results. In order to determine the amount of correction to apply to depth for accurate work, the following procedures can be used in an emergency:

> With the sleeve all the way back, immerse the thermal element in a cold and then in a warm (less than 105°F.) bucket of water. This will cause a long zero depth line to be drawn across the slide. Then place the slide in the viewer. The difference, in feet, of the trace above or below the zero depth line on the grid is the error for which you must make corrections at all depth readings.

BT's that have a depth error of more than 10 feet for a 200-foot instrument, 20 feet for a 450-foot instrument, or 40 feet for a 900-foot instrument should be replaced.

## THE EXPENDABLE BATHYTHERMOGRAPH

An expendable bathythermograph system (XBT), AN/SSQ-56, which is built by the Sippican

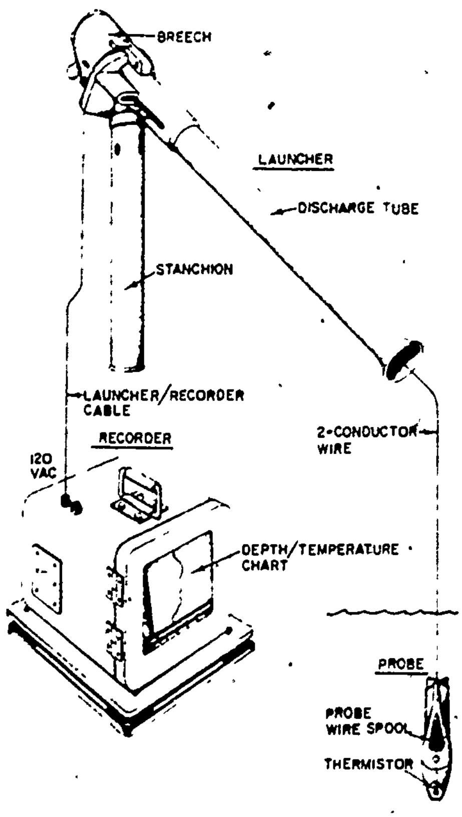


Figure 30.— Expendable bathythermograph (XBT) system.

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Corp., is used aboard ship for measuring the temperature of sea water in the water column from the surface down to a depth of 1,500 feet. (Measurements to depths of 2,500 or 5,000 feet can be obtained with special probes and recorder modifications.) The XBT can be used while the ship is hove to, but is especially designed to be used while the ship is underway. The XBT includes three components: the launcher, the recorder, and the expendable probe (figure 30).

The launcher (figure 31) includes the discharge tube, the breech, the stanchion, and the launcher/recorder cable.

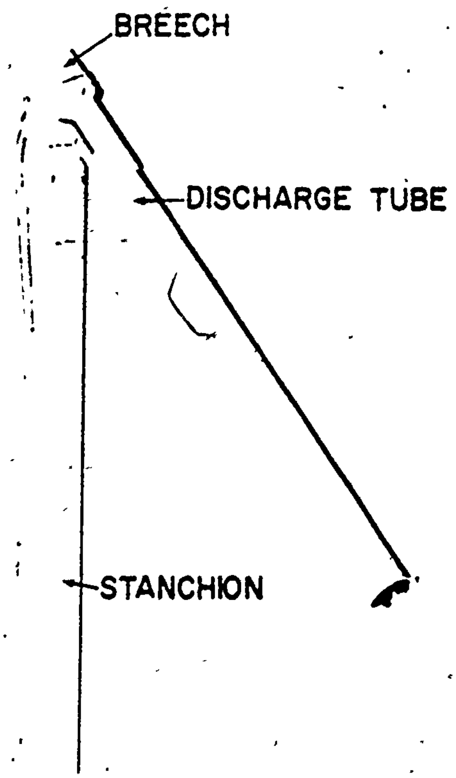


Figure 31.— XBT launcher.

The recorder (figure 32) is a conventional type, 120 VAC, 60Hz, analog recorder with a temperature scale from 28° to 96°F or -2° to 35°C. Special depth/temperature scaled chart paper is used in the recorder.

The expendable probe (figure 33) includes the canister, the probe with calibrated thermistor, two spools of wire, and the probe launch pin.

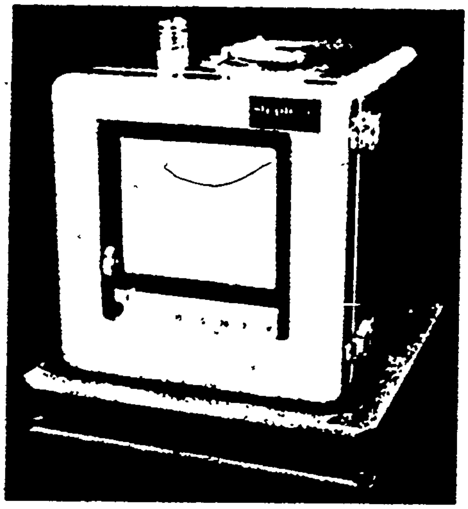

Figure 32.— Recorder.

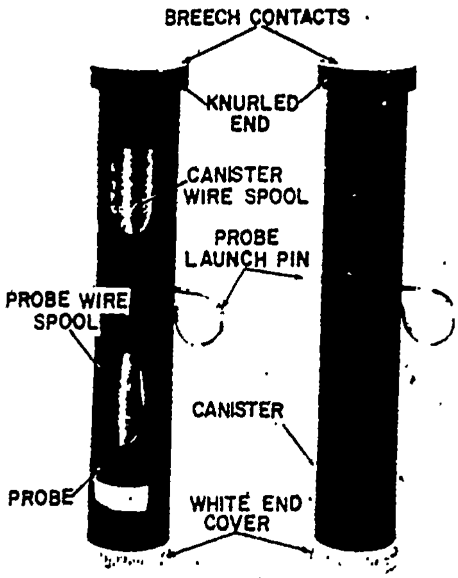


Figure 33.— Expendable probe and canister, Sippican model T-4 (cutaway view at left).

How the XBT Works

The thermal element of the XBT is the probe. It is a ballistically shaped device containing a calibrated thermistor in its nose. The thermistor is connected to a very fine two-conductor wire. (Various models of the XBT probe contain



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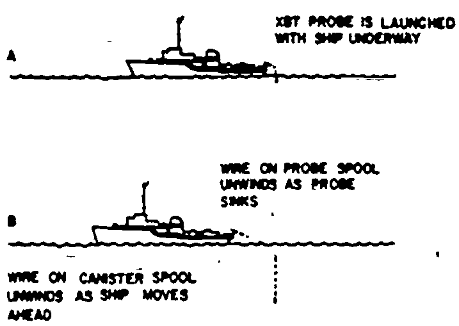


Figure 34.— Launching the XBT.

different lengths of wire, depending on the depth to be observed and the speed of the launching ship.) Approximately half of this wire is wound on a spool inside the probe, and the other half is wound on a spool inside the upper portion of the canister. The probe is held in place in the canister by the probe launch pin.

To take an XBT, place the canister case in the breech of the launcher and lock the breech, thus completing the electrical circuit from thermistor to recorder. Then pull the probe launch pin; the probe will fall through the discharge tube and into the water (figure 34A). When you launch the probe, the fine wire from both spools is free to unwind, permitting the probe to free-fall through the water and the ship to move away from the station without breaking the wire (figure 34B). As the probe drops through the water, the resistance of the thermistor in the probe changes with the water temperature. This causes voltage changes at the recorder, and the temperature and depth are recorded on an analog chart. (The chart paper drive speed is constant and is directly proportional to the probe's assumed rate of descent.) When all the wire on the spools is payed out, the wire breaks and the probe drops to the bottom of the sea.

## INSTALLATION OF XBT LAUNCHER AND RECORDER

Install the XBT launcher and recorder shown in figures 31 and 32 on the ship in accordance with manual R-467B, "Instructions for Installation, Operation, and Maintenance of Sippican Expendable Bathythermograph System."

In locating the components on the ship, give consideration to protection of the recorder from weather and spray; to line voltages, ambient temperatures, and electrical noise; to garbage chute and waste outlet locations; and to the location of any devices being towed by the ship. Store XBT probes in a cool place out of direct sunlight.

### Checking Out the XBT System

After installing the XBT launcher and recorder and always before beginning an operation aboard ship, check the recorder and the launcher to recorder circuit by performing the following steps:

Step 1. Plug in the recorder power cord to 120 VAC (the instrument does not have an On-Off switch). This will cause the red reload indicator signal (A) to light (figure 35).

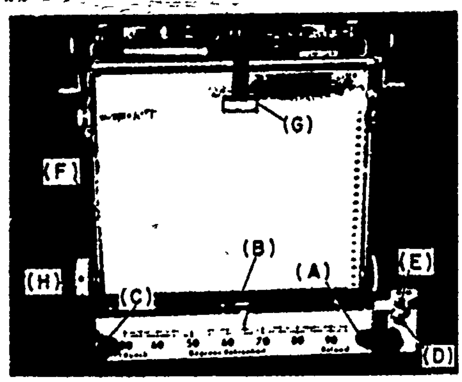


Figure 35.— XBT recorder panel.

Step 2. After a 15-minute warmup period, open the launcher breech and clean the contacts, using a clean rag and alcohol. Check the launcher discharge tube for salt deposit, and clean as necessary, using fresh water and a cloth swab. Insert the test canister. NOTE: Included with each XBT system is a test canister. Its circuit is shown in figure 36. The test canister should be calibrated every 6 months.

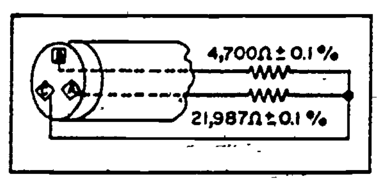


Figure 36.— Test canister circuit.

Step 3. Close the breech and lock it securely. The reload light will go out, the chart drive will operate for 2 seconds, and the chart stylus (B) will plot 62°F ± 0.2°F (16.7°C ± 0.1°C) for that period (figure 35). The chart drive will then stop, and the green launch light (C) on the left of the temperature scale will go on. NOTE: Check for jitter on the plot and adjust the gain if necessary.

Step 4. Press and hold the 30°/94° test switch (D) in the 94° position (figure 35) for 30 or 40 seconds. The launch light will go out, the chart drive will start, and the chart stylus will plot 94°F ± 0.2°F (34.4°C ± 0.1°C).

Step 5. Release the 30°/94° test switch, and press and hold it in the 30° position. Now the stylus will plot 30°F ± 0.2°F (-1.1°C ± 0.1°C). The chart paper will advance for 88 seconds ± 2 percent; then the chart paper drive will stop and the reload light will go on.

Step 6. Press and release the recycle switch (E) (figure 35). The reload light will go out. The chart drive will operate for 2 seconds with the chart stylus at 62° F ± 0.2°F (16.7° C ± 0.1°C). Then the chart drive will stop and the launch light will go on.

Step 7. Repeat steps 4 and 5 several times to make sure that the chart stylus is recording temperatures within tolerances, that the signal lights are operating properly, and that the chart paper drive advance time (step 5 above) is between 86.2 and 89.8 seconds. When the test switch is changed from the 94° to the 30° position, the stylus should require 1 second for a full scale excursion. Excessive overshoot or sluggishness of movement will require gain adjustment. If any tolerances are exceeded or any malfunctions are noted, the recorder should be calibrated as described in manual "Instructions for Installation, Operation and Maintenance of Sippican Expendable Bathythermograph System."

## Recording XBT Data

Record XBT data on the National Oceanographic Data Center Bathythermographic Log, NODC-EXP-3167/10 (Rev. 6-70). Record mechanical BT and XBT data on separate BT logs. Instructions for completing the items of the Bathythermograph Log are printed inside the cover of each pad of log sheets. For item 2, consider the XBT chart as a BT slide and number it accordingly. Obtain the sea surface reference temperature. Enter any comments concerning the conditions at the time the XBT was taken in the remarks space of the log sheet. Such comments might include: high seas, changing course, wire unspooling improperly, wire fouled on the side of ship, premature parting of wire, etc.

## Deployment of the XBT

After you have checked out the XBT system and the ship is coming up on a station, take the XBT by performing the following steps. NOTE: One person can take the XBT, however, this requires several trips between recorder and launcher; therefore, if two persons are available, one should be stationed at the recorder and the other should be at the launcher.

Step 1. Plug in the recorder power cord to 120 VAC. This will cause the red reload light indicator signal (A) to light (figure 35). Allow a 15-minute warmup period.

Step 2. Complete items one through three on the Bathythermograph Log.

Step 3. Remove the canvas cover from the launcher, and open the launcher breech fully clockwise; remove the expended canister used when taking the previous XBT, making sure no scrap wire remains in or around the discharge tube or breech.

Step 4. Take a canister from the packing case and remove the white end cover.

Step 5. Insert the canister in the breech (figure 37) guiding the probe launch pin loop through the launch pin slot until the knurled end is on the breech castings.

Step 6. Close the breech and lock the handle fully counterclockwise. This will cause the red reload light to go out at the recorder, and the chart drive to run for approximately 2 seconds. Check the chart paper to make sure that the "surface" line appears directly under the stylus. To adjust the paper, turn the knob (H) (figure 35) at the lower left of the chart drive, ending with clockwise motion to eliminate any backlash error.

Step 7. When the green launch indicator signal (C) (figure 35) goes on, pull the probe launch pin by grasping the loop and removing the pin with a firm, continuous motion. NOTE: If the sea

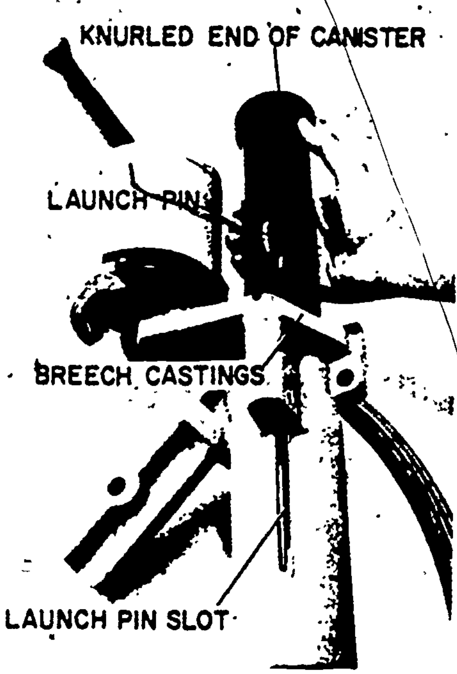


Figure 37.—Loading canister in breech.

is high, try to deploy the probe so it will hit the water between wave crests.

Step 8. When the chart drive stops and the red reload indicator signal goes on, annotate the chart with the following information: ship, cruise, latitude, longitude, time (GMT), day/month/year, e.g., 19/08/70, and consecutive chart number. In addition, indicate bottom depth beside the trace as is shown in figure 38.

Step 9. After completing the XBT observation, you may leave the charts on the takeup spool in the recorder or you may remove them individually. To remove XBT chart(s) from the recorder, cut the chart paper along the bottom of the chart paper locking plate (F) (figure 35) with a penknife. To reconnect the chart paper, attach the chart-saver clip (G) (figure 35) to the chart paper by stretching the clip elastic downward.

Step 10. Secure the XBT system by replacing the launcher canvas cover and disconnecting the recorder power cord.

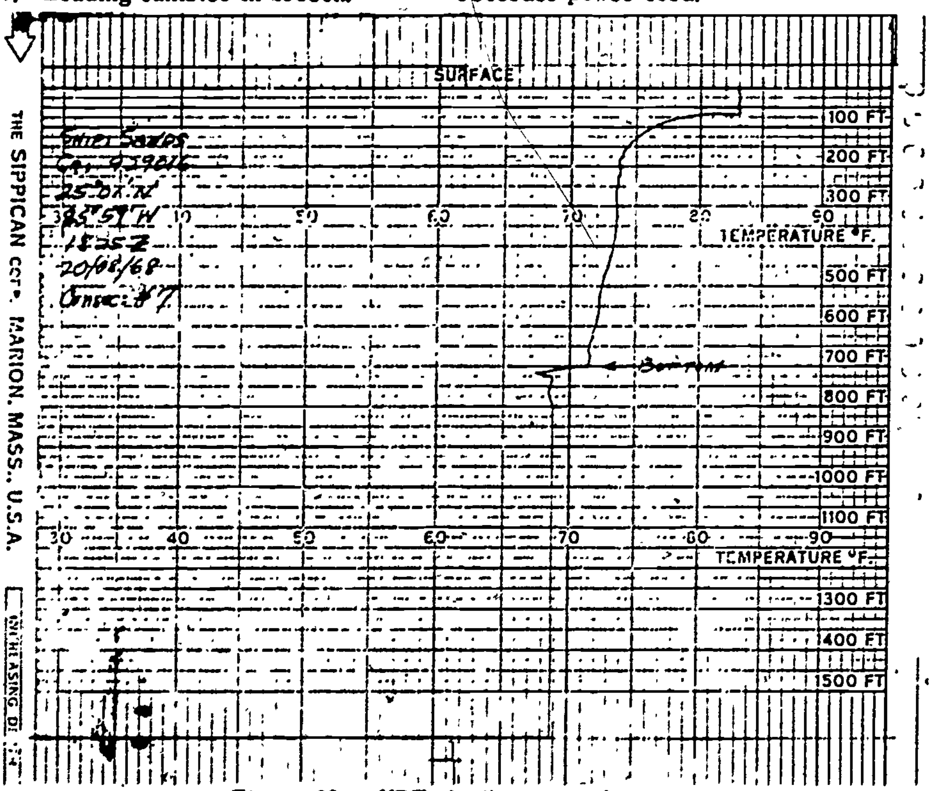


Figure 38.— XBT chart annotated.

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Step 11. Complete the Bathythermograph Log in accordance with instructions printed inside the cover of the pad of log sheets.

Step 12. If the XBT system will not be used within the next 4 hours, unplug the recorder power cord.

Mailing XBT Charts and Logs

At the completion of an operation, mail XBT charts and logs in accordance with COMDTINST 3161.1 series.

Observe the following steps for mailing:

Step 1. Cut charts (do not mail in a roll) so that each consecutive observation includes the baseline which was recorded above the surface line of the chart when a new probe was loaded in the launcher.

Step 2. Mail charts and logs together, but do not fold charts. Stack them and mail them flat. If pressure-sensitive chart paper was used, protect the charts by folding each log sheet and inserting the charts in the fold.

Step 3. Include all checkout charts made at the beginning of or during the operation with the XBT charts and logs.

XBT Maintenance

XBT routine and preventive maintenance and trouble-shooting instructions are presented in manual R-467B, "Instructions for Installation, Operation and Maintenance of Sippican Expendable Bathythermograph System."

Check the launcher discharge tube periodically for salt buildup. Remove any salt with fresh water and a cloth swab.

Inspect the insulation around the canister contacts in the launcher breech for contamination before inserting a canister. Remove any contamination with a cloth dipped in alcohol.

Installation of a new chart roll, chart alignment, and preventive maintenance should be performed by the operator. Recorder trouble shooting maintenance should be performed by an electronic technician. Recorder and test canister should be calibrated every 6 months, by an electronic technician.

It is important that you keep the test canister with the XBT system at all times. Consider the canister as an integral component of the system.

## ENCODING BATHYTHERMOGRAPH OBSERVATION

After taking a BT or an XBT, encode your observations on the Bathythermograph Log, NODC-EXP-3167/10 (Rev. 6-70). Instructions for completing the BT Log are printed inside the cover of each pad of log sheets. Figure 39 includes extractions from the Instructions for Preparing the Bathythermograpn Log Sheet.

# INSTRUCTIONS FOR PREPARING THE BATHYTHERMOGRAPH LOG SHEET

## INTRODUCTION

The bathythermograph (BT) log sheet is designed to meet three basic needs: 1. To provide a message format for radio transmission of synoptic BT data according to the specifications and standards established by the NATO Military Agency for Standardization; 2. To provide the National Oceanographic Data Center (NODC) with information required for BT analog and digital processing; and 3. To provide a method for keypunching BT data for local (non-NODC) analysis. This radio message format supercedes all other formats previously used for shipboard BT (BATHY) or aircraft BT (BAXBT) message reporting.

The instructions describe (1) how and where to mail slides, log sheets, and recorder charts; (2) how to obtain additional log sheets; (3) addressees for radio messages; (4) how to mark the BT slide and XBT recorder chart after the observation is taken; (5) the procedures for filling in the "Reference Information" and "Radio Message Information" portions of the log sheet which are to be used for all airborne, submarine and shipboard BT's; (6) the required interpretation of the temperature-depth trace; and (7) special instructions for Navy use. These instructions also serve to amplify the following directives, the latest editions of which are applicable and should be rigidly followed:

1. OCEANAVINST 3160.9
2. COMSTSINST P3121.3
3. COMSTSINST P3120.2
4. COMDT USCG INST 3161.1
5. CINCPACFLT INST 3160.7
6. NAVWEASERVCOMINST 3140.1

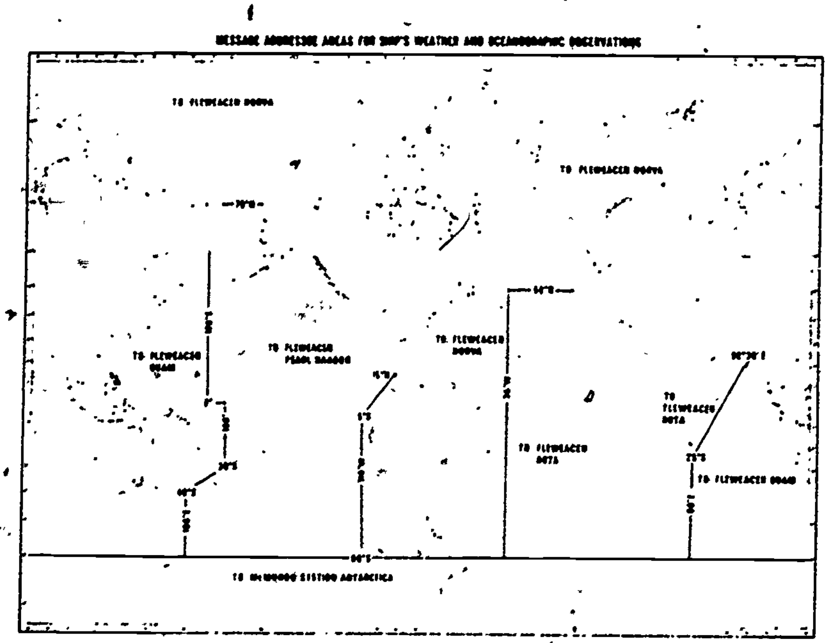
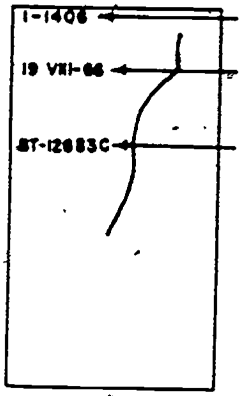


Figure 39.— Instructions for preparing the Bathythermograph Log Sheet.

## HOW TO MARK THE BT SLIDE AND XBT RECORDER CHART

Immediately after removing the BT slide from the bathythermograph, rinse the slide in fresh water, holding it by the edges to avoid marring of the Stebelley coating. Then mark the slide as indicated below, using a sharp pencil. Do not touch, write over, or otherwise obscure the trace.

*Sample of marked slide:*




Slide number —— GMT hours and minutes.

Day—month (roman numerals).

Year (use last two digits).

BT instrument number (found near nose of instrument and stamped on lower right side of BT grid). Report complete number with letter prefix and suffix if given. If the BT instrument number and the grid number (prefix and suffix) do not agree, do not use the BT.

The face of each XBT recorder chart should contain the information listed below in the same sequence. If the format of this information is not preprinted on the XBT recorder chart, write in the information. (A stamp containing this format may be obtained from: The Sippican Corporation, Marion, Massachusetts 02738.) DO NOT OBSCURE THE TEMPERATURE TRACE. Record N or S and E or W after latitude and longitude, respectively. Record time and date according to GMT.

Ship
Cruise
Latitude
Longitude
Time (GMT)
Da/Mo/Yr
Consec #

## REFERENCE INFORMATION

Record complete vessel name, country, log sheet number, full name of institution or activity sponsoring the cruise, and, when applicable, originator's cruise and station numbers. Enter the word "Aircraft" in the space labeled "Vessel" when observations are made from aircraft. Any remarks concerning apparent malfunction of the BT should be entered in the "Remarks" space at the bottom of the BT log sheet, along with other pertinent information.

## RECORDING THE REFERENCE INFORMATION

1. INSTRUMENT NUMBER——Record the complete instrument number (digits and letters) stamped on the nose of the instrument. Enter XBT when expendable bathythermographs are used.

2. CONSECUTIVE NUMBER——Number the slides or XBT recorder charts consecutively, starting with number 1 for the first BT taken after leaving port and ending with the last slide of the cruise.

3. DATE (GMT)——Enter the GMT day and month in arabic numericals; record the last two digits of the year in arabic numerals.

4. TIME (GMT)——Enter GMT hour and minute at which BT entered the water.

5. & 6. LATITUDE AND LONGITUDE——Enter the degrees, minutes, and north or south, east or west hemisphere of latitude and longitude, respectively, at time of BT lowering. Prefix zero (0) to complete degree field.

*Example:* If lat. is 9°30'N, enter 0930N; if long. is 6°21'W, enter 00621W.

7. SEA SURFACE REFERENCE TEMPERATURE——

$I_r I_r$ Instrument Precision and Unit Indicator ——Enter appropriate code from Table 1 to indicate precision and units of instrumentation. (Precision applies to reference instrumentation; depth units apply to both surface reference and subsurface temperature values.) When reference temperature observations are not made, enter code 98 or 99 as appropriate.

$T_r T_r T_r$ Reference Temperature——Enter the surface water temperature. When measuring to nearest whole degree, enter a zero in the last column of the temperature field. When surface reference temperatures have not been observed, enter the surface value from the BT trace. All Celsius (centigrade) temperature values of less than 0°C will be coded as $5T_r T_r$. (5 indicates that a negative reading follows.)

*Example:* —1.5°C is coded as 515.

8. SENSOR——Enter the appropriate code from Table 2 to indicate the instrumentation used to observe the reference temperature. If appropriate code is not given, identify the instrument used in the "Remarks" space.

Figure 39.— Instructions for preparing the Bathythermograph Log Sheet. (Continued)

## RADIO MESSAGE INFORMATION

To record the BAXBT-BATHY information properly, the following procedures must be followed.

A. Enter vessel's name in space provided. When observations are made from aircraft, enter the word "Aircraft" in the space labeled "Vessel."

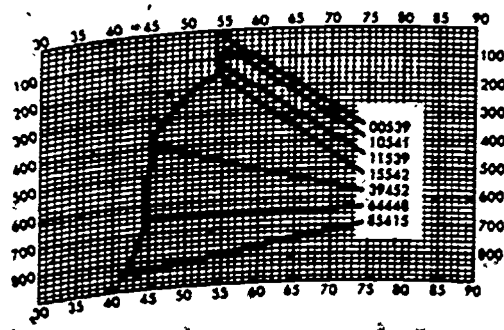
B. When interpreting and encoding the BT trace, always include:

1. Water temperatures at the sea surface and at the deepest point of the trace.

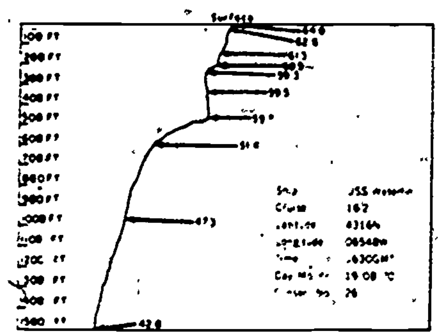
2. Sufficient inflection (flexure) points to describe the temperature structure and small irregularities in the surface layer (see examples below).

*Examples:*

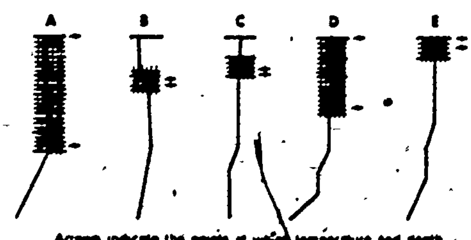
BRITISH UNITS




RECORDER CHART



The following examples of small irregularities in the upper layer are given to assist in recognizing these features which must be reported:




Arrows indicate the points at which temperature and depth values must be read in order to describe the features shown

Trace A - Slight Positive Gradient
Trace B - Positive Irregularity
Trace C - Negative Irregularity
Trace D - Slight Negative Gradient
Trace E - Negative Gradient at Near Surface

C. Do not adjust trace to agree with the reference temperature.

D. Do not routinely interpret trace of convenient depth increments (10 ft., 20 ft., 100 ft., or 5m., 20m., etc.) unless inflection points actually exist at these depths.

E. All values must be accurately recorded. (Every entry must be rechecked.)

F. All Celsius (centigrade) temperature values of less than 0°C will be coded as $5T_rT_r$. (5 indicates that a negative reading follows.)

*Example:* −1.5°C is coded as 515.

G. In the space provided in upper right of format, enter the day-time group, month, and year of the message transmission.

## RECORDING THE RADIO MESSAGE INFORMATION

The following item numbers correspond to the numbered fields of the radio message information portion of the log sheet.

1. MESSAGE PREFIX——The preprinted message prefixes BAXBT and BATHY identify aircraft and shipboard bathythermograph observations, respectively. Cross out the one which does not apply.

2. DATE (GMT)——
YY Day——Enter day of the month using numerals 01–31.
MM Month——Enter month using numerals 01–12.

2-3. AA Year——Enter last two digits of year (e.g., 1970 is encoded as 70). Enter first digit (i.e., 7) in DATE group (block 2) and second digit (i.e., 0) in TIME group (block 3).

3. TIME——
GGgg——Enter GMT hour (GG) and minute (gg) at which BT entered the water.

4. & 5. QUADRANT, LATITUDE AND LONGITUDE——
$Q_c$ —— Enter quadrant of the globe according to Table 3.
$L_aL_aL_aL_a$ and $L_oL_oL_oL_oL_o$ ——
Enter degrees and minutes of latitude and longitude, respectively, at time of BT lowering. Prefix zero (s) to complete degree field.
*Example:* If lat. is 9°30'; enter 0930; if long. is 6°21'; enter 00621.

6. SEA SURFACE REFERENCE TEMPERATURE——
$I_rI_r$ and $T_rT_rT_r$ ——
Follow instructions for item 7 under "RECORDING THE REFERENCE INFORMATION"

## RECORDING THE DEPTH-TEMPERATURE VALUES

Regardless of units, the surface depth-temperature group ($Z_oZ_oT_oT_oT_o$) is encoded as shown below.

| | |
|---|---|
| $Z_oZ_oT_oT_oT_o$ | SURFACE DEPTH-TEMPERATURE GROUP |
| $Z_oZ_o$ | Water surface, 00 is preprinted. |
| $T_oT_oT_o$ | Enter the surface water temperature value (°F or °C) as read from the BT trace to the nearest tenth of a degree. |

Figure 39.— Instructions for preparing the Bathythermograph Log Sheet, (Continued)

## RECORDING THE DEPTH-TEMPERATURE VALUES (CONT'D)

### SUBSURFACE DEPTH-TEMPERATURE GROUP

$ZZT_zT_zT_z$ This group is repeated as many times as necessary to adequately describe the BT trace.

ZZ For subsurface depths to 99 meters or 999 feet, enter in whole meters or tens of feet the depth at which corresponding temperature values are read from the trace.

*Example:* For 5m., record 05; for 97m., record 97. For 30 ft., record 03; for 520 ft., record 52; for 900 ft. record 90.

SPECIAL INSTRUCTIONS

999NN NOTE: Always include a 999NN group before recording depths of 100 meters or 1,000 feet, 200 meters or 2,000 feet, and each succeeding 100-meter or 1,000-foot interval to termination. NN is coded as 01 for 100 to 199 meters or 1,000 to 1,999 feet; 02 for 200 to 299 meters or 2,000 to 2,999 feet, etc. When the 999 NN code is entered, mark out the $ZZT_zT_zT_z$ heading.

ZZ For depths between 100 and 200 meters, 200 and 300 meters, etc., enter the tens and units digits only.

*Example:* For 101m., record 01; for 256m., record 56; for 375m., record 75. For depths of 1,000 feet or greater, enter the hundreds and tens digits only. *Example:* For 1,020 ft., record 02; for 1,250 ft., record 25; for 1,480 ft., record 48, etc.

$T_zT_zT_z$ Temperature Group—Enter water temperature at depth ZZ in °C or °F to tenths of degrees. All Celsius (centigrade) temperature values of less than 0°C will be coded as $5T_rT_r$. (5 indicates that a negative reading

**Table 1 INSTRUMENT PRECISION AND UNIT INDICATOR**

| CODE FIGURE | PRECISION OF SURFACE REFERENCE TEMPERATURE INSTRUMENTATION | UNITS DEPTH | UNITS TEMP. |
|---|---|---|---|
| 11 | Temp. to nearest 0.1° | FT | °F |
| 22 | Temp. to nearest whole degree | FT. | °F |
| 33 | Temp. to nearest 0.1° | M. | °F |
| 44 | Temp. to nearest whole degree | M. | °F |
| 55 | Temp to nearest 0.1° | FT | °C |
| 66 | Temp. to nearest whole degree | FT. | °C |
| 77 | Temp. to nearest 0.1° | M. | °C |
| 88 | Temp. to nearest whole degree | M. | °C |
| 98 | Reference temperature not measured | FT. | °F |
| 99 | Reference temperature not measured | M. | °C |

**Table 2 REFERENCE TEMPERATURE SENSOR CODE**

| CODE | SENSOR | CODE | SENSOR |
|---|---|---|---|
| 1 | Bucket Thermometer | 4 | Thermograph |
| 2 | Injection Thermometer | 5 | Special Calibration Thermometer |
| 3 | Reversing Thermometer | 6 | BT |

**Table 3 QUADRANT OF THE GLOBE**

| CODE | QUADRANT |
|---|---|
| 1 | NE |
| 3 | SE |
| 5 | SW |
| 7 | NW |

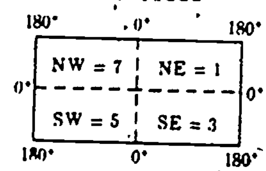



Figure 39.— Instructions for preparing the Bathythermograph Log Sheet. (Continued)

**REFERENCE INFORMATION**

| VESSEL Burton Island | COUNTRY USA | SHEET NO. 4 |
|---|---|---|
| INSTITUTE U.S. Coast Guard | CRUISE NO. | STATION NO. |

| 1 | 2 | 3 | | | 4 | |
|---|---|---|---|---|---|---|
| BT INSTRUMENT NUMBER AND LETTER | CONSECUTIVE SLIDE NUMBER | DATE (GMT) | | | TIME (GMT) | |
| | | DAY | MONTH | YEAR | HOUR | MIN |
| 1216A | 73 | 14 | 08 | 71 | 23 | 46 |

| 5 | | | 6 | | | 7 | | 8 |
|---|---|---|---|---|---|---|---|---|
| LATITUDE | | | LONGITUDE | | | SEA SURFACE REF. TEMPERATURE | | SENSOR |
| DEG | MIN | N/S | DEG | MIN | E/W | CODE | TEMP | |
| 41 | 20 | S | 174 | 76 | E | 11 | 540 | 1 |

Figure 40.— Example of the correct entries for the reference section of the Bathythermograph Log Sheet.

**RADIO MESSAGE INFORMATION**

VESSEL CGC Burton Island

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| MESSAGE PREFIX | DATE (GMT) DAY MONTH YR | YEAR / TIME (GMT) HOUR MIN | QUAD / LATITUDE DEG MIN. | DAY TIME GROUP / LONGITUDE DEG MIN | MONTH-YEAR / SEA SURFACE REF TEMP CODE TEMP |
| ~~B A X B T~~ | Y Y M M A | A G G 9 9 | $Q_c$ $L_a$ $L_a$ $L_a$ $L_a$ | $L_o$ $L_o$ $L_o$ $L_o$ $L_o$ | $I_s$ $I_s$ $T_s$ $T_s$ $T_s$ |
| BATHY | 14087 | 12346 | 54120 | 17416 | 11540 |
| | 16 17 | 18 – 21 | 23 – 27 | 28 – 32 | 33 – 37 |

**BATHYTHERMOGRAPH TRACE READINGS**

| DEPTH TEMP | DEPTH TEMP | DEPTH TEMP | DEPTH TEMP | DEPTH TEMP | DEPTH TEMP |
|---|---|---|---|---|---|
| 00539 | 10541 | 11539 | 15542 | 39452 | 64448 |
| 85415 | | | | | 3 |
| | | | | | MESSAGE SUFFIX 19991 |
| 38 – 42 | 43 – 47 | 48 – 52 | 53 – 57 | 58 – 62 | 63 – 67 |

Figure 41.— Example of the radio message section of the Bathythermograph Log Sheet.

# NANSEN CASTS

A Nansen cast consists basically of lowering a series of Nansen bottles (with reversing thermometers attached) into the water on a steel cable and bringing up water samples and temperature readings from selected depths. In the Coast Guard OSV oceanographic program, the water samples are analyzed for salinity and frequently for oxygen. The depths to be sampled and the wire lengths to be used are found in CG-410, Manual for Oceanographic Observations.

## NANSEN CAST ROUTINE

In the following subsection, we will consider the specific actions that Oceanographic Team members should take to properly make a Nansen cast and to collect the temperature and depth data and the water samples required. Figure 42 is a chronological chart of the Nansen cast routine; the chart defines the duties of each member of an Oceanographic Team.

We will now discuss the three phases of the Nansen cast routine—pre-cast, during the cast, and post-cast. This information is condensed into a Nansen cast check list in CG-410. We recommend that all personnel use this list.

### PRE-CAST

During the pre-cast phase, the following steps should be followed:

1. The OOD calls the safety officer and the oceanographic supervisor one hour prior to arrival or commencement of station.

2. The oceanographic supervisor or winch operator gets power to the winch so that the hydraulic fluid may be warmed up to the recommended operating temperature and so that the winch can be exercised by cast time. When operating in cold temperature, such as is experienced on BRAVO in the winter, it may be necessary to begin warming hydraulic fluid at least an hour before cast time.

3. The oceanographic supervisor fills out, in advance, as much as possible of the Oceanographic Deck Log, CG-4502; the oceanographic logbook; and the temperature message form (directions for completing these forms appear later in this section). He records wire lengths under the first column of the Oceanographic Deck Log. These wire lengths are the depths to be reached.

4. The oceanographic supervisor calls up the winch team.

5. The oceanographic supervisor estimates the expected wire angle and delivers the appropriate winch card to the winch operator.

6. The oceanographic supervisor and the platform man check out all Nansen bottles in the deck rack and ensure that:

a. The bottles are arranged in proper sequence and are correctly recorded on the Oceanographic Deck Log. It is recommended that bottles be arranged 1-20, from right to left, with bottle 1 being the surface bottle and bottle 14 normally being the 1500-meter bottle.

b. The bottles are in proper working condition. They check the working parts and also check the fulcrum screw (part no. 60-30-A) and the 3/8'' bolt which holds the fulcrum (part no. 60-5-B) to the arm (part no. 60-27-A) for looseness. Fulcrum screw and stud should be pinned in place with 1/8'' CRES pins as shown in CG Drawing 120086. Bottles with thermometers may be lost if these parts are loose.

c. The valves are open and that the petcock and air vent are closed.

d. The Nansen bottles are in the inverted position (main thermometer reservoirs down) and that all mercury has drained from the main thermometer bulbs.

| | OCEANO. OFFICER | OCEANO. SUPV. | PLATFORM MAN | BOTTLE PASSER | WINCH OPERATOR |
|---|---|---|---|---|---|
| PRE-CAST | CHECK PREPARATIONS<br>GET COMMS WITH OOD<br>GET OOD'S PERMISSION<br>CHECK SOUNDING | ESTIMATE WIRE ANGLE<br>SELECT WINCH CARD<br>FILL OUT IN ADVANCE DECK LOG<br>CALL UP TEAM.<br>SET UP NANSEN BOTTLES AND SALINITY BOTTLES<br>CHECK ARRANGEMENT AND OPERATION OF NANSEN BOTTLES<br>GET OCEANO OFFICER'S PERMISSION.<br>CHECK SOUNDING | ASSIST SUPV<br>ASSIST SUPV<br>PUT ON LIFEJACKET HARD HAT, SOTMNER'S HARNESS, ARM GUARD | | GET POWER TO WINCH<br>WARM UP HYDRAULIC OIL.<br>PICK UP WINCH CARD |
| CAST | GIVE GO AHEAD<br>WATCH FOR CORRECT AND SAFE PROCEDURES | START CAST DOWN<br>RECORD "START" TIME.<br>CLOSELY SUPERVISE ALL OPERATIONS<br>DIRECT WINCH OPERATOR WITH HAND SIGNALS.<br>LOWER SURFACE BOTTLE AND RECORD "DOWN" TIME.<br>WAIT TEN (10) MINUTES.<br>DROP MESSENGER AND MEASURE WIRE ANGLE.<br>WAIT FOR MESSENGER: 150 METERS MINUTE.<br>RECORD "MESSENGER" TIME. | PUT WEIGHT OVER AND ZERO METER.<br>HANG NANSEN BOTTLES AND MESSENGERS<br>CHECK NANSEN BOTTLES.<br>USE SAFETY LANYARD<br>FEND CAST AWAY. | CHECK NANSEN BOTTLES.<br>PASS NANSEN BOTTLES AND MESSENGERS<br>GET WEATHER AND POSITION FROM BRIDGE | FOLLOW WINCH CARD AND SUPV HAND SIGNALS.<br>LOWER CAUTIOUSLY<br>OPERATE WINCH GENTLY |
| | NOTIFY OOD SECURES | START CAST UP.<br>RECORD "START UP" TIME.<br>CHECK NANSEN BOTTLES FOR MALFUNCTION.<br>DIRECT WINCH OPERATOR WITH HAND SIGNALS AND SING OUT "IN SIGHT" AND "SURFACE".<br>RECORD "UP" TIME.<br>MAKE QUICK CHECK OF TEMPERATURES.<br>SECURE CAST. | UNHOOK MESSENGERS AND NANSEN BOTTLES<br>USE SAFETY LANYARD.<br>FEND CAST AWAY<br>BRING WEIGHT ABOARD | RECEIVE MESSENGERS AND NANSEN BOTTLES<br>RETURN NANSEN BOTTLES TO DECK RACK | FOLLOW SUPV. HAND SIGNALS.<br>RECORD DIFFERENCES IN "UP" AND "DOWN" METER READINGS.<br>SECURE WINCH. |
| POST-CAST | CHECK "T" MSG AND DELIVERED TO RELEASE OFFICER IMMEDIATELY<br>CHECK LOGS AND FORMS<br>CHECK "S" MSG<br>CHECK EQUIPMENT | DRAW SALINITY SAMPLES.<br>WAIT 25 TO 30 MINUTES THEN READ THERMS.<br>DRAFT "T" MSG: PRIORITY<br>REVERSE NANSEN BOTTLES.<br>CHECK THERMOMETERS.<br>RUN SALINITIES EVERY 3 TO 5 STATIONS.<br>COMPLETE LOGS AND FORMS<br>DRAFT "S" MSG: ROUTINE.<br>CLEAN AND REPAIR EQUIPMENT. | ASSIST SUPV<br>ASSIST SUPV.<br>ASSIST SUPV.<br>ASSIST SUPV.<br>ASSIST SUPV. | | |

Figure 42.— Typical Nansen Cast Routine

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e. Salinity sample bottles are under each Nansen bottle and that the numbers are properly recorded.

7. If the team makes a cast at night, the oceanographic supervisor checks for proper lighting of all areas, including the area over the side at the platform.

8. The platform man puts on a work lifejacket (or wet suit or other suitable flotation gear), hard hat, swimmer's harness with a safety line secured to the ship, and a leather arm guard. He inspects the A-Frame and platform to ensure that all pins are properly seated and all braces are installed. He also inspects the rigging of the meter wheel block to ensure that the shackle is properly seated and the remote counter and counter cable are rigged. The counter cable ends should be supported by small stuff. The counter cable should have sufficient slack to allow for movement of the meter wheel. He checks to ensure that the weight and the swivel between the weight and cable are properly shackled on. He also checks to make sure that the messengers are readily available, that the cable clamp is rigged for instant use, and that the safety lanyard is rigged.

9. Upon arrival on station, the OOD takes a sounding and delivers this information to the safety officer and oceanographic supervisor.

10. The oceanographic supervisor, after ensuring that all preparations for the cast have been made, so notifies the safety officer.

11. The safety officer double-checks all preparations and establishes communications with the OOD. He checks to ensure that wind and current are on the platform's side, checks on the sounding, requests any maneuvering necessary to set up for cast, and obtains permission to start the cast.

DURING THE CAST

During the cast, the following steps should be followed:

1. The OOD should provide for:

a. Constant communications with the Oceanographic Team.

b. Fathometer watch and soundings, especially if water is rapidly shoaling.

c. At least two navigational fixes during the station if Loran or other quick means are available. Use the average fix as the station position.

d. Weather observations required for the Oceanographic Deck Log.

2. The OOD should notify the safety officer of all significant changes in sounding.

3. The OOD should be cognizant of the current and wind conditions and observe their effect on wire angle. He should maneuver to prevent the cast from going under the ship or leading too much astern. He should also maneuver to keep the wire angle within 45°. Generally, the wind should be kept on the system's side and on the quarter or bow. Drift with the wind on the beam if the wire angle is reasonable and swells permit.

4. The safety officer gives the "go-ahead" and observes and double-checks for correct and safe procedures.

5. The oceanographic supervisor directly controls the performance of all members of the Oceanographic Team except the safety officer. He positions himself where he can see the cast entering the water and can see, and be seen by, all members of the team. He should also be able to see the remote counter. He directs the winch operator with hand signals and by voice. The oceanographic supervisor should make sure that the winch operator understands the hand signals used.

6. Upon direction by the oceanographic supervisor, the platform man swings the weight over the side and the winch operator lowers it to just below the surface of the water, allowing for enough depth to compensate for sea and swell waves and for ship rolls. The platform man zeroes the cable counter and hangs the first bottle (bottom bottle of cast). For the regular 14-bottle 1500-meter cast, this is bottle number 14. It is very important that the platform man zero the cable counter at this point. He does this merely by manually twisting the meter pointer (or pointers) to exactly zero. The oceanographic supervisor records the start time on the Oceanographic Deck Log.

7. The bottle passer passes Nansen bottles to the platform man, beginning with the highest numbered bottle of the cast and working towards the lower numbers. He checks to see that the Nansen bottle valves are open and that the petcock and air vent are closed. The Nansen bottles should always be carried in a vertical position and should be handled gently, so that the reversing thermometers are not damaged or caused to malfunction. The Nansen bottles should never be handled by the thermometer frames; it is too easy to squeeze the frames and crush the thermometers.

8. The platform man snaps a safety lanyard onto the operating rod of each Nansen bottle as he receives it. He secures the bottle to the cable, using only finger pressure on the clamp wing nut. The wing nut stud is silver-soldered in place, and undue force will pull it loose, causing loss of the bottle when it trips. Therefore, he should NEVER USE ANY SORT OF TOOL OR LEVER TO TURN THE WING NUT.

The safety lanyard is a length of line with a halyard snap on one end. It is secured to the platform within easy reach of the platform man to prevent loss of the Nansen bottle if it slips from the grasp of the platform man, and later it serves to prevent premature release of messengers. It should be secured with a quick release hitch so that if the cable accidently pays out while the lanyard is still fastened to a Nansen bottle on the cable, the lanyard can be immediately cast loose to prevent damage to the Nansen bottle.

9. The platform man double-checks the Nansen bottle valves, petcock, air vent, and thermometers after the bottle has been secured to the cable. He checks to see that the bottle is firmly secured to the cable and then takes the safety lanyard off the Nansen bottle and snaps it onto the cable below the bottle. He then hangs a messenger (or messengers if double messengers are needed) on the Nansen bottle (all except the bottom bottle). If the messenger slips from his grasp, the safety lanyard will prevent it from sliding down the cable and pre-tripping the cast.

10. The platform man removes the safety lanyard and signals the oceanographic supervisor when he is ready for the cast to be lowered. If the cast is in danger of touching the platform, the platform man fends the cast away from the platform with his leather arm guard.

11. The oceanographic supervisor directs the winch operator to lower away slowly until the Nansen bottle enters the water and then to lower at a faster rate if conditions permit. Winch speed should not exceed 100 meters per minute unless conditions are ideal. If a Nansen bottle enters the water too fast, the shock may trip it, resulting in pre-tripping of the whole cast below it and/or resulting in the bottle closing with trapped air and imploding, thus destroying the bottle and thermometers. The winch operator must use extreme caution in lowering the first bottle (bottom bottle), because it always goes down at a low wire angle and passes very close to the platform.

The oceanographic supervisor records meter wheel counter readings on the Deck Log under the heading "wire out." If the winch operator inadvertently lowers the cable past any of the planned depths, he should not haul up the cast. He should simply locate the bottle at a different point. The oceanographic supervisor should record the new wire length and the new meter wheel reading and also note this in the oceanographic logbook and in the remarks of the temperature message.

12. The winch operator must take particular care NOT TO PAY OUT THE CABLE TOO FAST, ESPECIALLY WHEN THE SHIP IS ROLLING. He must keep the winch speed within 100 meters per minute unless conditions are ideal. A sharp roll towards the cast when the cable is rapidly paying out may result in the cable slackening, thus causing the cable to become damaged. This is the primary cause of the loss of oceanographic gear. The winch operator should operate the winch smoothly. Sudden starts and stops may over load the cable, pre-trip the nansen bottles, or cause thermometer malfunctions.

13. Under the oceanographic supervisor's direction, the winch operator lowers the cast and the platform man hangs the bottles at predetermined cable lengths until the surface bottle is hung. Then the winch operator lowers the cast until the surface bottle does not quite break the surface of the water on the heaviest rolls of the ship away from the cast.

14. After the winch operator has lowered the cast to the proper depth, he allows it to "soak" for at least ten (10) minutes to permit the reversing thermometer to come to equilibrium with

the water temperature and to insure complete flushing of the Nansen bottles. The oceanographic supervisor records the "down" time on the Deck Log.

15. While the cast is soaking, the supervisor directs the bottle passer to obtain the navigational position and weather observations from the bridge, and then the supervisor records the data on the Deck Log. During the time on station, the OOD or navigator should be able to obtain at least two fixes. The Navigator's best average of positions during the time on station should be accepted and recorded as the station position. It is convenient to provide the bridge watch with "fill-in-the-blank" type weather observation forms. A suggested format is included in CG-410. NOTE: NEVER LEAVE A CAST UNATTENDED. Whenever there is equipment over the side, at least one member of the team should be assigned to keep a watch on it.

16. After the cast has been down for ten minutes, the oceanographic supervisor drops the messenger, measures the wire angle, and records the messenger time on the Deck Log.

17. The supervisor allows sufficient time for the messenger to travel down the cable at a rate of 150 meters per minute. It is prudent to add an additional minute for each 1000 meters of cable out. For example, if 1950 meters of cable are out, allow at least 15 minutes. After the proper time interval, the oceanographic supervisor directs the team to bring the cast in and records the "wire-in" readings.

18. The oceanographic supervisor directs the winch operator and signals him as each Nansen bottle comes in sight and again as each breaks the water's surface. The oceanographic supervisor also uses hand signals to indicate exactly when to stop the winch so as to bring the Nansen bottles to a proper height for the platform man to remove them from the cable. Extreme caution must be used in bringing the last bottle (bottom bottle) up. It always comes up at a low wire angle and passes very close to the platform.

19. As each bottle is brought to a stop at the proper height, the platform man snaps the safety lanyard onto each bottle, removes the messengers and hands them to the bottle passer, and removes each Nansen bottle from the cable and hands each to the bottle passer. The platform man removes the safety lanyard from each bottle as he passes each to the bottle passer. He again uses his leather arm guard to fend the cast off the platform, if necessary.

20. The winch operator watches the cable counter and the oceanographic supervisor, and begins to slow the winch when he gets to within 10 meters of a Nansen bottle.

21. The oceanographic supervisor watches the bottles as they come up and checks for malfunctions which may indicate the need for a recast. A recast may be necessary if bottles have slid down the cable or have failed to trip. The oceanographic supervisor also makes a quick check of the difference between protected and unprotected reversing thermometer readings, and compares them with $\Delta$Ts provided by the Coast Guard Oceanographic Unit. This comparison gives him both a rough estimate of the actual depths reached and of the performance of the pressure thermometers and an indication of whether or not there was pre-tripping or post-tripping. A recast of all bottles should be made in case any of the following occurs:

a. More than two pressure thermometers malfunction.

b. Pre-tripping or post-tripping of more than one bottle is indicated.

c. More than one bottle fails to trip.

22. The oceanographic supervisor records "up time" when inhaul begins and "in time" when the cast is secured.

23. As soon as the supervisor determines that the cast is acceptable, he has the platform man bring the weight aboard. The oceanographic officer then notifies the OOD that the cast is secured.

POST-CAST

During the post-cast phase, the oceanographic supervisor, normally assisted by the platform man, either supervises or performs the following procedures:

1. He immediately draws salinity samples into the sample bottles located beneath the Nansen bottles in the deck rack (an experienced

bottle passer can begin drawing these as the cast is coming up). The supervisor draws these samples before the water can freeze in the Nansen bottles and takes the sample bottles into the lab before they can freeze. He makes sure that the salinity samples are drawn into the proper sample bottles and that the sample bottle numbers are correctly recorded.

He rinses each sample bottle twice with sample water prior to filling. He also rinses the stopper or cap by pouring the rinse water out over them.

He fills up the sample bottles only to the shoulder and then inverts each sample bottle and checks each for leaky stoppers or caps. If he finds leaky stoppers or caps, he should substitute different bottles, making sure that the new bottle numbers are logged.

He should also draw an additional sample from the surface and bottom Nansen bottles of the cast to send to the Coast Guard Oceanographic Unit for quality control purposes. After he has drawn all of the samples, he drains the Nansen bottles.

2. After the cast is up, the supervisor must allow 25 to 30 minutes for the thermometers to come to equilibrium with the air temperature before he reads them. He reads the main thermometers to the nearest 0.01° C and the auxiliary thermometers to the nearest 0.1°C. He has one man read the thermometers and another man to record the readings on the Oceanographic Deck Log. Then the men should exchange positions and read again as a check. The readings of a thermometer should agree to within 0.01°C (main) and to within 0.5°C (auxiliary).

Readings of two or more protected thermometers in one bottle should agree to 0.1°C or less for the main thermometers. If the difference is more than 0.1°C, the men should place a dot next to the temperature value to indicate that they have rechecked their readings. The men should resolve any difference in readings immediately upon noting the difference.

All hands should avoid touching or breathing on the thermometers or Nansen bottles, because this can change the readings.

3. Immediately after reading the thermometers, the oceanographic supervisor makes up the temperature message. He assigns PRIORITY precedence to it, has it checked by the oceanographic officer, and ensures that it is delivered to the appropriate officer for release.

4. After the oceanographic supervisor has read the thermometers, he opens and inverts the Nansen bottles and closes the petcock and air vent. He checks the main thermometers to ensure that all of the mercury has drained from the bulb. (If the bulbs will not drain, see Chapter 6, N.O. 607, for the procedures to be followed.) The Nansen bottles and the reversing thermometers are now ready for the next cast.

5. He allows the salinity samples to come to temperature equilibrium with the Oceanographic Laboratory, the salinometer, and the standard water vials. This takes about 24 hours. He runs salinity analyses about every three to five stations. A greater frequency than this uses up too much standard water. He transmits the salinity data to the Coast Guard Oceanographic Unit by ROUTINE message.

6. He completes the Oceanographic Deck Log, attaches it to the left-hand page of the oceanographic logbook, and records any pertinent information in the oceanographic logbook. He ensures that all of the data and comments are legible and are detailed enough to explain any problems encountered during the cast that may affect the quality of the data.

7. The last step of a Nansen cast routine is to carry out appropriate cleaning, lubrication, or other necessary maintenance on equipment.

## DESIRED DEPTHS, WIRE LENGTHS, AND THE WINCH CARD

The primary product of a Nansen cast is a description of the water column at the geographic location of the hydrographic station. The oceanographer wants to know how temperature and salinity vary with depth. Ideally a cast is taken to the bottom, and as many levels as possible are sampled. Realistically, there are limitations upon the total depth of casts, the amount of equipment available and the amount of equipment that can be safely placed on the cable. Therefore, the oceanographer must decide at what depths to place a limited number of Nansen bottles and thermometers in order to best describe the water column.

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In the classical situation, the ocean can conveniently be divided into three layers. There is a mixed layer, which is nearly isothermal from the surface to a depth of about 50-300 meters depending upon the location, season, meteorological conditions, and other factors. Below the mixed layer the water column undergoes a rapid decrease in temperature with depth. This region is called the thermocline and may extend to 1000 meters in some areas. Below the thermocline, which is marked by steep temperature gradients, is the deep layer, where the temperature slowly decreases with depth.

In the middle latitudes, where all of the Coast Guard Ocean Stations and Standard Monitoring Sections are located in both the North Atlantic and the North Pacific, seasonal variations in the properties of the water column are greatest and they are greatest near the surface. Thus, most of the Nansen bottles will be concentrated within the first few hundred meters. For greater depths, bottle spacing is normally increased.

The present Coast Guard Time Series Oceanography Program on the Ocean Stations requires Nansen-equippped OSV's to take daily 14-or 15-bottle casts to a 1500-meter depth with one deep cast to near bottom once during the patrol. Nansen casts of 14-15 bottles are required on the Standard Monitoring Sections to 1500 meters or to near bottom for stations of bottom depths less than 1500 meters and to near bottom for selected stations with bottom depths greater than 1500 meters. The desired depths for bottle placement have been selected, based on historical data, to best describe the water column and to determine the changes that are taking place with time. The desired depths for each Ocean Station and Standard Monitoring Section are listed in CG-410. Desired depths will also be included on the thermometer arrangement sheets delivered to the vessel by the Coast Guard Oceanographic Unit or Commander, Western Area, prior to a project.

The cable with Nansen bottles and thermometers attached will usually assume an angle with the vertical, called the wire angle. In order to aim at locating bottles at desired depths, it is necessary to estimate the wire angle and to place out more cable (wire length) accordingly for each bottle. In actual practice, the oceanographic supervisor estimates the wire angle which will be experienced and selects the winch card for the wire angle range closest to his estimate. Each ship, through experience, should make up a table of wire angles for varying wind forces, sea states, and other factors.

The winch card reflects the wire lengths necessary to reach near desired depths for the particular wire angle. The winch card is made up from the Wire Angle/Wire Length Tables for each Ocean Station Project and Standard Monitoring Section Project.

The oceanographic supervisor is limited to four sets of wire lengths from which to make up his winch card, for wire angles of 0°, 5-15°, 20-30° and 35-45°, respectively. The reasons for the limitation to only four sets of wire lengths are that four sets facilitate quality control of the data by the Coast Guard Oceanographic Unit and that experience shows that estimation of wire angles more accurate than 10° is infrequent and really not necessary.

The oceanographic supervisor should make a set of four permanent-type winch cards for each project scheduled for the ship prior to each project. Then prior to each station, he estimates the wire angle, selects the appropriate winch card, and gives it to the winch operator. The winch card shows the total amount of cable that must be paid out when each Nansen bottle is hung on the cable. The figures on the winch card are the same figures which should show on the meter wheel counter each time a bottle is hung. The winch card is the basic guide to the winch operator; it tells him exactly where to stop his winch for each bottle to be hung.

Figure 43 shows a hypothetical series of desired sampling depths for a 14-bottle Nansen cast. Note that the upper levels are sampled at much closer intervals than are the lower levels. Figure 43 also shows the wire lengths to which the bottles are lowered in order to reach the desired depths for a 25° wire angle. Figure 43 includes the meter wheel counter readings at which the winch is stopped and the bottles are placed on the cable.

Meter wheel readings are determined from the wire lengths by simply subtracting the wire length value from the maximum wire length of cast, 1655 meters in this case. The meter wheel readings are presented on the winch card in the order in which bottles are placed on the cable, for

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| NANSEN BOTTLES | DESIRED DEPTHS | WIRE LENGTHS | METER WHEEL READINGS |
|---|---|---|---|
| 1 | 0 | 0 | 1855 |
| 2 | 10 | 10 | 1845 |
| 3 | 30 | 35 | 1820 |
| 4 | 50 | 55 | 1800 |
| 5 | 75 | 85 | 1570 |
| 6 | 100 | 110 | 1545 |
| 7 | 150 | 185 | 1490 |
| 8 | 200 | 220 | 1435 |
| 9 | 300 | 330 | 1325 |
| 10 | 400 | 440 | 1215 |
| 11 | 800 | 660 | 995 |
| 12 | 800 | 885 | 770 |
| 13 | 1000 | 1106 | 550 |
| 14 | 1500 | 1855 | 0 |

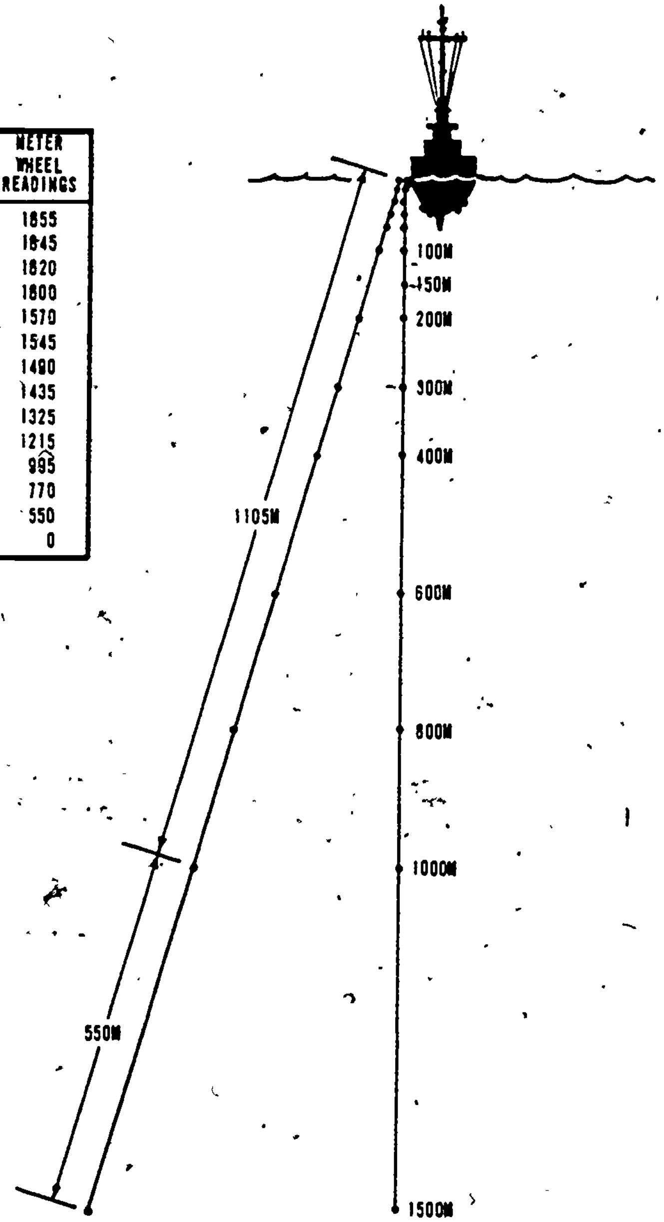


Figure 43.—Shallow Cast — 1500 Meters.



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example, OM-1655M for bottles 14-1, respectively. The use of the winch card in setting up a Nansen cast is as follows:

1. A wire angle of 25° has been estimated, the winch card has been selected, and the weight is being swung over the side.

2. The weight has been lowered into the water, the meter wheel counter is "zeroed," and the first Nansen bottle is hung. Note that this "first" bottle is the bottom bottle of the cast and in this 14-bottle cast is Nansen bottle number 14.

3. The winch operator lowers the cast until the meter reads the same as the next figure on his winch card. In this case, this is 550M. The winch operator stops the winch, and the second bottle, bottle number 13, is hung. The meter wheel reading of 550M was determined simply by subtracting the wire length of 1105M for bottle 13 from the maximum wire length of 1655M. This process continues.

4. The last bottle (number 1) is hung with the cable meter reading 1655. This is the "surface" bottle. The cast must now be lowered until this bottle is just below the water's surface and does not break the surface on the heaviest roll of the ship away from the cast. The cast is now set at the proper depth. Do not be confused by the fact that the meter wheel counter may read anywhere from 4-10 meters greater than the meter wheel reading when the surface bottle was put on the cable. It should. Remember that the meter wheel counter was zeroed when the bottom bottle was at the platform, not at the water's surface. The platform is the reference for all bottles. Therefore, the whole cast must be moved the distance from the platform to the water's surface, after the surface bottle is attached.

The "wire-in" reading is equally as important as the "wire-out" reading. Occasionally a winch operator will read the counter wrong when stopping the winch for a bottle placement; by checking each wire-in reading, a misplaced bottle can be caught and the new wire length corrected accordingly. On many deep casts, there will be a slippage of the wire during payout resulting in different (usually lesser) readings during inhaul; in this case the wire-in readings are usually more accurate and wire lengths should be corrected accordingly. If any wire-in reading differs by three meters or more from the wire-out reading, the winch operator should note this on his winch card and have the reading verified by the oceanographic supervisor before proceeding to the next bottle.

The supervisor should correct wire lengths, as necessary, prior to data transmission. Any variance of more than two meters between wire out and wire in requires an on-the-spot correction to wire length.

See figure 44, a completed Oceanographic Deck Log, for examples of corrected wire lengths (the reverse side of this Oceanographic Deck Log appears later in this section as figure 46). In the shallow cast, bottle 11 was apparently put on at 1005 rather than 995 meters, and bottle 6 was apparently put on at 1480 rather than 1490 meters. The supervisor corrected each of those two wire lengths by single-lining through the old wire length and writing in the actual wire length. Remember that the wire-in column plus the wire-length column must total the greatest wire-length, which in this case is 1655M. Note that no change was made to wire length 275M since the wire out and the wire in were within two meters. Similarly, the deep cast wire lengths are corrected as above.

## DEEP CASTS

Deep Nansen casts to near bottom are normally required once during an Ocean Station patrol and on most of the Standard Monitoring Sections. The deep cast is essentially no different from the 1500-meter shallow cast. There are, however, some tricky points which should be discussed.

The deep cast is usually the second cast of a two-cast station, the first (or shallow) cast having up to 14-15 Nansen bottles spaced from the surface down to 1500 meters and the deep cast having Nansen bottles spaced from 2000 meters on down to 150 and 50 meters off the bottom. The reason for splitting a station into two casts is to avoid exceeding the cable capacity by hanging too many Nansen bottles on the cable and to avoid the risk of losing a large amount of gear all at one time.

Ideally, the deep cast is made during the middle of the Ocean Station patrol and when weather

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# OCEANOGRAPHIC DECK LOG

CONSECUTIVE STA 007

ASSIGNED STA 007

DEPTH 3975 METERS

| | START | DOWN | MSGR | WIRE ∢ | UP | IN |
|---|---|---|---|---|---|---|
| CAST 1 | 1146 | 1210 | 1220 | 12° | 1232 | 1300 |
| 2 | 1345 | 1424 | 1424 | 16° | 1447 | 1526 |
| 3 | | | | | | |

SUPERVISOR MSTC PIERCE

BOTTLE MAN MST3 WATT

WINCH OP SN NORDSTROM

| WIRE LENGTH | WIRE OUT | WIRE IN | SAL BOT NO | BOT NO | NAN BOT | THERM NO | MAIN | AUX | THERM NO | MAIN | AUX | THERM NO | MAIN | AUX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1655 | 1655 | 15 | 8T | 1 | 855 | 8.90 | 5.0 | 856 | .05 | 5.4 | 967 | 7.87 | 5.3 |
| 30 | 1635 | 1625 | 16 | | 2 | 935 | 7.69° | 5.2 | 936 | 7.89° | 5.3 | | | |
| 55 | 1600 | 1600 | 17 | | 3 | 1001 | 7.95 | 5.4 | 1055 | 7.93 | 5.2 | | | |
| 85 | 1570 | 1569 | 18 | | 4 | 1009 | 7.87 | 5.3 | 1059 | 7.83 | 5.3 | | | |
| 110 | 1545 | 1545 | 19 | | 5 | 1053 | 6.57 | 5.4 | 1062 | 6.58 | 5.4 | | | |
| ~~165~~ 175 | 1490 | 1490 | 20 | | 6 | 1057 | FL | 5.4 | 1178 | 6.10 | 5.4 | | | |
| 220 | 1435 | 1434 | 21 | | 7 | 1061 | 5.70 | 5.6 | 1291 | 5.68 | 5.6 | 2220 | 7.80 | 5.0 |
| 275 | 1380 | 1379 | 22 | | 8 | 1152 | 5.53 | 5.2 | 1408 | 5.50 | 5.4 | | | |
| 330 | 1325 | 1324 | 23 | | 9 | 1205 | 5.25 | 5.4 | 1008 | FTB | 5.3 | | | |
| 440 | 1215 | 1214 | 24 | | 10 | 226 | 4.70 | 5.4 | 1016 | 4.73 | 5.4 | 2292 | 8.26 | 5.1 |
| ~~640~~ 650 | 985 | 1005 | 25 | | 11 | 1003 | 4.27° | 5.4 | 1056 | 4.38° | 5.4 | | | |
| 885 | 770 | 769 | 26 | | 12 | 1010 | 4.00 | 5.3 | 1059 | 4.03 | 5.4 | 2308 | 9.20 | 5.0 |
| 1105 | 550 | 549 | 27 | | 13 | 149 | 3.80 | 5.3 | 219 | 3.78 | 5.5 | 2670 | BI | 5.0 |
| 1655 | 0 | -1 | 28 | 8B | 14 | 223 | 3.45 | 5.5 | 224 | 3.44 | 5.4 | 2536 | 16.58 | 5.5 |
| | | | | | | | | | | | | | | |
| | *3432* | | | | | | | | | | | | | |
| 2030 36 | 1395 | 1389 | 57 | 8T-D | 10 | 226 | 3.09 | 5.5 | 1016 | 3.10 | 5.5 | 2292 | 19.06 | 5.4 |
| 2540 47 | 885 | 878 | 58 | | 12 | 1010 | 3.10 | 5.4 | 1059 | 3.12 | 5.5 | 2308 | 17.90 | 5.4 |
| 3045 53 | 380 | 372 | 59 | | 11 | 1003 | 9.04° | 5.5 | 1056 | 3.12° | 5.4 | | | |
| 3325 34 | 100 | 91 | 60 | | 13 | 149 | 3.08 | 5.1 | 219 | 3.07 | 5.4 | 2670 | 32.20 | 5.4 |
| 3425 35 | 0 | -10 | 61 | 8B-D | 14 | 223 | 2.97 | 5.2 | 224 | 2.96 | 5.4 | 2536 | 31.18 | 5.5 |
| | | | | | | | | | | | | | | |
| | * ASSUMES | 7 M. PLATFORM HEIGHT | | | | | | | | | | | | |

DEPT. OF TRANSP., USCG, CG-4362 (2-69)

Figure 44.— Oceanographic Deck Log.

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and sea conditions are calmest. In actual practice, it is best to take advantage of the best day you can expect during your patrol. Of course, if you wait two weeks and still have not found your day, you will want to settle for less and less ideal weather as the patrol nears conclusion. During Standard Sections you will have to accept whatever weather, short of too heavy for oceanographic operations, that you incur. Fair weather and mild sea conditions are essential for deep casts, because these conditions greatly reduce the risk of losing gear and greatly enhance the quality of the data obtained.

Take the deep cast in about the same position and within two and one-half hours of the shallow cast. The procedure for taking a deep cast is as follows:

1. Obtain an accurate fathometer sounding.

2. Make the best possible estimate of the wire angle.

3. Determine the wire lengths in order to place the Nansen bottles at the correct depths and at correct distances off the bottom. Remember the important restriction that AT NO TIME IS A GREATER AMOUNT OF CABLE PUT OUT THAN THE DEPTH OF WATER.

When the estimated wire angle is so large that the wire length necessary to obtain the maximum desired depth exceeds the depth to bottom, make up a set of restricted depths and a revised set of wire lengths. The upper bottles will not be affected, but the lower ones will. Place the bottom bottle at the end of the cable above the weight and place the next higher bottle 100 meters of wire length above it. Place the third bottle from the bottom at the wire length to reach the desired depth. If this wire length exceeds the water's depth or the revised wire length of the bottle below it or is less than 50 meters above the second bottle from the bottom, eliminate the third bottle from the bottom.

For an example of a deep cast having a wire length exceeding the depth to bottom, see figure 45. In this example, a deep cast of six Nansen bottles is planned. The depth to bottom is 3750 meters. Thus, the desired depths are 2000, 2500, 3000, 3500, 3600 (150M off bottom), and 3700 (50M off bottom). From the estimated wire angle of 25°, the theoretical wire lengths are shown. Note that the maximum wire length exceeds the depth to bottom. The wire lengths for all three bottom bottles are greater than the depth to bottom.

Since the maximum amount of wire length that can be put out is 3750M, the restricted depths and the revised wire lengths must be determined. In this situation, the top three bottles—9, 10, and 11—are given the same desired depths as they were given in the original set of figures. The bottom bottle, number 14, is placed at the end of the cable at a maximum wire length of 3750M, which, for a 25° wire angle, is a "restricted" depth of 3400M. Bottle 13 is placed 100 meters of wire length above 14, or 3650M, which is equivalent to a "restricted" depth of 3310M. Since the wire length of bottle 12 (3860M) exceeds the revised wire length of bottle 13 (3650M), bottle 12 is eliminated from the cast, and the cast becomes a five-bottle cast with a maximum wire length of 3750 meters.

In actual practice, wire angles for deep casts will generally be 15° or less, and it will not be necessary to restrict depths and revise wire lengths.

4. If you must eliminate a bottle for any reason, preferably eliminate a bottle without a pressure thermometer. There should always be a pressure thermometer at the top and at the bottom of every deep cast.

5. The meter wheel reading of the last bottle put on the deep cast (number 9 at 1545M in the example) is not equal to the maximum wire length of the cast (3750M) as is true of the shallow cast, which always has a surface bottle. Note in figure 45 that the final meter wheel reading when the cast is down is 3757M and not 3750M, the maximum wire length. This difference is to allow for the distance from the platform where bottles are hung, to the water's surface.

6. Make up the winch card. (Note in figure 45 that the winch card readings are the reverse order of the meter wheel readings. The reason for this reversal is that the bottles are placed from the bottom to the top, i.e. from bottle 14 to bottle 9.)

7. Obtain the position from the bridge. Use the average of this position and the position during the shallow cast for the station position.

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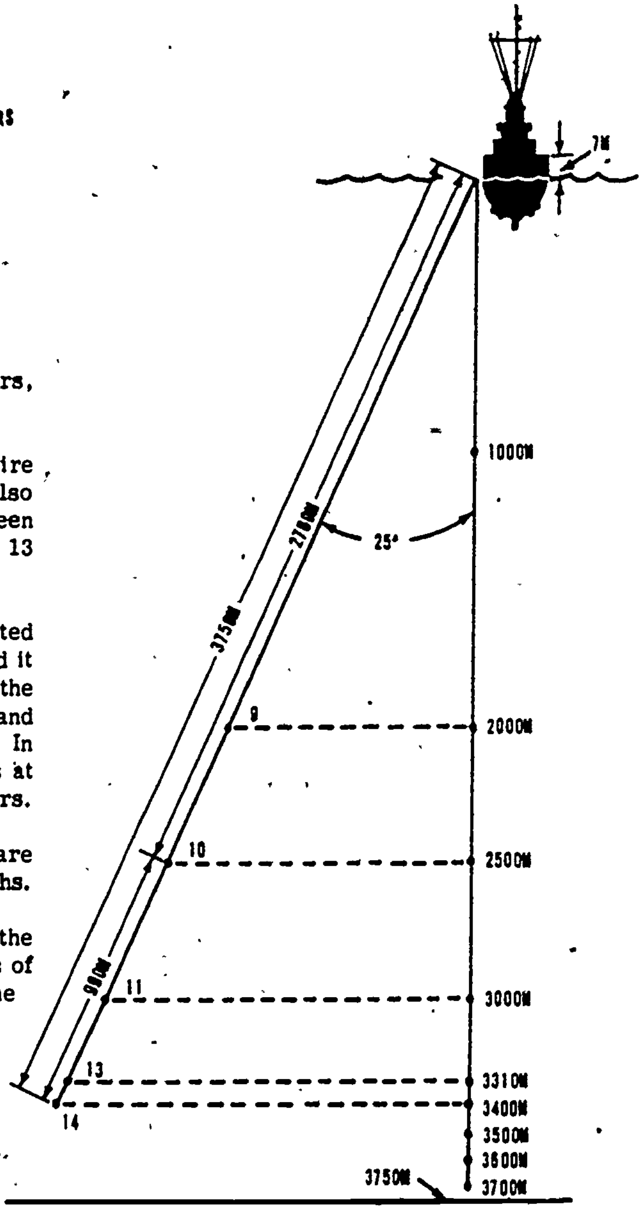
| HANSEN BOTTLE | DESIRED DEPTHS | WIRE LENGTHS | RESTRICTED DEPTHS | REVISED WIRE LENGTHS | METER WHEEL READINGS |
|---|---|---|---|---|---|
| 9 | 2000 | 2205 | 2000 | 2205 | 1545 |
| 10 | 2500 | 2760 | 2500 | 2760 | 990 |
| 11 | 3000 | 3310 | 3000 | 3310 | 440 |
| 12 | 3500 | 3860 | ELIMINATE[2] | ELIMINATE[2] | |
| 13 | 3600[1] | 3970 | 3310[4] | 3650[3] | 100 |
| 14 | 3700[1] | 4080 | 3400[4] | 3750[3] | 0 |

| HANSEN BOTTLE | WINCH CARD |
|---|---|
| 14 | 0 |
| 13 | 100 |
| 11 | 440 |
| 10 | 990 |
| 9 | 1545 |
| DOWN | 3757[5] |

FATHOMETER DEPTH - 3750 METERS




NOTES:

1. The bottom two bottles are 50 and 150 meters, respectively, off the bottom.

2. Bottle 12 is eliminated because its wire length exceeds the depth to bottom. It would also have been eliminated had its wire length been greater than the revised wire length of bottle 13 or within 50 meters of bottle 13.

3. The bottom two bottles are never eliminated from the cast. If the depths are restricted and it is necessary to revise the wire lengths, the bottom bottle is placed at the end of the wire and the next bottle is placed 100 meters above it. In this example, bottle 14, the bottom bottle, is at 3750 meters, and bottle 13 is at 3650 meters.

4. The restricted depths for bottles 13 and 14 are determined from their revised wire lengths.

5. The cast is taken down to 3757 meters (the maximum revised wire length plus 7 meters of wire length, which is the distance from the platform to the water level).

Figure 45.— Deep Cast.

If these positions differ by more than six miles, treat the casts as separate stations.

8. Include deep cast data and shallow cast data as one station in the message to the Coast Guard Oceanographic Unit. Include the deep cast messenger time and wire angle as is explained later in this section in figure 48.

9. Adjust for winch slippage of more than two meters just as you do for a shallow Nansen cast.

10. Follow all other procedures of a shallow Nansen cast routine.

## OCEANOGRAPHIC RECORDS AND OCEANOGRAPHIC CODE FORMATS

Nansen data collected are recorded for delivery to the Coast Guard Oceanographic Unit in real time and also for pickup by the Coast Guard Oceanographic Unit or the Commander, Western Area, during debriefing. The following paragraphs describe the forms and code formats required for recording the Nansen cast data and explain the proper disposition of these forms.

### OCEANOGRAPHIC LOGBOOK

The oceanographic logbook is an 8 x 10 1/2 bound book that contains all of the collected information, such as the station narrative, oceanographic deck log sheets, and the weather data. It is delivered to the Coast Guard Oceanographic Unit during debriefing and then is returned to the ship about three months later.

### OCEANOGRAPHIC DECK LOG FORM CG-4502

An Oceanographic Deck Log (figure 44) is an original record of Nansen temperature and depth data. Weather data are recorded on the back of this form (figure 46). After a log sheet is completed, it should be stapled or clipped to a left-hand page of the oceanographic logbook.

### WINCH CARDS

Winch cards for shallow Nansen casts are made up from tables found in CG-410. Four sets should be made up, preferably laminated, prior to each project. These should be made for wire angles of 0 degrees, 5-15 degrees, 20-30 degrees, and 35-45 degrees. These cards are permanent and are retained aboard the ship.

A permanent set of winch cards for deep casts is not necessary due to the infrequency of deep casts and the complications involved. Winch cards made for deep casts should be forwarded to the Coast Guard Oceanographic Unit with the original data for the particular station.

### NANSEN TEMPERATURE MESSAGE FORMAT

For real time priority transmission of information recorded on the Oceanographic Deck Log to the Coast Guard Oceanographic Unit, use the Nansen temperature message format shown in figure 47 as a guide for encoding the data. The form on which this format is used is for the use of radio personnel on the ship and is not submitted to the Coast Guard Oceanographic Unit during debriefing. Refer to figure 48 for specific instructions about the format and for an explanation of the symbolic form for the message format.

### NANSEN CONDUCTIVITY MESSAGE

This coded message is used to transmit salinometer conductivity readings to the Coast Guard Oceanographic Unit. It is normally transmitted every three to five days. See figure 49 for the symbolic form and format of the code and for a sample conductivity message.

### OXYGEN MESSAGE

At times, dissolved oxygen content is computed from a Nansen cast. This pamphlet does not consider how to encode these computations in an oxygen message; however, we do show the oxygen message format and its symbolic form and explain the code in figure 50. For complete data and details for encoding the message, consult CG-410.

NOTE: Since oceanography code forms are subject to almost constant change, the codes given in this pamphlet may or may not be up to date. To ascertain whether the code form given is in present use, consult CG-410.

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NOTE: Weather observations should be taken and recorded in accordance with Federal Meteorological Handbook No. 1, Surface Observations.

PROJECT CHARLIE

SHIP OWASCO

LATITUDE 52°46'N

LONGITUDE 35°26'W

DATE 13 NOV 1970

MSGR. TIME 1220 Z

ASSIGNED STATION NO. 007

DEPTH 1900 FM 3475 M

| SEA | | SWELL | |
|---|---|---|---|
| DIR. | | DIR. | 310 |
| HT. | 2 FT. | HT. | 3 FT. |
| PER. | 3 SEC | PER. | 5 SEC |

WIND DIRECTION 310

WIND SPEED 18 KTS

BAR. PRESS ____ IN. 1019.7 MBS

DRY BULB ____ F 4.9 C

WET BULB ____ F 3.8 C

PRESENT WEA. Partly Cloudy

CLOUD TYPE Cumulus

CLOUD AMT. 6/8

VISIBILITY 8 N.M.

SPECIAL OBS. Secchi - Down - 17m Up - 19m
Average - 18m

Figure 46.—Reverse side of Oceanographic Deck Log.

P

FM CGC OWASCO

TO COGARD OCEANO

BT

UNCLAS

A. .OCEANO

| $QL_aL_aL_aL_a$ | $L_oL_oL_oL_oL_o$ | YYGGg | $JJJW_aW_a$ | UDUDD | $C_1C_2C_3C_4C_5$ | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 75246 | 03526 | 13123 | 00712 | 03425 | 46004 | | | | |
| $B_nB_nB_nB_nB_n$ | $T_iT_iT_iT_iT_i$ | IMMMM | ϕIAAA | $T_rT_rT_rT_rT_r$ | IMMMM | ϕIAAA | $T_cT_cT_cT_cT_c$ | IMMMM | ϕ AAA |
| 00000 | 00855 | 70890 | 07050 | 00856 | 99999 | 07054 | 00967 | 70787 | 07053 |
| 00030 | 00935 | 70768 | 07052 | 00936 | 70789 | 07053 | | | |
| 00055 | 01001 | 70795 | 07054 | 01055 | 70793 | 07052 | | | |
| 00085 | 01009 | 70787 | 07053 | 01058 | 70783 | 07053 | | | |
| 00110 | 01053 | 70657 | 07054 | 01062 | 70658 | 07054 | | | |
| 00175 | 01057 | 91111 | 07054 | 01178 | 70610 | 07054 | | | |
| 220 meters through 1105 meters, data not shown | | | | | | | | | |
| 01655 | 00223 | 70345 | 07055 | 00224 | 70344 | 07054 | 02536 | 71688 | 07055 |
| 55555 | 12312 | 03425 | | | | | | | |
| 02036 | 00226 | 70308 | 07055 | 01016 | 70310 | 07055 | 02292 | 71906 | 07054 |
| 02547 | 01010 | 70310 | 07054 | 01059 | 70312 | 07055 | 02308 | 71790 | 07054 |
| 03053 | 01003 | 70904 | 07055 | 01056 | 70312 | 07054 | | | |
| 03334 | 00149 | 70308 | 07051 | 00219 | 70307 | 07054 | 02670 | 73220 | 07054 |
| 03435 | 00223 | 70297 | 07052 | 00224 | 70296 | 07054 | 02536 | 73118 | 07055 |

B.. REMARKS

NOTE: WHEN UNPROTECTED PRESSURE THERMOMETER USED, INSERT INFORMATION FOR IT ON SAME LINE DIRECTLY AFTER PROTECTED THERMS INFO. IN THIS CASE THERE WILL BE 10 GROUPS INSTEAD OF 7 GROUPS ON THE LINE. IF MORE THAN ONE CAST, FIRST GROUP OF SECOND CAST WILL BE 55555, FOLLOWED BY $GG_gW_aW_a$ AND UDUDD.

Drafted by ______________ Released by ______________

Figure 47.—Sample Nansen Temperature Message.

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EXPLANATION OF SYMBOLIC CODE MESSAGE FORMAT

Q = Quadrant

$L_aL_aL_aL_a$ = Latitude in degrees and minutes.

$L_oL_oL_oL_oL_o$ = Longitude in degrees and minutes. (PREFIX "0" in Longitude degrees column when less than 100°)

YY = Day of month

GG = Messenger time in hours GMT.

g = Tenths of hours.

JJJ = Station number (Consecutive).

$W_aW_a$ = Wire angle in whole degrees.

DDDDD = Depth to bottom in whole meters.

$C_1C_2C_3C_4C_5$ = Check Sum ($C_1$ = Sum of digits in the first group on line; $C_2$ = Sum of second group, etc.)

$B_nB_nB_nB_nB_n$ = Nansen Bottle location (wire length).

$T_1T_1T_1T_1T_1$ = Left thermometer number.

I = Indicator number for plus or minus temperature. Use 7 for + and 8 for -.

MMMM = Main thermometer. Reading to nearest hundredth degree Celsius.

ϕ = Auxiliary indicator, zero

AAA = Auxiliary temperature to nearest tenth degree Celsius.

$T_rT_rT_rT_rT_r$ = Right thermometer number.

$T_cT_cT_cT_cT_c$ = Center thermometer number, usually an unprotected thermometer.

55555 = First group of second cast (used only if more than one cast).

9 = Indicates malfunction group

Figure 48.—Symbolic Form of Nansen Temperature Message.

626

R

FM CGC GALLATIN

TO COGARD OCEANO

BT

UNCLAS

CONDUCTIVITY

A. KKKKK $RRRRJ_a$ $J_aJ_aJ_bJ_bJ_b$

PWTTT CCCCC NNTTT CCCCC NNTTT CCCCC NNTTT CCCCC NNTTT CCCCC

PWTTT CCCCC NNTTT CCCCC NNTTT (Ten groups per line)

B. KKKKK $RRRRJ_a$ $J_aJ_aJ_bJ_bJ_b$

As above

C. REMARKS

BT

Notes: 1. Originate new paragraph B, C, etc. only when using new salinometer or when new standarization value is obtained.

2. Samples must be collected in consecutively numbered bottles and run in that same order. If there is a discontinuity in your sample numbering, verify this in the remarks section of the message (e.g. SAMPLE NUMBER 17 —BOTTLE BROKEN).

3. Explanation of Code:

| | |
|---|---|
| KKKKK | Salinometer number. |
| RRRR | Average standardization value. |
| $J_aJ_aJ_a$ | Station number for first station run. |
| $J_bJ_bJ_b$ | Station number for last station run. |
| P | Standard water indicator. |
| W | Last digit of standard water batch number. |
| TTT | Standard water or sample temperature to nearest 0.1°C. |
| NN | Sample bottle number. |
| CCCCC | Average conductivity value (If > 1.00000, drop the units digit). |

CONDUCTIVITY

A. 04601 49010 01005

P0230 00005 01227 99917 02225 99934 03220 99834 04223 99602

P0231 00010 05225 00402 06218 00076 07220 99993 08224 99008

09238 98644 SAMPLES (10-31) DATA NOT SHOWN 32239 97986 33240 97641

P0232 00020 SAMPLES (34-50) DATA NOT SHOWN 51240 02492 52239 02528

P0231 00013 53225 00402 54218 00074 55227 99994 56224 99908

57238 98644 SAMPLES (58-68) DATA NOT SHOWN 69239 97987 70240 97641

P0232 00015

Figure 49.—Conductivity message format and symbolic form, notes, and sample conductivity message.

R
FM CGC DUANE
TO COGARD OCEANO
BT
UNCLAS
OXYGEN

A. JJJYY RRMMM
$B_nB_nB_nB_nB_n$ ØØOXY $B_nB_nB_nB_nB_n$ ØØOXY, etc.

B. JJJYY RRMMM
$B_nB_nB_nB_nB_n$ ØØOXY $B_nB_nB_nB_nB_n$ ØØOXY, etc.

(Continue as above for as many stations as are included in message)

C. REMARKS (as required)

BT

EXPLANATION OF CODE

| | |
|---|---|
| JJJ | Station number (consecutive). |
| YY | Day of month station taken. |
| RR | Reagent blank to nearest hundredth. |
| MMM | Average milliliters of sodium thiosulfate used in standardization (to 0.01 ml/l). |
| $B_nB_nB_nB_nB_n$ | Nansen bottle location (wire length). |
| ØØ | Thiosulfate indicator. |
| OXY | Average milliliters of sodium thiosulfate to 0.01 ml/l used to titrate sample at this wire length. |

Figure 50.— Oxygen Message.

# STD CASTS

The Navy's Anti-submarine Warfare Environmental Prediction Services (ASWEPS) is designed to furnish Fleet ASW forces with oceanographic information which will permit the optimum use of these forces. The development of an effective ASWEPS depends on the collection of considerable oceanographic data by all means available over large areas of the oceans for long periods. For forecasting purposes the data must be collected synoptically and must be processed in real time so that forecasts may be generated and distribution made to users in time to be of operational value. To ensure collection and processing of this data, the U.S. Naval Oceanographic Office and the U.S. Coast Guard have signed a Salinity-Temperature-Depth (STD) Measuring System Project Agreement.

According to the current agreement, OSV's are to provide synoptic oceanographic observations by using the STD on approximately 75% of the Ocean Station Patrols. STD casts are to be made in accordance with the current USNAVOCEANO-USCG agreement, which presently prescribes a minimum of two per day, plus such frequency of observations as support the USCG's own oceanographic objectives. Nansen casts will be used on the remainder of patrols and as a backup to the STD.

The Coast Guard has also agreed to provide synoptic oceanographic observations during travel to and from station when the STD system is aboard and on a not-to-interfere-with-other-missions basis. Enroute to and from an Ocean Station, casts are made either along Standard Monitoring Sections or every twelve hours along normal tracks. A BT observation is not taken when an STD cast is taken; however, if the STD system fails, a BT must be taken at this time. A Nansen cast is taken once daily on an Ocean Station; Nansen casts will replace STD casts if the STD system fails.

In addition to providing real-time data to ASWEPS, the STD data will also be used along with Nansen data for continuing the Coast Guard's Time Series Projects on each of the Ocean Stations and the Standard Monitoring Sections.

## STD CAST ROUTINE

### PRE-CAST

The following procedures should be performed during the pre-cast phase of an STD cast routine:

1. Make a check of the frequencies, using test equipment and procedures supplied by the Coast Guard Oceanographic Unit.

2. The vessel should be hove to with the wind on the STD system's side before the cast is commenced. During the time the STD sensors are at the surface and when the surface Nansen bottle is soaking, the sanitary system and other controllable overboard discharges should be minimized. Wire angles are essentially unimportant for STD operations. Criteria for not making a cast should be based on the possibility of damaging the sensor during immersion or recovery.

3. Man communications between the bridge, the winch, the recorder, and deck supervisor.

4. A party of at least five will be required:

   a. Deck supervisor (safety officer)

   b. Winch operator

   c. Recorder operator

   d. Deck handlers (2)

All stations will be manned at the start of the cast and will remain manned until the fish is safely aboard and stowed.

5. When ready for the cast, the recorder operator requests that the deck supervisor let out

the dampening device, place the fish over the side, and attach the bottom QC Nansen bottle with quad thermometer frame as close to the fish as practical, leaving enough space so the bottle will not hit the fish when the bottle reverses. After the bottle is attached, have the supervisor lower the fish one or two meters under the surface, i.e., deep enough so that the Nansen QC bottle will not come out of the water on a roll. Take care to prevent the fish from striking the side of the vessel. Attach the surface QC Nansen bottle containing three protected thermometers. Then lower the surface QC Nansen bottle to just under the sea surface to obtain the surface QC sample. Overboard discharges should be minimal at this time. Allow an eight-minute soaking period. During this time, energize the fish.

6. Prior to turning on the equipment, ensure that the chart table latch is lowered to disengage the chart from the pens and to prevent the pens from making erratic traces while the servos are returning to null; also ensure that the chart drive clutch release knob is disengaged. The above two items should have been disengaged at the time the fish was stopped just under the surface on the in-haul portion of the previous cast.

a. Turn on the regulated power supply located at the extreme bottom of the cabinet. This may be left on for the entire cruise.

b. Press the system line power switch.

c. Press the test/operate switch; each time this switch is pressed it will alternately light to operate and then to test. Press it for operate.

d. Turn the recorder line power toggle switch to ON.

7. Now the recorder operator adjusts the range selection switches so that the pens are not at either end of the chart paper or are not being overdriven. The salinity and temperature range selection switches are the only ones requiring adjustment since the depth switch remains on position 2 for 1500 meters or position 3 for 3000 meters. Make sure each small light above each range switch is lit; if not, you have problems. Since most operators will be aware of normal salinity and temperature, depending on the station being occupied at the time, the operator can set these dials to their proper position both when the fish is on deck and especially when first submerged. At this time, incorporate all available information on the chart in the spaces provided.

8. After eight minutes, trip the surface QC Nansen bottle and bring it aboard. Raise the STD fish so that it is at the level where the surface QC Nansen bottle was tripped. Rotate the manual chart drive by hand to set the pens at zero depth. The most forward pen is the salinity pen and is always set on zero; the temperature pen is exactly one paper division above the salinity pen. While rotating the manual chart drive, slowly raise the chart latch up to engage the pens with the chart paper. Contact should be made with the paper so that the pens are very slightly below zero. The paper is then rotated exactly to zero. Every possible attempt must be made to prevent the pens from making extraneous marks on the paper.

DURING THE CAST

1. Now the recorder operator engages the chart drive release knob and informs the deck supervisor that he is ready to have the fish lowered. Until such time as the cast team is familiar with the operation, hold the speed of the fish to about 20 meters per minute. Winch speed shall be controlled by the recorder operator. The sensor must be lowered through the thermocline slowly enough for the temperature sensor to react to the rapid temperature changes. Operate the winch at 50 meters/minute or less until through the thermocline. A speed of 80 meters/minute is recommended from the bottom of the thermocline to cast depth. Under no circumstances should the speed exceed 80 meters/minute. Sensor vertical speed and changes will be recorded on the chart.

2. The temperature and salinity scales must be indicated by an encircled range number on the chart paper near the trace start and at each scale change to show the new scale. Do not mark directly on a temperature or salinity trace. Remember that the temperature trace is offset from the depth scale (10M on 1500M scale). The trace is at 0 depth when located at 10M on the chart and at 1500M when it is located at 1510M on the chart.

3. The supervisor shall act as a safety watch and may call for the winch to be stopped for any unusual circumstance.

4. If the cast will go deeper than 2000 meters, attach the 1500-meter QC Nansen bottle when the depth of the STD, as per the STD recorder, reads "maximum depth of cast minus 1500 meters." For example, for a 2100-meter cast, attach the QC bottle when the fish is at 600 meters (2100 - 1500 = 600 meters).

5. As the full depth is approached, the deck supervisor will be alerted by the recorder operator to slow down and stop the winch when the fish reaches maximum depth. If the cast is 1500 meters or deeper, drop the messenger at this time. If the cast is shallower, wait the appropriate soaking time before dropping the messenger. As soon as the winch is stopped, record the frequency for the depth at the bottom of the trace and record the down time. The recorder operator then monitors depth frequency and instructs the winch operator to pay wire out or haul wire in to maintain a frequency within four cycles of the frequency recorded above. The fish should remain at a nearly constant depth for the entire messenger travel time.

6. To estimate trip time, use 150 meters/minute for the actual amount of cable out, not the depth indicated by the STD recorder. After the bottom bottle is tripped, immediately drop the chart paper away from the pens and release the chart clutch.

7. Roll the chart manually to the next sheet; position the pens on the appropriate meter marks, i.e., 750, 1500, or 3000-meter marks; engage the chart switch drive; ensure that all information is on the chart; and mark any changes of the range switches. The recorder operator requests the winch operator to commence uphaul. The cast will be retrieved under the same procedures as lowering. Record start-up time and at-surface time on the chart. The recorder operator will keep the winch operator advised of the depth to aid him in checking his wire length counter.

8. As the fish approaches the surface, the recorder operator should caution the deck supervisor to be on the lookout and stop the winch with the fish 1 or 2 meters under the surface. When the winch has stopped, disengage the chart clutch and the pens from the paper and shut off the line power switch on the recorder. Next, press the system line power switch; the test/operate switch light should go out. Then the recorder operator requests the deck supervisor to haul in and remove the bottom bottle and to stow the fish.

DATA RETRIEVAL

Retrieval of STD data involves the following procedures:

1. Carefully remove the STD analog traces from the recorder. There are two traces for each station, a "down" and an "up" trace. Ensure that you have filled in the information required on the lower portion of the STD chart paper for each trace. Be sure to indicate "up" or "down" next to the station number. (See figure 51)

2. Read the temperature and salinity trace from the "down" trace and record on the STD Summary Sheet (figure 52) the temperature and salinity values for the following standard depths: 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, and 1500. For 3000M stations, additional depths are 1750, 2000, 2500, and 3000 meters. For stations having depths less than 1500 meters, casts will be taken either to bottom minus 25 meters (B-25) or to bottom minus 50 meters (B-50) as specifically directed; standard depths are used from the surface down to the B-25 or B-50 depth.

In order to read the trace, use the plastic overlay and scales provided by the Coast Guard Oceanographic Unit. Lay the scales along the depth lines when reading the values. Read the temperature to 0.01°C; read the salinity to 0.005°/oo.

3. Read the significant temperature or salinity values that appear on the "down" trace between standard depths and record these values on the STD Station Summary Sheet (figure 52). A significant depth is defined as a point where temperature and/or salinity traces have a maximum deviation from a straight edge laid between two standard depth points on a trace (± 0.1°C for temperature and ± 0.05°/oo for salinity).

4. Record weather data and Nansen data for each station on the STD Weather and Quality Control Data Sheet.

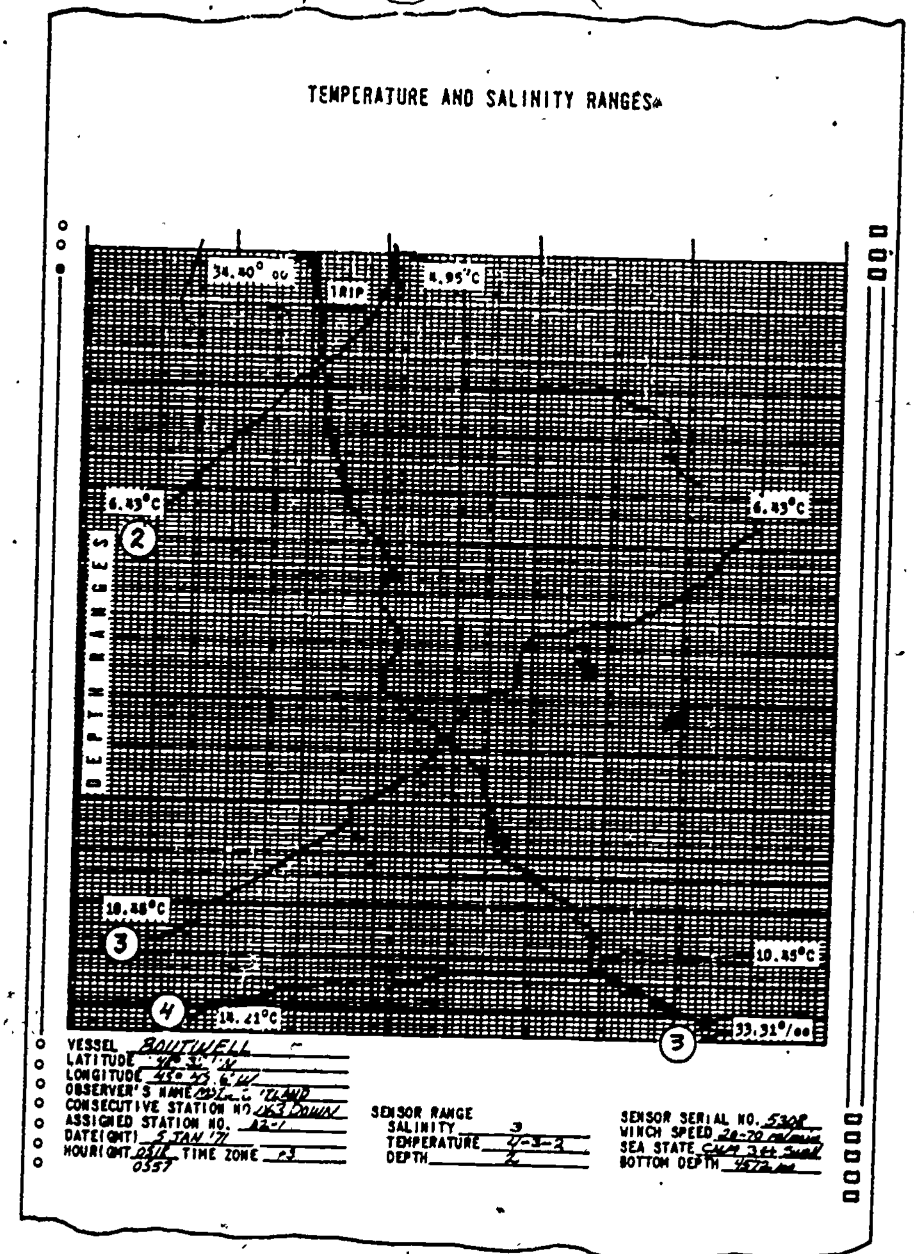


Figure 51.— Graph of Typical STD Cast.

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# OCEANOGRAPHIC
## STD STATION SUMMARY SHEET

SHIP McCULLOCH

PROJECT DELTA

CONSECUTIVE STA. No. 10

TRACE READ BY SUMST JOHNSON

TRACE CHECKED BY ENS HILL

DATE CAST TAKEN MAY 22, 1970

TIME CAST TAKEN 1126 Z

| FOR CGOU USE ONLY: | | |
|---|---|---|
| DEPTH | TEMP CORR. | SAL CORR. |

REMARKS:

| DEPTH | TEMP. (0.01°C) | SAL (0.005°/oo) | DEPTH | TEMP (0.01°C) | SAL (0.005°/oo) |
|---|---|---|---|---|---|
| 0 | 14.19 | 35.805 | 800 | 5.64 | 35.020 |
| 10 | 14.09 | 35.850 | 900 | 4.93 | 34.985 |
| 20 | 14.08 | 35.850 | 1000 | 4.62 | 34.985 |
| 30 | 14.08 | 35.855 | 1100 | 4.37 | 34.980 |
| 50 | 14.06 | 35.860 | 1200 | 4.21 | 34.975 |
| 75 | 13.90 | 35.830 | 1300 | 4.05 | 34.970 |
| 100 | 13.77 | 35.830 | 1400 | 3.95 | 34.965 |
| 125 | 13.55 | 35.760 | 1500 | 3.91 | 34.980 |
| 150 | 13.91 | 35.785 | 1750 | 3.75 | 34.980 |
| 160 | 13.90 | 35.790 | 2000 | 3.63 | 34.995 |
| 185 | 13.77 | 35.790 | 2500 | 3.36 | 35.010 |
| 200 | 13.92 | 35.910 | 3000 | 3.06 | 35.020 |
| 250 | 13.67 | 35.860 | | | |
| 300 | 12.85 | 35.680 | | | |
| 400 | 11.54 | 35.460 | | | |
| 500 | 9.33 | 35.150 | | | |
| 600 | 7.54 | 35.040 | | | |
| 700 | 6.33 | 34.985 | | | |
| 750 | 5.94 | 35.020 | | | |
| 760 | 6.07 | 35.040 | | | |

DEPT. OF TRANSP., USCG, CG-4744 (7-70)

Figure 52.— Sample STD Station Summary Sheet.

5. Maintain an oceanographic logbook including a narrative for each station and a description of significant occurrences. No data are required to be recorded in the logbook.

STD RECORDS, REPORTS, AND MESSAGE CODES

As we have already suggested, the STD analog traces represent the original STD temperature and salinity data (see figure 51). These data are subsequently recorded on the STD Station Summary (figure 52), During debriefing, these analog traces are submitted to the Coast Guard Oceanographic Unit.

The STD Station Summary, which is a record of standard and significant depths, is used to make up the real-time STD Data Messages. The Summary itself is submitted to the Coast Guard Oceanographic Unit during debriefing.

The STD Data Message is transmitted after every station in the format and code form shown in figure 53. Study this figure carefully.

Weather data, Nansen data, and other data required for STD stations are recorded on the STD Weather and Quality Control Data Sheet (figure 54). The sheet is used to prepare the Daily STD Quality Control Data Message and is subsequently submitted as part of the STD data during debriefing. The Daily STD Quality Control Data Message is sent daily after the last station of the GMT day and includes data for all stations taken during the day. Study figure 55; it shows the message's format and explains the message's code form.

The Conductivity Message is filled out at the completion of salinity runs, normally within five days, and is transmitted routine precedence to the Coast Guard Oceanographic Unit. Included in the message are Nansen conductivities for all stations run. See figure 49 for the format for this message.

In addition to these STD records and messages, an oceanographic report must be completed. The report is a narrative letter report of the cruise; it describes events, problems, and casualties and makes recommendations to the Coast Guard Oceanographic Unit via the district and area commanders. A copy of the report should be sent to District (e), and an advance copy should be delivered to the Coast Guard Oceanographic Unit during debriefing.

DEBRIEFING

The ship is debriefed by the Coast Guard Oceanographic Unit representative after return to port. At this time, the representative picks up the thermometers, the STD test equipment kit, the spare fish, the salinometers, and the records described above.

STD DATA MESSAGE FORMAT

P
FM SHIP's NAME
TO FWC NORVA
INFO NAVOCEANO
CANMARCOM HALIFAX (North of 30°N)
METEOROLOGICAL OFFICE, BRACKNELL, ENGLAND
BT CINC WESTERN FLEET WEATHER CENTER
UNCLAS FLENUMWEACEN

| 1 SHIP's CALL SIGN | 2 MESSAGE INDICATOR | 3 DAY MONTH YEAR | 4 YEAR TIME GMT | 5 QUADRANT LATITUDE | 6 LONGITUDE | 7 DEPTH TO BOTTOM METERS |
|---|---|---|---|---|---|---|
| | HISTD | DDMMY | $YGG_{gg}$ | $QL_aL_aL_aL_a$ | $L_oL_oL_oL_oL_o$ | $S_jS_jS_jS_jS_j$ |

| 8 DEPTH 2ZZZZ | 9 TEMPERATURE 3TTTT | 10 SALINITY 4SSSS | 8 DEPTH 2ZZZZ | 9 TEMPERATURE 3TTTT | 10 SALINITY 4SSSS | 8 DEPTH 2ZZZZ | 9 TEMPERATURE 3TTTT | 10 SALINITY 4SSSS |
|---|---|---|---|---|---|---|---|---|
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |

If End of Message Indicator
19991
BT

Note: This form to be used by the MST to record data and deliver to radio room for real-time transmission. Three levels data per line.

Figure 53 (cut apart)

## EXPLANATION OF CODE

| Item | Symbols | Explanation |
|---|---|---|
| 1 | | SHIP's CALL SIGN - Enter the four letters that comprise the ship's International Radio Call Sign. Note this is the only 4 character group in entire message. |
| 2 | HISTD | Identifies electronically observed data. Insert same for second group of text. |
| 3 | DDMMY | |
| | DD | DAY - Enter GMT day of month |
| | MM | MONTH - Enter GMT month (Jan 01, Feb 02, etc.) |
| | Y | YEAR - Enter 3rd digit of year (ex. 1968-6) |
| 4 | $YGG_{gg}$ | |
| | Y | YEAR - Enter last digit of year (ex. 1968-8) |
| | $GG_{gg}$ | TIME - Record GMT time to nearest minute at which observation was begun. |
| 5 | $QL_aL_aL_aL_a$ | |
| | Q | QUADRANT - Enter quadrant of globe where station taken. Northern Hemisphere use 7 for western longitudes and 1 for eastern longitudes. For Southern Hemisphere use 5 for western longitudes and 3 for eastern longitudes. |
| 6 | $L_aL_aL_aL_a$ | LATITUDE - Enter station position to nearest minute. |
| | $L_oL_oL_oL_o$ | LONGITUDE - Enter to nearest minute (ex. 47°50'W 04750) |
| 7 | $S_jS_jS_jS_jS_j$ | DEPTH TO BOTTOM - Record sonic depth to bottom in meters. Prefix with zeros to fill field. |
| 8 | 2ZZZZ | |
| | 2 | DEPTH IDENTIFIER |
| | ZZZZ | DEPTH of observation to nearest meter. Surface depth (ZZZZ-0000m) is preprinted. Include 24 standard depth plus significant depths. |
| 9 | 3TTTT | |
| | 3 | TEMPERATURE IDENTIFIER |
| | TTTT | TEMPERATURE - Enter to nearest 0.01°C |
| 10 | 4SSSS | |
| | 4 | SALINITY INDICATOR |
| | SSSS | SALINITY - Enter to nearest 0.01°/•• |
| 11 | 19991 | End of message indicator is 19991. |

**Figure 53 (cut apart)**

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SAMPLE STD MESSAGE

```
P       050730Z JUNE 68

FM      CGC HAMILTON
TO      FWC NORVA
INFO    NAVOCEANO
        CANMARCOM, HALIFAX
        METEOROLOGICAL OFFICE, BRACKNELL, ENGLAND
        CINC WESTERN FLEET WEATHER CENTER
BT      FLENUMWEACEN
UNCLAS

NEJL    HISTD   05066   80600   05245   03530   03475

20000   31521   43485   20010   31520   43485   20020   31518   43486
20030   31516   43486   20050   31510   43487   20065   31502   43487
20075   31480   43489   20092   31401   43490   20100   31350   43495
20125   31308   43497   20150   31211   43510   20183   31176   43505
20200   31151   43501   20250   31080   43498   20300   31023   43492
20400   30945   43490   20500   30895   43485   20600   30861   43481
20700   30822   43477   20800   30801   43470   20900   30753   43465
21000   30704   43462   21100   30658   43458   21200   30610   43455
21300   30575   43451   21400   30515   43448   21500   30468   43445
19991

BT
```

As Typed from STD Message Format by radio room and Transmitted by Teletype.

Note: Also include values for significant depths.

Figure 53.— STD Data Message.



G12

# STD WEATHER AND QUALITY CONTROL DATA SHEET

CONSECUTIVE STA 66 | START DOWN 0640 Z | SUPERVISOR MST3 SWANSON | STD SERIAL NO. 2532

ASSIGNED STA A6-1 | CAST DOWN 0711 Z | RECORDER OP MST2 DOESCHER | RECORDER SERIAL NO. 2532

DEPTH TO BOTTOM 5486 M | START UP 0722 Z | WINCH OP SO3 GORDON

DATE 10 SEPT 1970 | AT SURFACE 0752 Z

| DEPTH | NAN BOT | BOT NO | SAL. BOT NO SHIP | SAL. BOT NO CGOC | NAN SAL. | THERM NO | MAIN | AUX | THERM NO | MAIN | AUX | THERM NO | MAIN | AUX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | | 1 | 1T | | 1652 | 22.60 | 21.3 | 1667 | 22.61 | 21.2 | 1702 | 22.60 | 21.2 |
| 1500 | 14 | | 2 | 1B | | 394 | 4.56 | 21.0 | 402 | 4.65 | 21.0 | 2517 | 14.50 | 21.3 |

NOTES:

1. ASSIGNED STATION NUMBER IS SAME AS CONSECUTIVE STATION NUMBER EXCEPT ON STANDARD SECTION STATIONS OR SPECIAL OBSERVATIONS AT AN ASSIGNED POSITION.

2. DEPTH TO BOTTOM SHOULD BE IN METERS.

3. "BOT NO" COLUMN REFERS TO BOTTLES USED FOR OTHER PURPOSES SUCH AS OXYGEN OBSERVATIONS.

4. WEATHER INFO SHOULD BE CLEARLY DESCRIBED AND ENCODED EXCEPT PRESENT WEATHER, CLOUD TYPE, AMOUNT, AND VISIBILITY SHOULD BE DESCRIBED AND NOT ENCODED. DO NOT USE "UNCHANGED" OR "SAME AS BEFORE" FOR ANY DESCRIBED WEATHER INFO.

5. NANSEN SALINITY VALUES TO BE LEFT BLANK.

Figure 54. — Sample STD Weather and Quality Control Data Sheet.

FM SHIP
TO COGARD OCEANO
BT
UNCLAS
STDQC

A. JJJGG 00000 STDTT STDSS BBBBB STDTT STDSS

00000 $T_lT_lT_lT_lT_l$ IMMMM 0IAAA $T_rT_rT_rT_rT_r$ IMMMM 0IAAA $T_cT_cT_cT_cT_c$ IMMMM 0IAAA

BBBBB $T_lT_lT_lT_lT_l$ IMMMM 0IAAA $T_rT_rT_rT_rT_r$ IMMMM 0IAAA $T_pT_pT_pT_pT_p$ IMMMM 0IAAA

B. As above
C. As above
D. As above
E. REMARKS (as required)
BT

EXPLANATION OF CODE

| | |
|---|---|
| JJJ | Station number (consecutive). |
| GG | Nearest GMT hour of station. |
| 00000 | Surface value. |
| BBBBB | Trip depth of Nansen bottle immediately above STD fish. |
| STDTT | Temperature of STD to nearest 0.01°C (ex. 14.71 = 01471). For negative temperatures, add 50° to the absolute value. |
| STDSS | Salinity of STD to nearest 0.005°/₀₀. |
| $T_lT_lT_lT_lT_l$ | Left thermometer number. Use zero prefix when necessary. |
| I | Indicator number to indicate plus or minus temperature. Use 7 for +, 8 for -. |
| MMMM | Main thermometer reading to nearest 0.01°C. |
| 0 | Auxiliary thermometer indicator. |
| AAA | Auxiliary temperature to nearest 0.1°C. |
| $T_rT_rT_rT_rT_r$ | Right thermometer number. |
| $T_cT_cT_cT_cT_c$ | Center thermometer surface bottle. |
| $T_pT_pT_pT_pT_p$ | Pressure thermometer number. |

Notes: This message sent daily after the last station of the GMT day and should include data for all stations taken during that day.

Use additional line for second pressure thermometer if quad frame attached.

Figure 55.— Daily STD Quality Control Data Message.

# OBSERVATIONS OF WATER TRANSPARENCY AND COLOR

## DETERMINING WATER TRANSPARENCY WITH THE SECCHI DISC

The Secchi disc provides an approximate average index of transparency of sea water and is dependent upon the available illumination which varies with the time of day, cloud formation, and amount of cloud cover.

The Secchi disc (figure 56) is a white circular plate, having a standard diameter of 30 centimeters. A ring attached at the center of the disc allows a graduated line to be secured. A 5- to 7 1/2-pound weight is attached to the disc so it will sink rapidly and vertically. The line attached to the disc should be marked off in 1-meter intervals to at least 50 meters. A line with minimal stretching characteristics should be used. It is recommended that the bitter end of the disc line be secured on deck prior to lowering the disc over the side to preclude loss of the equipment.

To obtain Secchi disc readings, lower the disc, white side up, into the water from the shaded side of the vessel until the disc is just perceptible. Record the distance from the sea surface to that depth in meters. Then continue the lowering for approximately 5 more meters. Next slowly raise the disc until it is again barely visible. Record the distance from the sea surface to that depth. The average of the UP and DOWN readings is the desired value.

Vessels taking Secchi disc readings should record UP, DOWN, and average values on either the back of the Oceanographic Deck Log (figure 46) or the STD Weather and Quality Control Data Sheet (figure 54), both of which contain the desired associated meteorological data. Secchi disc readings should be taken approximately twice weekly, usually concurrent with a daytime STD or Nansen cast.

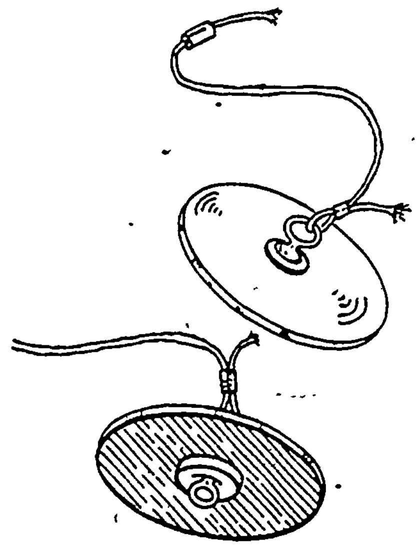

Figure 56.— The Secchi disc.

## DETERMINING WATER COLOR WITH THE FOREL SCALE

The standard Forel scale is used in conjunction with the Secchi disc for the purpose of determining water color. The scale consists of a series of 11 small vials containing ammoniacal copper sulphate and neutral potassium chromate in such proportions that a different graduation of color is imparted to each vial. These vials are numerically designated and are compared directly with the water in the manner described below.

After completion of the transparency measurement with the Secchi disc, raise the disc until it lies approximately one meter below the surface. (See figure 57.) Then compare each vial with the water in order to determine which vial blends most closely with the water color against the Secchi disc. The whiteness of the disc provides the background to which the color is referred; this color may not be the color of the surface visible away from the ship. Besure to shade the vials away from the open sunlight when making the determination. Afterwards, record the number of the vial that blends most closely with the water color.

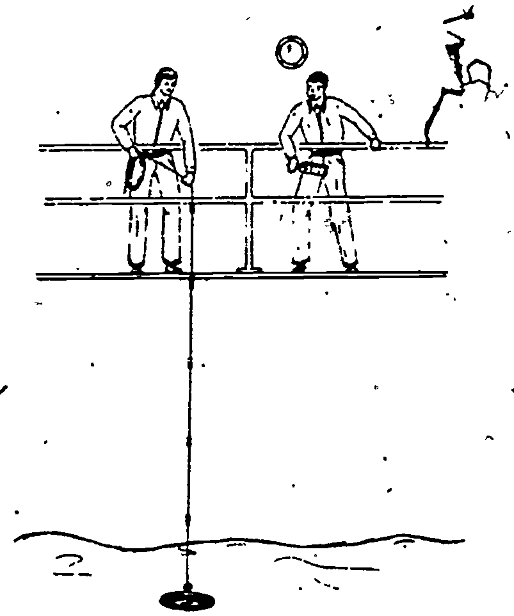

Figure 57.— Obtaining water color with the Forel scale.

# SAFETY PROCEDURES AND HAND SIGNALS FOR OCEANOGRAPHIC OBSERVATIONS

## SAFETY PROCEDURES

When conducting oceanographic observations, you run the risk of personal damage and damage to extremely expensive equipment and instruments. Therefore, it is important that, at all times, you follow prescribed operating, maintenance, and safety procedures. You have already considered many safety procedures for oceanographic observations, but to reinforce and emphasize these procedures, we have listed below general safety procedures and precautions that are applicable to any vessel conducting oceanographic observations.

1. The oceanography officer is responsible for ensuring that assigned projects are conducted in a safe and correct manner.

2. The oceanography officer should ensure that equipment necessary for the conduct of scheduled oceanographic projects is aboard, is in good condition, and is properly maintained.

3. The oceanography officer shall act as safety officer for as many casts as practicable.

4. It is essential that the oceanographic equipment be in excellent operating condition prior to patrol.

5. Follow the winch instruction manual religiously.

6. The winch operator should have a clear view of the oceanographic platform, A-frame, meter wheel, and the counter.

7. Take care when spooling wire rope or cable.

8. Know the causes of wire rope loss or damage.

9. Know the safety factor for wire rope.

10. Always test wire that is in poor condition prior to commencement of a cast.

11. Conduct an inspection of the wire on the last cast of a cruise.

12. Conduct wire inspections each time damaged wire is cut off.

13. The winch operator shall conduct a quick visual wire inspection each time the winch is stopped during a cast.

14. Wash wire rope or cable with fresh water after each cruise to remove the surface salt accumulation.

15. Carefully inspect Nansen wire older than four years and STD cable older than one year prior to using them and then use them with caution.

16. Know the difficulties that can occur with various wire angles.

17. Exercise caution so that the STD fish is not two-blocked into the meter wheel.

18. Rig the oceanographic platform and its accessories properly.

19. When bringing in the Nansen bottles, exercise caution when hoisting them to the platform.

20. Ready-rig a cable-grip in case of emergency.

21. The winch operator should be thoroughly familiar with emergency stopping procedures, hand signals, etc.

22. The platform man should wear flotation gear, a hard hat, safety shoes, and a swimmer's harness with a safety line secured to the ship. He should also wear a leather arm guard for use in fending the cable off the platform.

23. For a night cast, check all areas, including over the side, for proper lighting.

24. The safety officer should check all preparations.

25. The OOD should provide for a fathometer watch and soundings especially if depth is rapidly shoaling.

26. The OOD should maneuver the ship whenever conditions warrant.

27. The oceanographic supervisor directs the winch operator with hand signals and by voice.

28. Always carry Nansen bottles in a vertical position and never handle them by the thermometer frames.

29. Use a safety lanyard on each Nansen bottle prior to attaching the bottle to the wire.

30. If the cast is in danger of touching the platform, the platform man fends the cast off by use of the leather arm guard.

31. The winch operator shall use slow speed and operate the winch smoothly.

32. When the cast is over the side, never leave it unattended.

33. Use extreme caution in bringing the last bottle (bottom bottle) up.

34. Use a safety lanyard as each Nansen bottle is removed from the wire.

35. Slow the winch when a Nansen bottle is within 10 meters of the meter wheel.

36. The last step of a Nansen cast is the proper cleaning, lubrication, maintenance, and the storing of equipment.

37. At no time should you put out a greater amount of cable than the depth of the water.

38. Make sure the proper timing gear is used for the appropriate cable.

39. Use care to prevent equipment from striking the side of the vessel.

40. The recorder operator shall control the speed of the winch during an STD cast.

41. Secure all power to the STD before bringing the fish out of the water.

42. Be particularly cautious when working with large wire angles.

## HAND SIGNALS FOR OCEANOGRAPHIC CASTS

The following hand signals are to be used during oceanographic casts to ensure prompt and accurate communication between the supervisor and winch operator. More specifically, these hand signals are designed for the critical moments —lowering and raising of Nansen bottles. They may also be used for "STD" casts and other oceanographic operations.

### LOWERING

When the supervisor has determined that the Nansen bottle or STD fish is ready to be lowered, he will extend his arm well over his head, bend his wrist sharply, and point down with his index finger. Ensuring that the winch operator sees this, the supervisor commences making large, bold circular sweeping motions with his whole arm (see figure 58). He continues this signaling until the Nansen bottle or STD fish is completely submerged. Then he boldly lowers his arm through an arc of 180 degrees in front of him, still keeping his arm extended and his index finger pointing down (see figure 58). The winch operator now knows that the Nansen bottle or STD fish is well submerged and that he may increase the payout speed according to instructions that we have already described in this pamphlet.

### RAISING

When raising a cast, the winch operator should always slow down about 10 meters from the meter wheel reading where each bottle was placed on the cable. When the Nansen bottle or STD fish is in sight, the supervisor should boldly extend his arm high over his head with the index finger pointing up. At the same time, he should loudly shout "IN SIGHT." When the bottle breaks the surface, he commences making large, bold circular sweeping motions with his arm and loudly shouts "SURFACE." (See figure 58.)

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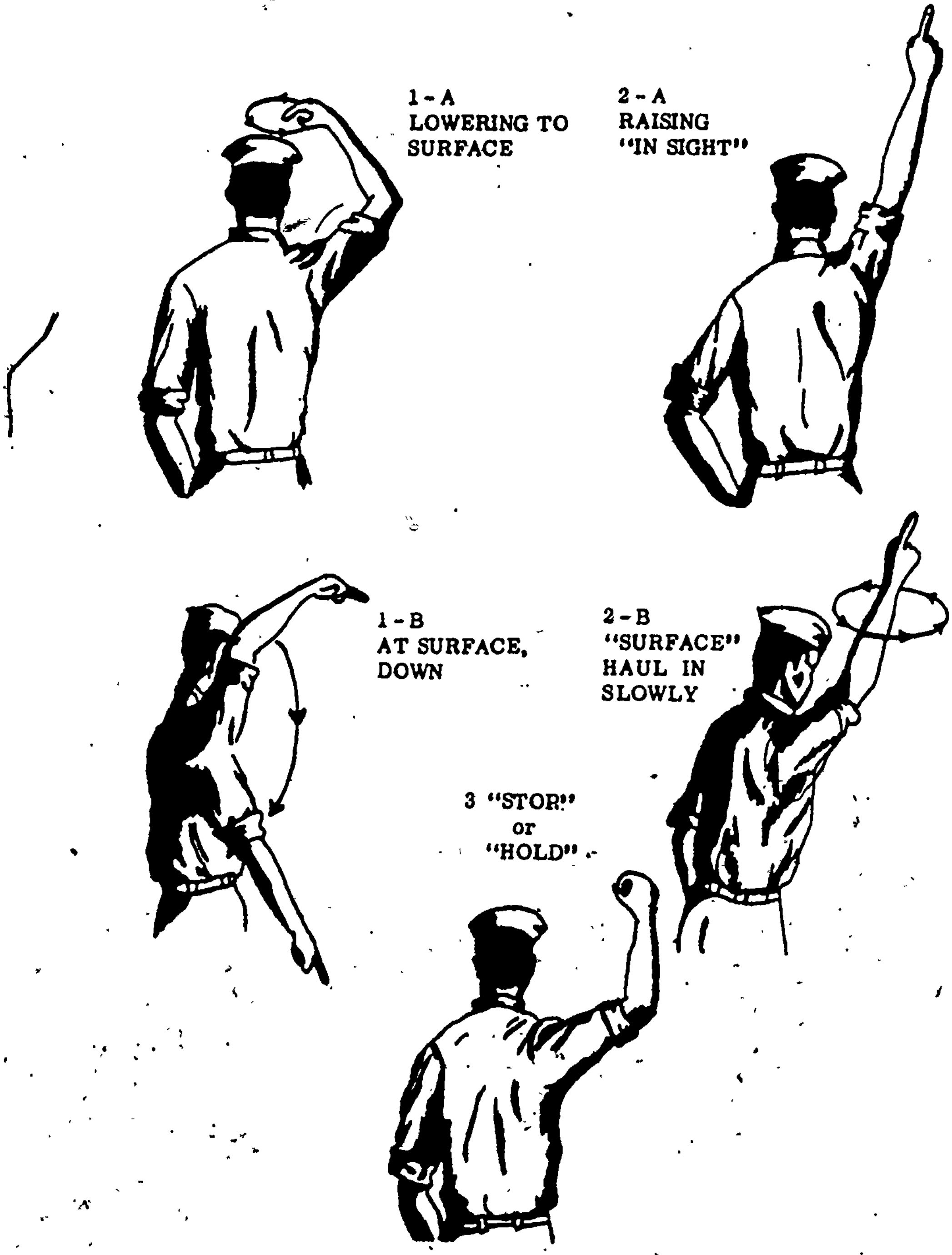


Figure 58.— Hand signals for Oceanographic casts.



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STOP (DURING LOWERING OR RAISING OR ANY EMERGENCY)

With his arm high over the head, the supervisor loudly shouts "STOP" or "HOLD" and clenches his fist. (See figure 58.)

NOTE: The immediate area must be clear of all unneeded people. The supervisor should ensure that, if possible, the winch operator is able to see as much of the cable as possible. Excessive winch speed is a major cause of a lost cast. Regardless of the wire angle, when the first bottle (bottom bottle) or STD fish is lowered, the supervisor must take extreme caution to keep the Nansen bottle or STD fish from striking the platform. The same is true also when raising a cast. Teamwork is essential for the observation. Improper planning, confusion, unnecessary people, and improper care of the winch, A-Frame/platform area, Nansen bottles, and all associated equipment are the enemies of the Oceanographic Team.

15-2 645

# DATA PROCESSING AND ANALYSIS

A correspondence course pamphlet consisting of original material developed at the Coast Guard Institute and excerpts from:

| | |
|---|---|
| Preparation and Use of Weather Maps at Sea | CIRCULAR R |
| Aerographer's Mate 3 & 2 | NAVPERS 10363-C |
| Radio Weather Aids | N.O. Pub. 118 |
| Manual of Surface Observations | FMH #1 |
| Aviation Weather, FAA Academy | C-7 |
| The Preflight Position, Volume II, FAA Academy | F-5/2 |
| Meteorology for Naval Aviators | NAVAER 00-80U-24 |
| Manual for Oceanographic Operations | CG-410 |
| Instruction Manual for Obtaining Oceanographic Data | N.O. Pub. 607 |


U.S. COAST GUARD INSTITUTE
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646

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WARNING

THE MATERIAL IN THIS PAMPHLET IS FOR TRAINING ONLY. IT SHOULD NEVER BE USED IN LIEU OF OFFICIAL INSTRUCTIONS, TECHNICAL ORDERS, OR OTHER CURRENT PUBLICATIONS ISSUED BY COMPETENT AUTHORITY. ALWAYS CHECK THE LATEST DIRECTIVES AND PUBLICATIONS ON THE JOB.

# DATA PROCESSING OF WEATHER INFORMATION

The processing of weather information involves the analysis of various charts, such as surface charts, upper air charts, AROWAGRAMS, etc., and the interpretation of the various messages received via teletype and of the charts received over the various facsimile circuits. The purpose of this section, therefore, is to discuss analysis of the basic weather charts—both surface and upper air—and interpretation of the more commonly used weather teletype messages and facsimile charts. The discussion will be general in nature, because it is beyond the scope of this course to cover completely every aspect of the analysis and interpretation of weather data.

## SURFACE ANALYSIS

The surface synoptic chart or plotted weather map is a valuable tool for forecasting weather. It presents to the forecaster and other interested parties a synoptic view of weather conditions. By comparing the situation depicted on the current map with preceding situations, you, as an MST, can forecast future trends.

## CONSIDERATION OF REPORTED ELEMENTS

After all available weather data have been plotted on a map, the map is ready to be analyzed. However, before we consider how to analyze the map, we should first understand the significance of the following data that is plotted on the map.

### Temperature

Temperature is a valuable element for locating fronts during the winter, but in many cases this element is over-used for this purpose. Temperature discontinuity is more readily used with dense coverage of information than with sparse coverage.

### Dew Point

Dew-point temperature is an important element for locating fronts having only a slight temperature difference, i.e. warm fronts, weak cold fronts, and stationary fronts. In warm air, there is generally a smaller spread between temperature and dew point than in cold air; that is, warm air is more humid than cold air.

### Pressure Change Discontinuity

In general, pressure falls ahead of a front and rises behind the front. However, for a stationary front, the pressure tendency is normally the same on both sides of the front. There are variations to these general patterns because of different rates of change on each side of the front, but the normal patterns still exist.

Remember that pressure reports taken by land stations are more representative than those taken by ships.

### Clouds and Precipitation

Generally, cold fronts and cold occluded fronts have cumuliform clouds and showery precipitation. Cold fronts and cold occluded fronts having shallow slopes are accompanied by stratiform clouds and continuous or intermittent precipitation. Warm fronts and warm occluded fronts normally have stratiform clouds and continuous precipitation.

### Wind Discontinuity

Accompanying most fronts, especially cold and occluded fronts, are wind shifts sharp enough to show up on the surface weather map. Wind shifts with speeds of 10 knots or greater are usually significant for locating fronts. To be significant, the shift MUST be along a trough line and not along a ridge line (wedge).

Wind data reported from ships are more representative than those reported from land stations.

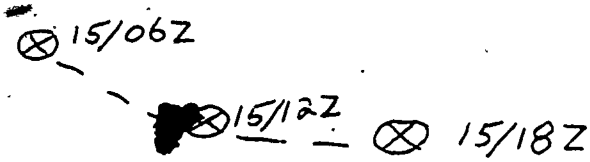


Figure 1.— Labeling pressure systems on a surface weather chart. The positions given are for 0600Z, 1200Z, and 1800Z; all positions are for the 15th of the month.

HISTORICAL SEQUENCE

The first step in the analysis of a surface weather map is to correct the previous chart by entering any late reports that have a bearing on the chart's analysis. The next step is to enter onto the present chart all pressure centers that occurred during the previous 24 hours. To do this, use black ink and mark each center with an "X" enclosed in a circle. Next, connect these positions with a dashed line to show movement. Label each position with the date and time. (See figure 1.)

After you have entered the positions of all centers, the next step is to enter the positions of all fronts from the previous chart (only the previous chart is used for fronts). Do this by tracing the past position in yellow.

PRELIMINARY ANALYSIS

The first step leading to the complete surface analysis consists of visually scanning the chart and noting from the data plotted around each station the areas of high and low pressure, the general wind flow about these areas, and the approximate positions of fronts. When scanning the chart and following the past history, you should be able to approximate what the final analysis should look like. Locate the station having the highest or lowest plotted pressure value in one particular area.

BASIC ANALYSIS

After visually surveying the chart, you are ready to start the basic analysis of the chart. The first sequence in basic analysis is isobaric analysis.

Isobaric Analysis

This phase consists of drawing lines in the areas of high and low pressure which connect

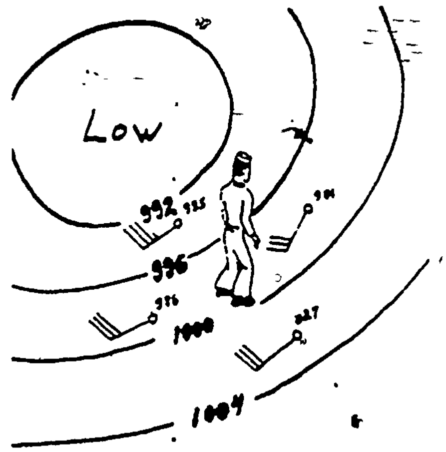


Figure 2.— Illustration of Buys-Ballot's law.

points of equal pressure. These lines, called isobars, outline areas of high and low pressure. Drawing an isobar is merely drawing a line which follows the general wind flow and which connects points having equal pressure values. The numerical values which you refer to when drawing isobars are the plotted pressure values to the northeast of each station circle.

Certain practices that you must follow when drawing isobars are described below.

Buys-Ballot's Law.— An isobar on a weather map represents a specific numerical value and must be drawn in such a manner that pressure values of greater numerical value occur on one side of the line being drawn, while lesser pressure values occur on the other side of the line. This principle is stated as Buys-Ballot's law, which states: "In the Northern Hemisphere, when one stands with his back to the wind, the pressure on his left hand will be lower than the pressure on his right hand." See figure 2 for an illustration of Buys-Ballot's law.

Drawing Isobars Downwind.— Isobars must always follow the general wind flow. However, remember that winds blow across isobars at a slight angle. The angle is inward toward a center of low pressure and is outward from a center of high pressure. (See detail C of figure 3.) If the terrain is smooth, this angle will be small; but the rougher the terrain becomes, the greater the angle will be. Over ocean areas, winds blow across isobars at angles of 10 to

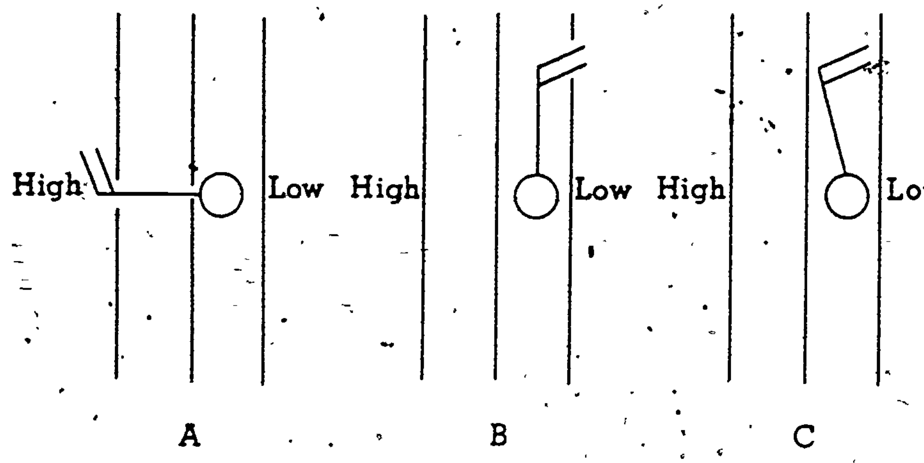


Figure 3.— Angles of wind direction to isobars: A, if the earth did not rotate; B, under the influence of the earth's rotation; and C, under the influence of both the earth's rotation and friction.

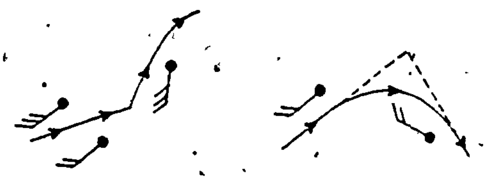

Figure 4.— Isobars drawn down the wind may turn sharply to the left but not to the right. The isobar should not turn sharply to the right as shown by the dashed line.

20 degrees, but over very rough land, the angle can be as much as 40 degrees.

Isobars drawn downwind may turn sharply to the left but not to the right. When there is a kink or sharp turn, it must always occur to the left and never to the right (see figure 4).

Drawing Isobars as Closed Curves or Curved Lines.— Isobars must always appear as either simple closed curves or closed lines. Isobars may originate and terminate in the following manner:

1. Originate on one edge of the chart, follow a path connecting points of equal pressure values, and terminate on the same edge of the chart.

2. Originate on one edge of the chart, follow a path connecting points of equal pressure values, and terminate on any of the other three edges of the chart.

3. Originate anywhere on the chart, follow a path connecting points of equal pressure values, and join ends to close on itself (form a closed curve).

4. Originate and/or terminate in an area where there are no reports.

ISOBARS CAN NEVER CROSS ONE ANOTHER, INTERSECT ONE ANOTHER, OR SPIRAL. Isobars can never touch except when two ends of the same isobar join to make a closed curve (see figure 5).

Interval of Pressure Change.— In order to eliminate overcrowding of isobars and yet maintain a clear indication of pressure centers, draw isobars for specific pressure values and at certain intervals. In the area between the Equator and 25 degrees north and south latitude, draw isobars for every 2 millibars of pressure. To determine the exact values to use, use 1000 millibars as the base value and proceed toward increasing and decreasing values in 2-millibar increments.

In areas between the poles and 25 degrees north and south latitude (areas for which most charts are plotted and analyzed), draw isobars for every 4 millibars of pressure. Determine the exact values to use by using 1000 as the

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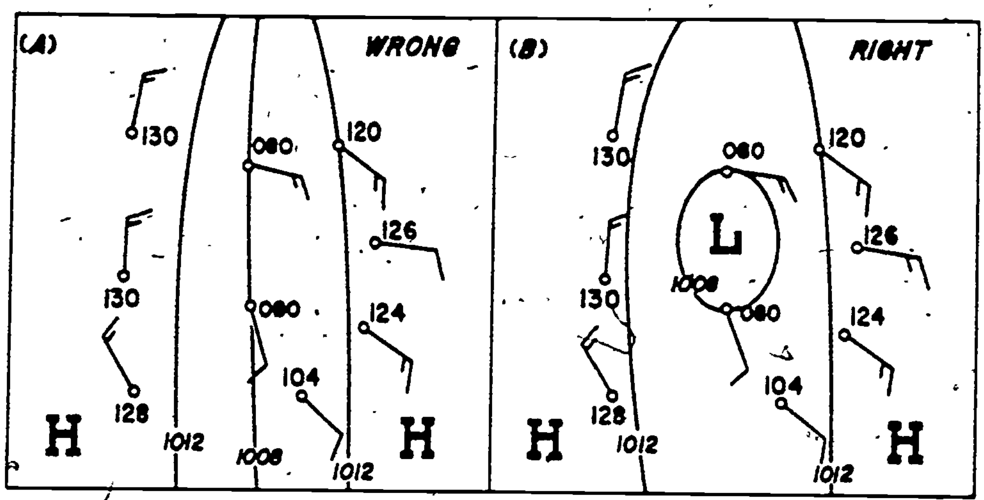


Figure 5.— A small pressure center between isobars.

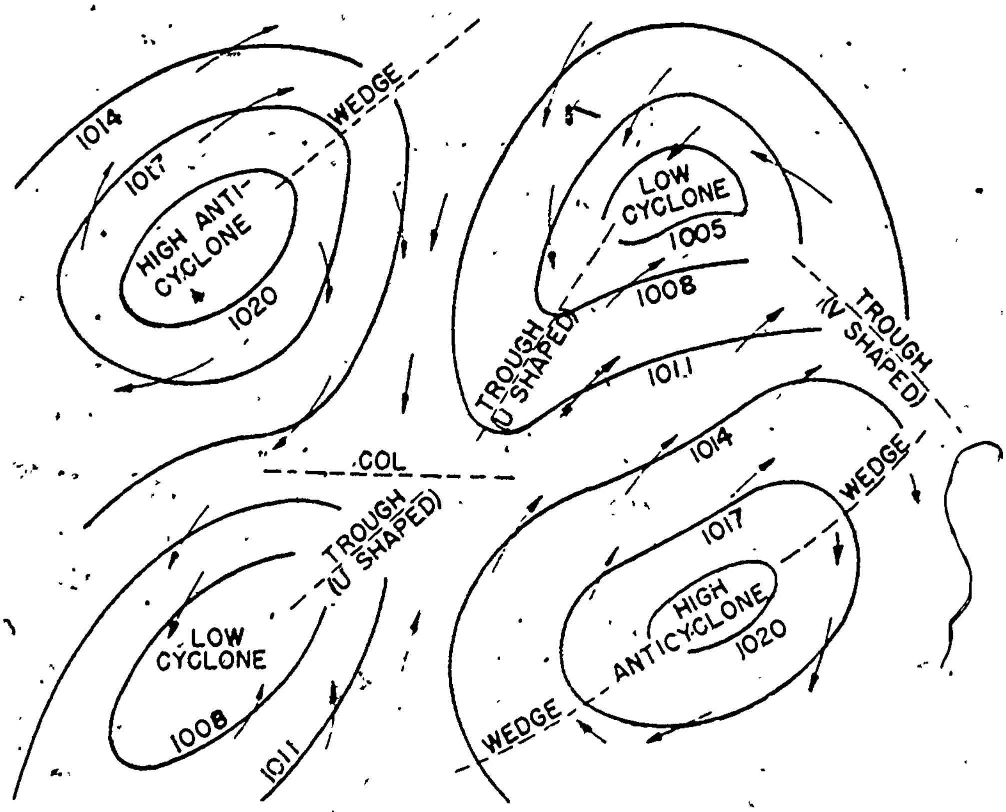


Figure 6.— Various forms of isobars with wind circulation indicated.



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base value and proceeding toward increasing and decreasing values in 4-millibar increments. For example, with 1000 as the base, the intervals are 1012, 1008, 1004, 1000, 996, 992, 988, etc. When first drawing the isobars, it is usually a good idea to sketch every other isobar. That is, sketch the 1000-millibar isobar, then the 1008-millibar isobar, etc.

Because of the varied distribution of pressure centers, you can seldom draw isobars for every standard value.

The Two-Station Method of Analysis.— To determine the flow of isobars, use the two-station method of analysis. The first step in this method is to locate areas of highest and lowest pressure values over a land surface. (Always start the analysis over land areas where reports are numerous; avoid starting the analysis over mountainous areas or ocean areas where reports are in short supply.)

Of the areas you have located, select one, either the highest or the lowest, and within this area locate one station having the highest (or lowest) pressure value and note its pressure. Go downwind from this station to the next station and note the pressure of this next station. Then, determine what standard isobaric value, if any, will fit between these two stations in a logical numerical order. If a standard isobaric value fits between these two stations, sketch lightly between the stations a short line that is more or less parallel to the wind direction but that has the wind crossing it toward LOWER pressure. If a standard isobaric value will not fit between the two stations, continue downwind to the next adjacent station and repeat the entire process.

Note the plotted pressure values at several stations immediately downwind from the point of origin. You will find that the isobar that you have begun to sketch will fit between only two of these stations. Project the short line that you have already drawn to this new point. (See figure 7.)

Repeat the search—ALWAYS DOWNWIND—and project the isobar to the new points. Continue this procedure until the isobar you are drawing either (1) circumscribes an area by returning to the point of origin and joining itself to form a closed curve or (2) enters an area where there are no reports and there is no justification for continuing.

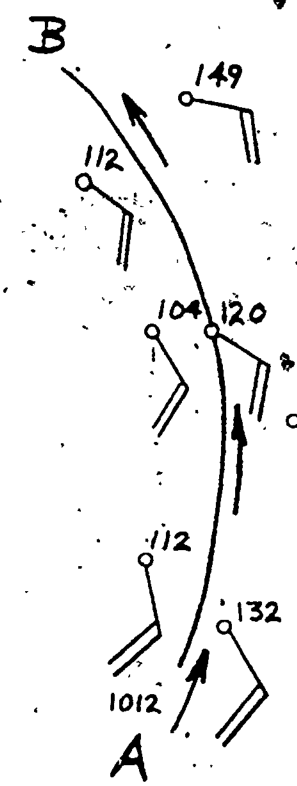


Figure 7.— The isobar for 1012 mbs is started at A and is drawn down the wind in the direction shown by the black arrowheads, the position of the line being determined by the coded barometric pressure readings.

Remembering that all points along an isobar represent the same numerical pressure value, move from any point of the finished isobar outward to an adjacent station. Determine if another isobar (of greater or lesser value) may be drawn between this station and the isobar just completed. If so, proceed in the manner outlined above. If not, continue outward in the same direction to the next adjacent station. Eventually, you will encounter an area between two stations where you can draw the next standard isobar. Draw this isobar in the manner described above.

Repeat the drawing of isobars until you have drawn an isobar for all standard pressure values. Of course, if there are few plotted

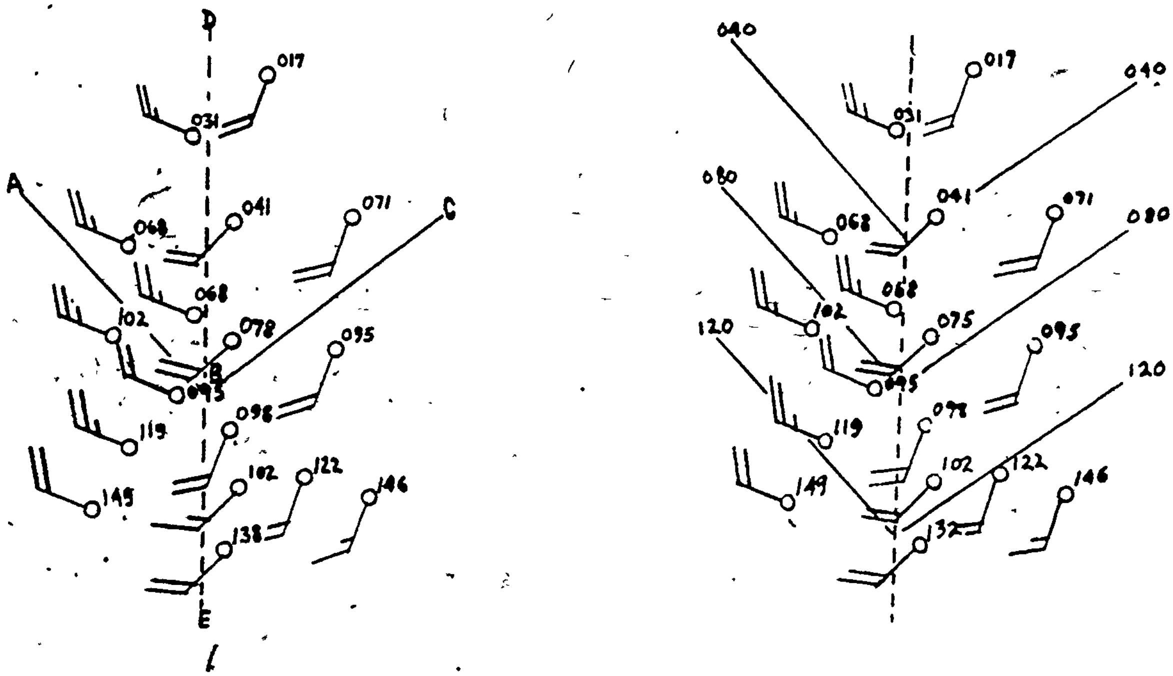


Figure 8.— At the left, when the isobars are drawn down the wind from A to C, a wind discontinuity is found along line DE. At right, the isobars have been drawn to fit the line of discontinuity. In both illustrations, a cold front is indicated by the wind shift and a well-defined pressure trough.

pressure values in an area, it may be impossible to draw isobars for all standard isobaric values. Therefore, it stands true that the greater the number of plotted stations, the more complete and accurate the analysis will be.

Frontal Analysis

After you have finished drawing isobars, the next step of basic analysis is to analyze the map for frontal systems.

Cold Front Analysis.— Cold fronts are located in well-defined pressure troughs, that is, where there is a marked density contrast between the two air masses involved. A careful analysis of the isobars will, in most cases, indicate the correct position of the pressure trough that contains the front (see figure 8). Other indications of a cold front's location are as follows:

1. Pressure Tendency - In advance of cold fronts, the pressure tendency is usually indicated by a steady or unsteady fall. After passage, it will be indicated by either a /, \/, or a \ tendency.

2. Wind - With the approach of the front, the wind is normally from the south to southwest. At frontal passage the wind usually shifts abruptly to the west or northwest and after passage is from the northwest. (See figure 8.)

3. Clouds - In advance of the front, the cloud types are typical of warm air. Towering cumulus, cumulonimbus, stratocumulus, and nimbostratus are associated with the passage of the front. After passage, these cloud forms may prevail for several hundred miles, as is the case with slow-moving (type I) cold fronts; but with the fast-moving (type II) cold fronts, very rapid clearing occurs. With both types of cold fronts, the only clouds normally found well back in the cold air after passage are fair-weather cumulus.

4. Precipitation - Showers and sometimes thunderstorms will be observed with a cold frontal passage. A type I (slow-moving) front will produce a very extensive band of weather which may persist for 150 to 300 miles behind the front. With the type II (fast-moving) front, a very narrow band of weather exists.

5. Temperature and Dew Point - Both temperature and dew point will be high before a cold frontal passage and will decrease rapidly after passage of the front.

6. Visibilities and Ceilings - With the approach and passage of the front, visibilities and ceilings will decrease rapidly and will remain low after passage (type I) or increase rapidly after passage (type II).

Warm Front Analysis.— You can generally locate active warm fronts from the pressure troughs on the weather chart. The troughs are seldom as pronounced as those observed with cold fronts; therefore, you must consider other elements in order to locate warm fronts accurately. These elements are as follows:

1. Pressure Tendency - Pressure usually falls for an appreciable length of time prior to the frontal passage and is normally steady after passage. The tendencies in advance of the front would, therefore, be a \ or a ⋀ tendency. A warm frontal passage is usually indicated by a ∟ tendency.

2. Wind - The wind in advance of a warm front is usually from the southeast; it shifts to the south-southwest after passage.

3. Clouds - Warm fronts are nearly always well defined by the following cloud forms: cirrus (700 to 1000 miles), cirrostratus (600 miles), altostratus (300 to 500 miles), and nimbostratus and stratus (300 to 0 miles).

4. Precipitation - The precipitation area of warm fronts extends about 300 miles in advance of the surface front and is of the steady type, either continuous or intermittent.

5. Temperature and Dew Point - Abrupt temperature and dew point changes like those characteristic of cold fronts do not accompany the warm frontal passage. Instead, the changes are gradual. These values start increasing slowly with the approach of the front and increase slightly more rapidly with the passage of the front.

6. Visibilities and Ceilings - These values are normally good until the precipitation begins. Then, they decrease rapidly. An improvement is usually experienced after passage.

Occluded Frontal Analysis.— To locate occlusions on the surface weather map, consider the following factors:

1. Historical Sequence - By following an unstable wave cyclone in its life cycle, you can generally determine when the occluding process will occur.

2. Location - Occlusions occur in very well-defined pressure troughs.

3. Pressure Tendency - Pressure usually falls at a considerable distance ahead of a cold-type occlusion and rises rapidly after passage. With the warm-type occlusion, the pressure changes may be very erratic with the passage of the upper-front but will rise after passage of the surface front.

4. Temperature - Temperature differences associated with occlusions are less marked than those associated with cold fronts or warm fronts. However, with the cold-type occlusion, the temperature after passage of the surface front will be slightly colder than the temperature in advance of the warm front. With the warm-type occlusion, the reverse is true.

5. Wind - A wind shift is one of the most characteristic features of occlusions. The wind shift associated with occlusions is very abrupt, sometimes amounting to as much as 180 degrees. In advance of the surface front, the wind direction is south or southeast; after passage, the wind shifts to the north or northwest.

6. Clouds and Weather - Since the occluded front is a combination of cold and warm fronts, the resulting clouds and weather are a combination of the conditions that exist along both fronts.

## FINAL ANALYSIS

After you have sketched all of the isobars and have determined the positions of the fronts, you are ready to complete the last step of surface analysis—final analysis.

Final analysis consists primarily of erasing and redrawing the isobars in order to smooth out any irregularities in the isobars which you drew during basic analysis (see figure 9). Simple isobars and basic wind patterns are much more probable than complicated isobars (although the

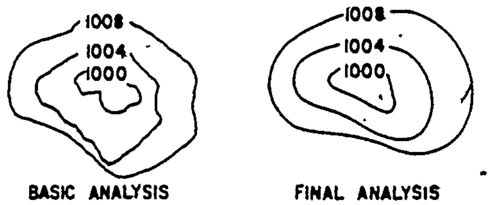


Figure 9.— Smoothing of isobars.

patterns sometimes have an unlikely appearance because of local conditions, topography, etc.). Therefore, in order for the isobars to conform to MOST logical situations, you should eliminate irregularities in the shape of isobars whenever possible. Irregularities in isobars are most frequently due to incorrect pressure computations and observing techniques at reporting stations.

When smoothing out the irregularities, erase the innermost isobar in a pressure center by using a freehand stroke. Then redraw the isobar so that it has a smooth shape or appearance, and label it with the appropriate millibar value it represents. Label isobars at all loose ends and at least once on a closed curve. Then, erase the next isobar away from the center and smooth and label it. Continue the smoothing process until you have erased, redrawn, and labeled all of the isobars which you sketched during the basic analysis.

The next step is to label all high pressure centers with a blue block letter "H" and to label all low pressure centers with a red block letter "L." With a high, the pressure decreases as you move away from the center; with a low, the pressure increases as you move away from the center. (See figure 10.)

Isobars must agree not only with pressure but also with the general wind flow. Winds blow in a clockwise direction about high pressure areas and counterclockwise about low pressure areas (in the Northern Hemisphere). Because of the effects of friction, winds blow across isobars at a slight angle from high to low pressure.

The spacing between isobars is directly related to wind speed. The closer the isobars are to one another, the stronger the wind speed; likewise, the wider the spacing, the lighter the wind speed (see figure 11). The principle of this phenomenon is as follows. When air moves across the earth's surface, the effect of the earth's rotation results in a tendency for the air to turn to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. (If it were not for the rotation of the earth, the wind would blow directly across the isobars from high to low pressure.) Therefore, north of the Equator the air does not move across the isobars but turns to the right, tending to move more nearly along the isobars. This tendency is least at the Equator and increases with latitude, becoming a maximum at the poles. When the tendency to turn to the right is balanced by the pressure gradient, which causes the wind to tend toward low pressure, the wind is said to be geostrophic. Therefore, it is evident that the greater the tendency to turn to the right, the greater the pressure gradient must be with a given speed of wind blowing along the isobar. The full explanation of the effect of the earth's rotation is by no means simple, but there is a useful relation between the speed of the wind and the spacing of the isobars, which is shown in the geostrophic wind table, table 1.

Table 1.— Geostrophic Wind Table. Distance between isobars over the ocean at four-millibar intervals for various wind speeds and latitudes.

| Wind speed observed (knots) | Approximate distance (in nautical miles) between isobars drawn for every four (4) millibars | | | |
|---|---|---|---|---|
| | 30° | 40° | 50° | 60° |
| 10 | 461 | 358 | 301 | 266 |
| 15 | 307 | 239 | 200 | 177 |
| 20 | 230 | 179 | 150 | 133 |
| 25 | 184 | 143 | 120 | 106 |
| 30 | 154 | 119 | 100 | 89 |
| 35 | 132 | 102 | 86 | 76 |
| 40 | 115 | 90 | 75 | 66 |
| 50 | 92 | 72 | 60 | 53 |
| 60 | 77 | 60 | 50 | 44 |

The last step of final analysis is to draw the frontal systems on the chart. Indicate the location of fronts as follows: red lines for warm fronts, blue lines for cold fronts, and purple for occluded fronts. Depict stationary fronts with alternately dashed red and blue lines. See figure 12, which lists the WBAN weather analysis symbols.

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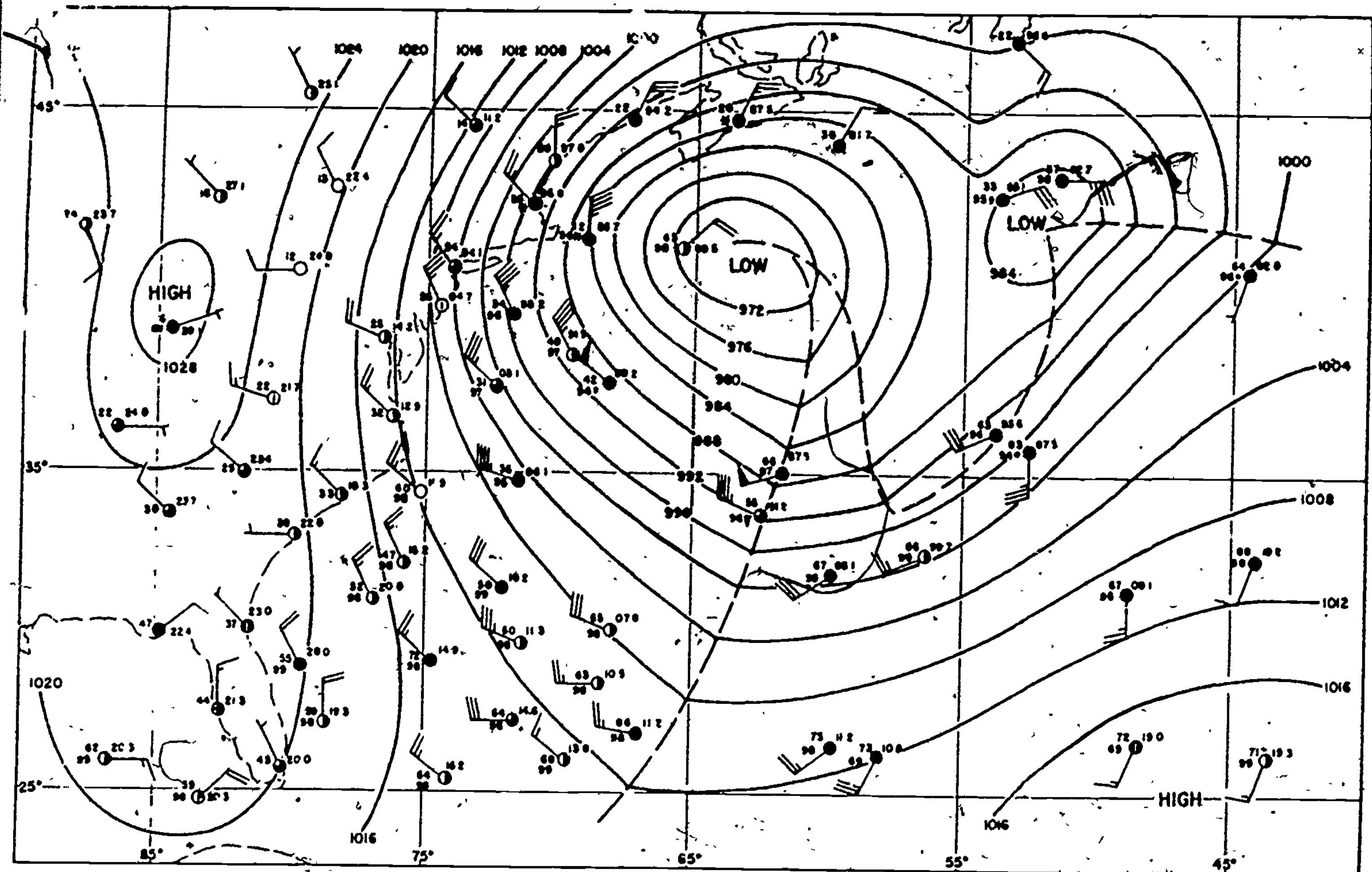


Figure 10.— Surface weather map. Dashed lines indicate location of fronts.

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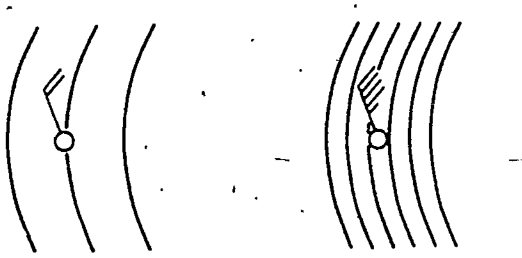

Figure 11.— Isobars are closely spaced with strong winds (right) and widely spaced with light winds (left).

SUMMARY

Surface weather maps, which present a synoptic view of weather conditions, are analyzed for the purpose of forecasting weather conditions. Analysis of a surface weather map involves performing a series of procedures in a logical, prescribed sequence.

The first procedure, the historical sequence, involves entering the past record of the movement (direction and speed) of pressure centers and fronts onto the chart. Enter this past data only after updating the previous chart with any late reports or corrections. The next sequence is preliminary analysis of the chart, which entails scanning the chart to locate areas of high and low pressure, the general wind flow about these areas, and the approximate positions of fronts.

After visually scanning the chart, you are ready to begin basic analysis. Draw isobars as either simple closed curves or simple curved lines with loose ends at the edges of the chart. Sketch the isobars lightly, keeping in mind Buys-Ballot's law (with your back to the wind in the Northern Hemisphere, the low pressure is on the left). Use the two-station method of analysis for determining the flow of isobars and draw the isobars as nearly with the wind as possible. Draw isobars for the specific pressure values which we have already defined. The end result of this isobaric analysis is a picture of the flow of wind and pressure.

After drawing the isobars, analyze the map for frontal systems. Base your analysis on factors such as pressure tendency, wind, clouds, precipitation, temperature, dew point, visibility, ceilings, and location.

The final step of surface analysis consists basically of smoothing out any irregularities in the isobars due to errors from the reporting stations. As you smooth the isobars, label them with the appropriate pressure values. After labeling the pressure centers as either high (a blue "H") or low (a red "L"), draw in the frontal systems with colored lines to indicate what type of front you are depicting. This concludes surface analysis.

UPPER AIR CHART ANALYSIS

Map analysis includes not only surface weather charts but also upper air charts. The upper air charts used in conjunction with the surface charts are essential for accurate forecasting. With the aid of upper air charts, the forecaster gets a 3-dimensional view of the synoptic situation.

The flow pattern of the air in the free atmosphere above the layer of frictional influence next to the earth is indicative of the type of weather that will occur at the surface of the earth. The direction in which pressure systems, fronts, tropical storms, and the like move depends upon the wind flow above the frictional layer of the atmosphere. Therefore, it is necessary to determine the flow pattern from upper air charts.

The basic upper air charts in use today are termed CONSTANT PRESSURE CHARTS, since they depict conditions existing along a constant pressure surface. They are a valuable aid in forecasting any weather conditions for any locality.

A constant pressure chart is a chart showing meteorological data at a particular standard level. The meteorological data for these charts are obtained from radiosonde and rawinsonde observations. The standard pressure levels mentioned are those levels for which mandatory data are transmitted in the radiosonde code. These include the 1000-, 850-, 700-, 500-, 400-, 300-, 250-, 200-, 150-, 100-, 70-, 50-, 30-, 20-, 10-, 7-, and 5-mb levels.

Although constant pressure charts may be prepared for any or all of the mandatory levels, the most common charts in use are the 850-, 700-, 500-, 300-, 200-, and 100-mb charts. The approximate heights of the constant pressure surfaces are as follows:

## WBAN WEATHER ANALYSIS SYMBOLS

| (I) ANALYSIS FEATURE | (II) SYMBOL ON STATION CHARTS | COLOR | (III) SYMBOL ON CHARTS TO BE REPRODUCED IN ONE COLOR — Black and White |
|---|---|---|---|
| 1. Cold front—surface | | Blue | |
| 2. Cold front aloft | | Blue | |
| 3. Cold front aloft—becoming surface | | | |
| 4. Cold front—surface—going aloft | | | |
| 5. Warm front—surface | | Red | |
| 6. Warm front aloft | | Red | |
| 7. Warm front aloft—becoming surface | | | |
| 8. Warm front—surface—becoming aloft | | | |
| 9. Quasi-stationary front—surface | Red, Blue, Red, Blue, Red | Red and Blue | |
| 10. Quasi-stationary front aloft | Red, Blue, Red, Blue | Red and Blue | |
| 11. Occluded front—surface | | Purple | |
| 12. Occluded front aloft | | Purple | |
| 13. Frontogenesis, resulting in the formation of a cold front at the surface | | Blue | |
| 14. Frontogenesis, resulting in the formation of a warm front at the surface | | Red | |
| 15. Frontogenesis, resulting in the formation of a quasi-stationary front at the surface | Red Blue Red Blue Red Blue Red Blue | Red and Blue | |
| 16. Frontogenesis, resulting in the formation of a cold front aloft | | Blue | |
| 17. Frontogenesis, resulting in the formation of a warm front aloft | | Red | |
| 18. Frontogenesis, resulting in the formation of a quasi-stationary front aloft | R B R B R B R B | Red (R) and Blue (B) | Red Blue Red Blue Red |
| 19. Cold front at the surface undergoing frontolysis | | Blue | |
| 20. Warm front at the surface undergoing frontolysis | | Red | |

## WBAN WEATHER ANALYSIS SYMBOLS
(Continued)

| (I) ANALYSIS FEATURE | (II) SYMBOL ON STATION CHARTS | COLOR | (III) SYMBOL ON CHARTS TO BE REPRODUCED IN ONE COLOR — Black and White |
|---|---|---|---|
| 21. Quasi-stationary front at the surface, undergoing frontolysis | R B R B R B R B R B R B R B R B R | Red (R) and Blue (B) | |
| 22. Occluded front at the surface, undergoing frontolysis | | Purple | |
| 23. Cold front aloft undergoing frontolysis | | Blue | |
| 24. Warm front aloft, undergoing frontolysis | | Red | |
| 25. Quasi-stationary front aloft, undergoing frontolysis | R B R B R B R B R B R B R B R B R | Red (R) and Blue (B) | |
| 26. Occluded front aloft, undergoing frontolysis | | Purple | |
| 27. Instability line (non-frontal line along which squalls or other evidences of marked instability exist) | | Purple | |
| 28. Trough line | | Brown | |
| 29. Ridge line | | Brown | |
| 30. Shear line or surge line (tropical analysis) | | Blue | |
| 31. Line of convergence (tropical analysis) | | Brown | |
| 32. Line of divergence (tropical analysis) | + + + + + + | Brown | + + + + + + |
| 33. Center of tropical cyclonic circulation (strongest wind Beaufort Force 8 to 11 inclusive) | | Red | |
| 34. Tropical hurricane center (strongest wind Beaufort Force 12 or greater) | | Red | |
| 35. Intertropical convergence zone | | Red | |

### NOTES

1. In symbols 1-12 inclusive, Column III, barbs may be separated more than shown, but a continuous line will always be drawn through the bases of the barbs.
2. In symbols 13-18 inclusive, Column III, the barbs will always be separated and will always be drawn without a connecting line.
3. In symbols 19-26 inclusive, Column III, the barbs may be spaced a greater distance than shown here, but the length of the dash between barbs should equal the space between the dash and each adjacent barb.
4. In symbol 35, Columns II and III, the spacing between the continuous lines will normally be about ½ inch, but may be greater when the intertropical convergence zone is broad.

Figure 12.— WBAN Weather Analysis Symbols.

| Millibar chart | Meters | Feet |
|---|---|---|
| 1,000 | 110 | 370 |
| 850 | 1,460 | 4,780 |
| 700 | 3,010 | 9,880 |
| 500 | 5,570 | 18,280 |
| 400 | 7,180 | 23,560 |
| 300 | 9,160 | 30,050 |
| 200 | 11,790 | 38,660 |
| 150 | 13,620 | 44,680 |
| 100 | 16,210 | 53,170 |

As previously mentioned, constant pressure charts are primarily used as an aid in weather forecasting. They are used in conjunction with surface synoptic charts to accomplish the following:

1. Determine movements of weather systems.

2. Determine cyclonic and anticylonic windflow.

3. Help define air masses.

4. Locate moist and dry areas.

5. Aid in forecasting the formation, intensity, and dissipation of pressure systems.

6. Determine the actual slopes of fronts.

7. Determine the vertical extent of pressure systems.

8. Forecast the jetstream.

## PLOTTED DATA

The meteorological data entered are the height of the standard pressure level above sea level, the temperature and dew-point depression at the standard pressure level, and the wind speed and direction at the standard pressure level. Just as a surface chart may be analyzed to show pressure systems, fronts, windflow, and the like, these constant pressure charts may also be analyzed to show these variables.

The meteorological plotting chart used for plotting constant pressure data is the same as that used for surface synoptic data. It is properly labeled for whatever pressure value the chart is being constructed (850 mb, 700 mb, etc.); it is also marked with date and time.

The information plotted on a constant pressure chart is obtained from the radiosonde and rawinsonde reports received by teletype or radio. These charts are usually plotted and analyzed every 12 hours; they represent the data obtained from the 0000 and 1200 GCT radiosonde and rawinsonde releases. The following is a representative entry of data on a constant pressure chart (700 mb):

(TT) 14.5 6 191 (hhh)

(DD) 3.0

The explanation of the above data is as follows:

hhh Height of the 700-mb level in whole meters (hundreds, tens, and units).
Note: For levels at 500-mb and higher, the heights are reported in tens of meters (thousands, hundreds, and tens).

TT Temperature in tens, units, and tenths of degrees Celsius.

DD Dew-point depression to the nearest 0.1 of a degree C.

6 Wind direction and speed entered in the same manner as on winds aloft charts.

## UPPER AIR FEATURES

The surface weather chart depicts pressure systems only in a horizontal extent. The vertical extent and orientation of the pressure systems depend on the temperature of the atmosphere.

The rate of change of pressure with height depends primarily on the temperature. The pressure changes most rapidly in a vertical plane when the temperature is low, least rapidly when it is high. Remember that pressure is a function of the weight of the atmosphere and that the weight of the atmosphere depends upon the density. Cold air is denser than warm air. Therefore, cold air must exert more pressure at a given altitude. Assume that two columns of air are exerting the same pressure at the surface; the column containing the warmer air has to extend to a greater altitude to exert a pressure at the surface equal to that exerted by a column of colder and denser air. Since the height of the colder column is less, it follows that the pressure must decrease more rapidly with altitude in the colder air and that the vertical spacing of isobars is closer together. For this reason, a pressure system on the surface does not necessarily exist aloft. On the other hand, under the proper temperature conditions, a pressure system may intensify with height.

High- and low-pressure systems are classified as either cold core or warm core systems.

### Cold Core High

A cold core high is one in which the temperatures on a horizontal level decrease toward the center.

Because the temperature in the center of a cold core high is less than toward the outside of the system, it follows that the vertical spacing of isobars in the center of this system is closer together than on the outside. Although the pressure at the center of these systems on the surface may be high, the pressure decreases rapidly with height. (See figure 13.) (For the purpose of illustration, figures 13 through 16 are exaggerated from the way that they appear in actual atmospheric conditions.)

Examples of cold core highs are the North American High and the Siberian High.

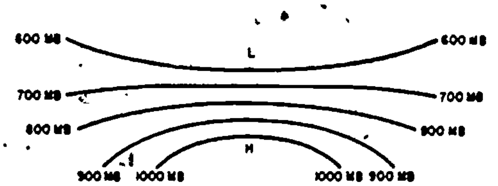


Figure 13.— Cold core high.

### Warm Core High

A warm core high is one in which the temperatures on a horizontal level increase toward the center.

Because the temperatures in the center of a warm core high are higher than on the outside of the system, it follows that the vertical spacing of isobars in the center is farther apart than toward the outside of the high. For this reason, a warm core high increases in intensity with altitude. (See figure 14.)

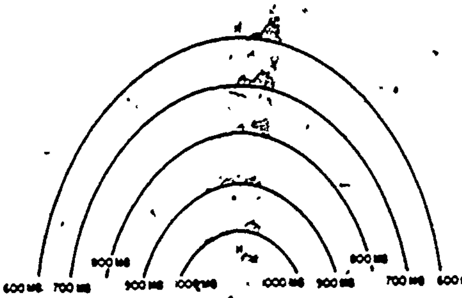


Figure 14.— Warm core high.

Examples of warm core highs are the Azores or Bermuda High and the Pacific High.

### Cold Core Low

A cold core low is one in which the temperatures decrease on a horizontal level toward the center.

Because the temperatures are colder in the center of a cold core low, it follows that the isobaric surfaces in a vertical plane are closer together in the center. For this reason, cold core lows increase in intensity with height. (See figure 15.)

Examples of cold core lows are the Aleutian Low and the Icelandic Low.

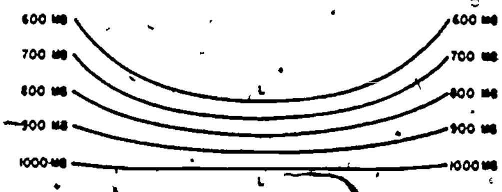


Figure 15.— Cold core low.

### Warm Core Low

A warm core low is one in which the temperatures increase toward the center in a horizontal plane.

Because the temperatures are greatest in the center of a warm core low, it follows that the isobaric surfaces in the center are farther apart in the vertical than toward the outside where the temperatures are lower. For this reason, warm core lows disappear rapidly with altitude. (See figure 16.)

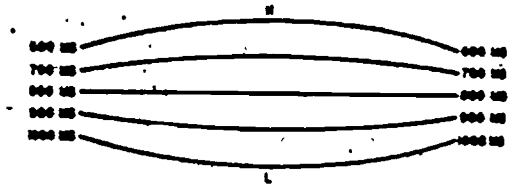

Figure 16.— Warm core low.

Examples of warm core lows are the Equatorial Low and the thermal lows that form over land areas during the summer.

### Vertical Axes

The vertical axes of pressure systems are seldom perpendicular. Lows tend to slope toward colder air aloft and highs toward warmer air. Thus, the position of pressure centers in the upper air will not necessarily coincide with their position on the surface. (See figure 17.)

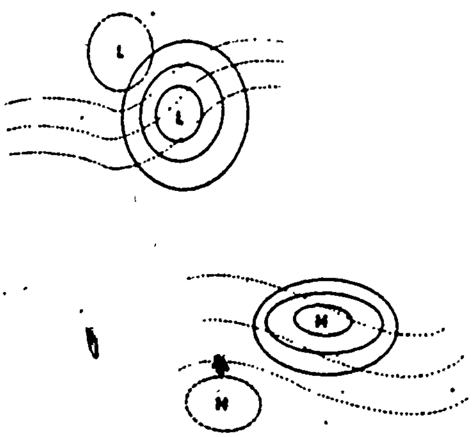

Figure 17.— Comparison of pressure systems.

## CONSTANT-PRESSURE CHART ANALYSIS

As a Marine Science Technician, you are frequently called upon to analyze constant pressure charts. In order for you to be able to carry out these duties, it is necessary that you know the vertical structure of highs and lows, frontal positions aloft, and the basic techniques of constant pressure chart analysis.

### Analysis Elements

Contours.— Contours or isoheights are lines of equal height drawn on a constant pressure chart. These contours show the height of the constant pressure surface in question; draw them for 30-meter, 60-meter, or 120-meter intervals as appropriate. For constant pressure charts up to the 300-mb level, draw contours for 60-meter intervals. For levels at and above the 300-mb level, use 120-meter intervals. In cases in which the gradient is weak or in order to delineate pressure centers, you may use intermediate intervals (30-meter or 60-meter). Contours are the upper air equivalent of isobars. They look about the same as isobars, but are usually much smoother. Draw them for meter intervals rather than pressure intervals, as are the isobars. Label contours in accordance with the specifications listed in table 2.

The contours on the constant pressure charts show smooth, sweeping orientations of troughs and ridges instead of the confused pressure distribution often found on surface charts. Normally, they parallel the wind direction and are spaced inversely proportional to the wind speed. Closed high- and low-pressure systems appear less frequently on constant pressure charts than on surface charts.

You can locate high and low areas from the reported height values. Lows have a lower height value than the surrounding reported heights, and highs have higher reported heights than the surrounding reported heights (figure 17). Label high and low systems on constant pressure charts in the same manner as on surface charts. An "H" in blue denotes a high, and a red "L" denotes a low.

Fronts.— You can normally locate fronts on the constant pressure charts up to and including the 700-mb level from the wind direction, temperature, and moisture distribution. Draw fronts on the charts in the same manner as surface charts or simply show them with a trough line.

Isotherms.— Isotherms are lines of equal temperature; they are drawn for every 5° of temperature, beginning with any value divisible by 5. The standard color for isotherms is red.

### Analysis Technique

As with the surface chart, constant pressure chart analysis should consist of the following four steps:

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Table 2.— Standard upper air chart markings.

| Element | Marking | Interval | Label: Where | Label: Units |
|---|---|---|---|---|
| Contours (isoheights). | Solid black pencil line. (Dashed black pencil line for intermediate interval.) | 60-meter interval up to 300-mb level. 120-meter interval at and above 300 mb. | | Thousands, hundreds, and tens. |
| Isotherms | Solid red lines | 5° C | * | Degree Celsius. |
| Isodrosotherms. | Very light solid green lines. | 10° C | * | Degree Celsius. |
| Fronts, highs, lows, troughs, and ridges. | Standard WBAN symbols | | In accordance with WBAN requirements. | |
| Forecast movements. | Red: Low and trough. Blue: High and ridge. 6 hr → 12 hr ⟹ 24 hr ⇛ (Black) | | At present location, pointing in direction of forecast movement. | |
| Past movement (centers). | ⊗→⊗→⊗→⊗ (In ink.) | | At past position. | |
| Isotachs | Short dashed green lines. | 20 knots | At edges of chart—around closed axes. | Knots. |
| Jetstream | Thick solid purple line with arrowhead. | Minimum wind speed of 50 knots | Along axis of maximum wind speed. | |
| Tropopause | (Black pencil.) | | Where observed. | |
| Thickness lines. | Dashed, black lines | 60-meter | | Thousands, hundreds, and tens. |
| Advection arrows. | Cold—Blue arrow. Warm—Red arrow. | At every upper and lower contour intersection. | | |

*See footnote at end of table.



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Table 2.— Standard upper air chart markings (continued).

| Element | Marking | Interval | Label | |
|---|---|---|---|---|
| | | | Where | Units |
| Rise and fall lines. | Rise—Solid blue pencil lines. Fall—Solid red pencil lines. (Connecting points of equal rise or fall.) Zero—Purple. | 60-meter | * | Meters |
| Rise and fall centers. | Same as movement (centers). | | | |

*At edges of chart and around closed systems, usually at the top and/or bottom of the closed isopleths.

NOTE: Miscellaneous isopleths, such as potential temperature lines or tropopause isopleths, may be drawn in the manner of contours when they are the primary features and contours are not used in that particular analysis.

1. Before accomplishing anything else, review the previous charts for the PAST HISTORY of the constant pressure surface in question. As with the surface analysis, first make any corrections to the previous analysis that may be necessary due to late or additional reports. Trace the pertinent features of this past history onto the chart being analyzed. In many units the past history is traced to the latest chart before it is even plotted.

2. Preliminary analysis.— Before actually drawing a constant pressure chart, first visually survey the chart to get the general overall idea of the windflow and height pattern that exists.

3. Basic analysis.— After visually checking the chart and noting the general overall idea of the windflow and height pattern, you may start the actual analysis.

First, sketch the contours lightly. As stated previously, contours nearly always parallel the wind direction. As with isobars, contours are close together when the wind speed is strong and far apart when the wind speed is weak.

Next, sketch the fronts and trough lines. After sketching the fronts and trough lines, sketch the isotherms.

4. Final analysis.— When the basic analysis is complete, make the final analysis. Smooth the contours and draw them heavily. Label all contours with their correct values. Draw the fronts and trough lines. Indicate fronts in the same manner as on the surface chart. Indicate troughs as dashed brown lines. Smooth the isotherms and label each with the representative temperature value. Label the high and low height areas.

A summary of the recommended procedure for analyzing a constant pressure chart is as follows:

1. Study past history; trace it on the current chart.

2. Sketch the contours lightly.

3. Sketch the fronts or troughs.

4. Smooth the contours and draw them heavily. Label all contours with their correct values and in the correct manner.

5. Draw the fronts or troughs heavily.

6. Sketch the isotherms.

7. Draw the isotherms heavily and label them correctly.

8. Label the high and low height areas.

WINDS ALOFT CHARTS

A complete and properly plotted series of winds aloft charts is extremely valuable to the flight forecaster. The current wind direction and speed for most flight levels and routes are available at a glance.

At stations in the United States, winds aloft charts may be received over the facsimile circuit. At weather units where this service is not available or when additional levels are required, winds aloft charts are plotted using upper wind data received by teletype.

The wind direction is entered to the nearest tens of degrees, and the wind speed is represented by wind barbs. One small barb represents 5 knots; each long barb represents 10 knots; 50 knots are shown by a pennant at the end of the wind shaft. Examples of various plotted station models on winds aloft charts are as follows:

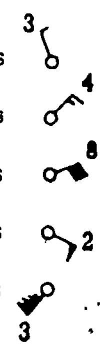
330 degrees — 5 knots

040 degrees — 15 knots

080 degrees — 40 knots

120 degrees — 50 knots

230 degrees — 115 knots




THE AROWAGRAM

In making short-range weather forecasts, it is of primary importance for you to be able to correctly predict the presence of fog, low cloudiness, the height of the freezing level, icing, turbulence, the possibility of thunderstorms, height of clouds, thickness of cloud layers, maximum and minimum temperatures, and stability indexes.

In order to make the correct predictions and to be able to use the information gathered by upper air observations, you need some sort of thermodynamic worksheet. The AROWAGRAM is just such a worksheet. It was developed in the late 1950's during project AROWA, which stands for A-pplied R-esearch in O-perational W-eather A-nalysis.

GENERAL

On the AROWAGRAM are found five (5) lines. One is vertical, two are curved, and two are slanted. An explanation of these lines is as follows.

Isobars

Isobars are the curved horizontal green lines. These lines of constant pressure have a range of 1050 millibars to 200 millibars on the main form and up to 10 millibars on the right-hand corner inset.

Dry Adiabats

Dry adiabats are the slanting green lines running from the lower right to the upper left side of the chart. They have a range of plus 50 degrees Celsius to minus 80 degrees and are labeled from the lower left to the upper right with the temperature at which they intersect the 1000-millibar isobar. They represent lines of constant potential temperature and indicate a lapse rate of 1 degree Celsius per 100 meters (the dry adiabatic lapse rate). Any temperature lines drawn that are parallel to these lines are equal to the dry adiabatic lapse rate.

Saturation Adiabats

Saturation adiabats are the semi-curved black lines which extend upward from the bottom of the chart and curve to the left. They are drawn for even values of temperature from minus 20 degrees Celsius to plus 40 degrees. They are labeled just below the 500-mb isobar with the temperature at which they intersect the 1000-mb isobar. They indicate a lapse rate of .55 degrees Celsius per 100 meters (moist adiabatic lapse rate) and in the upper levels approach the dry rate.

Mixing Ratio Lines

Mixing ratio lines are the light black lines which are slanted slightly to the left of the vertical. The values of these lines vary in a range of 48 gms/kg to .01 gms/kg with saturation in respect to water and, at temperatures lower than -40° C., in respect to ice. Mixing ratio is another means of expressing relative humidity; however, the relative humidity is expressed in gms/kg, which is parts per thousand, instead of in percent, which is parts per hundred.

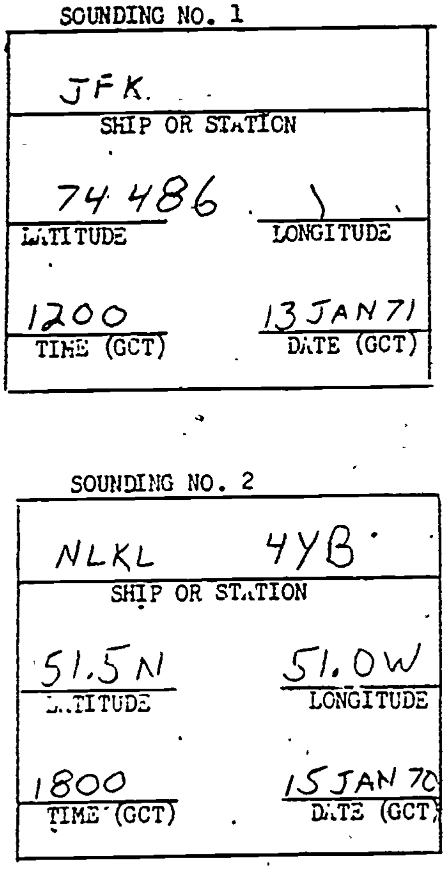



Figure 18.— Sample Sounding blocks.

### Isotherms

Isotherms are the vertical green lines. They are lines of equal temperature and are labeled from left to right with a range of minus 80 degrees Celsius to plus 50 degrees.

## PLOTTING THE AROWAGRAM.

When plotting the AROWAGRAM, the first step is to complete the station identifier block with the station name and your name. Next fill in the block for the sounding that you are plotting. This is the block labeled Sounding No. 1. From time to time, two soundings will be plotted on the same chart, so it is important that you fill out the correct block, correctly. Figure 18 gives two examples showing how to fill out both a land station report and a ship report.

### Plotting Mandatory Levels

After receiving the coded radiosonde message, decode the mandatory levels and plot them as described below. (See figure 19.)

Plot the dry-bulb temperature on the isobar representing the mandatory level where the isobar intersects the isotherm for that particular temperature. Plot this temperature by putting a dot with a circle around it.

Plot the dew-point temperature on the same isobar where you plotted the dry-bulb temperature. Plot this by putting a dot with a triangle around it. Find the dew point by algebraically subtracting the depression from the dry-bulb temperature. The dew point will always be the same or LOWER than the dry-bulb temperature—never higher.

Write the actual height of the mandatory level, in meters; in the right-hand margin of the chart next to the isobar representing that level. Remember, for the 850-mb level you must precede the actual height with a "1," and for the 700-mb level you must precede the actual height with a "2" or a "3." For the 500-mb level, put a zero after the actual height.

Plot the wind of the mandatory level using the same technique that you used for the upper air chart. Plot the wind on the 45° isotherm for each mandatory level. At 400 millibars and up, use the 0° isotherm.

### Plotting Significant Levels

Decode the significant levels from the coded message and starting with the surface level, plot the dry-bulb temperature for each significant level where the isobar for that pressure and the isotherm for that temperature intersect. (See figure 19.) Plot this element with a dot and a circle around it. Then, after plotting the temperature, plot the dew point on the same pressure line. Obtain the dew point in the same manner as you found it when plotting the mandatory levels. Plot it with a dot surrounded with a triangle.

### Plotting Curves

Plotting curves involves drawing the dry-bulb temperature and dew-point curves in the manner described below. (See figure 19.)

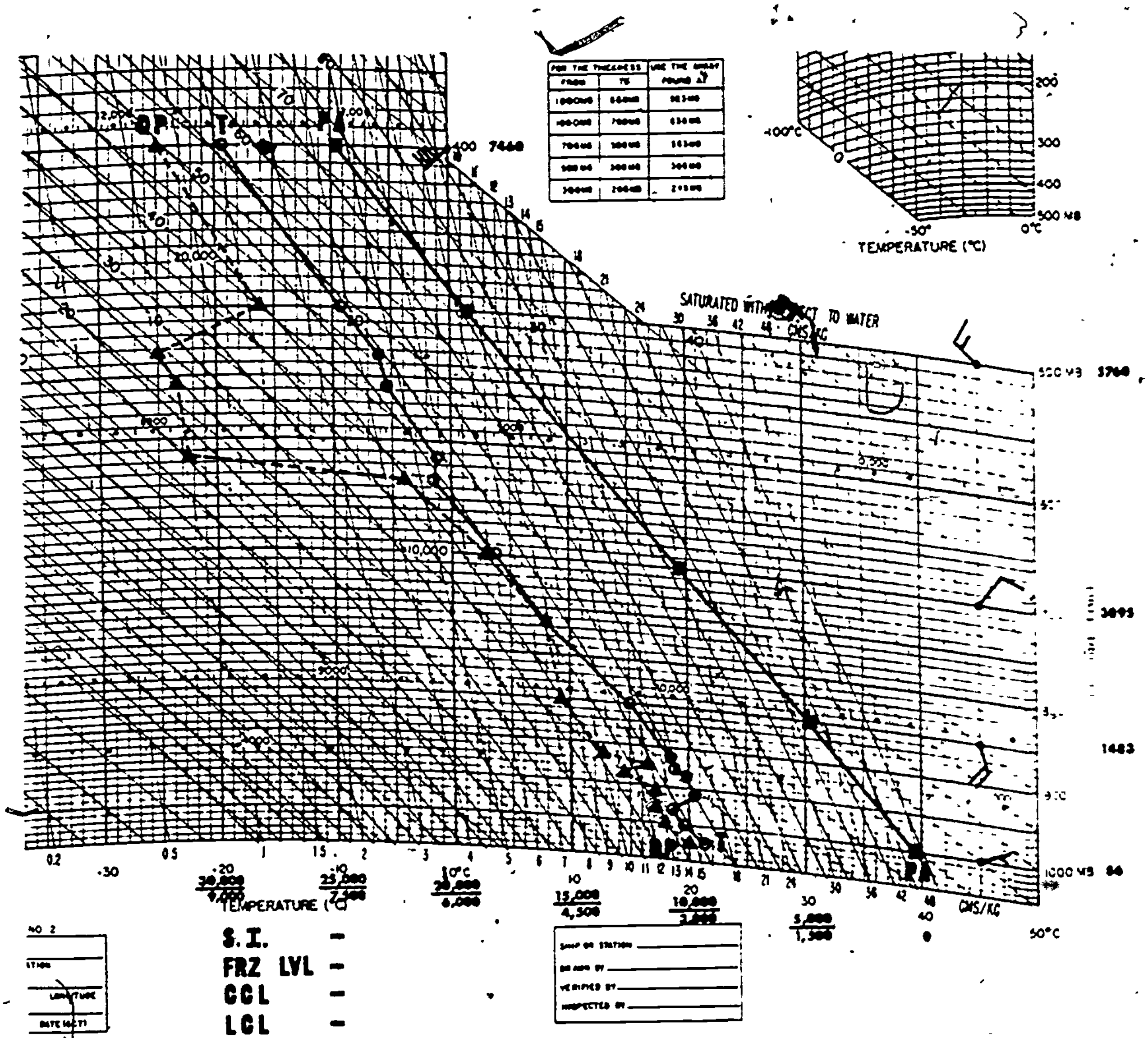



Figure 19. — A sample plotted AROWAGRAM.

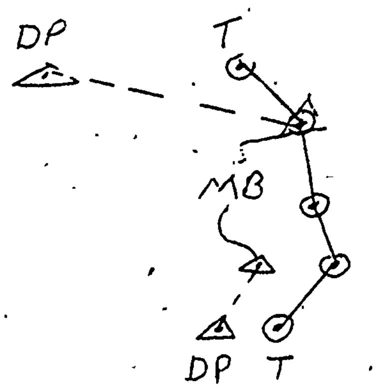



Figure 20.— A motorboating plot.

Starting at the SURFACE plotted dry-bulb temperature, move upward and connect each plotted temperature with a solid line through each point. Label both the top and the bottom of this line with a "T."

Starting at the SURFACE plotted dew point, move upward and connect each plotted dew point with a dashed line through each point. Label both the top and bottom of this line with "DP." When the dew-point depression is sent out as slants (//), it is considered to be motorboating (i.e. too low to be measured). In this case, connect the last plotted dew point to the first one

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that comes back. Connect these two points with a wavy line and label the middle of this stratum with a large "MB." (See figure 20.)

In the case of a missing data stratum (both the temperature and dew-point depression are coded as slants) draw the temperature line through the stratum as a dashed line and mark a large "M" in the center along the dashed line. There is no line drawn through the dew point stratum; instead place a large "M" in the center.

Plotting the Height
(PA or Pressure Altitude)

Beginning at the 40° isotherm, write a zero under the number 40 (along the bottom). (See figure 19.) This is considered to be the surface. Next, under the 30° isotherm, write 5000/1500; under the 20° isotherm, write 10000/3000; under the 10° isotherm, write 15000/4500; under the 0° isotherm, write 20000/6000; under the -10° isotherm, write 25000/7500; and under the -20° isotherm, write 30000/9000. Thus, you have constructed a height scale where each 10 degrees is equal to 5000 feet or 1500 meters. Each single degree is equal to 500 feet or 150 meters.

Take the actual height that you have written in the margin for 1000 millibars and plot it on the 1000-mb line in relation to the scale you have just constructed. A height of 150 would be plotted at 39 degrees. Plot this height with a dot and a square around it. Do the same with each mandatory level up to and including the 400-mb level. (For example, the 850-mb height of 1500 meters is plotted on the 850 line at the 30-degree isotherm.) Take a straight edge and connect each point with a straight line. Label the top and the bottom, which is where the 40-degree isotherm intersects the surface pressure, with a large "PA."

If the surface pressure is less than 1000 millibars, the PA curve will start at the 40-degree isotherm at the surface pressure, and the height of the 1000-mb level will be a theoretical value BELOW the surface.

When drawn, the PA curve will always be a straight line with a slight tendency to lean to the left with increasing altitude. If the PA curve does not conform to the foregoing, recheck all of your computations, because an error in plotting has probably occurred.

Plotting in the Right-Hand Inset

The AROWAGRAM is normally plotted up to and including the 400-millibar level. If it is necessary to plot levels above 200 millibars, use the inset. This will happen with extremely high altitude operations (above 40,000 feet).

ANALYZING THE AROWAGRAM

After an AROWAGRAM has been plotted, it is ready to be analyzed. The following paragraphs describe only a few of the many types of information to be obtained from analysis of an AROWAGRAM.

Freezing Level

The freezing level is the easiest information to determine during analysis. Find the freezing level by drawing a short horizontal line at the intersection of the temperature curve and the 0° isotherm. Label this line "FRZ LVL."

Next, move across the chart to the right, and at the same pressure determine the height of the freezing level from the scale constructed along the bottom. For example, if the temperature curve crosses the 0° isotherm at exactly 700 millibars and if the PA curve crosses 700 millibars at exactly the 20° isotherm, the height of the freezing level is 10,000 feet or 3,000 meters, according to the scale at the bottom.

Convective Condensation Level (CCL)

Another type of information that you can obtain during analysis is the convective condensation level. This is the level at which any clouds formed by convective heating will have their bases.

The first step in determining the convective condensation level is to determine the average mixing ratio, which you can determine in one of the following ways:

1. If the lapse rate is normal, average the plotted DEW POINTS for the first 100 millibars of the sounding in relation to the mixing ratio lines.

2. If an inversion is present, average the plotted dew points for the first 100 millibars of the sounding or to the base of the inversion, whichever is LOWER.



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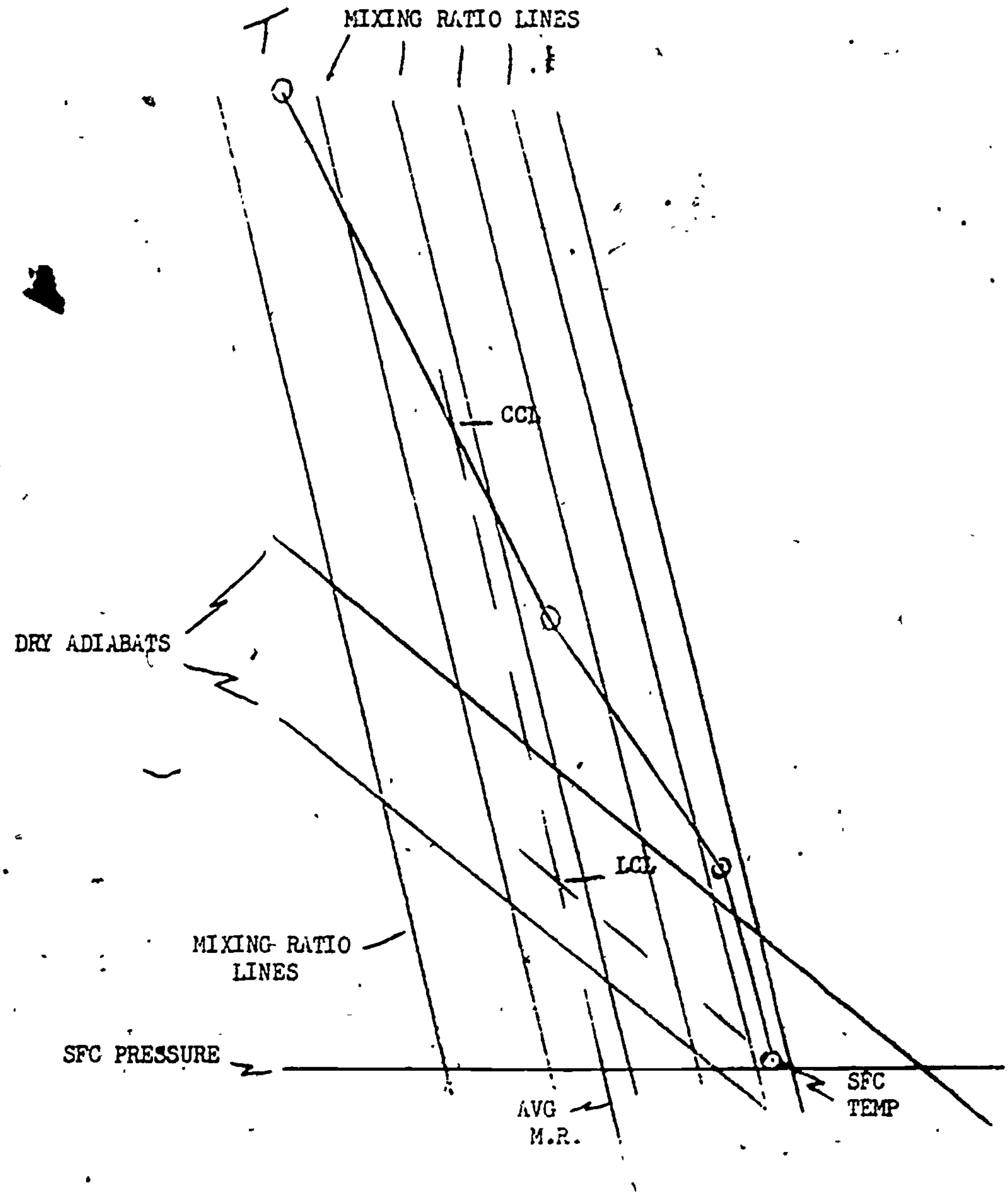


Figure 21.— Determining CCL and LCL.

3. If there is a surface-based inversion, use the surface dew point in relation to the mixing ratio lines as the average mixing ratio.

4. If there is NOT a dew point exactly 100 millibars above the surface, put one there and use it in averaging the dew points.

This is the average mixing ratio for the entire sounding.

The next procedure is to use the value of the average mixing ratio and draw upward a line parallel to the mixing ratio lines until the line crosses the temperature curve. (You are actually drawing in the average mixing ratio.) The point where the line crosses the temperature curve is the point called the convective condensation level. Draw a short horizontal line at this point and label it "CCL." (See figure 21.)

In order to determine the height of the convective condensation level, move across the AROWAGRAM to the PA curve and determine the height from the scale at the bottom.

Lifting Condensation Level (LCL)

The lifting condensation level is the level at which any clouds formed by mechanical lifting will have their bases. You determine this level and its height in a manner very similar to the way you determined the convective condensation level.

First, from the plotted surface temperature, draw a line parallel to the nearest DRY ADIABAT upward until it intersects the average mixing ratio line (the line you just drew). (See figure 21.) Draw a short horizontal line where these two lines intersect and label it "LCL." Then, move across to the PA curve and determine the height in the manner described above. This is the height of the lifting condensation level.

Stability

In order to ascertain the stability of an air mass, determine positive and negative areas. To determine positive and negative areas, use the mechanical lifting method or the convective lifting method. Only one method need be used. If mechanical lifting is expected, use the mechanical lifting method, but if convective lifting is expected follow the convective lifting method. The methods are described below.

Mechanical Lifting.— To determine positive areas for mechanical lifting, trace a line from the LCL parallel to the nearest moist adiabat upward to the top of the chart. Positive areas are all areas that are to the right of the temperature curve and that are bounded by the temperature curve and by the moist adiabat extended upward from the LCL. They are shaded red.

To determine negative areas, trace from the LCL a line parallel to the nearest moist adiabat upward to the top of the chart. From the surface temperature, trace a line upward parallel to the nearest dry adiabat until the line intersects the average mixing ratio line at the LCL. Negative areas are all areas that are to the left of the temperature curve and that are bounded by the temperature curve and by the moist adiabat extended from the LCL and the dry adiabat extended from the surface temperature. (See figure 22.) They are shaded blue.

Convective Lifting.— To determine positive areas for convective lifting, trace a line from the CCL parallel to the nearest moist adiabat upward to the top of the chart. Positive areas are all areas that are to the right of the temperature curve and that are bounded by the temperature curve and by the moist adiabat extended upward from the CCL. (See figure 23.) They are shaded red.

To determine negative areas, draw a line from the CCL parallel to the nearest dry adiabat DOWNWARD to the surface pressure line. Draw in the surface pressure line connecting the temperature curve and the projected dry adiabat. The area in the triangle thus formed is a negative area. (See figure 23.) It is shaded blue.

If the area covered by positive areas (shaded red) is greater than the area covered by negative areas (shaded blue), the air mass is stable and thunderstorms, turbulence, etc. are probable. Note that the size of the areas is considered—not how many areas are present.

Stability Index.— The stability index is a numerical value that is assigned to the atmosphere and that can be applied to various equations and formulae in determining thunderstorm activity. (We will not go into any of the formulae involved.) This numerical value enables you to tell at a glance whether the atmosphere is stable or unstable and to what degree the atmosphere is stable or unstable. The stability index is normally included at the end of the coded message, but you may be called on to compute it.

The first step in computing the stability index is to trace a line from the temperature at the 850 millibar surface upward parallel to the nearest dry adiabat until you reach the mixing ratio value of the 850-millibar level. From this point, trace a line upward parallel to the nearest moist adiabat to the 500-millibar level. Find the numerical value of the difference between the temperature of this line and the ACTUAL temperature at the 500-millibar level. This is the stability index.

Next, you must determine whether the stability index is a positive or a negative number. If the ACTUAL temperature is higher (WARMER)

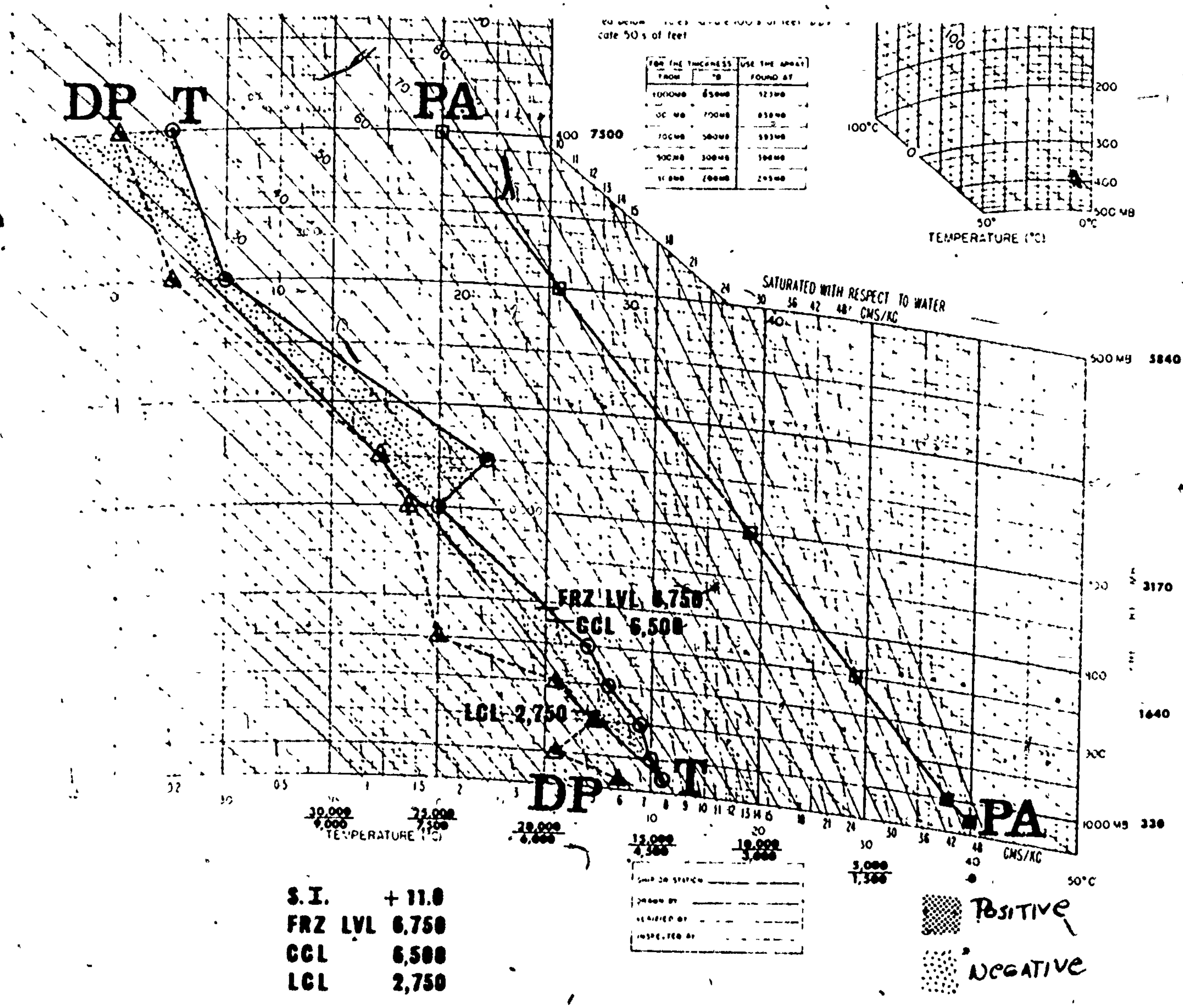


Figure 22.— AROWAGRAM analyzed for mechanical lifting. Notice that there are no positive areas on this AROWAGRAM.

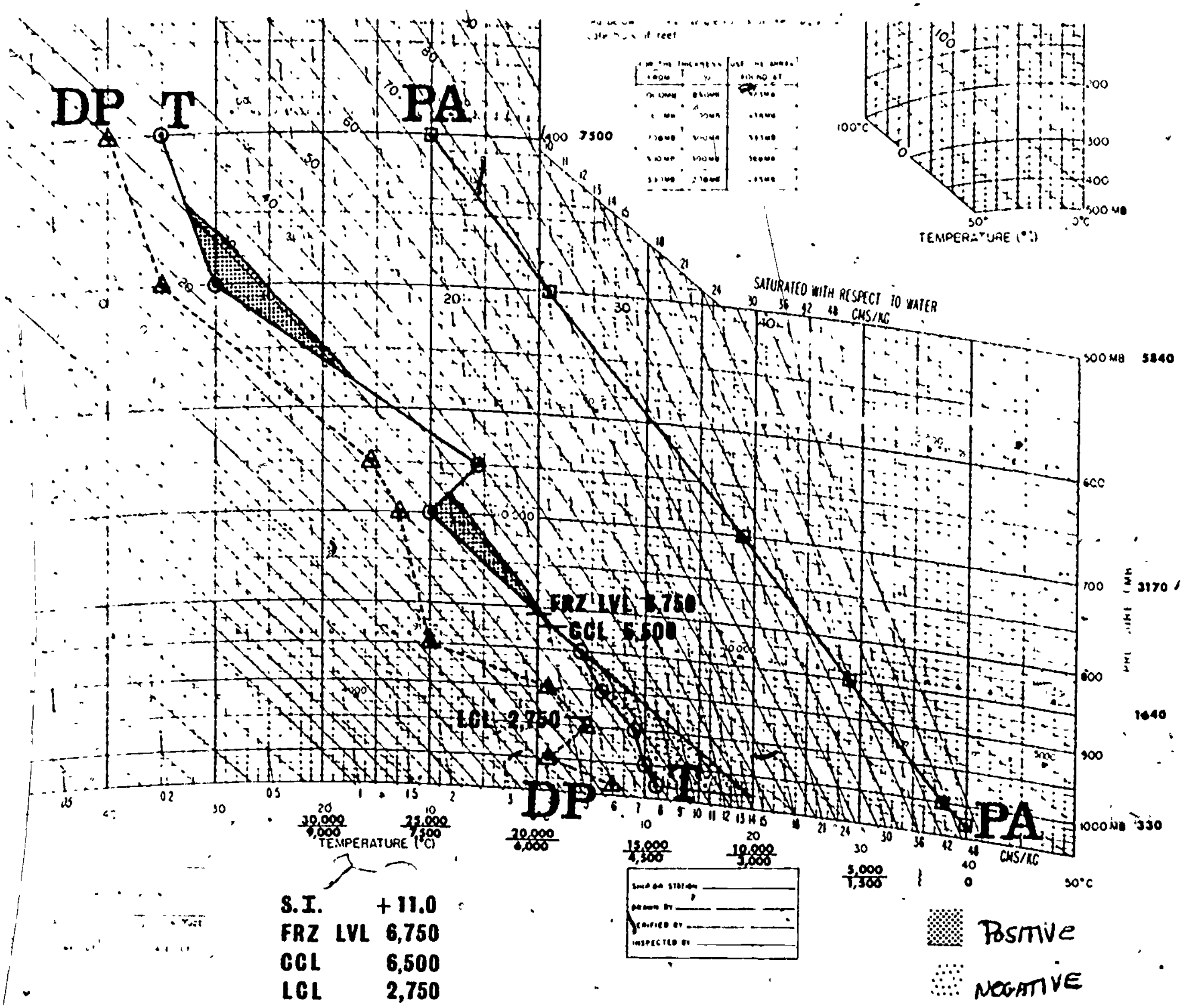


Figure 23.— AROWAGRAM analyzed for convective lifting.

```
UIL  TT  5400/ 72797

LGA  TT  5512/ 72503 99030 11040 ///// 00330
10059 ///// 85640 04064 ///// 70170 10129 /////
50584 30150 ///// 40750 35150 ///// 88999 77999

VV  5512/ 72503 00030 11040 11950 09046 22900
06050 33650 05560 51515 SUPER 65-50V
```

Figure 24.— Radiosonde message from which figures 22 and 23 were plotted and analyzed.

than the temperature of the line that you drew, the value is positive and the air mass is stable. If the ACTUAL temperature is colder (LOWER) than the temperature of the line you drew, the value is negative and the air mass is unstable.

The higher the numerical value, the greater the degree of stability or instability, depending on the sign.

## COMMUNICATIONS SYSTEMS

### COMMUNICATIONS NETWORK

After weather observations have been taken and entered on the appropriate forms, they must be transmitted to other ships and stations. The rapid communication of weather information is imperative for reliable forecasting, as the weather is often a rapidly changing condition. The weather services use two means of transmission: landline and radio.

Landline is a network used for transmitting data directly over fixed wire circuits from station to station or from a control station to a group of stations. The transmission and receipt of printed data over landline circuits are accomplished by the use of teletypewriters. The transmission and receipt of charted data, such as weather maps, over landline circuits are accomplished by the use of facsimile equipment.

Radio is used to transmit and receive data where the use of landline circuits is either impracticable or impossible. Radio is the means by which Fleet Weather Centrals, Fleet Weather Facilities, Fleet Numerical Weather Facilities, and National Weather Service and FAA activities transmit data to ships and overseas land stations, and vice versa. Data are transmitted by radio on predetermined frequencies and at predetermined times.

Printed data are transmitted and received either by radioteletype or by radiotelegraphy. Charted data are transmitted and received by radio facsimile.

The communication facilities employed for the transmission and reception of weather data include Federal Aviation Administration (FAA) circuits, the CONUS Meteorological Teletype System (COMET), National Weather Service circuits, and naval communications.

### Federal Aviation Administration

The Federal Aviation Administration (FAA) is responsible for establishing, operating, and maintaining communications systems and circuits required for the collection and dissemination of meteorological information utilized by civil aviation. The FAA also provides and operates a communications system for the collection and dissemination of meteorological information required by the National Weather Service. The National Weather Service, which serves the general public, determines the form and content of meteorological information to be scheduled on the FAA fixed weather communications circuits, and the extent of distribution required. The civil weather communications systems serving the various U.S. meteorological agencies are the FAA Weather Teletype Services A, C, and O. In addition, the National Facsimile Network and the High Altitude Facsimile Service are under the control of the National Weather Service.

Service A.— The Federal Aviation Administration Service A Data Interchange Systems (ADIS) circuitry, operating at a standard speed of 100 wpm, consists of 15 area circuits, 14 supplementary circuits, and local circuits between ADIS Centers, National Weather Service Flight Advisory Weather Service (FAWS) offices, and other meteorological offices. A transcontinental express circuit (857 wpm) interconnects these circuits through the ADIS Centers. Continental Naval Weather Service Units normally have a receive-only capability drop on one of the 15 area circuits.

Weather data received from this network include hourly, special, and supplementary aviation weather reports; radar weather reports and summaries; pilot weather reports; notices to airmen (NOTAMS) and summaries; winds and temperatures aloft forecasts; aviation area forecasts; aviation terminal forecasts; severe weather forecasts and convective outlook forecasts; abbreviated hurricane advisories; flight advisories; regional weather prognosis; and surface analyses and prognoses.

Service C.— The Service C system, operating at 100 wpm, is composed of six circuits interconnected by two relay stations (Denver and Louisville). Naval weather units utilizing this system may have either send or receive capabilities, or both.

Weather data received from this network include synoptic surface reports; raob, rawin, and pibal reports; selected upper level data; hurricane bulletins and advisories; upper air fallout data; surface and upper air analyses; aviation terminal forecasts; weather summaries; and 5-day daily prognoses.

Service O.— The Service O system is composed of both domestic and overseas foreign fixed aeronautical communications circuits, including teletype, radiotelegraph, and radioteletype. On this system, certain weather units have a receive-only capability drop.

Data received from this network include hourly and surface synoptic weather reports; area and terminal forecasts; raob, rawin, and pibal reports; selected upper air levels data; cloud information from meteorological satellites; surface and upper air analyses and prognoses; pilot weather reports; weather summaries; and hurricane bulletins. Most of this transmitted weather data is in a coded format (e.g., FM 51C for terminal forecasts, FM 45C for analyses and prognoses, FM 11C for synoptic reports, etc.). These codes are discussed elsewhere in this training course.

Modernized A, C, and O Communication Systems.— At this writing, the FAA Communications System is being completely redesigned and modernized. This improved system will combine all message switch and relay functions of Services A, C, and O into one major center. The circuit control and message switching functions will be performed automatically by an electronic computer as a real-time (instantaneous) communications message switch.

With one major switching center, data distribution procedures become more flexible and data from the three Services A, C, and O may be easily intermixed over a single line when desirable to do so. However, collection functions will continue to be organized primarily in terms of A and C types of data, as was just discussed.

National Weather Facsimile Network.— The National Facsimile Network is operated by the National Weather Service using circuits leased from Western Union. Most of the charts are prepared and transmitted by the National Meteorological Center (NMC) located at Suitland, Maryland. Other charts are prepared and transmitted by the Weather Service Radar and Severe Local Storm Units at Kansas City.

There is a great variety of charts transmitted over this facsimile network. They include both surface and upper air analyses and prognoses, weather depiction, radar summary, cloud charts, etc. We will consider these charts in detail later in this pamphlet.

High Altitude Facsimile Service.— The High Altitude Facsimile Service is under the control of the National Weather Service, and the transmission of data is from five Weather Service forecast centers distributed across the United States, plus Montreal, Quebec.

Charts transmitted over this system are high altitude data on winds aloft, significant weather, etc., for the purpose of providing forecast service for high altitude aircraft operations.

CONUS Meteorological Teletype System (COMET)

The modern, high performance aircraft used in naval operations require a myriad of nationwide weather data to assure flight safety and mission completion. The COMET System, a USAF managed component of the Defense Communications System (DCS), was designed to meet this requirement.

The COMET System consists basically of three parallel, eight-circuit teletype networks,

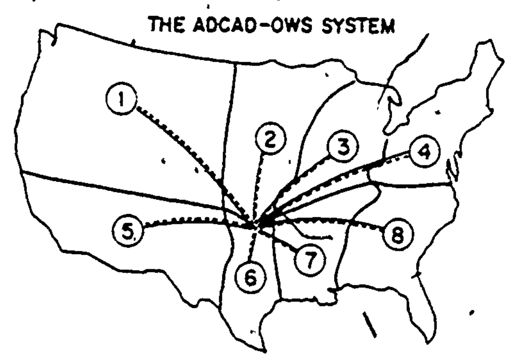


Figure 25.— The ADCAD/OWS System.

and one four-circuit network operating at 100 wpm, and radiates from the Weather Relay Center (WRC) at Tinker AFB, Oklahoma, to various contributing and receive-only weather stations within the continental United States. These four networks are the Airways Data Collection and Dissemination (ADCAD), which is termed COMET I; the Operational Weather Support System (OWS), a duplex system which is composed of COMET IIA and COMET IIB; and the SYNOPTIC Network, which is termed COMET III. The sixteen COMET I and COMET IIA circuits terminate at the ADCAD/OWS Programer at WRC, Tinker AFB. (See figure 25.) This programer was designed to accomplish numerous switching and control functions in order to receive the maximum circuit utilization and to provide for an orderly exchange of weather data.

ADCAD Network (COMET I).— COMET I is used exclusively for the collection and primary distribution of airways surface observations.

Most naval weather units in the continental United States have both a receive and send capability drop on COMET I. The unit is then able to transmit its hourlies and specials on this network and receive hourlies and specials from other specified stations.

OWS Network (COMET IIA and COMET IIB).— COMET IIA is used for the collection of all CONUS military weather data other than surface observations. This includes TAFOR's PIREP's, RAREP's, NOTAM's and other miscellaneous data.

COMET IIB is used for the dissemination of the various data collected on COMET IIA.

In addition, COMET IIB and COMET I are electronically interconnected for approximately the first 10 minutes of each hour. This procedure allows the rapid dissemination of military hourlies to all users. In this manner, any station having COMET IIB and COMET I will receive all CONUS military hourlies by ten minutes past each hour.

Naval Communications

Navy-originated weather reports which are not entered on civil weather circuits, the COMET system, or other common-user circuits are transmitted by naval communications. Weather information prepared by the Fleet Weather Centrals/Facilities is disseminated to the operating forces of the Navy by naval communications through the scheduled fleet, general, and multipurpose broadcasts.

There are several types of broadcasts made by major Navy radio stations which contain weather information. In general, the fleet broadcasts disseminate warnings of hazardous or destructive weather phenomena, or high seas conditions; for example, typhoon/hurricane/storm warnings. The general broadcasts disseminate weather information, such as storm warnings; area forecasts; map analyses; surface weather reports; and upper air, upper wind, and aircraft reports. The fleet facsimile broadcasts disseminate weather analyses and prognoses. Multipurpose broadcasts, by use of multiplex techniques, combine radioteletypewriter and facsimile signals into the same frequency for simultaneous transmission of both types of information. Such broadcasts are activated when there is a need for large volumes of raw weather data and graphical products. Requirements for these weather broadcasts are determined by Fleet and Force Commanders and approved by the Chief of Naval Operations. Each designated weather activity, by careful selection and editing, then establishes the specific content of the broadcast deemed necessary to provide maximum weather information to the operating forces within its area of responsibility. Frequencies and schedules of these broadcasts are contained in JANAP 195 and in N.O. Pub. No. 118.

COMMUNICATIONS MANUALS

To ensure the proper utilization of all available communication facilities, you should

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be familiar with the following publications and manuals.

Federal Aviation Administration

Service A Weather Schedules.— The FAA publication 7330.5 ( ) contains detailed operating instructions and distribution schedules for the dissemination of meteorological and NOTAM information on the FAA Service A Data Interchange System (ADIS). This publication also contains a complete description of all data transmitted on this system.

Service C Weather Schedules.— This publication, ATP 7330.3( ), contains detailed operating arrangements for the distribution of meteorological information on the Service C communications system.

Service O International Weather Schedules.— The publication ATP 7330.4( ) contains detailed operational weather scheduling arrangements for the distribution of synoptic and operational meteorological information over the Service O network to serve the specific requirements of international aviation.

CONUS Meteorological
Teletype System (COMET)

Air Force Communications Service Manuals.— AFCSM 105-2, Volumes I and II, provides instruction and general procedural policy for the collection and distribution of weather data via USAF and/or Defense Communications System (DCS) weather communications networks and associated facilities. These procedures apply to all personnel responsible for the preparation of weather messages transmitted on the COMET System.

Air Weather Service Manual 105-2.— Volume II of AWSM 105-2 describes meteorological messages (teletype and facsimile) which are available on CONUS USAF weather communications systems.

Operating Instructions ADCAD-OWS Weather System Manual.— This manual was prepared by the American Telephone and Telegraph Company to be used by weather units utilizing the COMET System. This manual contains a description of the COMET System concept, procedures for weather data transmission, and operating procedures for the transmitting and receiving equipment.

Navy Radio Weather Aids

The basic naval publications currently in use that contain the necessary information for the reception of weather information by radio are listed below.

NWP 16.— Chapter 7 of NWP 16 contains instructions concerning requirements for transmission and receipt of weather information and lists those Fleet Weather Centrals/Facilities which prepare regularly scheduled weather broadcasts.

JANAP 195.— This publication lists frequencies and schedules of all Navy broadcasts which carry weather information.

N.O. Publication No. 118.— This publication contains detailed information concerning contents, schedules, and frequencies of worldwide civil and military broadcasts. Contents of weather portions of Navy general and fleet facsimile broadcasts are listed in this publication. The primary purpose of this publication is to furnish detailed information to operating units afloat on those weather broadcasts which contain storm warnings, forecasts, map analyses and prognoses, and collections of weather reports for specific geographical areas. N.O. 118 also contains information on all weather reporting codes.

## TELETYPE WEATHER MESSAGES

As you have just learned, many different kinds of weather messages are transmitted over the Weather Teletype Services A and C. These circuits are designed primarily for aviation uses, but they are an invaluable source of weather information to you as a Marine Science Technician wherever your duty station.

You have already learned the format and breakdown of surface synoptic reports and upper air reports. To continue our discussion of these topics, let us now consider the use and breakdown of the most commonly used weather messages, various weather message headings, and contractions.

## PLOTTING THE AIRWAYS CODE

When bad or hazardous weather is approaching the station, it often becomes necessary to

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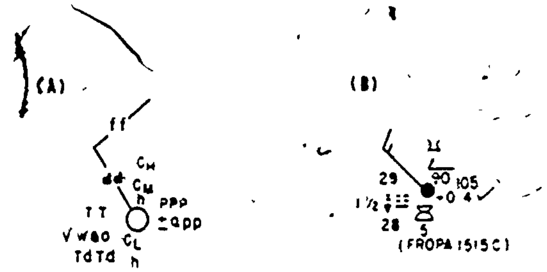


Figure 26.— (A) Station model for plotting airways reports; (B) plotted airways station model.

supplement the 6-hourly synoptic map with 3-hourly airways maps. These may be either a regular synoptic type chart or a sectional chart. At times it may even be necessary to enter hourly airways maps. Over a limited area these charts give detailed analyses of the relation of pressure systems, fronts, temperature, and humidity to operationally significant weather elements. These maps also enable the forecaster to keep a "weather eye" on the situation and to note any sudden or unusual changes which are occurring.

The airways (aviation) code is probably the most familiar of all weather codes. It is used not only when weather reports are made, but can be used to plot airways charts and to fill in areas of sparse or little data on synoptic charts.

Since the airways maps, when plotted, are subject to careful scrutiny, it is imperative that they be entered both rapidly and accurately. The size, type, and scale of the map, and the amount of data to be plotted are governed by local requirements.

The arrangement of data around the station circle is essentially the same as for the land synoptic code plotting model. Figure 26A and B shows a typical station model and a plotted model used for plotting the 3-hourly airways code data.

The entries made on this chart are as follows:

s — Airways symbol representing the greatest sky cover.

V — Actual visibility.

W & O — Weather and obstructions to vision. Enter, using synoptic symbols. Use combinations and intensity symbols. Intermittent precipitation is shown in remarks.

PPP — Enter as given.

TT — Enter as given.

$T_dT_d$ — Enter as given.

dd — Same as synoptic entry (G or Q may be placed at the end of the shaft to indicate gusts or squalls, and the maximum wind in the gusts or squalls may also be placed at the end of the shaft).

ff — Same as the synoptic entry (see dd note for additional entries).

app — Entered the same as 6-hourly synoptic reports.

$1C_LC_MC_H$ — Enter the symbol representing the type of low, middle, and high clouds. Directly below the low and middle clouds enter the height (h) of these clouds using the standard procedure for entry of cloud heights. (Use height of lowest middle or low clouds when there is more than one layer.)

The altimeter setting is not entered. Remarks, as appropriate, should be entered. See figures 27 and 28 for a breakdown of the aviation code.

WEATHER RADAR REPORTS

Detection

Weather radar is used primarily for detecting and tracking severe storms such as thunderstorms, tornadoes, and hurricanes. Weather Service and military weather radar equipment is adjusted to a wavelength that gives the best return signal (echo) from water droplets and other precipitation particles. As a comparison, air surveillance radar employs a wave length which minimizes the echo from small water drops and polarizing devices that minimize echoes from the larger water drops.

A storm does not produce a radar signal. Instead, water drops or ice particles produce "echoes" on the radar scope. The size and number of drops as well as the distance of the drops from the antenna affect the strength of the echo. The radar meteorologist evaluates the strength of echoes to determine intensity. He correlates the radar presentation with surface reports, pilot reports, and many other types of meteorological data as part of his evaluation. Echoes classified as "heavy" or "very



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U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU
SILVER SPRING, MD.

DECODING AVIATION WEATHER REPORTS
Based on Instructions in Federal Meteorological Handbook No. 1, Surface Observations

STANDARD AVIATION REPORT FORMAT FOR MANNED STATIONS

EXAMPLE OF AN OBSERVATION AS FOUND ON HOURLY SEQUENCES

PIT -X M11V⊕38 7/8VL-FK 146/66/65/2713/967/ R10LVR26V55 FK3 /⊕27/CIG 9V12 VSBY 1/2V1

REMARKS. Visibility variable between 1/2 and 1 mile.

REMARKS. Ceiling variable between 900 to 1200 feet.

BASES AND TOPS OF CLOUDS. Tops broken layer 2700 ft. msl. Height of bases not visible at the station precede sky cover symbol. "U" indicates layer amount unknown. If the report is more than 20 minutes old, the time (GMT) precedes the entry.

REMARKS. Fog and Smoke hiding 3/10 of sky.

RUNWAY VISUAL RANGE. Runway 10L, Visual Range variable between 2600 and 5500 ft. in past 10 minutes. When visual range is constant for past 10 minutes, only the constant value is reported, e.g., R10LVR60+.

ALTIMETER SETTING: 29.67 inches. Three figures, representing units, tenths and hundredths of inches, indicate the altimeter setting. "Low" is used preceding figures to indicate values below 29.00 inches.

WIND: 270° true, 13 kts. To decode direction, multiply first 2 digits by 10. If product is >500, subtract 500 and add 100 to speed. Gusts and squalls are indicated by "G" or "Q" following speed and peak speed following the letter.

DEWPOINT: 65°F.
TEMPERATURE: 66°F. A minus sign indicates temperatures below zero.

SEA LEVEL PRESSURE. 1014.6 millibars. Only the tens, units and tenths digits are reported.

WEATHER AND OBSTRUCTIONS TO VISION: Light Drizzle, Fog & Smoke. Symbols used in reporting weather and obstructions to vision are in Table 1. Algebraic signs (Table 1) following symbols indicate intensity.

PREVAILING VISIBILITY: Seven eighths statute mile and variable by the amount given in REMARKS.

SKY & CEILING. Partly obscured sky, ceiling measured 1100 ft., variable broken, 3800 ft. overcast. Figures are height of each layer in 100s of feet above ground. A number preceding an X indicates vertical visibility into phenomena. A "V" indicates height varying by amount given in REMARKS. Symbol after height is amount of sky cover (Table 2). The letter preceding height indicates that height to be the ceiling and the method used to determine the height (Table 3).

TYPE OF REPORT "R" omitted when observation is in hourly sequence.

STATION IDENTIFICATION. Identifies report for Pittsburgh by using FAA identifier.

SUPERSEDES TABLE ... WHICH IS OBSOLETE AND EXISTING STOCK SHOULD BE DESTROYED

NOTE: Tables 1, 2, and 3 are listed in figure 28.

Figure 27.— Decoding Aviation Weather Reports.

heavy" in intensity usually indicate a storm with severe or extreme turbulence, hail, and heavy icing conditions. Echoes of "light" or "very light" intensity may indicate snow, light rain, or drizzle.

Types of Reports

Weather radar reports are distributed to the users in two forms. One form, identified as "SD," is an individual report while the other form, identified as "SD-1," is a composite summary of all individual reports in the United States.

Individual Weather Radar Report.— Radar reports originate mainly from Weather Service stations, but are supplemented by military and FAA control radar. The most effective storm detection radar in use today is the Weather Service's WSR-57 and military versions of the same set. The WSR-57 radars have a range of



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TABLE 1

WEATHER SYMBOLS

| | | | |
|---|---|---|---|
| T | Thunderstorm | RW | Rain Showers |
| T+ | Severe Thunderstorm | S | Snow |
| A | Hail | SG | Snow Grains |
| IC | Ice Crystals | SP | Snow Pellets |
| IP(W) | Ice Pellets (Showers) | SW | Snow Showers |
| L | Drizzle | ZL | Freezing Drizzle |
| R | Rain | ZR | Freezing Rain |

OBSTRUCTIONS TO VISION

| | | | |
|---|---|---|---|
| BD | Blowing Dust | H | Haze |
| BN | Blowing Sand | D | Dust |
| BS | Blowing Snow | F | Fog |
| BY | Blowing Spray | GF | Ground Fog |
| K | Smoke | IF | Ice Fog |

WEATHER INTENSITY SYMBOLS

| | | |
|---|---|---|
| -- | Very light | Absence of symbol indicates moderate except for T, A and IC |
| - | Light | |
| + | Heavy | |

TABLE 2

SKY COVER SYMBOLS

| | |
|---|---|
| -X | Partly obscured sky (0.1 to 0.9 sky hidden by surface-based obscuration) |
| X | Obscuration (1.0 sky hidden by surface-based obscuration) |
| O | Clear (0.0 sky cover) |
| ⦶ | Scattered (0.1 to 0.5 sky cover) |
| ⦷ | Broken (0.6 to 0.9 sky cover) |
| ● | Overcast (1.0 sky cover) |

A minus sign (-) preceding a ⦶, ⦷ or ⊕ symbol indicates that layer is thin, i.e., 1/2 or more of the summation amount for that level is thin

TABLE 3

CEILING DESIGNATORS

| | | | |
|---|---|---|---|
| M | Measured | B | Balloon |
| A | Aircraft | E | Estimated |
| W | Indefinite | R | Radar |

Figure 28.— Tables to be used for encoding and decoding airways messages.

250 nautical miles and are strategically placed for surveillance of most of the U. S. east of the Rocky Mountains; it is this area where severe storms are most frequent. Figure 29 shows the locations and types of weather radars in the 48 contiguous states.

Radar reports are made hourly by WSR-57 equipped stations at H+45. These reports are called record radar observations. Weather radar stations equipped with other type radar, such as the WSR-1, also make record observations at H+45, but this schedule is not routine for some of those stations within about 100 nautical miles of a WSR-57 or specified military radar. Special radar reports are also made at any other time when important echo patterns are observed. If a radar report is a "special," the term "SPL" and the time (GMT) of the radar observation are inserted following the radar station identifier. Service A transmission of individual radar reports has a time group (GMT) for all record as well as special observations.

Table 3 shows the order and content of the individual weather radar report, and the following paragraphs describe the content of an individual weather radar report.

Location Identifier: A three-letter group identifies the station which makes the radar observation.

Time of Report: The time of the observation (if given) is in Greenwich Mean Time. The time is always included for special observations or any report transmitted on Service A. If the time is omitted, it is a record observation taken at H+45.

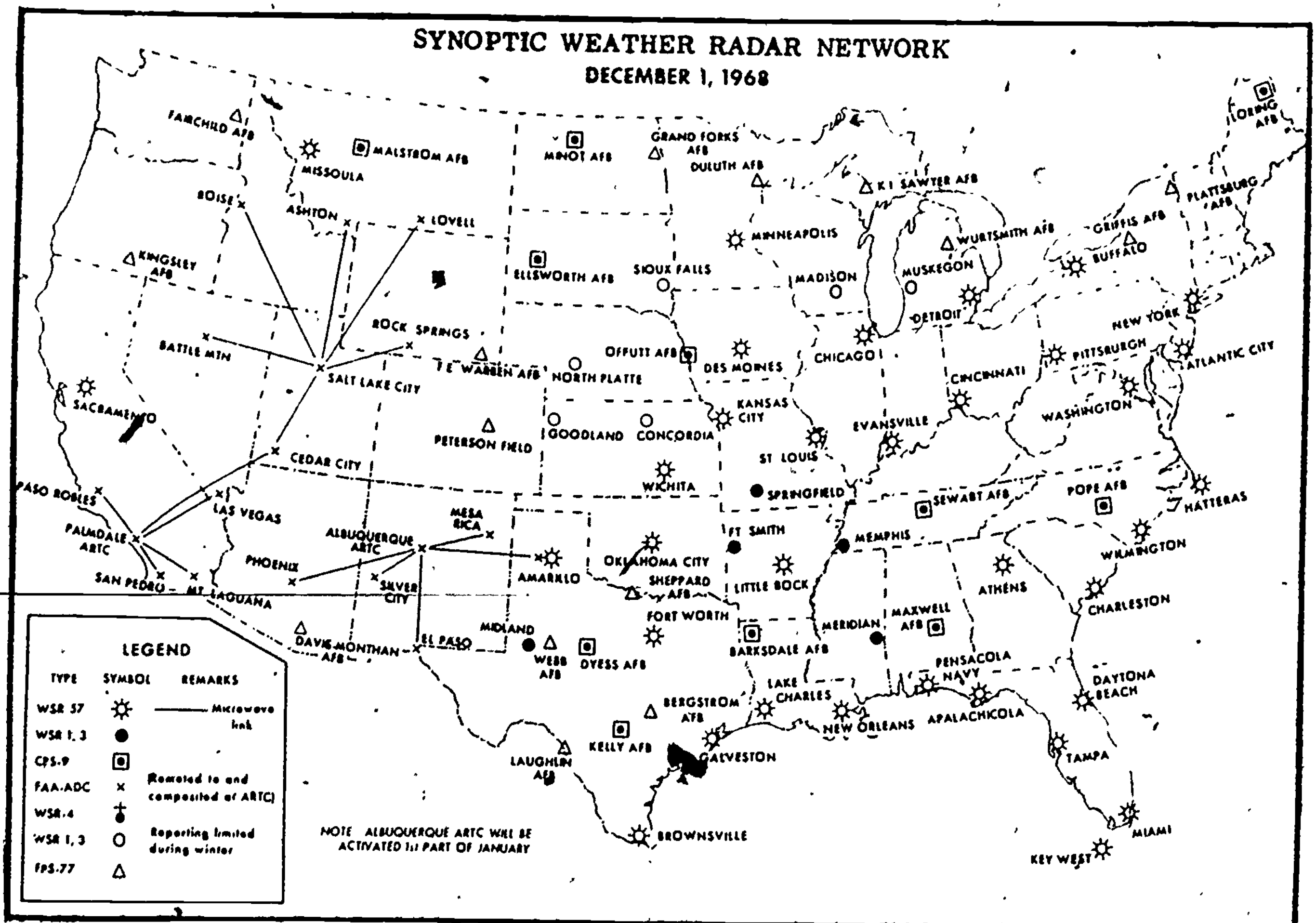


Figure 29.— Weather radar stations in the contiguous U.S.

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Table 3.— Order and Content of Individual Weather Radar Report.

DCA SPL SD 1612 AREA ⊕ TRW-/+ 316/83 D50 2730 MAX TOP 350
a. b. c. d. e. f. g. h. h. i. j.

2 INCH HAIL RPRTD 316/83
k.

a. Location identifier

b. The contraction "SPL" if the report is a special (if the report is not a special this contraction is omitted)

c. The contraction "SD" meaning storm detection

d. Time of the report (GMT) (if a special, otherwise omitted)

e. Character of echoes

f. Weather and intensity

g. Intensity trend

h. Location and dimensions of echoes

i. Movement

j. Altitude of bases and/or maximum top of echoes

k. Remarks, notes, and operational status

Character of Echoes: The character of echoes describes coverage and shape (area, line, cell, spiral band area, layer or fine line). The echo patterns are classified as a line only if the echoes are arranged in recognizable or organized lines such as might be reflected from a squall line or front. Spiral band areas are reported mainly with storms of tropical origin. Table 4 lists the symbols that indicate the character of echoes in the individual weather radar report.

Weather and Intensity: The types of precipitation associated with radar echoes are given by the same symbols as used for surface weather reports, i.e., R for rain, S for snow, etc. The intensity of precipitation may be denoted by signs following the precipitation symbols. For example, -- means very light, - means light, + means heavy, ++ means very heavy, the absence of sign means moderate, and U intensity unknown. However, no intensities are given for drizzle, hail, or snow. If liquid and frozen precipitation are reported in the same system, the liquid precipitation is given first, for example, TRW+A.

Intensity Trend: The intensity trend of precipitation is indicated by symbols following the intensity symbols and are separated from the intensity symbols by a slant bar. Table 5 lists the intensity tendency symbols and their meanings.

Location and Dimension of Echoes: Location of echoes is relative to the radar station. The azimuth (degrees true) is given in three digits followed by the distance from the observing station (range in nautical miles). The azimuth is separated from the distance by a slant bar. Thus, the group 316/83 means 316 degrees true and 83 nautical miles.

If the echoes are arranged in a straight line, the azimuth and distance to the ends of the line are given. If echoes are arranged in a curved or irregular line, the azimuth and distances are given for as many points along the center of the line as are necessary to establish the shape of the line. If an irregularly shaped area is covered by echoes, the perimeter of the echoes is reported at as many points as necessary to outline generally the contour of the

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Table 4.— Character of Echoes.

| CONTRACTION | ECHO SYSTEM | DEFINITION |
|---|---|---|
| CELL | Isolated Echo | Independent convective echo |
| AREA WDLY⦶ | Widely scattered area | Related or similar echoes covering less than 1/10 of the reported area |
| AREA⦶ | Scattered area | Related or similar echoes covering 1/10 to 5/10 of the reported area |
| AREA ⦷ | Broken area | Related or similar echoes in a pattern that covers 6/10 or more of the reported area but contains breaks or corridors |
| AREA ⊕ | Solid area | Contiguous echoes covering, usually, more than 9/10 of the reported area |
| LN WDLY ⦶ | Line of widely scattered echoes | Related echoes in an extended pattern covering less than 1/10 of the reported area |
| LN ⦶ | Line of scattered echoes | Related echoes in an extended pattern covering 1/10 to 5/10 of the reported area |
| LN ⦷ | Broken line of echoes | Related echoes in an extended pattern that covers 6/10 or more of the reported area but contains breaks or corridors |
| LN ⊕ | Solid line of echoes | Contiguous echoes in an extended pattern covering, usually, more than 9/10 of the reported area |
| SPIRAL BAND AREA (⦶ or ⦷) | Spiral band area (broken or scattered) | Echoes associated with tropical storms, hurricanes, or typhoons and systematically arranged in curved lines. This grouping may include a wall cloud |
| LYR (⦶, ⦷, or ⊕) | Stratified elevated echo | Precipitation aloft |
| FINE LN | Fine line | Narrow nonprecipitation echo pattern associated with a meteorological discontinuity such as cold air outflow in advance of a squall line or the leading edge of a sea breeze |



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Table 5.— Intensity Trend.

| SYMBOL | MEANING |
|---|---|
| – | Decreasing |
| NC | No change |
| + | Increasing |
| NEW | New echo(s) |

clear-cut echo area. If a single echo, such as a thunderstorm cell, or an area of echoes of roughly circular shape is observed, the azimuth and range to the center of the cell or area are reported.

The dimensions of echoes are given as width (W) or diameter (D) in nautical miles. For example, 50W means 50 nautical miles wide, and D20 means 20 nautical miles in diameter. Mean widths of lines and mean diameters of cells or roughly circular areas are reported. The terms AVG W or AVG D are used for <u>average</u> <u>width</u> and <u>average</u> <u>diameter</u>, respectively.

<u>Movement</u>: Direction and speed of movement are indicated by means of a four-digit group. The first two digits indicate the direction to the nearest 10 degrees from which the echoes are moving, and the last two indicate the speed in knots. To indicate the movement of individual cells within an area of echoes, the word CELL or ELEMENT precedes the movement code; i.e, CELLS 2720 indicates cells are moving from 270 degrees at 20 knots. Direction is given with reference to true north.

<u>Height</u>: Height of maximum echo tops is given in hundreds of feet above mean sea level. The word TOP precedes the height indicator. Thus, MAX TOPS 400 indicates the maximum tops of the echoes are 40,000 feet MSL.

<u>Remarks, Notes, and Operational Status</u>: Certain types of severe storms produce distinctive patterns on the radar scope. For example, a hook-shaped echo is often associated with a tornado; a spiral band, with a hurricane. The melting level is sometimes reported if the radar observer sees an intensified radar signal a short distance below the freezing level. If hail, strong winds, and other adverse weather phenomena are known to be associated with identified echoes on the radar scope, the location and type of phenomena are given in remarks.

Table 6 lists the contractions used separately, or in combination with other observational data or remarks, to indicate the operational status of the radar.

Radar Report Summary.— A summary of weather radar observations is prepared by the weather radar analysis unit at Kansas City, Missouri (MKC) and entered hourly on Service A. Additional hourly weather radar summaries are available on Service A from Salt Lake City for the area covered by the SLC Air Route Traffic Control Center. This summary is prepared by Weather Service specialists who observe weather echoes on the long-range air traffic control radars. A radar summary in teletypewriter form usually consists of the following information:

A heading which includes the originating location for the summary (MKC or SLC); the identifying letters "SD-1" for storm detection; and a six-figure date-time group (GMT) for the observation time. The observation time is 45 minutes past each hour. The transmission time of the summary can be as late as 55 minutes after the observation time and as early as the beginning of the first scan period.

The summary report describing the configuration of the radar echo pattern. Intensity is given as very light (– –), light (–), moderate (no symbol), heavy (+), and very heavy (++). The type of precipitation (occurring either at the surface or aloft) identified with the echoes is given using standard teletypewriter symbols. The echo pattern location is described in terms of distance (nautical miles) and direction (true) from well-known locations. Maximum height of echo tops is given in hundreds of feet (MSL); e.g., 600 is 60,000 feet. The direction of movement of lines, areas, and cells is indicated to the nearest ten degrees (true north) and gives the direction from which they are moving, (i.e., 33 is the code for 330 degrees and means that the movement is from 330 degrees.) The speed of movement is in knots. Thus, the direction and speed of movement are given in a four-digit

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Table 6.— Contractions used to report operational status of radar.

| | |
|---|---|
| PPINE | Equipment performance normal in PPI mode; no precipitation echoes observed; surveillance continuing. |
| PPIOM | Equipment inoperative or out of service for preventive maintenance. |
| PPINA | Observation omitted or not available for reasons other than PPINE or PPIOM. |
| ROBEPS | Radar operating below performance standards. |
| ARNO | A scope or A/R indicator inoperative. |
| RHINO | Radar cannot be operated in RHI mode. Height data not available. |

```
MKC SD-1 022045

CKTS 27-30
AREA BKN R-RW-NC BNDD 30 N ICT 50 E OKC 30 N MWL 25 S CVS
25 NW GUY NERN PTN WDLY SCTD TOPS 120 CNTRL AND SRN PTN TOPS
200 MOVMT 2215
LN BRKN RW- DCRG 15 WIDE 30 W TUL 20 W GGG 40 SSW PSN MOVMT 2715
AREA SCTD RW- NC 50 WIDE 60 SE GSW 30 ENE BWD TOP 160 MOVMT 2315
AREA SCTD RW-NC 150 WIDE 25 E GGG 140 S BRO TOP 200 MOVMT 2715
WITH LN SLD TRW NC 20 WIDE 30 SW LFK 15 W HOU 60 E CRP TOP 330
TRW+ INCRG 15 SW HOU TOP 500
AREA BRKN RW INCRG 75 DIAM 50 SE ACT MAX TOPS 350 MOVMT 1810

FCST
ALL ECHOES EXCP LN ERN TEX WILL DCR INTENSITY AND COVERAGE IN
TWO TO THREE HRS. LN TRW ERN TEX WILL CONT EWD WITH NO CHG
INTENSITY NEXT THREE HRS
```

Figure 30.— Radar report summary.

group, the first two digits of which give the direction of movement while the other two digits give the speed of movement (i.e., 3425 indicates that the movement is from 340 degrees at 25 knots.) The movement group is preceded by the contraction MOVMT.

A forecast on expected movement and changes in intensity for the next few hours. This section appears every three hours at 0040Z, 0340Z, etc. on the MKC SD-1.

Figure 30 shows a radar report summary. The summary interpretation is as follows:

Broken area of light rain and light rain showers, showing no change in intensity, bounded 30 (nautical miles) north of Wichita (Kansas), 50 miles east of Oklahoma City, (Oklahoma), 30 miles north of Mineral Wells (Texas), 25 miles south of Clovis (New Mexico) to 25 miles northwest of Guymon (Oklahoma). Northeastern portion widely scattered with tops at 12,000 (feet MSL). Tops central and southern portion 20,000. Area is moving from 220 degrees at 15 knots.

Broken line of light rain showers, decreasing in intensity, 15 miles wide located from 30 miles west of Tulsa (Oklahoma) to 20 miles west of Longview (Texas) to 40 miles south southwest of Palestine (Texas). The line is moving from 270 degrees at 15 knots.

Scattered area of light rain showers, with no change in intensity 50 miles wide located from 60 miles southeast of Greater Southwest International Airport (Texas) to 30 miles east northeast of Brownwood (Texas) with tops to 16,000. The area is moving from 230 degrees at 15 knots.

Scattered area of light rain showers, showing no change in intensity, 150 miles wide located from 25 miles east of Longview (Texas) to 140 miles south of Brownsville (Texas), tops to 20,000. The area is moving from 270 degrees at 15 knots and contains a solid line of thunderstorms and moderate rain showers, showing no change in intensity, 20 miles wide located from 30 miles southwest of Lufkin (Texas) to 15 miles west of Houston (Texas) to 60 miles east of Corpus Christi (Texas) with tops to 33,000. A thunderstorm with heavy rain showers, increasing in intensity, is located 15 miles southwest of Houston (Texas) with tops of 50,000.

Broken area of moderate rain showers, increasing in intensity, 75 miles in diameter centered 50 miles southeast of Waco (Texas). Maximum tops 35,000. The area is moving from 180 degrees at 10 knots.

Forecast. All echoes except for the line in eastern Texas will decrease in intensity and coverage in two to three hours. The line of thunderstorms and moderate rain showers in eastern Texas will continue eastward with no change in intensity during the next three hours.

## TERMINAL FORECASTS

Terminal forecasts, as the name implies, cover specific terminals. Each terminal forecast includes heights and amounts of sky cover, ceiling identifier "C" when appropriate, visibility, weather and/or obstructions to vision, surface wind, and any necessary remarks. Terminal forecasts do not include specific information concerning cloud tops or hazards such as icing and turbulence. They are issued in two forms, the 12-hour and 24-hour terminal forecasts plus amendments.

### 12-Hour Terminal Forecasts

Twelve-hour terminal forecasts are valid for 12 hours. They are made every six hours and transmitted on Service A; they replace prior issuances. Selected relays are distributed from nearby circuits, while relays from distant circuits may not be received. Figure 31 gives an example of an FT1.

The filing time, valid time, and time changes in the body of the forecast are in Greenwich Mean Time. The weather conditions stated immediately following the terminal identifier (XYZ in figure 31) are expected to occur at the beginning of the valid time (1100Z).

Symbols and Notations.— Symbols and notations used in terminal forecasts are the same as those used in aviation surface reports and appear in the same order.

Ceiling Identifier.— The forecast ceiling is identified by the letter "C" immediately preceding the height figures for the layer representing the ceiling.

Cloud Heights and Sky Cover.— The heights of cloud bases or vertical visibility into a total surface based obscuration are indicated in ascending order above the ground. Cloud coverage and surface based obscurations are indicated by the standard symbols ○, ⦶, ⦷, ⊕, -⦶, -⦷, -⊕, -X, and X. Sky cover includes all cloud layers up to and including the ceiling layer (if any) and any layers significant to flight operations above a broken layer, for example, 8⦶C17⦷50⊕. Adjacent broken or overcast layers with bases above 5000 feet are considered as one layer when the top of the lower layer is less than 3000 feet from the base of the upper layer. Thus, if the forecaster expected conditions of C60⦷80⊕, he would code this condition C60⊕.

Visibility, Weather and Obstructions to Vision.— The prevailing visibility appears in the forecast if it is expected to be 8 statute miles or less. Weather and/or obstructions to vision follow the visibility value when the visibility is forecasted to be 6 statute miles or less, for example, 7, 6K, 3R. Visibility is omitted if it is expected to be greater than 8 statute miles.

Surface Wind.— Surface wind is shown using two numbers to indicate the direction (in tens

Terminal Forecasts for 12 hours · Date Time (Greenwich)

**FT1 061045**

Valid Time (Greenwich) · Day of Week

**1100-2300 TUE**

Station Designator · Ceiling Designator · Cloud Amount · Weather · Wind

**XYZ C34⊕3RW-FK 1815**

Cloud Height · Visibility · Obstruction to Vision

Figure 31.— Terminal forecast, FT1.

XYZ C34⊕3RW-FK 1815. 1530Z COLD FROPA 10⊘C15⊕2RW 3320 OCNLY C10⊖1TRW 3320G35. 1700Z 25⊘ 3315. .

Figure 32.— Terminal forecast showing expected changes in weather conditions during the 12-hour period.

of degrees with reference to true north) from which the wind is expected to blow, followed by the speed in knots. If the wind speed is forecast to be less than 10 knots, the entire wind group is omitted. Gusty winds are indicated by the letter "G" following the speed; i.e., 2425G means "wind two four zero degrees, 25 knots and gusty." Peak gusts are shown following the "G" when gusts are expected to equal or exceed 35 knots; i.e., 2425G35 means "wind two four zero degrees, 25 knots, peak gusts 35 knots."

Expected Changes in Weather Conditions.— Expected changes in weather conditions are not stated in figure 31. In other words, this forecast indicates there will be uniform conditions at XYZ from 1100Z until 2300Z on the 6th. Figure 32 shows how the forecast in figure 31 would appear if changes were forecast during the 12-hour period.

Note in figure 32 that a figure group (in GMT) shows the time that changes are expected to occur. At 1530Z a cold frontal passage is expected with conditions generally 10⊘C15⊕2RW 3320 but occasionally lower, as stated, in thunderstorms and moderate rain showers until 1700Z. After 1700Z conditions are expected to become 25⊘3315 and remain essentially unchanged until expiration of the forecast period at 2300Z.

Remarks.— Remarks are added whenever they help explain weather conditions expected at the terminal and cannot be covered elsewhere in the forecast.

Examples:

30⊕V⌽
CB VCNTY
OCNLY C5X1/2R+

A gradual transition from one condition to another is indicated by modifying remarks, such as:

LWRG TO C10⊕3R-BY 1500Z

24-Hour Terminal Forecasts

The 24-hour terminal forecast is valid for 24 hours and has the same format as the 12-hour terminal forecast except that the call sign of the center originating the forecast appears in the heading. It is issued only for major terminals and distributed on Service C teletypewriter circuits every six hours. All FT2 forecasts are relayed on Service C to achieve

```
XYZ C34⊕3RW-FK 1815. 1530Z COLD FROPA 10⦶C15⊕2RW 3320 OCNLY
C10⊕1TRW 3320G35. 1700Z 250 3315. 0100Z ○. 0900Z -X2F. .
```

Figure 33.— Terminal forecast, FT-2. Same example as in figure 32 extended 12 additional hours.

```
FT1 151045
11Z-23Z WED

066
AMA 100⦶ 1610. 2000Z 270-⦶. .
GAG C80⦶270⦶ 1712. .
LWK ⦶V⦶. 2000Z 250-⦶. .

066
LBB C100⦶270⦶. 1700Z 100⦶C270⦶ WDLY SCTD RW- PSBL TRW-. 2200Z 270-⦶. .

067
PNC C100⊕ ⊕V⦶. 1600Z 100⦶C250⦶. 2100Z 150-⦶. .
```

Figure 34.— 12-hour terminal forecast as it appears over Service A.

```
FT2 JFK 221723
17Z WED-17Z THU


LGA  45⦶ 3214 ⦶V⦶. 0000Z ○. 1100Z ○5K. 1500Z 40⦶. .
JFK  45⦶ 3215 ⦶V⦶. 0000Z ○. 1100Z ○5K. 1500Z 40⦶. .
EWR  45⦶ 3215 ⦶V⦶. 0000Z ⦶. 1100Z ○5K. 1500Z 40⦶. .
ACY  40⦶C80⦶ 3212 ⦶V⦶. 2000Z 45⦶ 3213 ⦶V⦶. 0000Z ○. 1500Z 45⦶. .
ALB  C35⦶70⦶ 3015 ⦶ OCNLY ⊕- 0100Z 40⦶C70⦶. 1500Z 40⦶ OCNL C40⦶. .
```

Figure 35.— 24-hour terminal forecast (FT2) as it appears on Service C.

nationwide distribution for flight planning purposes. If the forecast for station XYZ in figure 31 also appeared in a 24-hour terminal forecast, the extended time period would appear as shown in figure 33.

### Amended Terminal Forecasts

The aviation forecaster issues an amended terminal forecast whenever he considers it advisable for the safety and efficiency of aircraft operations. He considers VFR and IFR minimums at each terminal along with forecasted changes of various weather elements.

### Examples of Terminal Forecasts

Figures 34, 35, and 36 show 12-hour, 24-hour, and amended terminal forecasts as they appear on teletypewriter. Table 7 interprets portions of a terminal forecast. Remember that omission of wind or visibility implies a forecasted condition just as though it were explicitly stated.

## AREA FORECASTS

Area forecasts describe weather over an area—weather which a pilot will encounter in flight. Area forecasts are excellent for aviation

AMENDED FT1 SEA 061540
1540Z-2300Z THU
BFI C4⊕1/2LF. 2000Z C10⊕2L--F 2212..

Figure 36.— Amended terminal forecast.

Table 7.— Terminal Forecasts.

| EXAMPLES | INTERPRETATION |
|---|---|
| 30⦶C50⦶ | THREE THOUSAND SCATTERED, CEILING FIVE THOUSAND BROKEN, (VISIBILITY GREATER THAN 8 MILES, WIND LESS THAN 10 KNOTS). |
| C3X1/2R-F | CEILING THREE HUNDRED, SKY OBSCURED, VISIBILITY ONE-HALF (MILE) LIGHT RAIN AND FOG, (WIND LESS THAN 10 KNOTS). |
| O | CLEAR, (VISIBILITY GREATER THAN 8 MILES, WIND LESS THAN 10 KNOTS). |
| 50⦶100-⦶C250⊕ 3615G | FIVE THOUSAND SCATTERED, ONE ZERO THOUSAND THIN BROKEN, CEILING TWO FIVE THOUSAND OVERCAST, (VISIBILITY GREATER THAN 8 MILES), WIND THREE SIX ZERO DEGREES, ONE FIVE KNOTS AND GUSTY. |

Table 8.— Area forecast by sections.

1. Heading
2. Forecast area
3. Height statement
4. Synopsis
5. Clouds and weather
6. Icing
7. Turbulence
8. Outlook

briefing and operational planning. Forecasters at aviation forecast offices prepare them at six-hour intervals for distribution over Service A. In Alaska, area forecasts are amended by unscheduled, amended area forecasts. In all other areas, inflight advisories and severe weather forecasts provide information for updating area forecasts.

Format and Content

Table 8 lists the separate sections of an area forecast. The forecast states specific weather expected for a 12-hour period with a more general outlook for an additional 12 or 18 hours. Forecasters use either abbreviated plain language or symbolic coded groups similar to coding in SA's and FT's.

Heading.— The heading identifies the type of forecast (FA), the forecast office, the scheduled filing time, and the valid period of the forecast, that is, the first 12-hour period. All times are in Greenwich Mean Time.

Forecast Area.— The forecast area identifies the geographical area covered by the forecast.

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Height Statement.— The height statement, "HGTS ASL UNLESS NOTED," alerts the user that height values quoted in the forecast refer to mean sea level unless otherwise indicated by the text.

Synopsis.— A brief synopsis describes locations and movements of significant fronts, pressure systems, and circulation patterns. It may also refer to significant moisture and stability conditions.

Clouds and Weather.— The clouds and weather section describes the expected amount and height of sky cover, cloud tops, surface visibility, state of weather, and obstructions to vision, and surface wind.

Sky Cover: Sky cover is expected coverage of each layer, instead of the summation principle used in surface aviation observations and terminal forecasts. Adjacent broken or overcast layers with bases 5000 feet or higher above ground and with less than 3000 feet vertical separation are forecast as one layer.

Cloud Heights: Cloud heights are in hundreds of feet with reference to mean sea level unless stated otherwise. One hundred-foot intervals up to 3000 feet are forecast in plains and valley areas. Otherwise intervals of 500 to 1000 feet are used. Examples of heights not with reference to MSL are:

C30⊕
100⦶ AGL,

which mean ceiling 3 thousand overcast and 10 thousand scattered above ground level, respectively. (The identifier C or contraction CIG always means above ground since ceiling, by definition, means above ground.)

Cloud Tops: The height of cloud tops is stated for cloud layers with bases 20,000 feet MSL or lower. Cloud tops are in hundreds of feet identified by "TOPS." Example:

C5⊕ TOPS 30

means ceiling 5 hundred overcast with tops at 3 thousand MSL.

Visibility: Surface visibility of more than 8 statute miles is generally omitted from the forecast. When visibilities are forecasted to be 6 statute miles or less, weather and obstructions to vision are included. This criteria is the same as for terminal forecasts.

Table 9.— Areal coverage of showers and thunderstorms.

| Adjective | Coverage |
|---|---|
| Isolated | Extremely small number |
| Few | 15% or less of area or line |
| Scattered | 16% to 45% of area or line |
| Numerous | More than 45% of area or line |

Weather and Obstructions to Vision: Weather and obstructions to vision are in contractions (i.e., SNW, DRZL) when included with a plain language statement. The symbolic form (S, L, etc.) with a plus or minus sign, as appropriate, is used in a symbolic group, such as C8⊕3S-.

When the forecaster expects showers or thunderstorms, he usually describes the activity in a specified area as few, scattered, or numerous. Table 9 gives the expected areal coverage corresponding to each of these adjectives.

Surface Winds: Surface winds are in symbolic form for any area of expected sustained speeds of 25 knots or more. Directions refer to true north, and speeds are in knots. The contraction "SFC WND" precedes the direction and speed group. Gusty surface winds in a plain language or abbreviated text are denoted by the term "GUSTY" or "GUSTS TO...." or, when in a symbolic group, by the form "25G," "25G40," or "30G65."

Icing.— The icing section, identified by the contraction "ICG," includes a statement of expected icing conditions and the height of the freezing level. Contractions such as CLR, RIME, or MXD indicate types of icing (clear, rime, or mixed). Icing intensities are trace, light (LGT), moderate (MDT), or heavy (HVY). Sometimes contractions such as ICGIC, ICGIP, and ICGICIP meaning, respectively, icing in clouds, icing in precipitation, and icing in clouds and in precipitation appear in combination with icing and intensity. For example:

MDT CLR ICGICIP.

Qualifying terms such as probably, likely, and locally are used when these add to the value of the forecast, such as:

MXD ICGIC LKLY.

"NONE" indicates a forecast of no icing. Heights of icing and the freezing level are in hundreds of feet above mean sea level.

Turbulence.— The contraction "TURBC" identifies the turbulence section. The contractions "LGT," "MDT," "SVR," and "EXTRM" describe intensity, while the height of turbulence is in hundreds of feet MSL. A forecast of no turbulence is explicitly stated.

Outlook.— The contraction "OTLK" followed by the valid time in GMT identifies the outlook portion. It contains a brief statement of weather conditions expected in the 12- or 18-hour period immediately following the first 12 hours of the forecast. Only the FA valid beginning at 1300Z contains an 18-hour outlook.

Examples of Area Forecasts

Figure 37 is an example of an area forecast with each paragraph identified and translated. Figure 38 shows an area forecast as it appears on Service A.

WEATHER MESSAGE HEADINGS

Most weather messages have a heading that precedes the weather data and enables the MST to identify at a glance the type and origin of the data received. Normally the heading consists of four letters. The first two letters identify the type of weather data, and the remaining two the geographical area in which the data originated. The following list contains six categories of type-of-report designators:

1. Surface data (observations) (S)
   - SA Hourly and/or half-hourly (airway hourly)
   - SD Radar
   - SE Seismograph earthquake
   - SF Atmospherics
   - SG Microseismograph
   - SI Intermediate hours (3-hourly synoptic)
   - SM Main hours (6-hourly synoptic)
   - SP Special (aviation)
   - SR River and special service
   - SW Supplementary airway weather
   - SX Miscellaneous surface

2. Upper air data (observations) (U)
   - TW Thermal winds
   - UA Aircraft report (PIREP)
   - UB ABTOP
   - UC Combined pilot balloon and RAWIN collective
   - UD Maximum wind
   - UF Upper air fallout data
   - UG Pilot (part B, FM 32.C)
   - UH Pilot (part C, FM 32.C)
   - UI Pilot (part A and B, FM 32.C)
   - UJ Combined RAOB & RAWIN collective
   - UK Temp (part B, FM 35.C)
   - UL Temp (part C, FM 35.C)
   - UM Temp (parts A and B, FM 35.C)
   - UN Rocketsonde data
   - UO Tropopause
   - UP Pilot balloon (part A, FM 32.C)
   - UR Reconnaissance flight (regular and hurricane)
   - US Radiosonde/rawinsonde
   - UT Transosonde
   - UV Vector wind differences
   - UW Rawin (electronic)
   - UX Miscellaneous upper air

3. Forecasts and Prognoses (F)
   - FA Aviation forecasts (combination)
   - FB Aviation forecast
   - FC Terminal forecast in TAF code
   - FD Winds aloft forecasts
   - FE Extended forecast
   - FF Flight forecast
   - FG Radio warning service (radio propagation) forecasts
   - FH High altitude forecast
   - FI Ice forecast
   - FM Temperature extreme forecasts
   - FN Regional forecasts
   - FO Operational forecasts
   - FP Public forecasts
   - FR Route forecast
   - FS Surface prognostic chart
   - FT Aerodrome forecasts
   - FU Upper air prognostic chart
   - FW Winter sports forecast with data
   - FX Miscellaneous forecasts
   - FZ Marine forecasts

4. Analyses (A)
   - AB Weather summaries

(HEADING)
FA MKC 061845
19Z TUE–07Z WED

(FORECAST AREA)
NEB EXCP PHNDL IA KANS MO

(HEIGHT STATEMENT)
HGTS ASL UNLESS NOTED

(SYNOPSIS)
SYNOPSIS. OCLD FRONT NEAR SIOUX CITY LINCOLN CONCORDIA GAGE LN AT 19Z MOVG EWD 20 TO 25 KT RCHG ERN IA SE KANS BY TUE EVE.

(CLOUDS AND WEATHER)
CLDS AND WX. E OF OCLD FRONT. OVR IA NEB 30–40⦶V⊕ AGL 100–120⊕ AGL BCMG C30–40⊕ TOPS 180 SCTD RW– 50 TO 75 MI E OF FRONT. OVR KANS MO 15⦶V⊕40⊕120⊕ ALL AGL TOPS 200 LCLY C10⊖ SE KANS WITH WDLY SCTD SHWRS

W OF OCLD FRONT GRDL CLRG

(ICING)
ICG. OCNL LGT ICGIC IN FRONTAL ZONE. FRZG LVL 100 E OF FRONT AND 60–90 W

(TURBULENCE)
TURBC. NONE

(OUTLOOK)
OTLK 07Z–19Z WED. MOSTLY 100–120⦶V⊕ OVR RGN WITH LWR SC SPRDG INTO NRN IA AND NE NEB ERLY MRNG.

**Heading**
Area forecast issued by Kansas City (MKC), 6th day of month at 1845 GMT; Valid from 1900 GMT Tuesday until 0700 GMT Wednesday.

**Forecast Area**
Forecast area includes Nebraska except panhandle and all of Iowa, Kansas, and Missouri.

**Height Statement**
Heights are all above sea level unless specifically indicated above ground.

**Synopsis**
Occluded front near Sioux City (Iowa), Lincoln (Nebraska), Concordia (Kansas), Gage (Oklahoma) line at one nine zero zero Greenwich moving eastward two zero to two five knots reaching (to) eastern Iowa and southeast Kansas by Tuesday evening.

**Clouds and Weather**
East of occluded front, over Iowa and Nebraska 3000 to 4000 scattered variable to broken, 10,000 to 12,000 broken (both layers above ground level). Becoming ceiling 3000 to 4000 overcast, tops to 18,000 (with) scattered light rain showers 50 to 75 nautical miles east of front. Over Kansas and Missouri 1500 scattered variable to broken, 4000 broken, 12,000 broken all layers above ground, tops 20,000 ASL, locally ceiling 1000 overcast in southeast Kansas with widely scattered showers.

West of occluded front gradual clearing.

**Icing**
Occasional light icing in clouds in frontal zone. Freezing level 10,000 ASL east of front and between 6000 and 9000 west of front.

**Turbulence**
None

**Outlook**
From 0700 GMT until 1900 GMT Wednesday, mostly 10,000 to 12,000 scattered variable to broken MSL over region (forecast area) with lower stratocumulus clouds spreading into northern Iowa and northeastern Nebraska by early morning.

Figure 37.— Area forecast (FA) with translation.

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FA MSY 111245
13Z WED–01Z THU
LA SRN HALF MISS MOBILE AREA OF ALA FLA W OF 65 DEG CSTL WTRS
HGTS ASL UNLESS NOTED
SYNOPSIS. RDG OVER LWR MISS VLY WL BUILD LTL AS WK COLD FRONT ALG GLF CTS LOSES IDENTITY BY 19Z
CLDS AND WX. OVR AREA GENLY 300–⊕
ICG. NONE. FRZLVL 120–130
TURBC. NONE OF CONSEQUENCE
OTLK 01Z–19Z THU. LTLCG

Figure 38.— Area forecast as it appears on Service A.

AC Convective analyses
AH Thickness analyses
AL Zonal wind analyses (hemispheric)
AS Surface
AT Three-hourly analyses
AU Upper air
AV Vertical motion analyses
AW Wind analyses
AX Miscellaneous
AZ Zonal analyses (hemispheric)

5. Climate Data (C)
   CS Surface climate data
   CU Upper air climate data

6. Warnings (W)
   WH Hurricane warnings (or advisories)
   WW Warnings other than hurricane

The third and fourth letters, when used, identify the geographical location. A partial list is reproduced here.

Geographical Designators:
AA Antarctica
AC Arctic Region
AK Alaska
AS Asia
AU Australia
BS Bering Sea
CA Caribbean
CN Canada
EC East China Sea
EM Middle Europe
EN Northern Europe
EU Europe
EW Western Europe
GA Gulf of Alaska
GL Greenland
GM Guam
HK Hong Kong
ID Indonesia
IN India
IO Indian Ocean
KO Korea
MC Central Mediterranean
ME Mediterranean Area
MM Mediterranean
MW Western Mediterranean
MX Mexico
NA North America
NT North Atlantic
NZ New Zealand
PA Pacific
PH Philippines
PN North Pacific
PS South Pacific
RA U.S.S.R. (Asia)
RS U.S.S.R. (Europe)
SJ Sea of Japan
SS South China Sea
ST South Atlantic
UK United Kingdom
UR Ukrainian S.S.R.
US United States
WK Wake Island

For example, using all of the 4-letter designators in combination, you have a report headed: UPPA. The UP indicates that the report to follow contains upper wind data confined to data up to and including the 100-mb level (53,000 ft), and the PA designators indicate the report(s) is/are from the Pacific.



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The weather data text follows the weather data heading in the message. Normally, the weather text is in a coded form; i.e., FM 11.C for land synoptic reports, FM 35.C for land radiosonde reports, etc. A complete listing of these codes may be found in N.O. Pub. 118. However, an MST may at times be required to transmit weather data to naval units that do not have trained weather personnel assigned. A plain language weather message, utilizing universal contractions, is transmitted in cases like this.

COMMON CONTRACTIONS

The following is a list of some of the abbreviations for words or groups of words for use in transmission of weather information, including forecasts and the remarks to be found at the end of teletyped reports.

| Words | Abbreviations |
|---|---|
| about | ABT |
| above | ABV |
| accompany | ACPY |
| across | ACRS |
| advance | ADVN |
| after | AFT |
| after dark | AFDK |
| afternoon | AFTN |
| aircraft | ACFT |
| airmass | AMS |
| airport | ARPT |
| airway | AWY |
| aloft | ALF |
| along | ALG |
| altimeter setting | ALSTG |
| amount | AMT |
| around | ARND |
| barometer | BRM |
| become | BCM |
| becoming | BCMG |
| before | BFR |
| begin | BGN |
| behind | BHND |
| below | BLO |
| between | BTN |
| broken | BRKN |
| ceiling | CIG |
| center | CNTR |
| central | CNTRL |
| change | CHG |
| clear | CLR |
| clearing | CLRG |

| Words | Abbreviations |
|---|---|
| cloud | CLD |
| coastal | CSTL |
| commence | CMNC |
| condition | CND |
| continuing | CONTG |
| correction | CQN |
| cumulonimbus | CB |
| daybreak | DABRK |
| daylight | DALGT |
| decrease | DCR |
| decreasing | DCRG |
| deepen | DPN |
| delayed | DLAD |
| delayed weather | PDW |
| dense | DNS |
| develop | DVLP |
| dewpoint | DWPNT |
| diminish | DMSH |
| dissipate | DSIPT |
| dissipating | DSIPTG |
| distant | DSNT |
| divide | DVD |
| drift | DRFT |
| drizzle | DRZL |
| during | DURG |
| early | ERY |
| ending | ENDG |
| entire | ENTR |
| estimate | EST |
| evening | EVE |
| extend | XTD |
| extreme | XTRM |
| falling | FLG |
| field | FLD |
| flurry | FLRY |
| follow | FLW |
| forecast | FCST |
| forming | FRMG |
| freeze | FRZ |
| frequent | FQT |
| from | FM |
| front | FNT |
| frontal passage | FROPA |
| frost | FRST |
| forenoon | FORNN |
| generally | GENLY |
| gradual | GRDL |
| ground | GND |
| ground fog | GNDFG |
| group | GRP |
| hailstone | HLSTO |
| hard freeze | HDFRZ |
| hazy | HZY |



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| Word | Abbreviations | Words | Abbreviations |
|---|---|---|---|
| heavy | HVY | mountain | MTN |
| heavier | HVYR | move | MOV |
| high | HI | nautical miles | NLM |
| higher | HIER | night | NGT |
| high broken | HBRKN | northern | NRN |
| high overcast | HOVC | numerous | NMRS |
| high scattered | HSCTD | obscure | OBSC |
| horizon | HRZN | observe | OBS |
| hundred | HND | occasion | OCN |
| hurricane | HURCN | occasional | OCNL |
| hurricane report | HUREP | occasionally | OCNLY |
| icing | ICG | occluded front | OCFNT |
| icing in precipitation | ICGIP | occlusion | OCLN |
| icing in clouds | ICGIC | outlook | OTLK |
| ice on runways | IR | over | OVR |
| improve | IPV | overcast | OVC |
| increase | INCR | overhead | OVHD |
| indefinite | INDFT | on top | OTP |
| inoperative | INOPV | partly | PTLY |
| instrument | INST | pilot balloon observation | PIBAL |
| intense | INTS | | |
| intermittent | INTMT | not observed, because of clouds | PICO |
| in vicinity of | INVOF | | |
| knollsman | KOL | not observed, no helium | PIHE |
| knots | KTS | | |
| latitude | LATD | not observed, because of rain | PIRA |
| layer | LYR | | |
| level | LVL | period | PRD |
| lift | LFT | persisting | PRSTG |
| light | LGT | possible | PSBL |
| lightning | LTNG | portion | PTN |
| likely | LKLY | precipitation | PCPN |
| little | LTL | pressure | PRES |
| little change | LTLCG | prevail | PVL |
| local | LCL | quadrant | QUAD |
| locally | LCLY | radiosonde data | RADAT |
| longitude | LONG | radar winds aloft | RAWIN |
| lower | LWR | ragged | RGD |
| lower broken | LWRBRKN | range | RNG |
| lower overcast | LWROVC | rapid | RPD |
| lower scattered | LWSCTD | rapidly | RPDLY |
| mean sea level | MSL | reach | RCH |
| middle | MID | redeveloping | REDVLPG |
| midnight | MIDN | reforming | REFRMG |
| mild | MLD | region | RGN |
| mile (statute) | MI | remain | RMN |
| miles per hour | MPH | remark | RMRK |
| millibars | MBS | ridge | RDG |
| missing | MISG | river | RVR |
| mixed | MXD | runway | RNWY |
| moderate | MDT | scattered | SCTD |
| morning | MRNG | schedule | SKD |
| mostly | MSTLY | sections | SXNS |

| Words | Abbreviations |
|---|---|
| several | SVRL |
| severe | SVR |
| shallow | SHLW |
| shift | SHFT |
| shower | SHWR |
| sleet | SLT |
| slightly | SLGTLY |
| smoke | SMK |
| snow | SNW |
| somewhat | SMWHAT |
| spreading | SPRDG |
| sprinkle | SPKL |
| squall | SQAL |
| squall lines | SQLNS |
| station | STN |
| storm | STM |
| surface | SFC |
| sunrise | SUNRS |
| synopsis | SYNS |
| telephone | TLFO |
| temperature | TMP |
| terminal | TRML |
| thick | THK |
| thin | THN |
| thousand | THSD |
| threaten | THTN |
| throughout | THRUT |
| thunder | THDR |
| thunderhead | THD |
| thundershower | TSHWR |
| thunderstorm | TSTM |
| tonight | TNGT |
| topping | TPG |
| toward | TWD |
| trough | TROF |
| turbulence | TURBC |
| unknown | UNK |
| unlimited | UNL |
| unsteady | UNSTDY |
| until | TIL |
| upper | UPR |
| upward | UPWD |
| valley | VLY |
| variable | VRBL |
| vicinity | VCNTY |
| visibility | VSBY |
| visible | VSB |
| warm | WRM |
| weak | WK |
| weaken | WKN |
| weather | WX |
| western | WRN |
| westerly | WLY |

| Words | Abbreviations |
|---|---|
| westward | WWD |
| widely | WL |
| will | WL |
| wind | WND |

WORD ENDINGS

| | |
|---|---|
| able | BL |
| al | L |
| ally, erly, ly | LY |
| ary, ery, ory | RY |
| ance, ence | NC |
| der | DR |
| ed, ied | D |
| ening | NG |
| er, ier, or | R |
| ern | RN |
| ically | CLY |
| iest, est | ST |
| iness, ness | NS |
| ing | G |
| ity | TY |
| ive | V |
| ment | MT |
| our | US |
| s, es, ies | S |
| tion, ation | N |
| ward | WD |

WEATHER CHARTS TRANSMITTED BY THE NATIONAL WEATHER FACSIMILE NETWORK

Many different charts are transmitted daily over the National Weather Facsimile Network; these include surface and upper air analyses, surface and upper air progs, significant weather progs, vorticity and vertical velocity progs, precipitable water analyses, stability index, winds aloft charts, weather depiction charts, and radar summaries. These charts are transmitted both by landline and radio and can be received either ashore or at sea. (See figure 39 for the schedule of the National Weather Facsimile Network.)

As an MST you will be required to have the ability to interpret many of these charts for present weather patterns and future weather trends. This section will cover briefly some of the charts which are the primary concern of the weather forecaster and will place particular emphasis on the charts that an MST2 will have

# NATIONAL WEATHER FACSIMILE NETWORK SCHEDULE

Effective July 1, 1964

| GMT | No. | From | Chart Description | TX | GMT | Area | MANOP |
|---|---|---|---|---|---|---|---|
| 0000 | 1 | NMC | Extended Forecast Charts<br>5-Day Forecasts (Mon-Wed-Fri)<br>72-Hr Surface Prog (Sun-Tue-Thur-Sat)<br>30-Day Outlook (1st and 15th) | 40 | V12 | FH | FEXN |
| 0040 | 2 | | Nephanalyses | 10 | | | |
| 0050 | 3 | MKC | Radar Summary | 12 | 00 | US | ADUS |
| 0102 | 4 | NMC | Prog 72-Hr 500 MB | 10 | V12 | FH | FUXW 56 |
| 0112 | 5 | NMC | Snow Cover | 10 | 00 | US4 | AXOS |
| 0122 | 6 | NMC | Maximum Temperatures | 10 | 00 | US | ABUS 1 |
| 0132 | 7 | NMC | Surface Analysis – 6 | 35 | 00 | US | ASUS |
| 0207 | 8 | NMC | 500 MB Analysis | 12 | 00 | SEC 1A | AUNA 58 |
| 0219 | 9 | NMC | Weather Depiction | 18 | 01 | US | ABUS |
| 0237 | 10 | NMC | 12-Hr Pressure Change<br>850 MB Analysis | 10 | 00 | NA<br>US | AXUS 3 |
| 0247 | 11 | NMC | Vorticity + 500 MB Initial Conditions 12-Hr, 24-Hr, 36-Hr Barotropic Progs | 15 | 00 | US | FUUS 5 |
| 0302 | 12 | NMC | Prog – Surface, Clouds + Precip<br>12-Hr<br>24-Hr | 10 | V12<br>V00 | <br>US | FXUS |
| 0312 | 13 | NMC | Winds Aloft – Lower Levels | 10 | [illegible] | US | ULUS 1 |
| 0322 | 14 | NMC | Winds Aloft – Intermediate Levels | [illegible] | [illegible] | US | ULUS 2 |
| 0332 | 15 | NMC | Prog – Hi Level Significant [illegible] | [illegible] | V18 | US | FUUS 2 |
| 0342 | 16 | NMC | Winds Aloft – U[illegible]<br>Tropopause [illegible] | 10 | 00 | US | ULUS 3 |
| 0352 | 17 | MKC | R[illegible] | 12 | 03 | US | ADUS |
| 0404 | 18 | N[illegible] | [illegible] Precipitable<br>[illegible] Freezing Level | 10 | 00 | US | ADUS 1 |
| 0414 | 19 | [illegible] | [illegible] MB Analysis | 10 | 00 | Sec 1 | AUNA 7 |
| 0424 | 20 | [illegible] | Open | 10 | | | |
| 0434 | 21 | NMC | Surface Analysis – 3 | 20 | 03 | US | ASUS |
| 0454 | 22 | NMC | Surface Analysis – 6<br>with 1000-500 MB Thickness | 13 | 00 | FH | ASXW |
| 0507 | 23 | NMC | Weather Depiction | 18 | 04 | US | ABUS |
| 0525 | 24 | NMC | Maximum Wind Analysis<br>Wind Shear Analysis | 10 | 00 | US | AWUS |
| 0535 | 25 | NMC | 300 MB Analysis | 10 | 00 | Sec 1 | AUNA 3 |
| 0545 | 26 | NMC | 200 MB Analysis | 10 | 00 | Sec 1 | AUNA 2 |
| 0555 | 27 | MKC | Radar Summary | 06 | 05 | US | ADUS |

This schedule is a sample only. It is subject to frequent changes, and no attempt will be made to keep it current in this pamphlet.

Figure 39.— Facsimile Schedule.

to know, such as weather depiction charts and radar summaries. These charts are designed primarily for aviation purposes, but are invaluable to anyone interested in presenting weather information.

PROGNOSTIC CHARTS

Prognostic (prog) charts are simply the basic charts projected into the future. Among the many prog charts, the most commonly used and the most important ones are the surface prog charts, the constant pressure prog charts, sea condition prog charts, severe weather outlook charts, significant weather (high level) prognoses, and the 5-day prog charts.

Prog charts constitute a future analysis for the level and element in question. There is little need to describe them further, because they are very similar in appearance to the basic charts; that is, the surface prog chart resembles the surface chart, the 700-mb prog chart resembles the 700-mb chart, etc. Perhaps the major difference in appearance of prog charts and basic charts is that the prog charts do not contain plotted weather reports.

TROPOPAUSE DATA

Charts containing tropopause heights, temperatures, and wind direction and velocity for selected stations in the United States are transmitted twice daily on the upper levels, winds aloft chart.

NUMERICAL WEATHER CHARTS

A large number of the weather charts transmitted over the facsimile network are prepared by numerical methods, using electronic digital computers (EDC). The electronic digital computer is capable of both the analysis and prognosis of most weather charts. Charts prepared in this manner are identified by the inclusion of NWP (numerical weather prediction) in the title block of the chart. A few of the numerical weather charts prepared are surface, upper air, vorticity, thickness, and sea conditions charts.

Presently, there are three Numerical Weather Prediction units in the United States. The Naval Weather Service operates a Fleet Numerical Weather Facility in Monterey, Calif.; the National Weather Service operates a unit at the National Meteorological Center in Suitland, Md.; and the U.S. Air Force operates a Global Weather Center at Offutt AFB, Nebraska.

SATELLITE CLOUD CHARTS

The satellite cloud chart is a graphical depiction of cloud distribution and type which is prepared from cloud photos taken along a programed orbit. These charts are referred to as nephanalyses (neph) charts and are transmitted regularly over the fleet and national facsimile networks.

These charts are utilized by flight forecasters in briefing flight crews, especially for transoceanic flights. In addition, nephanalyses charts may be used to augment entries on synoptic charts in areas of sparse reports.

Application of Satellite Data

Great progress has been made in the weather satellite program since the first weather satellite, TIROS I, (Television Infrared Observation Satellite) was launched in 1960. TIROS weather satellites have produced tens of thousands of excellent cloud pictures. Shortcomings of previous satellites are continually being eliminated so that future satellite data coverage will be greatly improved and expanded.

At the present time, the data received from weather satellites enable the trained analyst to detect and track tropical and extratropical cyclones; determine positions of fronts, troughs, and ridges; and detect jetstream positions. For examples of satellite photographs and nephanalyses charts with corresponding surface charts, see figures 40 and 41. Much progress has been made in estimating wind speeds in tropical storms by analyzation of cloud patterns around the vortex. Considerable knowledge has been gained on airmass identification and forecasting winds, shears, and flow patterns using satellite data. It is expected, in the near future, that data received from satellites will enable analysts to determine cloud tops and ocean and land temperatures.

MISCELLANEOUS CHARTS

Other charts used by weather units are the freezing level chart, which indicates the height of the freezing level; the precipitable water analyses, which indicates the moisture content

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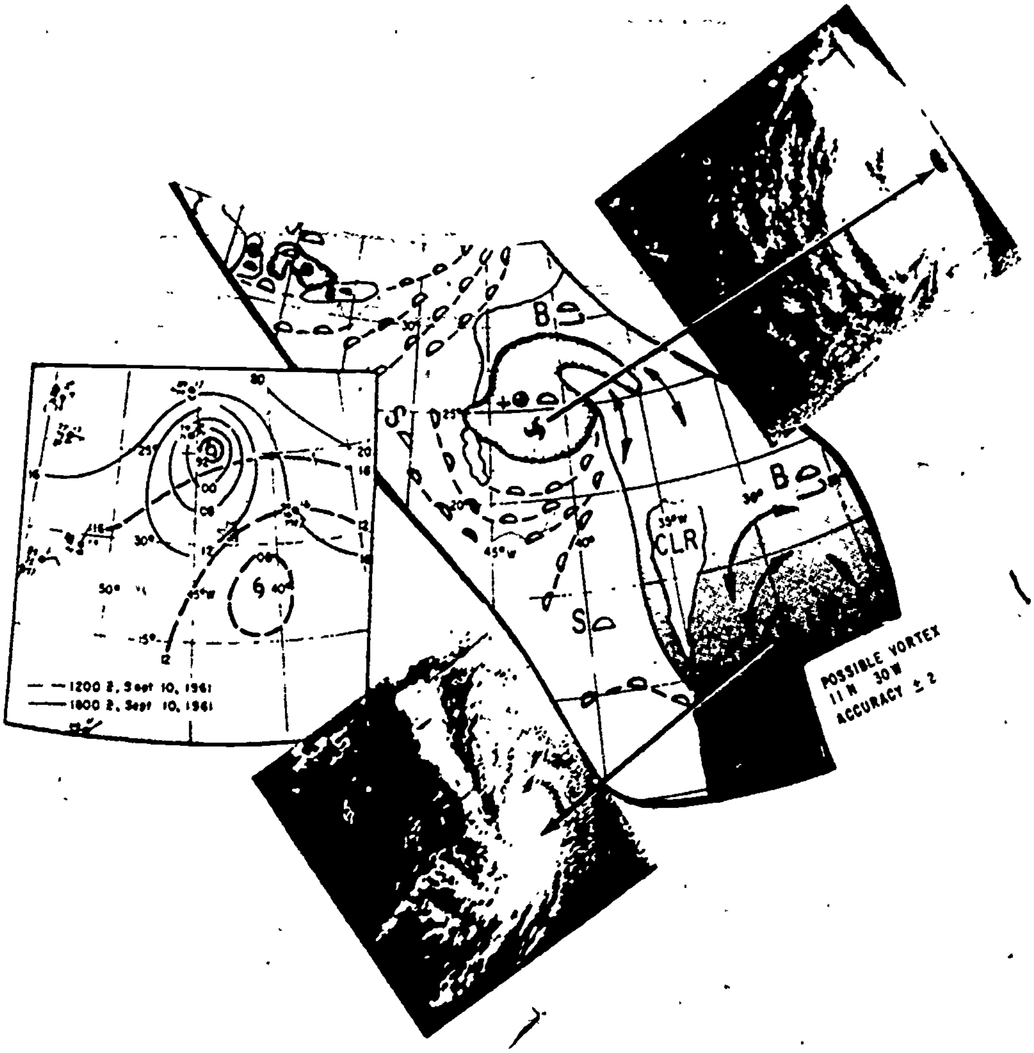


Figure 40.— Meteorological satellite photos, nephanalyses charts, and surface weather analysis (tropical storms).

from the surface up to 500 millibars; the stability index chart, which outlines areas of stability and instability; the rainfall and snow cover chart; and the maximum and minimum temperature chart.

WEATHER DEPICTION ANALYSIS

Weather depiction analyses (figure 42) drawn on a scale of 1:10,000,000 are issued eight times daily (every three hours) for a region covering all of the contiguous United States. These charts are based on hourly aviation weather reports at 0100Z, 0400Z, etc. The weather depiction charts are transmitted about 1 to 1 1/2 hours after the observation time. For example, the 1300Z chart is received between 1400Z and 1430Z. This chart contains the following information:

Valid Time

The time of observation in Greenwich Mean Time is plotted in the lower left portion of the chart.

Stations

Weather stations are represented by station circles similar to the station circles on the



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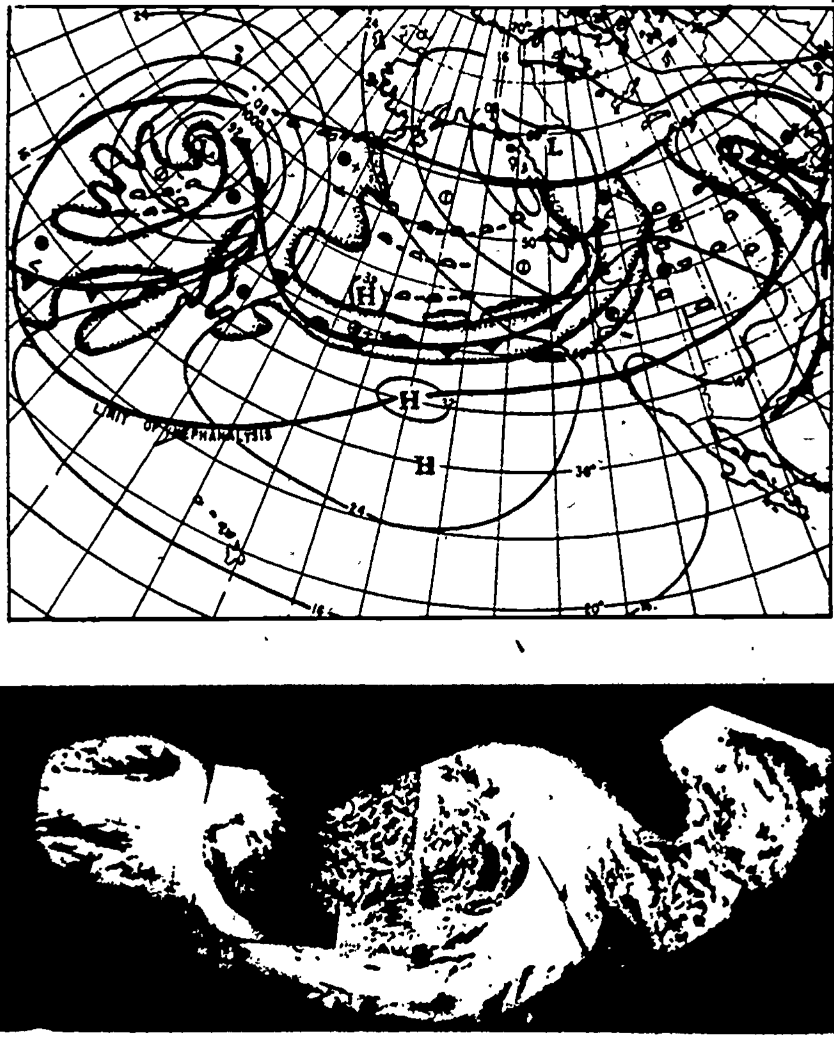

Figure 41.— Meteorological satellite photos and nephanalyses and surface weather chart (North Pacific frontal system).

surface analysis. Because station identifiers are not given, you must rely on your knowledge of geography to identity them.

### Sky Coverage

The total sky coverage at each station is reported as clear, scattered, broken, overcast, or obscured. The coverage is indicated by the following symbols:

| Sky Coverage | Symbol |
|---|---|
| Clear | ○ |
| Partial Obscuration—no other sky cover layers present | ○ |
| Scattered or thin scattered | ◔ |
| Broken or thin broken | ◕ |
| Overcast or thin overcast | ● |



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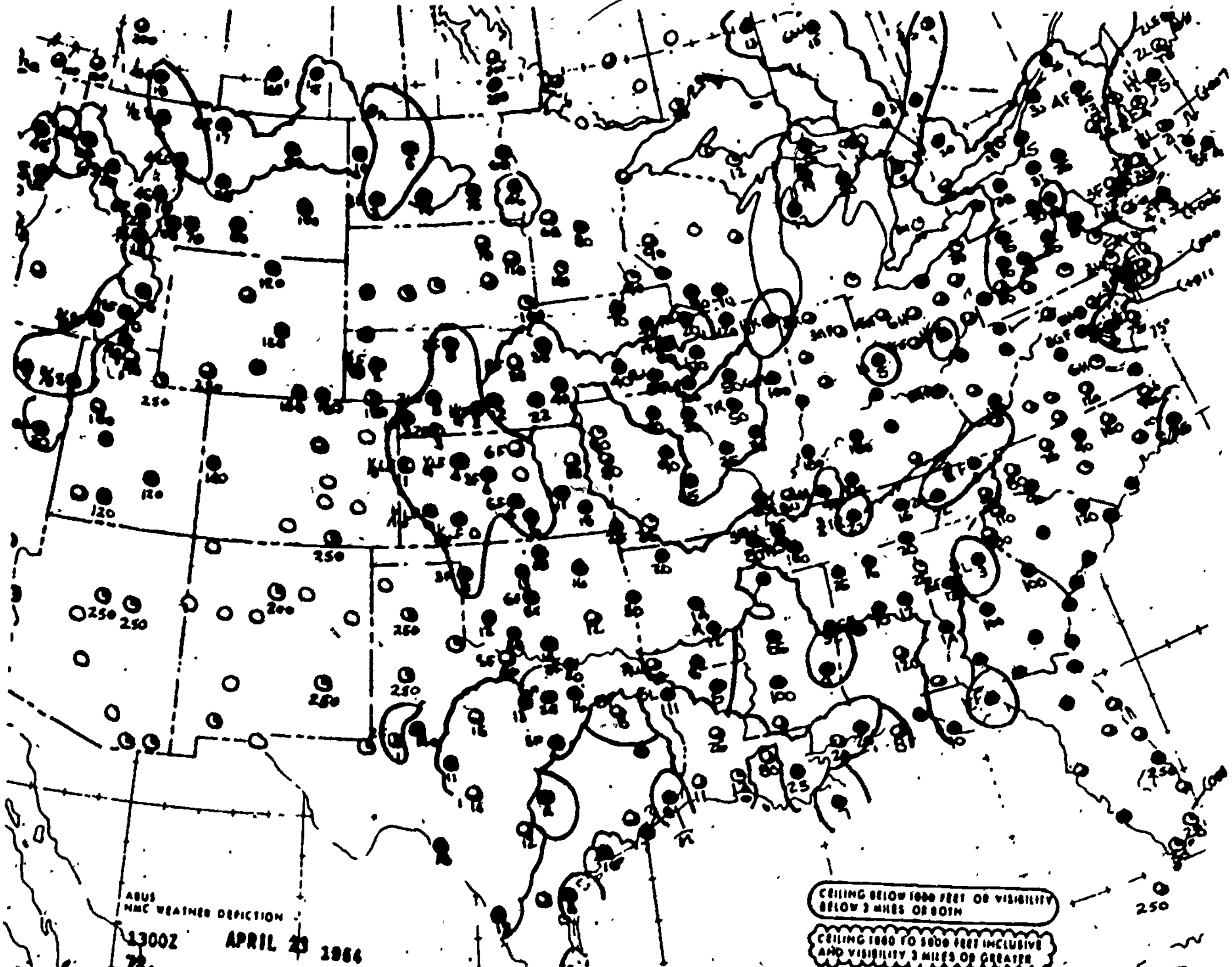


Figure 42.— Weather depiction chart.

| Sky Coverage | Symbol |
| --- | --- |
| Overcast with breaks | ◕ |
| Obscured | ⊗ |

Cloud Heights and Ceilings

If a station is reporting only scattered clouds the height is plotted in hundreds of feet beneath the station circle. Therefore, 10, signifies 1,000 scattered, 45 signifies 4,500 scattered, and 160 signifies 16,000 scattered.

If the sky condition is indicated as broken, overcast or obscured, the height of the ceiling is given under the station circle in hundreds of feet above ground level. Thus, 50 is a broken ceiling at 5,000 feet, 90 is an overcast ceiling at 9,000 feet, and 8 is an obscured ceiling at 800 feet.

Weather and Obstructions to Vision

The weather depiction chart classifies weather and obstructions to vision as significant weather. The same symbols that appear on teletypewriter are used on the weather depiction chart. Intensities of precipitation and thunderstorms are not plotted. Thus, T+ is plotted as T and R- as R. These significant weather elements are plotted to the left of the station circle. Following is a list of the significant weather symbols used on this chart:

| Symbol | Meaning |
| --- | --- |
| T | Thunderstorm |
| R | Rain |
| L | Drizzle |
| ZR | Freezing Rain |
| ZL | Freezing Drizzle |
| S | Snow |
| E | Sleet |
| W | *Shower |
| H | Haze |
| K | Smoke |
| F | Fog |
| GF | Ground Fog |
| BD | Blowing Dust |
| BN | Blowing Sand |
| BS | Blowing Snow |
| ╤ | Clouds topping nearby ridges |

*Used in conjunction with R, S or E to indicate type of shower; e.g., RW for rain showers, etc.

Visibility

When the visibility is 6 miles or less, it is indicated to the left of the station circle preceding the significant weather symbols. A visibility value always appears whenever obstructions to vision are reported, but may be missing (to denote 7 miles or better) if only weather is reported. Thus, 6F● denotes 6 miles in fog, 3TR● denotes 3 miles in a thunderstorm and rain, R● denotes 7 miles or better in rain, and ○ denotes 7 miles or better with no significant weather.

Isolines

Continuous lines (either solid or scalloped) outline areas where conditions at stations have specified ceiling and visibility conditions. The specified conditions are given below. NOTE: Smaller-scale fluctuations in ceilings and visibility between stations due to variations in terrain, local storms, etc., are not intended to be portrayed on this chart.

Areas Enclosed By Solid Line.— Areas where all stations have either a ceiling less than 1,000 feet or visibility less than 3 miles, or both, are outlined by a solid line.

Areas Enclosed By Scalloped Line.— Areas where all stations have ceilings from 1,000 feet to and including 5,000 feet and visibility of 3 miles or better are outlined by a scalloped line.

Remaining Area.— Areas that are not outlined by isolines indicate that at all stations the ceiling is unlimited with a visibility of 3 miles or

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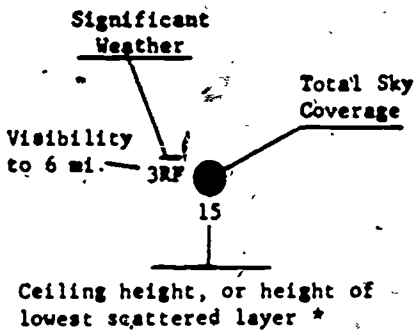
Table 10.— Symbolic notation used on weather depiction charts.

**Station Model**




| Total Sky Coverage | Significant Weather | |
|---|---|---|
| Clear | L | Drizzle |
| Scattered | F | Fog |
| Broken | ZL | Freezing Drizzle |
| Breaks in Overcast | ZR | Freezing Rain |
| Overcast | GF | Ground Fog |
| ⊗ Obscured | H | Haze |
| | R | Rain |
| | W | Shower |
| | E | Sleet |
| | K | Smoke |
| | S | Snow |
| | T | Thunderstorm |
| | | Clouds topping ridges |

ANALYSIS

| Ceiling and visibility classes: | | Color Code for On-Station Shading: |
|---|---|---|
| 1. Ceiling below 1000 feet or visibility below 3 miles, or both | Outlined | Red |
| 2. Ceiling 1000 to 5000 ft. inclusive and visibility 3 miles or greater | Scalloped Outline | Blue |

Notes:

1. Precipitation will always be entered when reported as occurring at the station at the time of observation, except that no more than two symbols for significant weather will be entered.

2. Obstructions to vision other than precipitation will be entered when visibility is reduced to 6 miles or less, except that if two forms of precipitation are reported, the other obstructions to vision will not be entered. Haze and smoke will be omitted if precipitation is reported.

3. Visibility values of 6 miles or less will be entered in miles and fractions.

4. All ceiling heights will be entered in hundreds of feet.

5. The analysis of the ceiling-visibility classes will be based on the reports themselves and is not meant to include possible between-station orographic effects, or even systematic interpolations between stations.

* 6. The height of the lowest scattered clouds will be plotted at those stations reporting scattered clouds only.

better, or the ceiling is greater than 5,000 feet with the visibility of 3 miles or better.

Table 10 summarizes all factual information concerning the weather depiction chart.

Alternate Sources.— Many bits and pieces of this same information are contained in various observations and in forecast material, but the best substitute for this chart is one plotted and analyzed at the station. The sky condition, cloud heights, visibility, weather and obstructions to vision can be plotted from the hourly aviation reports from Service A and, once the plotting is finished, the two ceiling-visibility classification areas can be enclosed by the proper isolines.



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## RADAR ANALYSES

Charts showing the distribution of radar echoes are sent thirteen times daily, for 0000Z and each 3 hours plus five intermediate charts. These charts (figure 43) are prepared from the analyses of the hourly radar reports and indicate the location and coverage of echoes reported, echo movements, echo tops, and other pertinent radar information. These charts originate at Kansas City, Mo. A 1:10,000,000-scale map covering an area east of the Rocky Mountains is used for the scheduled summaries; selected sections are used for the intermediate charts.

### Valid Time

The observation time in Greenwich Mean Time is plotted on the lower left corner of the chart.

### Legend

A legend of radar types is transmitted on each chart to identify the radar type at each site. This legend appears in the lower left portion of the chart.

### Stippled Areas

Areas where there is no radar sampling due to absence of weather radars are stippled. These stippled areas include all points more than 75 nautical miles from a WSR-1 or -3 radar and more than 125 nautical miles from a WSR-57, CPS-9 or SP-1 radar.

### Echo Pattern

If the radar echoes are arranged in a line, an elongated rectangular box ▭ is used to show the location of the echoes. If the echoes are not arranged in a line, scalloping is used to indicate the location of the area of echoes.

### Types of Echoes

The echoes are classified as cellular, stratified, or a mixture of cellular and stratified. Cellular echoes denote vertically-developed clouds, and on the radar summary chart the symbol ⌒ is used if cellular echoes are predominant. Stratified echoes denote horizontally-developed clouds, and on the radar summary chart the symbol ___ is used if stratified echoes are predominant. The symbol ⌒ is used to identify a combination of cellular and stratified echoes where neither is predominant.

### Echo Coverage

The following symbols are used to denote the number of tenths echo coverage within an enclosed area or line:

| Symbol | Tenths Coverage | Called |
|---|---|---|
| ⊕ | Over 9/10 | solid |
| ⦶ | 6/10 to 9/10 | broken |
| ⦶ | 1/10 to 5/10 | scattered |
| ⊙ | less than 1/10 | widely scattered |

The echo type is plotted above or below the echo coverage symbols. For example ⦶ signifies broken cellular echoes, ⊕ signifies solid stratified echoes and ⦶ signifies scattered cellular and stratified echoes. Sometimes when echoes are cellular, the symbol that indicates this is omitted. Thus, ⦶ signifies broken cellular echoes, and ⊕ signifies solid cellular echoes.

A strong or very strong echo identified by only one radar station is shown by the symbol ●. A strong or very strong echo identified by two or more radar stations is shown by the symbol ✱.

### Types of Surface Weather Associated with Echoes

The surface weather associated with echoes is identified by these standard teletypewriter symbols:

| Symbol | Meaning |
|---|---|
| R | Rain |
| RW | Rain showers |
| S | Snow |
| E | Sleet |
| SW | Snow showers |
| L | Drizzle |
| T | Thunderstorm |

### Intensity and Trend of Precipitation

The precipitation associated with an area or line of echoes is classified according to its intensity and its trend. The intensity symbol

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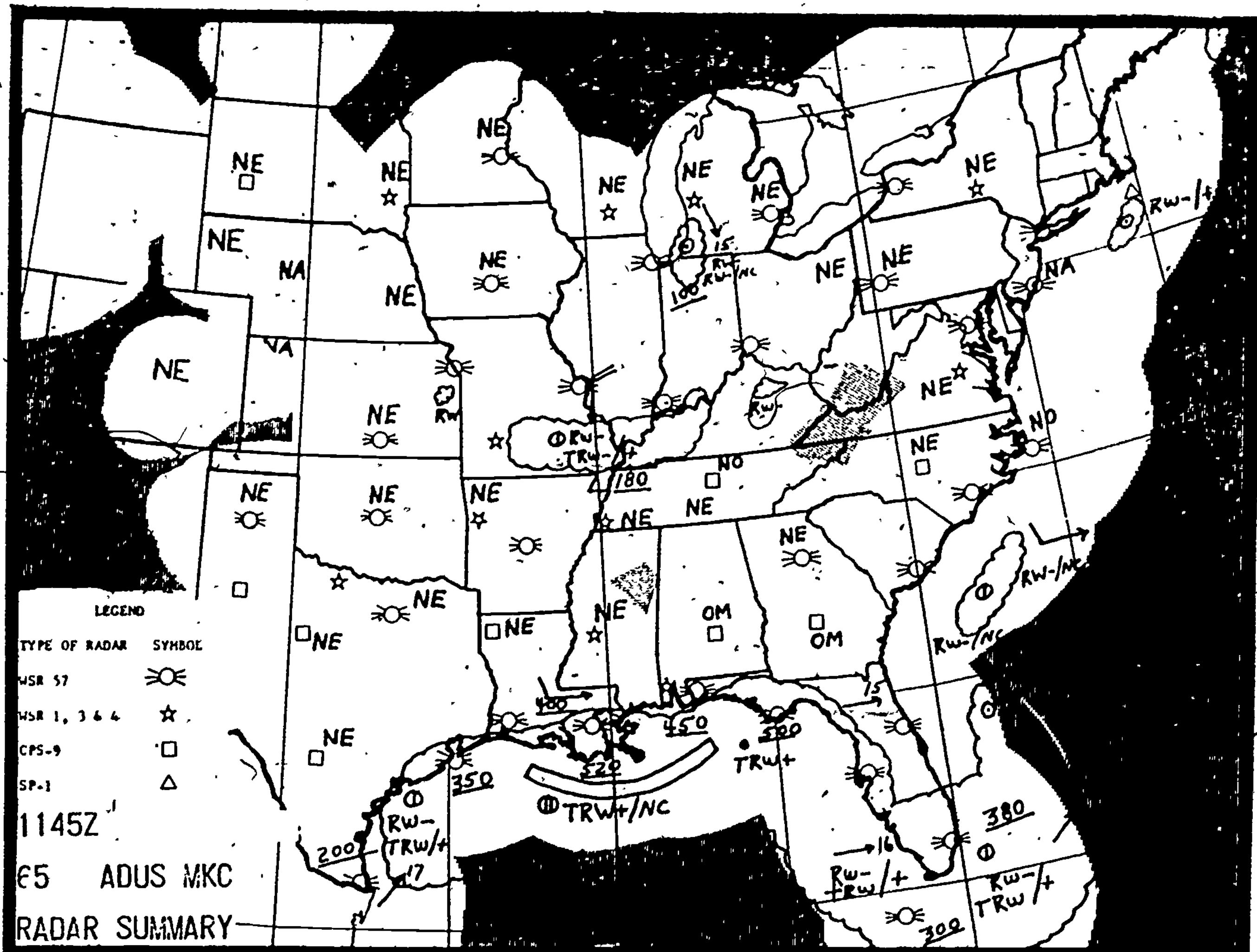


Figure 43.— Radar summary chart.

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follows the precipitation symbol and the trend symbol follows the intensity. The intensity is separated from the trend by a slant bar. Listed below are the intensity and trend symbols:

INTENSITY

| Symbol | Meaning |
|---|---|
| - - | Very light |
| - | Light |
| (no sign) | Moderate |
| + | Heavy |
| ++ | Very heavy (usually associated with severe weather) |
| U | Unknown |

TREND

| Symbol | Meaning |
|---|---|
| + | Increasing |
| - | Decreasing |
| NC | No change |
| NEW | New |

Thus, R-/+ indicates light rain increasing in intensity; TRW/NC indicates a thunderstorm and moderate rain showers showing no change in intensity.

Heights of Echo Bases and Tops

Heights of echo bases and tops are denoted by two or three figures. These figures represent hundreds of feet above sea level. A line beneath the numbers signifies that the value represents the height of the echo tops and a line above the number signifies that the value applies to echo bases. Thus, $\underline{220}$ signifies tops 22,000 feet MSL, $\overline{120}$ signifies bases 12,000 feet MSL, and $\underline{330}$ signifies maximum tops at 33,000 feet MSL.

Height of Melting Level

The height of the melting level is represented by three numbers above a wavy line. Thus, $\underset{\sim}{125}$ signifies the melting level is at 12,500 feet MSL.

Movement of Echoes

Echoes may have two movements. One movement is the direction and speed of the individual echoes, and the other is the direction and speed of a cluster of echoes (line or area). That is, in a given line or area, the echoes might be moving to the northeast while the line or area is moving southeast. Both movements are represented by arrows; the echo movement is shown by a number at the head of an arrow, and the line or area movement is shown by barbs at the end of the arrow. Thus, →20 means the echoes are moving to the east at 20 knots, while → means the line (or area) is moving to the east at 20 knots.

Additional Information

Sometimes reports from a particular radar station may not appear on the radar summary chart. Symbols plotted at the radar station give the reasons. Following are symbols used and their meanings:

| Symbol | Meaning |
|---|---|
| NE | No echo (equipment operating but no echoes observed) |
| NA | Observation not available |
| NO | Equipment not operating |
| OM | Equipment out for maintenance |

If a severe weather watch bulletin (WW) is in effect at the time of issuance of the radar summary chart, the area affected by the WW is outlined by a dotted or dashed line. The number and valid time of the WW is entered on the chart. See figure 44 for a complete resume of the symbols used on the radar summary chart.

Alternate Sources

The same data used in the make-up of the radar summary chart is available on Service A in the form of a radar summary (SD-1). The coded radar summary is sent by 40 minutes past each hour.



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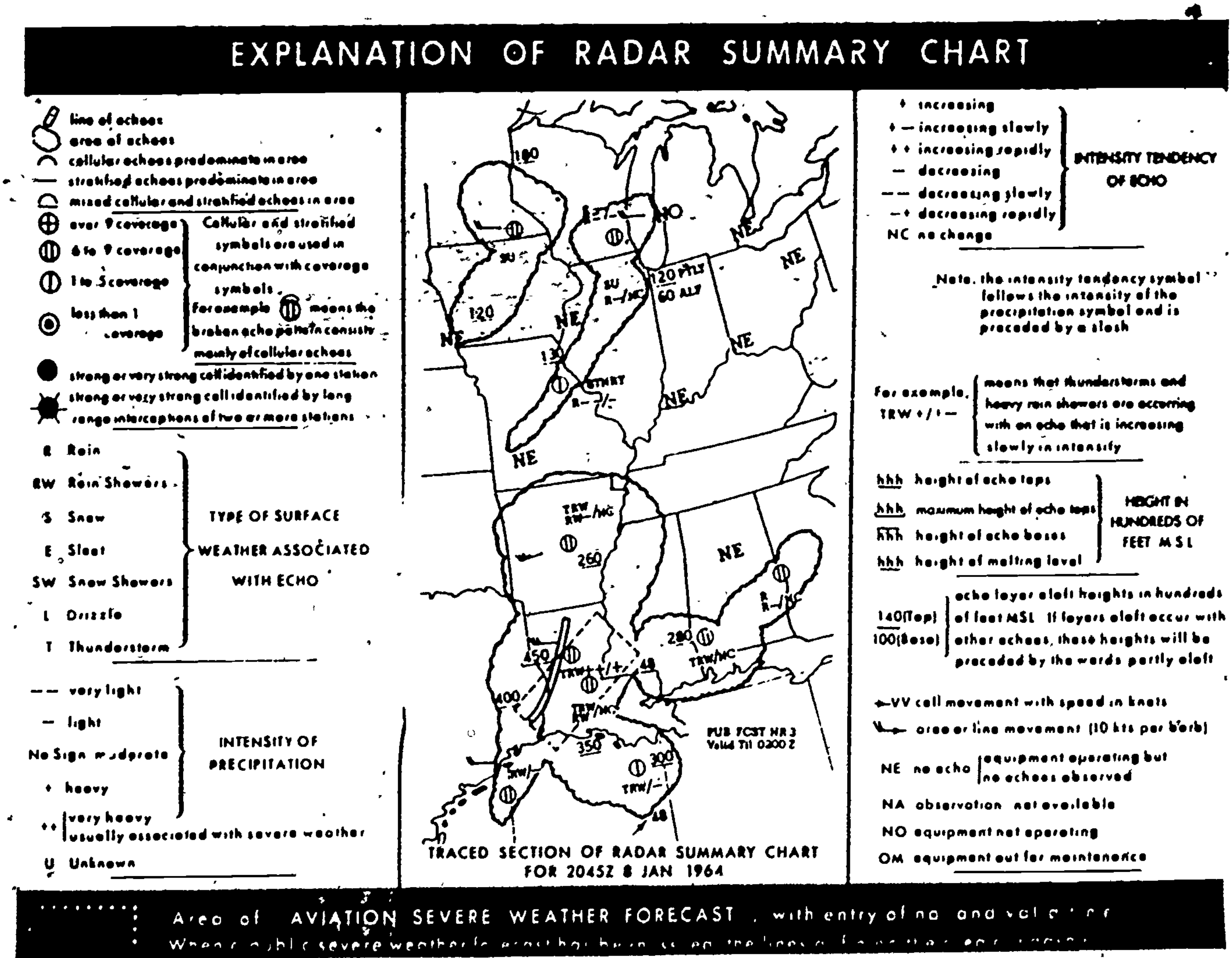


Figure 44.— Explanation of radar summary chart.

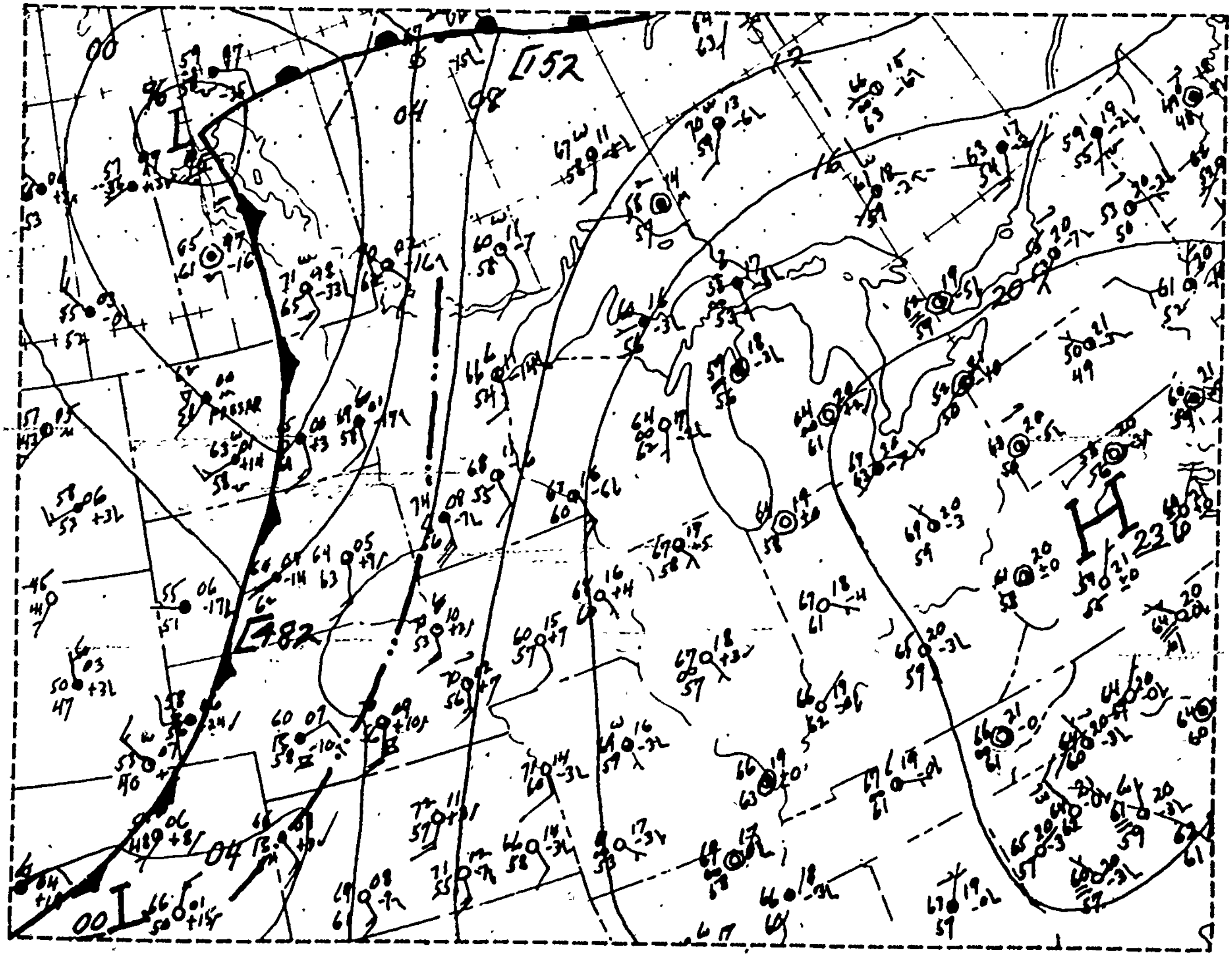

Figure 45.— Section of a surface analysis.

Table 11.— Facsimile chart legends.

To understand fully the facsimile charts, you must know the meanings of the various symbols used on the charts. Some of the symbols shown in table 11 are well known; others have only recently come into common usage.

1. Symbols most generally used by the National Meteorological Center:

   a. Cold front
   b. Cold front aloft
   c. Warm front
   d. Stationary front
   e. Occluded front
   f. Cold frontogenesis
   g. Warm frontogenesis
   h. Stationary frontogenesis
   i. Cold frontolysis
   j. Warm frontolysis
   k. Stationary frontolysis
   l. Occluded frontolysis
   m. Instability (squall) lines
   n. Trough
   o. Ridge

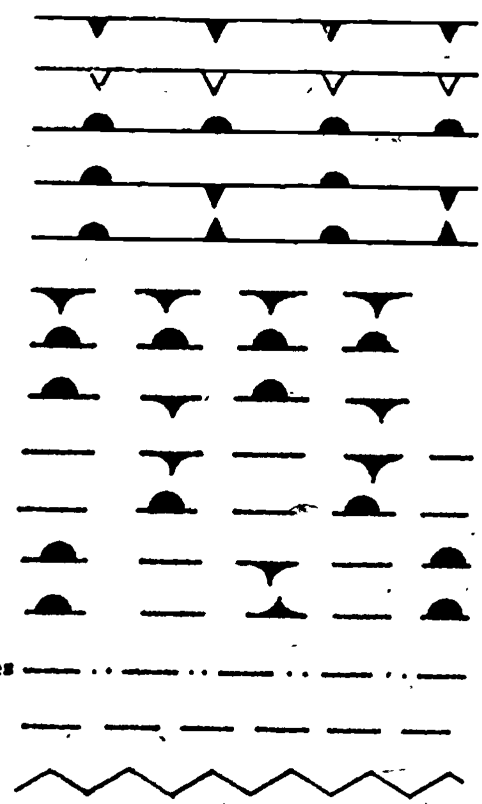



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Table 11.— Facsimile chart legends (continued).

2. Fronts on facsimile charts are normally labeled with a three-digit group showing type of front, intensity of front, and character of front ($F_tF_iF_c$).

a. Type of Front ($F_t$)
Code
Figure
0 Quasi-stationary front
1. Warm front
2. Warm occlusion
3. Upper warm front
4. Cold front
5. Cold occlusion
6. Upper cold front
7. Instability line
8. Intertropical front
9. Occlusion

b. Intensity of front ($F_i$)
Code
Figure
0 No specification
1. Weak, decreasing (including frontolysis)
2. Weak, little or no change
3. Weak, increasing (including frontogenesis)
4. Moderate, decreasing
5. Moderate, little or no change
6. Moderate, increasing
7. Strong, decreasing
8. Strong, little or no change
9. Strong, increasing

c. Character of front ($F_c$)
Code
Figure
0 No specification
1. Frontal activity area, decreasing
2. Frontal activity area, little change
3. Frontal activity area, increasing
4. Intertropical
5. Forming or existence suspected
6. Quasi-stationary
7. With waves
8. Diffuse
9. Position doubtful

3. National Meteorological Center surface plotting model

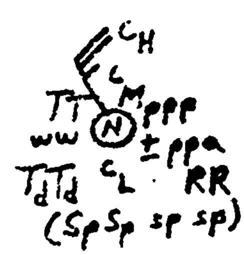

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Table 11.— Facsimile chart legends (continued).

4. Types of lines

a. 500-mb. contours } on vorticity
Vorticity } progs.

b. Intermediate contours and isobars.

c. Lines depicting flow pattern.

d. Height contours or surface isobars.

e. Average vertical wind shear in the layer of maximum wind.

f. Precipitation areas on 30-hour prognosis; areas of frozen precipitation on QPF charts.

g. Height of maximum wind.

h. Isotherms when shown on upper-air analysis.

i. Isotachs when shown on upper-air analysis and progs.

j. Jet stream or axis of maximum (50 knots or more) wind spee

k. Zero change
Plus change — Isallobars on 12-hr. pressure change chart.
Minus change

l. Isolines of equal precipitable water (surface to 500 millibars)

m. Areas of forecast showery precipitation.

n. 1000-500-mb thickness lines.

o. Forecast precipitation isohyets.

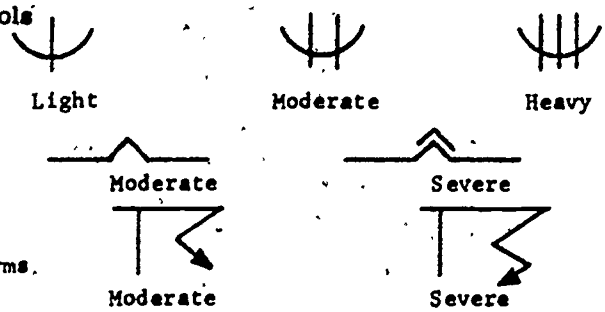
p. Forecast snow depth.

5. Other Fax Symbols

a. Icing

b. Turbulence

c. Thunderstorms



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# PROCESSING OF OCEANOGRAPHIC DATA

As an MST, one of your primary jobs is the collection and the processing of oceanographic data. To accomplish this job you are required on many occasions to expend great amounts of time and personal effort. The Coast Guard has also expended a great amount of time and money to train you, to provide an observational platform, and to position that manned platform in an observational area. The point to be made is that the data collected is of value, and you, as an MST, shoulder a great responsibility to ensure the quality of the data.

## QUALITY CONTROL

To be of value, data gathered must be as near a true measure of the property under consideration as the purpose for which the results are being used require. In the case of survey data, the end use of which may not be known at the time of observation, the data should be as near the true value as the instrumentation will permit in order to ensure maximum future utility. All measurements are, in reality, only a best estimate of the true value and must be considered in the light of the reproducibility which has been obtained. It must be assumed that all measurements have been made with equal care and skill, that accidental errors have been reduced to a minimum, and that systematic errors have been eliminated. Actually, to be above reproach, repeated measurements should be made of each sample until a sufficient number of readings are availabe to establish the mean and range of the probable error. The limited time, money, equipment, and personnel as well as the vastness of the ocean will not permit this scientific luxury in oceanography, so some measure of quality control is required to ensure that all data is within the desired limits of accuracy.

Quality control is a series of techniques and procedures designed to maintain the required accuracy of observations and measurements within specified limits. It embraces the philosophy of measurements, and its success is equally dependent upon the attitude of the observer or processor, the skill of the observer, the accuracy of the instruments, and the design of the sampling program. It is analogous to quality control of a manufacturing process where the characteristic of a product is maintained within prescribed limits without measuring or testing each item. In your work, the product is data, and a quality control program is established for each parameter to ensure that all data collected is accurate to the limits of the instrument's calibration and characteristics, the skill of the operator, and the designed limits of the sampling program.

A list of definitions are offered below to assist your understanding of some of the broader aspects of quality control:

Accuracy.— The degree of conformity of a measure to a standard or true value.

Aliasing.— Fictitious cycles or features in data resulting from sampling procedures.

Calibration.— The comparison of an instrument with an accepted standard.

Discrete measurement.— A single measurement made without relation to another in space or time.

Error.— The amount of deviation from a standard.

Precision.— The degree of refinement with which an operation is performed or a measurement stated.

Reproducibility.— The degree to which successive readings of the same sample or a parameter agree.

Response time.— A period required for an instrument to adjust to a change in environmental conditions or power input.

Sensitivity.— The capacity of an instrument to respond to variations in environment parameters or power input.

Time-series measurements.— Measurements made consecutively with space either being constant or assumed to be constant. They are usually made in a periodic manner.

Space-series measurements.— Measurements made sequentially in space with time either being constant or assumed to be constant.

The following recommendations apply to time-series, space-series, and discrete measurements to satisfy quality control requirements for such measurements:

1. All readings shall be made only to the smallest unit consistent with the instrument graduation, e.g., 0.02° C. on reversing thermometers with 0.2° C. graduations.

2. Measurements shall only be made to the limit of an instrument's calibration.

3. If two observers are present, each shall make readings independent of the other. Differences shall be resolved on the spot.

Whenever possible, check instruments by frequent simultaneous measurements of the same sample or parameter. In reference to data recording, each time data is recorded or transcribed from one record to another, 100% verification is required.

Keep a station narrative with all data collections. This narrative enables data processors to resolve minor problems or questions that may arise during processing. The more thorough the narrative, the better. Enter any information that may prove useful later; and if there is any doubt about a data entry, make the entry anyway. Excess information is better than lack of information.

## PROCESSING SALINITY DATA

In the Coast Guard, salinity samples are processed by an inductive salinometer. The models used for this purpose are the RS-7A, RS-7B, and Hytech 6220. In this course, we have previously discussed the 6220's general characteristics. The following comments are of a general nature covering the setting up of a salinometer, the associated calibration, and the processing of samples.

### SETTING UP THE SALINOMETER

Set up the salinometer in a rack secured to the work table to be used so there is adequate room beneath the instrument for the bottles to be filled and for a drain bucket. Remove the front cover and connect the power cord to the power supply. While the standard source of power is 60 cycle, 115 VAC, the 6220 has a switching action that will allow 230 VAC to be used. Note that a three-wire cord is used to allow for adequate instrument grounding. Turn on the salinometer at least two hours, preferably four hours, prior to processing salinity samples.

### PRELIMINARY CHECKOUT

A preliminary checkout of the salinometer is recommended after you have set up the instrument. Prior to applying power to the instrument, check the NULL INDICATOR pointer to ensure that it reads exactly zero. If the pointer does not read zero, adjust the small screw below the pointer to zero it. It should be noted here that any rubbing of the meter cover might create a static charge which deflects the meter. You can remove this charge by breathing on the meter cover.

Now turn the power switch to the on position and allow one minute for the instrument's circuits to stabilize. You can check the circuit balance by observing the NULL INDICATOR. With CONDUCTIVITY RATIO dials set to 0.00000, the FUNCTION SELECTOR set on SALINITY, and an empty cell, the NULL INDICATOR should read zero. The pointer may be off the zero mark up to one large division before any further adjustment is necessary.

The next step is to check for meter sensitivity. First set the STANDARDIZATION dials to read 5000; then adjust the CONDUCTIVITY RATIO dials to read 0.00010. The pointer deflection should be between 1 and 1 1/2 small divisions. Continue to adjust the CONDUCTIVITY RATIO dials to read 0.00020, 0.00030, 0.00040, and 0.00050; with each setting the deflection should be the same as the first deflection or linear in nature if the correct sensitivity is observed.

PROCESSING SAMPLES

After the instrument has had the required time to warm up, you are ready to process samples. To allow for cell temperature equilibrium and to ensure that there are minimal salinity differences, rinse the cell and drain it several times prior to standardizing the instrument. Standard Copenhagen Water retained from previous salinity runs is recommended for this purpose. If no Standard Sea Water is available for the first run, use any room temperature sea water. The following procedures are recommended:

1. Place the fill tube in the rinse sample. Avoid touching that portion of the fill tube that is immersed into the sample bottle. Also, avoid introducing into the sample any salt deposit that may have formed on the threaded portion of the sample bottle.

2. Position the three-way valve to permit the sample to flow through the fill tube into the sampling cell.

3. Set the STIR/FILL switch to FILL and adjust the fill knob to a normal rate of filling. Avoid filling the cell too rapidly, because this action tends to induce bubble formation resulting in an incomplete rinsing of the sample cell.

4. Fill the cell until the sample starts to enter the air tube at the top of the sample cell. Allow some of the sample to pass through the air tube to ensure adequate rinsing of the stirrer. Close the three-way valve to retain the sample in the cell.

5. Set the STIR/FILL switch to STIR for a few seconds to thoroughly mix the rinse sample.

6. Position the three-way valve to drain the sample from the cell. Repeat the rinsing cycle at least four times.

To ensure thorough emptying of the cell and drain tube, leave the three-way valve open following each draining. Then make a visual check to ensure that all of the sample has drained before inserting the fill tube for another sample. After the last filling of the cell from each sample, turn the three-way valve to the position used to fill the sample cell. The sample will then drain back into the sample bottle by gravity and allow complete rinsing of the fill tube.

You are now ready to standardize the salinometer. First determine the conductivity ratio setting for the Standard Copenhagen Water used. Use the formula SALINITY = 1.80655 x CHLORINITY. Look up the conductivity ratio from tables in the manufacturer's instruction book based on computed salinity. Set the value obtained on the CONDUCTIVITY RATIO dials. Fill out the Salinity and Conductivity Ratio sections of the heading on the log sheet with these computed values. Write the chlorinity value used in the upper left-hand corner of the log sheet for further reference.

The sample cell is filled by gravity directly from the Standard Water ampule. During standardization do not fill the sample cell by pumping. Be sure to wipe off both ends of the ampule prior to inserting one end of the ampule into the filling tube. This action will reduce the chance of contaminating the sample. A tight fit of the filling tube on the ampule is required. A piece of tubing of smaller size must be used with the 6220 to ensure such a fit.

Now you are ready to energize the stirrer. While the sample is being stirred, set the FUNCTION SELECTOR switch to TEMPERATURE. Read the temperature to the nearest one-hundredth on the RS-7A and/or RS-7B and to the nearest one-tenth on the 6220. Read the temperature value directly from the NULL INDICATOR on the 6220; however, read the RS-7A and RS-7B temperature values from dials used to zero the NULL INDICATOR. These two models also require an adjustment on the TEMPERATURE COMPENSATION dials as outlined in the manufacturer's instruction book. After obtaining the temperature reading, set the FUNCTION SELECTOR to SALINITY on the RS-7A and RS-7B. The salinity switch on the 6220 is automatic.

Now that you have properly rinsed the salinometer's cell and have determined a sample's temperature, fill the cell with a second sample and adjust the STANDARDIZATION controls until a reading of zero is indicated on the NULL INDICATOR. Three different sample readings are required from the STANDARDIZATION controls. These readings must agree within three digits; if not, repeat the above procedure until you obtain three consecutive readings within three digits. Average the three readings to be used and set the STANDARDIZATION dials on the salinometer to this value. The standardization setting is not changed during the processing of samples EXCEPT in the following cases:

1. If the power is removed from the instrument for any reason.

2. If the temperature of the sample varies more than 2.5° C. from the standardization temperature.

3. If the Standard Water processed as an unknown differs from the standardization conductivity ratio by more than the following amounts:

a. RS-7A or RS-7B - 0.00050

b. 6220 - 0.00030

Record the standardization setting to be used on the log sheet. (See figure 46.) If more than one log sheet is required for a particular salinity run, record the standardization value at the beginning of each log sheet used. This value does not require recording with each individual sample of the same salinity run; however, any pertinent remarks, such as bubbles, insufficient sample, or mud in sample can be entered in the "carboy standardization" column next to the sample number and temperature data.

The sample to be measured should be within 1 or 2 degrees of the Standard Water's temperature at the time of standardization of the salinometer and should NEVER EXCEED a temperature difference of 2.5° C.

To ensure a thorough mixing of the sample to be run and to help eliminate bubbles in the sample cell, shake each sample vigorously prior to pumping each into the sample cell. Pump the sample into the cell until the cell is full; then stir the sample, read the sample's temperature, turn the stirrer off, drain the sample cell into a bucket, and record the sample's temperature on the log sheet next to the sample number. Refill the sample cell, stir the sample, adjust the CONDUCTIVITY RATIO dials until the NULL INDICATOR reads zero, turn the stirrer off, drain the sample cell into a bucket, and record the conductivity value on the log sheet (figure 46). Refill the sample cell a third time and follow the above procedure until two successive fillings agree within 10 units of conductivity ratio (0.00010). It is not necessary to repeat the temperature measurement with the refills of the same sample. After reading the last filling of the cell and determining its validity, turn the three-way valve to the FILL position. The sample will drain back into the sample bottle by gravity and allow the fill tube to empty completely.

Run four water samples after you have standardized the salinometer. Then run a Standard Water sample as an unknown. If the conductivity ratio reading of this sample is within the limits previously mentioned, continue the processing of additional water samples; otherwise, you must restandardize the salinometer and run four more water samples and then run another Standard Water as an unknown. When the salinometer is functioning properly, you may run 29 additional samples between samplings of the first Standard Water run as an unknown and the next Standard Water run as an unknown. You may continue this procedure as long as the conductivity ratio readings of the unknown do not exceed the standardization readings by the values set for the salinometer model being used. Always run a Standard Water as an unknown at the completion of a day's salinity run.

COMPUTING SALINITY VALUES

Use the information recorded on the salinity log sheet to compute salinity values for the water samples that you have processed on the salinometer. This information consists of sample number, sample temperature, and sample conductivity ratio readings. Use an average of the conductivity ratio readings in conjunction with a salinity conversion table in the rear of the salinometer manual or folder provided with the instrument used to process the samples.

Enter the value obtained from the salinity table on the log sheet in the column labeled "uncorrected salinity." The value to enter for salinity is an interpolated value, because the conductivity ratio value is a five-place decimal and the conductivity ratio given in the table is given to four decimal places only.

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| DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4503 (3-67) | INDUCTIVE SALINOMETER SALINITY LOG SHEET | DATE 1-1-67 |
|---|---|---|
| | | PAGE NO. 2 |
| OPERATORS NAME | STATION NO. | INDUCTIVE SALINOMETER NO. 4601 |

| ROOM TEMP. °C | TEMP. COMPENSATION SETTING | CONDUCTIVITY RATIO FOR COPENHAGEN STANDARD SEA WATER | SALINITY | CONDUCTIVITY RATIO FOR CARDOY SUB STANDARD SEA WATER | SALINITY |
|---|---|---|---|---|---|
| | | | | | |

| SAMPLE BOTTLE NUMBER | SAMPLE TEMP. DIAL READING | CARDOY STANDARDIZATION / REMARKS | CONDUCTIVITY RATIO: BRIDGE READING | CONDUCTIVITY RATIO: AVERAGE BRIDGE READING | UNCORRECTED SALINITY S ‰ | APPLIED TO UNCORRECTED SALINITY: TEMP. CORR. | APPLIED TO UNCORRECTED SALINITY: SHEAR CORR. | CORRECTED SALINITY S ‰ |
|---|---|---|---|---|---|---|---|---|
| 8 | 22.4 | 4901 | .99007 | .99008 | 34.610 | .000 | -.003 | 34.607 |
| | | | .99008 | | | | | |
| 9 | 23.8 | | .98644 | .98644 | 34.468 | -.002 | -.003 | 34.463 |
| | | | | .98644 | | | | |
| | | | 22 SAMPLES RUN (BOTTLES 10-31); DATA NOT SHOWN | | | | | |
| 32 | 23.9 | | .97988 | .97986 | 34.209 | -.002 | -.006 | 34.201 |
| | | | .97984 | | | | | |
| 33 | 24.0 | | .97642 | .97641 | 34.074 | -.002 | -.006 | 34.066 |
| | | | .97640 | | | | | |
| P-40 | 23.2 | | 1.00018 | 1.00020 | 35.008 | .000 | -.006 | 35.002 |
| | | | 1.00020 | | | | | |
| | | | 1.00020 | | | | | |
| | | | 1.00020 | | | | | |
| | | | 27 SAMPLES RUN (BOTTLES 34-50); DATA NOT SHOWN | | | | | |
| 51 | 24.0 | | 1.02492 | 1.02492 | 35.982 | .000 | -.003 | 35.979 |
| | | | 1.02492 | | | | | |
| 52 | 23.9 | | 1.02528 | 1.02528 | 35.996 | .000 | -.003 | 35.993 |
| | | | 1.02529 | | | | | |
| P-40 | 23.1 | | 1.00012 | 1.00013 | 35.005 | .000 | -.003 | 35.002 |
| | | | ~~1.00014~~ | | | | | |
| | | | 1.00013 | | | | | |

Figure 46.— Sample Inductive Salinometer Salinity Log Sheet (continued).

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| DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4563 (3-67) | INDUCTIVE SALINOMETER SALINITY LOG SHEET | | DATE 1-1-67 / PAGE NO. 1 |
|---|---|---|---|
| OPERATORS NAME SAN JULE MST1 | | STATION NO. 1-5 | INDUCTIVE SALINOMETER NO. 4601 |

| ROOM TEMP. °C | TEMP. COMPENSATION SETTING | CONDUCTIVITY RATIO FOR COPENHAGEN STANDARD SEA WATER | SALINITY | CONDUCTIVITY RATIO FOR CARDOT SUB STANDARD SEA WATER | SALINITY |
|---|---|---|---|---|---|
| 22.7°C | —— | 1.00005 | 35.002 | NA | —— |

| SAMPLE BOTTLE NUMBER | SAMPLE TEMP. DIAL READING | CARDOT STANDARDIZATION / REMARKS | CONDUCTIVITY RATIO: BRIDGE READING | CONDUCTIVITY RATIO: AVERAGE BRIDGE READING | UNCORRECTED SALINITY ‰ | APPLIED TO UNCORRECTED SALINITY: TEMP. CORR. | APPLIED TO UNCORRECTED SALINITY: SHEAR CORR. | CORRECTED SALINITY ‰ |
|---|---|---|---|---|---|---|---|---|
| P-40 | 23.0 | 4903 | 1.00005 | - | | | | |
| | | 4900 | 1.00005 | | | | | |
| | | 4900 | 1.00005 | | | | | |
| | | 4901 | 1.00005 | - | 35.002 | .000 | .000 | 35.002 |
| | | | | | | | | |
| 1 | 22.7 | | .99915 | .99917 | 34.968 | -.001 | .000 | 34.967 |
| | | | .99919 | | | | | |
| | | | | | | | | |
| 2 | 22.5 | | .99933 | .99934 | 34.974 | .000 | -.001 | 34.973 |
| | | | .99934 | | | | | |
| | | | | | | | | |
| 3 | 22.0 | | .99835 | .99834 | 34.935 | .000 | -.001 | 34.934 |
| | | | .99834 | | | | | |
| | | | | | | | | |
| 4 | 22.3 | | .99602 | .99602 | 34.844 | .000 | -.002 | 34.842 |
| | | | .99602 | | | | | |
| | | | | | | | | |
| P-40 | 23.1 | | 1.00009 | 1.00010 | 35.004 | .000 | -.002 | 35.002 |
| | | | 1.00010 | | | | | |
| | | | 1.00010 | | | | | |
| | | | | | | | | |
| 5 | 22.5 | | 1.00400 | 1.00402 | 35.158 | .000 | -.002 | 35.156 |
| | | | 1.00404 | | | | | |
| | | | | | | | | |
| 6 | 21.8 | | 1.00077 | 1.00076 | 35.030 | .000 | -.002 | 35.028 |
| | | | 1.00074 | | | | | |
| | | | | | | | | |
| 7 | 22.0 | | .99995 | .99993 | 34.997 | .000 | -.002 | 34.995 |
| | | | .99991 | | | | | |
| | | | | | | | | |
| | | | | | | | | |

Figure 46.— Sample Inductive Salinometer Salinity Log Sheet.

| DEPARTMENT OF TRANSPORTATION U. S. COAST GUARD CG-4501 (1-67) | INDUCTIVE SALINOMETER SALINITY LOG SHEET | DATE 1-1-67 / PAGE NO. 3 |
|---|---|---|

| OPERATORS NAME | STATION NO. | INDUCTIVE SALINOMETER NO. 4601 |
|---|---|---|

| ROOM TEMP. °C | TEMP. COMPENSATION SETTING | CONDUCTIVITY RATIO FOR COPENHAGEN STANDARD SEA WATER | SALINITY | CONDUCTIVITY RATIO FOR CARBOY SUB STANDARD SEA WATER | SALINITY |
|---|---|---|---|---|---|
| | | | | | |

| SAMPLE BOTTLE NUMBER | SAMPLE TEMP. °C READING | CARBOY STANDARDIZATION / REMARKS | CONDUCTIVITY RATIO: BRIDGE READING | CONDUCTIVITY RATIO: AVERAGE BRIDGE READING | UNCORRECTED SALINITY S ‰ | APPLIED TO UNCORRECTED SALINITY: TEMP. CORR. | APPLIED TO UNCORRECTED SALINITY: SHEAR CORR. | CORRECTED SALINITY S ‰ |
|---|---|---|---|---|---|---|---|---|
| 53 | 22.5 | 4901 | 1.00400 | 1.00402 | 35.158 | .000 | -.003 | 35.155 |
| | | | 1.00404 | | | | | |
| 54 | 21.8 | | 1.00077 | 1.00074 | 35.029 | .000 | -.003 | 35.026 |
| | | | 1.00071 | | | | | |
| 55 | 22.7 | | .99995 | .99994 | 34.998 | -.001 | -.003 | 34.994 |
| | | | .99993 | | | | | |
| 56 | 21.4 | | .99907 | .99908 | 34.964 | .000 | | |
| | | | .99909 | | | | | |
| 57 | 23.6 | | .98644 | .98644 | 34.468 | -.002 | -.003 | 34.463 |
| | | | .98644 | | | | | |
| | | | 12 SAMPLES RUN (BOTTLES 58-68); DATA NOT SHOWN | | | | | |
| 69 | 23.9 | | .97988 | .97987 | 34.210 | -.002 | -.004 | 34.204 |
| | | | .97986 | | | | | |
| 70 | 24.0 | | .97642 | .97641 | 34.074 | -.002 | -.004 | 34.068 |
| | | | .97640 | | | | | |
| P-40 | 23.2 | | 1.00016 | 1.00015 | 35.006 | .000 | -.004 | 35.002 |
| | | | 1.00015 | | | | | |
| | | | 1.00015 | | | | | |

Figure 46.— Sample Inductive Salinometer Salinity Log Sheet (continued).

Two additional corrections are required to compute a corrected salinity value. These corrections are temperature and shear (drift). Enter both of these corrections as a three-place decimal, either positive or negative in value. Derive the correction for temperature from a temperature correction table in the salinometer manual or folder that is supplied with each instrument. To obtain the shear correction, compute the difference between the Standard Water used for standardizing the instrument and the Standard Water run as an unknown sample or the difference between two Standard Waters run as an unknown.

Referring to the salinity log shown in figure 46, compute the shear corrections as follows:

1. Compute the difference in salinity values between the original standardization value and the first Standard Water sample run as an unknown:

| | | |
|---|---|---|
| First P-40 | 35.002 | |
| Second P-40 | 35.004 | (value after correction |
| | -0.002 | for temperature) |

2. Count the number of samples to be sheared. The total is 5 samples—samples #1, #2, #3, #4, and P-40—in this case.

3. Divide the number of samples into the amount of shear between the first and second P-40:

$-0.002 \div 5 = -0.0004$

4. Add this correction for shear to each uncorrected salinity value in a cumulative manner, rounding off the correction to three decimal places. In our example in figure 46, the shear correction of the first P-40 is 0.000, sample #1 is 0.000, sample #2 is -0.001, sample #3 is -0.001, sample #4 is -0.002, and the second P-40 is -0.002.

If a second or third set of corrections is required, the procedure is the same as the previous example. The difference to be determined now is between two Standard Waters run as unknowns. Refer to our example in figure 46:

1. Determine the difference between Standard Waters run as unknowns:

| | |
|---|---|
| Second P-40 | 35.004 |
| Third P-40 | 35.008 |
| | -0.004 |

2. Count the number of samples run: #5, #6. . . . #32, #33, and third P-40. The total is 30 samples.

3. Divide the number of samples into the amount of shear.

$-0.004 \div 30 = -0.00013$

4. Add this correction for shear to each uncorrected salinity value in a cumulative manner, rounding off the correction to three decimal places and adding the rounded correction to the shear value of the previous sample's correction. In our example in figure 46, the shear correction for sample #10 is 6 x -0.00013 = -0.00078 (the number of samples times the amount of shear), or -0.001 + -0.002 (the value of the previous sample) = -0.003; sample #20 is -0.004; sample #30 is -0.005; and sample P-40 is -0.006.

The corrected salinity value is the sum of the temperature correction and the shear correction added to the uncorrected salinity value algebraically. In the case of sample #33 in figure 46; the corrected salinity value is computed as follows:

$34.074 + (-0.002) + (-0.006) = 34.066.$

The processing of salinity samples is not difficult, but you must be very careful about the manner in which you handle the data obtained during the processing. Exercise care when recording the sample's number, temperature, conductivity ratio readings, uncorrected salinity value, temperature correction, shear correction, and corrected salinity. At no time should you erase ANY figures used; if a figure is in error, draw a single line through the erroneous figure and enter the correct figure above the erroneous figure.

## MODIFIED WINKLER METHOD FOR DISSOLVED OXYGEN ANALYSIS

### DISSOLVED OXYGEN IN SEA WATER

The concentration of dissolved oxygen in sea water may vary from supersaturation near

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the surface, where photosynthetic activity by the phytoplankton is very high, to no oxygen in stagnant basins or deep fjords. The values, therefore, may be anything from 0 to 10 milliliters or more per liter of sea water.

The analysis for dissolved oxygen in sea water is important for numerous reasons: it aids in the interpretation of biological processes taking place in the ocean; it is finding increased use in studies of oceanic current and mixing processes; and it is sometimes used as an index for detecting malfunctional sampling equipment and erroneous values.

BASIS OF THE WINKLER METHOD

In waters which are relatively free of such substances as nitrites, ferrous salts, and organic matter, the Winkler method may be used for determining dissolved oxygen. These conditions are usually found in most areas of the open ocean. While the chemical reactions involved in this analysis are rather complex and the complete reaction unknown, the analysis itself is not difficult to perform if the necessary precautions are taken in preparing the reagents, cleaning the glassware, and carrying out the treatment of the samples and the titrations.

The Winkler method requires that the sample be treated with an alkaline manganous solution while protected from oxygenation by air. A white precipitate of manganous hydroxide forms first:

$$Mn^{++} + 2OH^- \longrightarrow Mn(OH)_2$$

This precipitate rapidly turns brown in the presence of dissolved oxygen, which reacts with the manganous hydroxide to form a tetravalent manganese compound:

$$2Mn(OH)_2 + O_2 \longrightarrow 2MnO(OH)_2$$

When this solution is acidified to excess in the presence of an iodide, iodine is released quantitatively; i.e., free iodine (more correctly, triiodide ion) is liberated from the iodide which is equivalent to the amount of dissolved oxygen present in the sample:

$$MnO(OH)_2 + 4H^+ + 3I^- \longrightarrow Mn^{++} + I_3^- + 3H_2O$$

This free iodine (or triiodide ion) is titrated with a standardized solution of sodium thiosulfate:

$$I_2 + I^- \rightleftarrows I_3^-$$

$$I_3^- + 2S_2O_3^{--} \longrightarrow 3I^- + S_4O_6^{--}$$

APPARATUS AND GLASSWARE

A list of recommended apparatus and glassware was given in the pamphlet on Instruments and Equipment. That list constitutes a minimum requirement for an effective oxygen analysis program aboard ship. Duplication of certain items is necessary because of their fragile nature. Spares must be carefully packed and stowed in safe areas. In addition, the following instructions concern the modification and proper use of several items.

Light-Proofing Reagent Containers

Certain reagents will undergo photochemical reactions upon exposure to light and must be shielded.

Manganous Sulfate and Alkaline Iodide Reagent Bottles.— It is frequently convenient to keep these two reagents near the Nansen bottle rack for treating the dissolved oxygen samples immediately after collection. Two 500-ml polyethylene bottles are best suited for this purpose. Keep them in a well-shaded area and light-proof them by spray painting their exterior surfaces with black paint. The alkaline iodide reagent is especially susceptible to photo-chemical change. Label the bottles clearly to avoid confusion, since the order in which they are used is critical.

0.01 N Sodium Thiosulfate Bottle.— Spray a one-gallon polyethylene bottle with black paint for use with this reagent. Keep it in a shaded area of the laboratory.

Potassium Biiodate Bottle.— This reagent is usually already supplied in a dark colored container. Dilutions of the stock material must also be stored in dark colored containers.

Volumetric Glassware

This term applies to glassware that has been carefully constructed to measure precise and accurate volumes of liquid.

Volumetric Flasks.— This type of flask has a flat bottom, wide base, and a long narrow neck, on which a ring mark had been etched. They are designed to contain the amount specified when filled to the ring mark with the liquid meniscus just tangent to the line. (See figure 47.)

Volumetric Pipets.— This type of pipet is characterized by a bulbous center section and a ring mark etched on the tube above it. (See figure 48.) They will deliver the specified volumes when used correctly. Fill the pipet by immersing the tip in liquid and drawing the solution up past the ring mark with the aid of a rubber squeeze bulb. Then remove the bulb and quickly cover the end of the pipet with the index finger to prevent drainage. Withdraw the tip and wipe the outside surface of the pipet with a tissue. Adjust the liquid in the pipet by slowly and carefully venting the pipet until the meniscus is just tangent to the ring mark. You may wipe off the tip again, but do not touch the tissue to the orifice. When draining, vent the pipet and hold the tip above the liquid surface in the container. You may transfer a droplet hanging from the tip after draining to the rest of the liquid by touching the tip to the container wall. Do not remove the small amount of residual liquid remaining within the tip itself.

Automatic Pipets.— Automatic pipets are similar to the volumetric pipets described above except for a stopcock assembly located near the top above the bulb. (See figure 51.) The stopcock eliminates manual adjustment of the liquid level to a ring mark. The liquid is drawn into the pipet by applying suction from a vacuum line to the top of the pipet with the stopcock aligned in the fill position. When the liquid level rises in the stopcock bore, it is turned 90° to the off position. The pipet now contains the exact amount of liquid specified and all that is required before draining is wiping the surface with a tissue. Draining is accomplished by turning the stopcock 180° from the fill position. This will align an air vent channel and allow free drainage. Since the stopcock is constructed of ground glass, it must be properly greased for smooth operation. A thin, light, even coating of silicone stopcock grease will suffice. Excess grease will clog the vent channel and prevent its operation.

Automatic Burette.— The automatic burette consists of a long graduated tube with a three-way teflon stopcock at the bottom. (See figure 51.) The stopcock makes alternate connections with the tip and filling arm. The top of the burette contains an overflow chamber having an overflow spout and draining arm. When the stopcock is aligned in the fill position, the liquid rises in the tube by gravity and will overflow the spout at the top. Cut off the flow by turning the stopcock 90° to misalign its bores. Then turn the stopcock another 90° to align the bores in the drain position just long enough to allow some of the liquid to run out of the tip. Wipe off excess liquid on the surface of the tip with a tissue. Do not touch the orifice with the tissue. Again turn the stopcock to the fill position just long enough to allow a few drops to overflow at the top. The burette is now properly filled and zeroed. The volume of the liquid used when titrating is read directly off the scale along the bottom of the meniscus. The ten-ml automatic burette is calibrated with small scale divisions of 0.05 ml and may be accurately read to 0.01 ml. (See figure 49.) Teflon stopcocks are never greased.

Automatic Plunger-Type Pipets

This type of pipet consists of a tapered nozzle glass barrel affixed to a metal casing which houses a small rubber bulb and adjustable plunger assembly. You may adjust them to draw and deliver up to two ml of liquid by setting the side slots and thumb screw on the plunger. Find the correct setting for the desired amount of liquid by trial and error. Use a ten-ml graduate to check on the volumes at each setting. Two of these pipets, set to one ml, are used with the manganous sulfate and alkaline iodide reagents contained in the black plastic bottles by the Nansen rack. They may be conveniently rigged for using the reagents and sealing the bottles afterwards by fixing a one-hole rubber stopper on each of the barrels. (See figure 50.) The stopper should make a tight fit with the bottles. Another pipet must be set to two ml for use with acid. No rubber stopper is required for this one, and it must be removed from contact with the acid and rinsed after use to prevent corrosion.

Oxygen Sample Bottles

Serially number the 125-ml oxygen bottles and attach rubber ties to the caps and necks. It is advisable to construct a sectioned carrying case out of wood for transporting about 16 oxygen samples between the bottle rack and lab. Determine the bottle volume once by filling

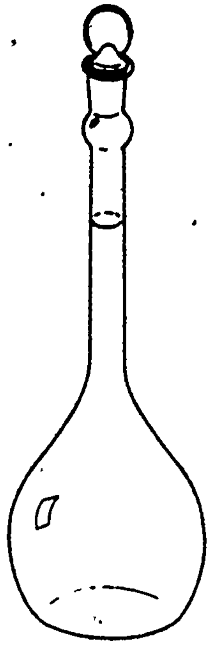

Figure 47.— Volumetric flask.

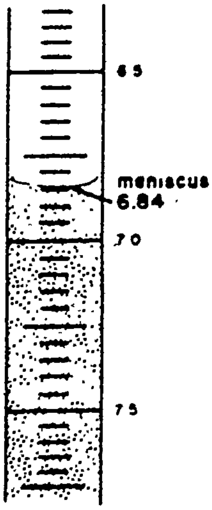


Figure 49.— Burette reading.

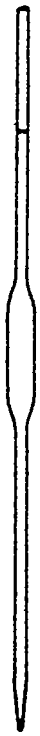

Figure 48.— Volumetric pipet.

Figure 50.— Automatic plunger-type pipet.

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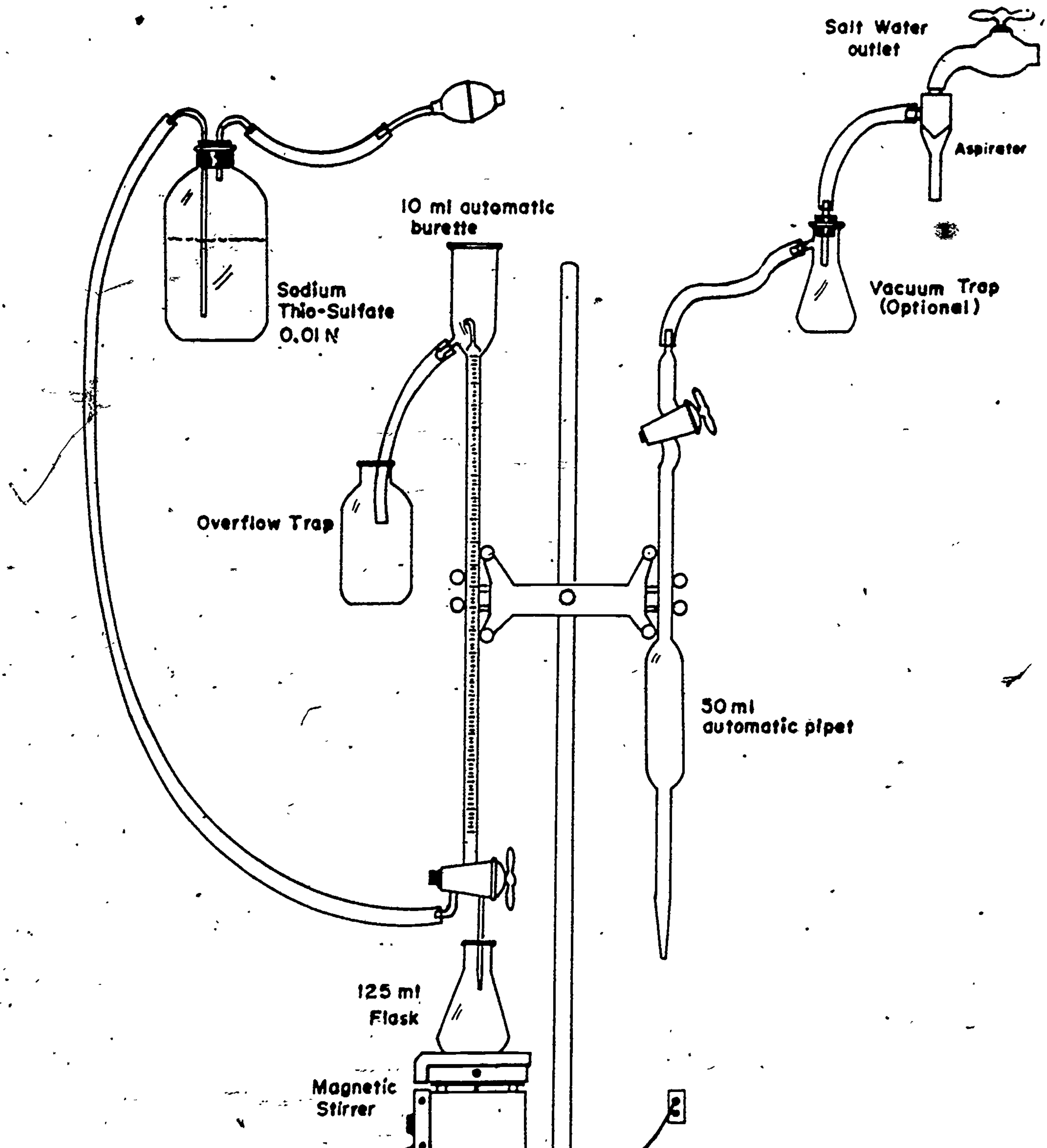


Figure 51.— Complete laboratory setup.

any one of the bottles to overflow with tap water. Seat the ground glass stopper, remove the volume, and measure it by pouring the contents into a graduated cylinder. This is the value of "B" to be used in the formula given later for oxygen calculations.

### Apparatus Set Up

The complete laboratory set up is shown in figure 51 and is described below.

Sodium Thiosulfate Reservoir-Automatic Burette.— Insert a two-hole rubber stopper in the neck of the sodium thiosulfate bottle. Through one of the holes insert a section of bent glass tubing with the bend above the stopper. The straight end within the bottle should extend to the bottom of the container. Either a single piece of glass tubing may be used, or the section extending to the bottom of the bottle may be made out of clean 3/8" tygon tubing and joined to the shorter glass tube in the stopper. Join the external end of the bent glass tube to a length of 3/8" clean tygon tubing which you connect to the filling arm of the 10-ml automatic burette. Insert a second piece of bent glass tubing through the other hole with the bend above the stopper. The end should extend only about two inches into the bottle and never below the surface of the liquid. Fit the external end of this glass tube to a six-inch long section of 3/8" tygon tubing having a rubber pressure bulb attached at the other end. Initiate the gravity feed to the burette by pumping the pressure bulb a few times. The bottle must be set higher than the top of the burette in order to maintain the siphoning action.

Vacuum Assembly.— A vacuum source is required to operate the 50-ml automatic pipet. The vacuum is supplied by an aspirator attached to a salt water outlet. A vacuum trap may be set in the line between the aspirator and pipet. The trap consists of a side arm filtering flask (500-ml) fitted with a one-hole rubber stopper. Slip a section of bent glass tubing through the hole with a bend above the stopper. The section of tubing within the flask should extend only about 3/4" below the side arm. Connect lengths of thick wall 1/4" I.D. tygon tubing from the side arm of the flask to the top of the pipet and from the bent tubing outlet to the arm of the aspirator. Create the vacuum by running the salt water outlet near full force.

## CHEMICAL REAGENTS

All of the reagents required for the analysis are commercially available in solution form. Any source of supply is acceptable providing the material conforms to American Public Health Association, Winkler (or modified Winkler) specifications or MIL-C 20640A specifications. Standard potassium biiodate solutions might not be marketed under these specifications, but are acceptable if the normality is certified to one ten-thousandth (0.0001) of a normality unit. You may procure sodium thiosulfate solution, sulfuric acid, and standard potassium biiodate solution in stronger concentrations than those required for performing the analysis, but you must dilute them according to the instructions given below. In a situation where certain reagents cannot be procured in solution form, it is permissible to prepare them from dry "reagent grade" chemicals and distilled water. However, this will necessitate using a scale for weighings. To avoid such problems, make procurements well in advance of a cruise.

### Manganous Sulfate (or Chloride) Solution

One liter of solution contains from 400 to 500 grams of solid reagent-grade crystals dissolved in distilled water. Store the solution in a light-proof container.

### Alkaline Iodide Reagent

One liter of distilled water solution contains from 350 to 500 grams of solid reagent-grade potassium (or sodium) hydroxide plus 140 to 170 grams of solid reagent-grade potassium iodide. Store this solution in a light-proof container. Avoid spillage and contact with skin and clothing. It is odorless, but very caustic and corrosive. Its highly viscous and slippery nature makes it difficult to remove, but copious water washings followed by neutralization with vinegar will be effective.

### Acid

Use either hydrochloric or sulfuric acid in the sample treatment step. Hydrochloric acid is preferred and is always used at full strength. No dilution is necessary. If you procure concentrated sulfuric acid, dilute it to approximately 35% by measuring out in a graduated cylinder 63 ml of distilled water and adding to it 37 ml of the concentrated acid. CAUTION: ALWAYS

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ADD ACID TO WATER, AND BE AWARE THAT MIXING THE TWO LIQUIDS MAY GENERATE SUFFICIENT HEAT TO MAKE THE GLASS CONTAINER TOO HOT TO HANDLE. Exercise extreme care in handling the acids. Avoid contact with skin and clothing and avoid breathing the fumes. Wear protective clothing, gloves, and eyeglasses and work in a well ventilated area. In the event of contact with skin, apply sodium carbonate immediately and rinse with a copious amount of tap water.

Sodium Thiosulfate Solution

The normality of the sodium thiosulfate solution will be close to 0.01 N. Less than 10 ml of 0.01 N sodium thiosulfate will be required to titrate the samples in most cases. A sodium thiosulfate solution having a normality other than 0.01 N may have been procured. The concentrations generally encountered are 0.1 N and 1.0 N. You may dilute these to 0.01 N, preferably by using volumetric pipets and flasks, since the resulting solutions will be quite close to the expected 0.01 normality. However, if the appropriate volumetric glassware is not available, you may make the dilutions by using graduated cylinders. In either case, you will determine the exact normality in the standardization procedure. The following are the dilution factors for making 0.01 N sodium thiosulfate.

| Normality of stock sodium thiosulfate | ml of stock | to be diluted to |
|---|---|---|
| 0.1N | 100 ml | 1000 ml |
| 1.0N | 10 ml | 1000 ml |

If the solution does not contain a preservative, you may add a few drops of chloroform to retard bacterial growth. You can also make a 0.01 N sodium thiosulfate solution by dissolving 7.45 grams of solid reagent-grade sodium thiosulfate in 3 liters of distilled water. However, to obtain a solution with a normality close to 0.01 N, perform the weighing on a balance capable of weighing accurately to a hundredth of a gram.

Potassium Biiodate Standard Solution

The strength of the potassium biiodate solution used for standardization is 0.01 N. If the standard potassium biiodate solution procured is not 0.01 N, you may dilute it to the appropriate concentration by taking an aliquot with a volumetric pipet, transferring it to a volumetric flask, and filling the flask to its ring mark with distilled water. Secure the stopper tightly, shake the flask well, and store it in a darkened area. You cannot prepare this standard in the field from solid potassium biiodate. You must purchase it as a standardized solution. Potassium biiodate standardized solutions are usually supplied as 0.025 N or 0.1 N. Some manufacturers mark the normality on their labels with the letter "N" followed by some number. This is interpreted as a fraction. For example, N 40 means 1/40 or 0.025 normal. You can dilute the following stock standards of 0.025 N and 0.100 N to 0.0100 N using the given dilution factors:

| STD | Volumetric pipet | | Volumetric flask |
|---|---|---|---|
| .025 N | 100 ml | — | 250 ml |
| .100 N | 10 ml | — | 100 ml |
| | or | | |
| | 100 ml | — | 1000 ml |

Starch Indicator Solution

Use the commercially prepared starch indicator solution at full strength and keep a medicine dropping bottle full for convenience during titrating. You may also prepare the starch solution by adding an excess of dry soluble potato starch to distilled water, boiling the water, and then pouring off the clear liquid into a storage bottle. A few drops of chloroform will retard bacterial action.

PROCEDURE

Drawing the Sea Water Sample for Dissolved Oxygen Analysis

You must draw the samples for this purpose first and as soon as possible after the completion of the cast. Use ground glass stoppered bottles of approximately 125-ml capacity to contain the sea water samples. Before drawing the samples, thoroughly rinse the bottles by adding a small amount of sample water and shaking the bottles vigorously. Be sure to pour the rinse water over the ground glass stopper. Rinse the stopper and bottle at least twice. Carefully withdraw the samples from the Nansen bottle to avoid contamination with atmospheric oxygen. Prepare a delivery tube for this purpose. It consists of a piece of 3/8 inch O. D.

tygon or flexible rubber tubing about six inches long with a four-inch glass tube inserted in one end. The glass tube is fire-polished smooth and slightly constricted. The stepwise procedure for filling is as follows:

1. Attach the rubber end of the delivery tube to the drain petcocks and insert the glass tip to the bottom of the sample bottle.

2. Turn the drain petcock to allow a slow flow and invert the sample bottle.

3. Swirl the glass tip around the bottom of the bottle and allow the washings to run out over the glass stopper.

4. With the glass tip held against one side at the bottom of the bottle, slowly turn the bottle right side up and allow it to fill. A faster flow rate may be tolerated while filling.

5. When the sea water overflows the neck of the bottle, withdraw the glass tip. Do not turn the petcock off until you have withdrawn the tube from the sample bottle.

6. Insert the end of the ground glass stopper into the mouth of the bottle in such a way that no bubbles of air are trapped and allow it to seat. This will spill a small amount of water but will ensure the proper volume of sample for analysis.

The entire rinsing procedure should waste only about 75 ml of sample water. Be sure that no air bubbles enter the sample, since this will tend to give higher oxygen values upon analysis. If you observe any air bubbles, discard the sample and begin over again.

Process dissolved oxygen samples immediately after you have drawn them. Stepwise instructions for carrying out the analysis are given below.

Treating Sea Water Samples

Follow these instructions carefully to avoid air entrainment and to ensure thorough mixing of reagent and sample.

1. Withdraw one ml of manganous sulfate (or chloride) reagent with an automatic plunger-type pipet.

2. Immerse the tip of the pipet well below the surface of the dissolved oxygen sample and slowly depress the plunger.

3. Keep the plunger depressed and withdraw the pipet.

4. Follow steps 1 through 3 for all of the samples.

5. Withdraw one ml of alkaline iodide reagent with an automatic plunger-type pipet.

6. Immerse the tip of the pipet well below the surface of the dissolved oxygen sample and slowly depress the plunger.

7. Keep the plunger depressed and withdraw the pipet.

8. Follow steps 5 through 7 for all of the samples.

9. Carefully seat the ground glass stoppers without trapping any air bubbles. The samples should show a brownish precipitate at this point.

10. Secure the stoppers tightly and shake each bottle vigorously with a snapping action of the wrist until the brown precipitate is evenly distributed throughout the sample.

11. Allow the samples to set for one half hour.

12. Shake each sample as before and allow each to set until the precipitate settles to the bottom.

Acidification

The precipitate from step 12 above usually settles within an hour, and the samples should not stand longer than three hours before acidification.

1. Withdraw two ml of concentrated hydrochloric acid (or, if 35% sulfuric acid is used, withdraw one ml).

2. Immerse the tip of the pipet an inch below the surface of the treated sample and depress the plunger slowly.

3. Keep the plunger depressed and withdraw the pipet.

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4. Secure the stopper carefully and shake the bottle until the precipitate dissolves completely.

The prescribed acid addition will usually be adequate to dissolve all of the precipitate. However, if there is still some undissolved precipitate remaining, allow it to settle and then add another 1/2 ml of the acid or more if necessary to clear it. If the samples consistently show evidence of undissolved precipitate, set the automatic plunger-type pipets to deliver more acid. After the samples are acidified, they are ready for titration. They should not stand for longer than six hours before titration.

The introduction of the reagents causes a liberation of part of the nitrogen dissolved in the samples of sea water. In addition, the acid may cause a small amount of carbon dioxide ($CO_2$) to be liberated. As a result, small bubbles of gas may occur in the sample after the precipitate has dissolved. This gas developed in the sample before titration and affects the results only by diminishing the volume of the bottle's contents. It is of no importance since an aliquot or measured portion of the sample is used for titration.

Titration of Treated Sample

1. Withdraw a 50-ml aliquot of the acidified sample with the 50-ml automatic pipet-vacuum assembly.

2. Drain the 50-ml aliquot into a 125-ml Erlenmeyer flask containing a teflon coated magnetic stirring bar. You should have previously rinsed the Erlenmeyer flask and stirring bar with distilled water, but they need not be dry.

3. Fill and zero the 10-ml automatic burette with standardized sodium thiosulfate solution.

4. Titrate by slowly adding the sodium thiosulfate from the 10-ml automatic burette to the sample with the magnetic mixer on. Control the stirring speed so no splashing occurs. Continue the titration until the yellow color of the solution in the flask starts to fade. A sheet of plain white paper between the magnetic stirrer and flask will provide a good background for viewing the color change.

5. Add five drops of starch indicator solution to the flask. The solution should turn blue.

6. Continue adding the sodium thiosulfate solution dropwise slowly, stirring until just a faint trace of blue color remains.

7. Wash down the inside walls of the flask with a small portion (1 ml or less) of distilled water. This will return any droplets splashed up on the walls of the flask to the solution.

8. If the solution contains the faintest trace of blue color at this point, the addition of one drop or less will be sufficient to turn it colorless. This is the end point, and you must carefully find it to within the one drop of sodium thiosulfate which causes the color change.

9. Read and record the volume of sodium thiosulfate used to arrive at the end point.

10. Discard the solution and rinse the Erlenmeyer flask and stirring bar.

11. Refill and zero the automatic burette.

12. Repeat steps 1 through 9 with the same sample.

13. The second determination should agree with the first to within $\pm 0.03$ ml of sodium thiosulfate.

14. Average and record the results in the log sheet.

Standardization of Sodium Thiosulfate Solution

The color changes observed during the titration and the techniques employed for arriving precisely at the end point are the same as described above for the sample treatment procedure. The sodium thiosulfate should be standardized at least once every other day when stations are taken.

1. Obtain a representative sample of sea water by draining a small amount of sample from each Nansen bottle of the first cast into a clean one-pint bottle. You may use this sea water until it is expended.

2. Add approximately 50 ml of the above representative sea water to a 125-ml Erlenmeyer flask containing a teflon coated magnetic stirring bar.

3. Add 3 ml of concentrated hydrochloric (or 35% sulfuric) acid to the flask and turn on the magnetic stirrer.

4. IMPORTANT—Add to the flask dropwise, slowly, and with constant stirring, one ml of the same alkaline iodide reagent which is used in the sample treatment procedure. The solution should be clear; if not, add more acid.

5. Add to the flask one ml of the same manganous sulfate solution used in the sample treatment procedure.

6. After the above mixture is well stirred, add, with a volumetric pipet, 5 ml of the 0.01 N potassium biiodate standard and continue the stirring. The solution will have a yellow appearance at this point.

7. Fill and zero the 10-ml automatic burette with the sodium thiosulfate solution.

8. Titrate the solution in the flask with the sodium thiosulfate solution from the 10-ml automatic burette.

9. When the yellow color starts to fade, stop and add 5 drops of starch indicator solution to the flask. The solution will turn blue.

10. Continue titrating with the sodium thiosulfate until the end point is precisely determined.

11. Read the burette and record the results on the log sheets.

12. Refill and zero the 10-ml automatic burette. Rinse out the Erlenmeyer flask.

13. Repeat steps 2 through 10 with a second standardization sample.

14. Record the results. The volumes of sodium thiosulfate used to arrive at the end point should agree to within $\pm 0.03$ ml. If they do, average the results. If not, make another run.

15. Calculate the normality according to the following formula:

$$\text{Normality of Sodium Thiosulfate} = \frac{0.05}{\text{average ml of sodium thiosulfate used (burette reading at end point)}}$$

Blank Determination

A numerical blank value is not required for computations, since it has already been accounted for in the standardization procedure. However, you must make blank determinations as periodic checks on the quality of the reagents. Exercising the same care as described in the standardization step, make the blank determination according to the following steps.

1. Add 50 ml of freshly boiled distilled water to an Erlenmeyer flask.

2. Add 2 ml of acid.

3. Add 1 ml of alkaline iodide reagent.

4. Add 1 ml of manganous sulfate reagent.

5. Add five drops of starch indicator solution.

If the reagents are perfectly good, no blue color will be evident. If a blue color is present, titrate with the sodium thiosulfate solution. If more than 0.1 ml of sodium thiosulfate is required to decolorize the blank, replace the contaminated reagent or reagents if possible. The reagent most likley to turn bad first is the alkaline iodide. Make certain that you have made the blank determination correctly before discarding reagents.

CALCULATIONS

Record all data on the oxygen log sheets (figure 52). Note any peculiarities observed or possible sources of error which may account for discrepancies. Record all the computations for normality determination and oxygen content.

Concentration of oxygen in water samples:

$$\text{Oxygen (ml/L)} = N \times V \times \frac{B}{B-2} \times 112$$

N = Normality of sodium thiosulfate
V = ml of sodium thiosulfate (burette reading)
B = Volume of oxygen sample bottle
112 = Constant

Securing

After completion of the survey, dismantle the apparatus and clean all of the equipment

DISSOLVED OXYGEN DETERMINATION - MODIFIED WINKLER METHOD

| STATION NO. | CRUISE | DATE | STANDARD | |
|---|---|---|---|---|
| | | | BLANK | |
| | | | BTL. VOL. | |

| DEPTH | TEMP. | SALINITY | AVG. ML OF THIOSULF. | BOTTLE NO. | ML OF THIOSULF. OF EACH RUN | | |
|---|---|---|---|---|---|---|---|
| | | | | | 1st. | 2nd | 3rd |
| | | | | | | | |
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Figure 52.— Dissolved Oxygen Determination—Modified Winkler Method.

thoroughly with detergent. Rinse the equipment well with distilled water. Package all items carefully and stow them in a safe area. Discard any bottles less than one half full of reagent. Take extreme care with the stowage of acid and alkaline iodide reagents. Keep them in an area where there is an extremely small chance of breakage. If breakage should occur, they should be in a location where it would be immediately noticeable but would not present a threat to personnel and ship operations. Remember that it is far better to discard reagents than to permit unsafe stowage.

## PROCESSING STATION DATA

Physical oceanographic measurements taken at sea require careful examination, correction, and conversion before they can be put in a form suitable for analysis. Such processing of oceanographic data involves a considerable amount of practical experience to judge the reliability of the records from instruments which operate blindly below the sea surface. Corrections for instrumental errors and for errors inherent in the methods of obtaining data are necessary in order to determine the basic values of temperature and salinity for different depths in the sea. Conversion of sea observations to standard units is desirable for comparison with other oceanographic data. Also, certain calculations are required to derive dependent quantities, such as specific volume, density, and currents.

Processing of data is a time-consuming operation, and many short cuts have been devised. The choice of method depends upon the amount of data to be processed and upon individual preference. For these reasons the following section gives the fundamental formulae and outlines a choice of procedures for correcting and converting field data in order to obtain the desired results.

Although this section deals with processing ashore, much of the processing could be accomplished aboard ship. Processing aboard ship has the advantage that the results provide an immediate guide for future observations. On the other hand more space and more time are usually available on shore, as well as more stable conditions, resulting in more accurate work. Regardless of where the work is carried on, the following procedures, examples, and tables should prove useful for the processing of physical oceanographic data.

Some necessary computations include correcting protected thermometer readings, averaging water temperatures, correcting unprotected thermometer readings, calculating thermometric depths, and determining accepted depths. To perform these calculations, the Reversing Thermometer Calibration and History Record PRNC-NAVOCEANO-3167/53 (Rev. 2-64) for each thermometer used is required, and an L-Z Graph NAVOCEANO 3167/62 (Rev.2-64) for each cast of the oceanographic station is required.

## CORRECTING THERMOMETERS

After a deep sea reversing thermometer is manufactured and before you can use it in taking an oceanographic station, the thermometer must be calibrated. This calibration process determines the deep sea reversing corrections that you will apply to the temperature scales etched on the main and auxiliary stems of the thermometers. It also establishes the volume of mercury. ($V_0$), at zero degrees Celsius, in the thermometer reservoir and main stem capillary. In addition, the calibration determines the "Q" Factor, or pressure factor, for unprotected thermometers at 1,000-, 2,000-, 3,000-meter, etc., depth increments. "Q" Factors for 500-meter depth increments are determined when required. Thermometers are calibrated at the National Oceanographic Instrumentation Center, and the results are recorded on the Reversing Thermometer Calibration and History Record (figure 53).

The record includes the following information: The thermometer number, make (manufacturer's name), $V_0$ in °C., makers $V_0$ in °C. "K" value (glass-mercury coefficient of expansion constant), range (main stem scale), smallest scale division, protected or unprotected, owner, purchased new or used, purchased from, cost, and date acquired. In addition, the record includes Deep Sea Reversing Thermometer Corrections at various temperatures for both main and auxiliary thermometers and "Q" Factors for unprotected thermometers. The record also includes an interpolation table for temperature corrections that you will make. Instrumentation personnel performing and certifying the calibration, the date calibrated, the adherence to contract specifications, and the functioning of the instrument are shown on the record. The bottom of the form contains a Thermometer History Record for you to record cruise, dates thermometer was used, and performance.

A method for correcting both protected and unprotected thermometers is outlined in N.O. Pub. 607, Chapter F. In the same chapter, the recommended computation of thermometric depth is given.

## DETERMINING ACCEPTED DEPTH

Determine the accepted depth (D) by the L-Z graphical method. Use the L-Z Graph, NAVOCEANO-3167/62 (Rev. 10-64) (figure 54) to facilitate the calculations. The procedures used to construct the L-Z graph follow:

1. On the vertical side of the graph, lay off the wire length depth (L), starting with zero at the upper left for the shallow cast and upper right for the deep cast. Use a convenient depth increment for each cast which will allow sufficient space for the maximum wire depth sampled.

2. Across the top of the graph, lay off the depth difference (L-Z) scale for each cast. Use a convenient L-Z increment for each cast which will allow sufficient space for the maximum L-Z observed.

3. From the origin (upper left or right zero depth), construct a line making an angle from the vertical which represents the wire angle. Do this as follows:

| NUMBER | MAKE | $V_0$ = 139.6 °C / MAKERS $V^0$ = 146 °C | "K" VALUE = 6098 | RANGE | SMALLEST SCALE DIVISION | |
|---|---|---|---|---|---|---|
| 195-64 | Kessler | | | -2 °C TO + 30 °C | 0.1 °C | ☐ PROTECTED ☒ UNPROTECTED |

| OWNER | | | |
|---|---|---|---|
| U. S. NAVAL OCEANOGRAPHIC OFFICE | | ☒ PURCHASED NEW ☐ PURCHASED USED | PURCHASED FROM: KESSLER CO. PRICE: $92.30 DATE ACQUIRED: June 1964 |

DEEP SEA REVERSING THERMOMETER CORRECTIONS

| MAIN THERMOMETER TEMPERATURE | MAIN THERMOMETER CORRECTION | AUXILIARY THERMOMETER TEMPERATURE | AUXILIARY THERMOMETER CORRECTION | "Q" FACTOR 1000 METERS |
|---|---|---|---|---|
| 0 °C | -0.002 | 0 °C | 0.00 | 1 = 0.0080448 |
| 5 °C | +0.011 | 10 °C | -0.10 | 2 = 0.0080272 |
| 10 °C | +0.028 | 20 °C | -0.08 | 3 = 0.0080364 |
| 15 °C | +0.032 | 30 °C | -0.10 | 4 = |
| 20 °C | +0.012 | 40 °C | -0.08 | 5 = |
| 25 °C | -0.009 | 50 °C | -0.08 | 6 = |
| 30 °C | -0.040 | °C | | 7 = |
| °C | | °C | | 8 = |
| °C | | °C | | 9 = |
| °C | | °C | | 10 = |
| CALIBRATED BY E.H. Blackwell/S | | ADHERENCE Ex | | 11 = |
| CERTIFIED BY Louis Martin/S | | FUNCTIONING Ex | | 12 = |
| DATE 5 Oct 1964 | | | | |

MAIN — INTERPOLATION TABLE — AUXILIARY
APPLY THERMOMETER CORRECTIONS ALGEBRAICALLY

| T° | CORR | T° | CORR | T° | CORR | T° | CORR | T° | CORR | T° | CORR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | | 21.67 | | | | | | | | 0 | |
| | 0 | | 0 | | | | | | | | 0 |
| 2.69 | | 24.05 | | | | | | | | 5 | |
| | +.01 | | -.01 | | | | | | | | -.1 |
| 6.18 | | 25.96 | | | | | | | | 50 | |
| | +.02 | | -.02 | | | | | | | | |
| 9.12 | | 27.68 | | | | | | | | | |
| | +.03 | | -.05 | | | | | | | | |
| 16.75 | | 29.19 | | | | | | | | | |
| | +.02 | | -.04 | | | | | | | | |
| 19.25 | | 30.00 | | | | | | | | | |
| | +.01 | | | | | | | | | | |
| 21.67 | | | | | | | | | | | |

1. Always store thermometer in the carrying case with the large reservoir DOWN, unless the stored thermometer will be subjected to temperatures colder than -10 °C.

2. Reverse the thermometer at least once every day.

3. Keep a complete history of this thermometer. Explain condition as accurately as possible under remarks below.

THERMOMETER HISTORY RECORD

| CRUISE | DATE | SEPARATES | DOESN'T BREAK | BREAKS IMPROPERLY | FLOODS | TOTAL CASTS USED | REMARKS | EST. OF COND. | OBSERVER'S NAME |
|---|---|---|---|---|---|---|---|---|---|
| MICHELSON | 3-65/7-65 | | | | 1 | 32 | 28-Ex 2-High 1-Low | EXC. | T.A.B. |
| SAN PABLO | 10-65/11-65 | | | | 1 | 36 | 32-Ex. 4-Low | EXC | D.H.H. |
| REHOBOTH | 12/65 | | | BA | | | NOT USED | | F.A.A. |

RANGE °C TO °C | UN PRO ☐ | PRO ☐ | MAKE | NUMBER

REVERSING THERMOMETER CALIBRATION AND HISTORY RECORD NAVOCEANO-3167/53 (Rev. 3-64)

Figure 53.— Reversing Thermometer Calibration and History Record.

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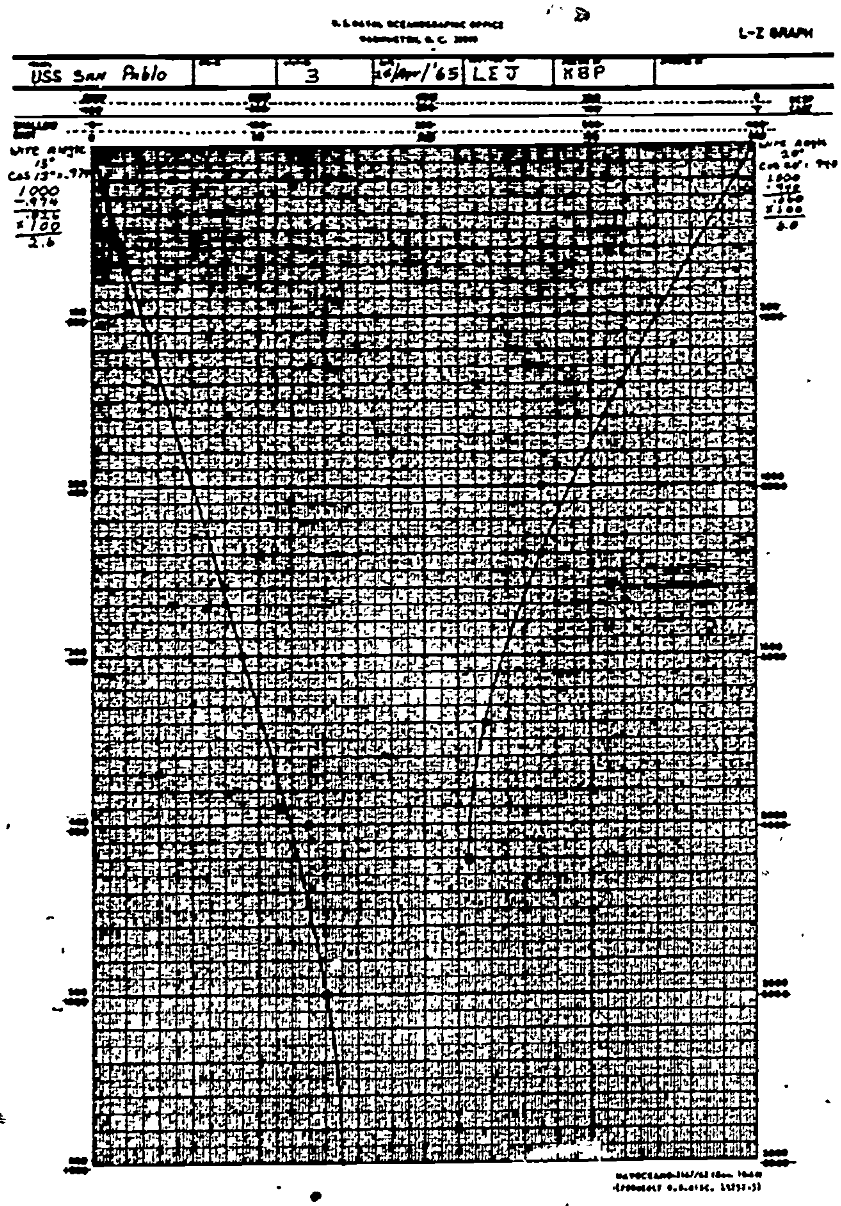


Figure 54.— The L-Z graph with typical curves.

From a table of trigonometric functions, find the cosine of wire angle (1). Subtract the cosine from 1.000. Multiply the remainder by 100. Plot the product as L-Z at L equals 100, and construct a line passing through the origin and this point.

Cosine of 13° is .974

1.000 − .974 = .026

.026 x 100 = 2.6

4. Plot L-Z Obs values at Wire Length Depth (L) values; make a circle around each point plotted.

5. Construct a reasonably smooth curve through the origin of the graph and as many points as possible.

6. From the curve, pick off L-Z values for every Nansen bottle of the cast. Enter these values in the appropriate L-Z Used block.

730

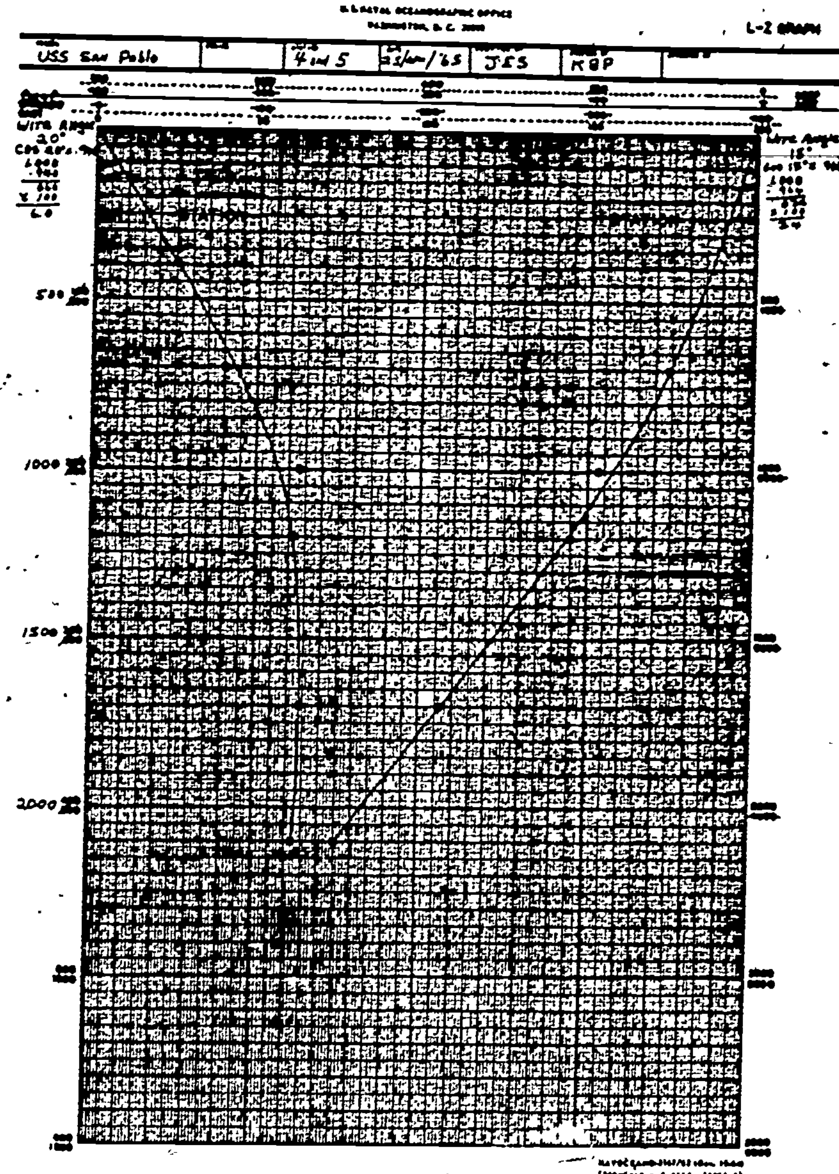

Figure 55.— The L-Z graph with atypical curves.

7. To determine the accepted depth, subtract the L-Z Used value from the Wire Length Depth (L) value. The remainder is the Accepted Depth (D).

PLOTTING STATION DATA

The observed oceanographic station data obtained by taking a Nansen cast, such as temperature, salinity, dissolved oxygen, various nutrients, and depth, should be consolidated or summarized on one log sheet and plotted on Oceanographic Station Plotting Sheets. Use the Station Summary, Oceanographic Log. Sheet-E, PRNC-NAVOCEANO-3167/5 (Rev. 1-63), (figure 56) to consolidate and summarize the observed oceanographic surface observations, temperatures, depths, and water sample analysis results. In addition, space is provided on the E-Sheet for recording computed density ($\sigma_t$), sound velocity, and dynamic calculations and for recording standard depth interpolated data values.

Use Oceanographic Station Plotting Sheet, PRNC-NHO-3167/55 (3-62) (figure 57), for plotting profiles of various oceanographic data. These graphs and profiles serve many uses in studies and interpretation of the data. For example, some of the immediate important shipboard applications

OCEANOGRAPHIC LOG SHEET E
PRNC-NAVOCEANO-3167/5 (Rev. 1-63)

U. S. NAVAL OCEANOGRAPHIC OFFICE
WASHINGTON 25, D. C.

STATION SUMMARY
FOR USE WITH H.O. PUB. NO. 607

| Ship . Cruise | Station Number | Month | Day | Year | GMT | Latitude | N-S | Longitude | E-W | Sonic Depth to Bottom | Max Sample Depth | Layer Depth | Spec. Obs. | Vessel |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DAVIS | 3 | July | 23 | 1965 | 23:20 | 42 54 | N | 167 10 | W | 4755 meters | 866 meters | — | — | DAVIS |

Computed by [signature]
Checked by [signature]
Approved by [signature]

| Wind Speed | Wind Dir | Wind Force | Baro-meter | Dry Bulb | Wet Bulb | Humidity | Weather (Code) | Cloud Type | Cloud Amt | Sea Dir | Sea Amt | Swell Dir | Swell Amt | Visibility | Water Color | Water Trans | Consecutive Station Number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 Kts | 079° | — | — | 1031.3 | 19°C. | 77°C. | — | Drizzle | Sc | 10/10 | 081° | 1' | 166° | 3' | 3 MI | — | 3 |

| Serial No | Accepted Depth | T °C | Salinity ‰ | σt | O2 ml/l | | | Std Depth | T °C | Salinity ‰ | σt | δ | Mean δ | ΔD | ΣΔD | O2 ml/l | Sound Velocity m/sec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 35 | 00 | 15.49 | 33.49 | 24.73 | | | | 0000 | 15.49 | 33.49 | 24.73 | | | | | | 1507.0 |
| 36 | 08 | 15.50 | 33.49 | 24.72 | | | | 0010 | 14.44 | 33.55 | 25.00 | | | | | | 1507.2 |
| 37 | 12 | 13.56 | 33.60 | 25.22 | | | | 0020 | 12.63 | 33.67 | 25.46 | | | | | | 1501.1 |
| 38 | 25 | 12.13 | 33.71 | 25.59 | | | | 0030 | 11.72 | 33.74 | 25.68 | | | | | | 1496.7 |
| 39 | 42 | 10.96 | 33.80 | 25.88 | | | | 0050 | 10.70 | 33.82 | 25.93 | | | | | | 1492.9 |
| 40 | 63 | 10.43 | 33.84 | 26.00 | | | | 0075 | 10.42 | 33.94 | 26.07 | | | | | | 1491.5 |
| 41 | 83 | 10.42 | 33.99 | 26.12 | | | | 0100 | 10.28 | 34.03 | 26.17 | | | | | | 1492.0 |
| 42 | 125 | 10.08 | 34.07 | 26.24 | | | | 0150 | 9.95 | 34.06 | 26.25 | | | | | | 1491.6 |
| 43 | 166 | 9.74 | 34.06 | 26.29 | | | | 0200 | 8.87 | 33.92 | 26.31 | | | | | | 1490.9 |
| 44 | 207 | 8.75 | 33.91 | 26.33 | | | | 0250 | 8.39 | 33.95 | 26.42 | | | | | | 1487.8 |
| 45 | 248 | 8.41 | 33.95 | 26.42 | | | | 0300 | 7.84 | 33.95 | 26.51 | | | | | | 1487.2 |
| 46 | 331 | 7.42 | 33.95 | 26.56 | | | | 0400 | 6.19 | 33.94 | 26.71 | | | | | | 1484.7 |
| 47 | 415 | 5.98 | 33.94 | 26.75 | | | | 0500 | 5.15 | 33.94 | 26.85 | | | | | | 1480.3 |
| 48 | 499 | 5.16 | 33.94 | 26.85 | | | | 0600 | 4.47 | 33.99 | 26.95 | | | | | | 1478.5 |
| 49 | 674 | 4.08 | 34.10 | 27.09 | | | | 0800 | 3.64 | 34.21 | 27.22 | | | | | | 1477.1 |
| 50 | 866 | 3.52 | 34.26 | 27.27 | | | | 1000 | | | | | | | | | 1478.2 |
| | | | | | | | | 1200 | | | | | | | | | |
| | | | | | | | | 1500 | | | | | | | | | |
| | | | Computed | using | | | | 2000 | Interpolated values | | | | | | | Computed using | |
| | | | SP-11 | or SP-68 | | | | 2500 | from Oceanographic | | | | | | | SP-68 | |
| | | | (Table 10) | | | | | 3000 | Station Plotting Sheet | | | | | | | (TABLE 12) | |
| | | | | | | | | 4000 | | | | | | | | | |
| | | | | | | | | 5000 | | | | | | | | | |
| | | | | | | | | 6000 | | | | | | | | | |

Figure 56.— Oceanographic Log Sheet-E.

include checking for possible errors in computations, sample analyses, and Nansen bottle spacing; determining which thermometer of a pair to accept when they differ by more than .06° C.; and interpolating standard depths from the plotted observed values.

### Station Summary of Observed Oceanographic Values

After completing the data computations and computing water sample analysis results, consolidate the oceanographic station data on the Station Summary, Log Sheet-E; then, have another person check each entry to make certain that you have transcribed the data correctly. The following checking procedure is recommended: As the checker verifies each item, he should place a dot (with a colored pencil) over the correct entry on the E-Sheet. DO NOT ERASE TO CORRECT. With a colored pencil, enter the correct value above the incorrect item. DO NOT CODE ITEMS ON THE E-SHEET. Space limitations in several of the blocks on the E-Sheet heading may require that further information be given on the back of the log sheet.

Compute density ($\sigma_t$) for each observed temperature-salinity value by using table 10, Determining Density of Sea Water, in Special Publication 68 (SP-68), Handbook of Oceanographic Tables, U.S. Naval Oceanographic Office. Compute sound speed for each observed temperature-salinity-depth value by using table 12, Sound Speed, in (SP-68). Enter density in the Observed Values $\sigma_t$ column and sound velocity in the right-hand column on the E-Sheet.

### Plotting Observed Oceanographic Values

After you have entered and verified the surface observations, serial number, accepted depths, temperatures, and water sample analysis results on the E-Sheet, plot the observed oceanographic values on the Oceanographic Station plotting sheet. Draw all graphs and profiles with great care. Use a pencil no softer than a number 3H drawing pencil. Keep the point sharp and draw fine clear lines. Plot all data accurately.

To aid in the interpretation of data, use the U.S. Naval Oceanographic Office standard set of data symbols given in table 12. The point in the symbol indicates the data value, and the symbol indicates the type of observation.

Table 12.— Standard oceanographic data symbols.

| TYPE OF OCEANOGRAPHIC DATA: | SYMBOL: |
|---|---|
| TEMPERATURE (°C or °F) | ┼ |
| SALINITY ‰ | ▲ |
| OXYGEN ml/L | ⊙ |
| SOUND VELOCITY (ft/sec. or m/sec) | ⊡ |
| DENSITY ($\sigma_t$) | ∇ |

Use french or ship curves to construct lines. Draw curves through the plotted points in such a manner that the points appear to lie on the curve rather than being connected by curved lines. This can be done easily with a little practice.

If the station depth exceeds the length of the graph, extend the plot by attaching part of another sheet to the bottom with rubber cement. A longer version of the plotting sheet (NDW NAVOCEANO 3167/56 (Rev. 3-66) is available for very deep oceanographic stations.

### Temperature-Salinity (T-S) Curves

The T-S curves are useful in detecting possible errors in the determination of temperature and salinity, water masses and their characteristics, and the variation of temperature and salinity with depth. To plot temperature salinity relationships, the U.S. Naval Oceanographic Office uses the Temperature-Salinity Plotting Sheet, NHO-3166/59 (figure 58). This graph indicates density values for the range of temperature and salinity it covers.

Using the data for observed temperature and salinity values, plot each point and draw a smooth curve through the plotted points. When interpolated values at standard depths have been determined, indicate the points on the T-S curve and enter the standard depth to the right of the curve.

You may interpolate oceanographic data values of temperature, salinity, dissolved oxygen, sound velocity, and density ($\sigma_t$) for standard depths from plotted observed value curves, or you may obtain interpolations by electronic computer data analysis.

To find an interpolated value on the Oceanographic Station plotting sheet, simply locate the

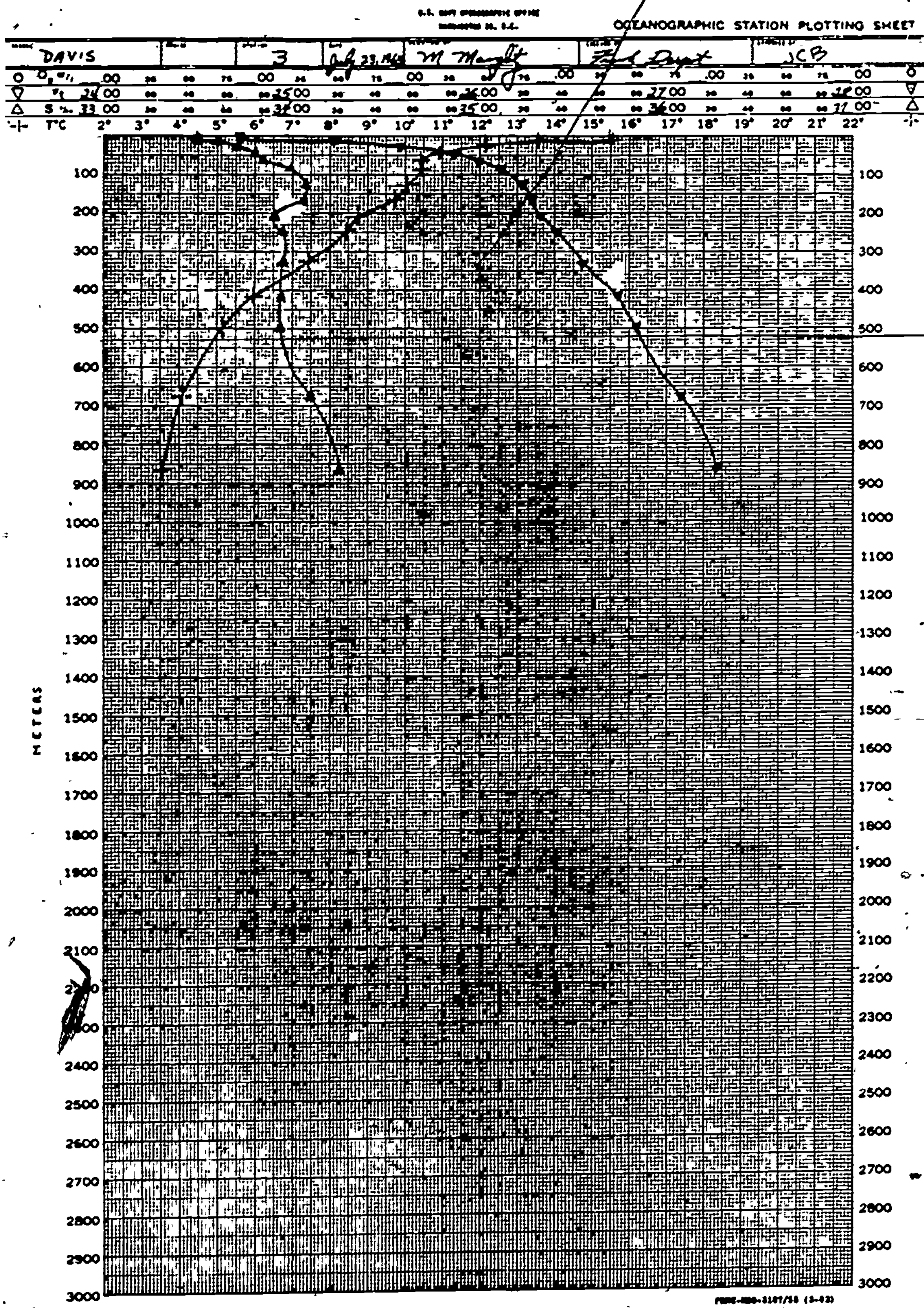


Figure 57.— Oceanographic Station Plotting Sheet.



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intersection of the curve and the horizontal line which represents the desired standard depth; then read the corresponding value at the top of the graph. Enter interpolated values on the E-Sheet.

To obtain interpolated values by electronic computer data analysis, CODE THE DATA on the Physical and Chemical Data Form for Oceanographic Stations, NODC-EXP-3167/25 (3-64), (figure 59), and forward the form to the National Oceanographic Data Center (NODC). Code the data in accordance with Publication M-2, Processing Physical and Chemical Data from Oceanographic Stations, National Oceanographic Data Center. After the data are computer-processed by NODC, a computer listing (figure 60) will be available, and the data will be on file on punchcards for use in computer analysis programs.

A comparison of interpolated values taken from the graphs and the computer listing indicates that slight differences may exist because of the choice of the curves used in the determinations.

Horizontal Charts and Vertical Sections

The presentation of processed physical oceanographic data in graphical form for analysis and publication is most useful, since the oceanographically important time and space variables can be used as one of the coordinates. The construction of horizontal and vertical sections requires proper selection of units and spacing of values to bring out the desired oceanographic variables. Another precaution is to maintain the consistency between graphs and quantities of different types.

Horizontal Charts.— Horizontal charts are used to show the geographical variation in oceanographic quantities by contours of equal values.

A standard contour interval cannot be established to meet all requirements. In mid-latitudes the open sea temperature sections are usually plotted by whole degrees, salinity by 0.5°/₀₀, oxygen by 0.5 ml/L, and $\sigma_t$ by 0.5 intervals. In extreme latitudes, different seasons, and inshore areas, these intervals must be modified to bring out the desired features.

In any one study, the contour interval should be consistent throughout. The contour spacing should normally be equal, but if a particular feature requires intermediate contours, they must contrast with the standard contours by different weight or style of line.

When a section is made up of a large number of lines, it is desirable to make every fifth line heavier than the others. In this way individual contours may be followed more easily by reference to the heavier line (see figure 61).

Charts showing the dynamic topography of one isobaric surface relative to another are typical of one method of presenting scalar oceanographic data. You may obtain a three-dimensional picture of relative currents from a series of such charts, each showing the dynamic topography of a different isobaric surface relative to the same reference surface.

You can also obtain a similar three-dimensional picture from a series of level charts, on which the intersections of isobaric surfaces are plotted. The methods are entirely comparable, and you may use either to depict the fields of any scalar quantity. This latter method of showing isopleths of constant temperature, salinity, etc., on equilevel surfaces is most popular because of its ease of construction.

Vertical Sections.— In vertical sections the horizontal scale is frequently distance or time. In either case the scale should be continuous, regardless of the spacing of plotted values. The vertical scale, which represents a depth in the sea, should normally be continuous. In rare instances, if the surface features are to be emphasized or in cases where variables become nearly constant at great depths, you may change the vertical scale at some depth, such as 1,000 meters and compress the deeper scale. Conspicuously mark the break in scale.

Vertical sections usually depict variables along a straight line of stations. If the stations are not arranged along a straight line, you should make clear the direction of the section. You may accomplish this by an inset horizontal chart with reference (station) numbers on both the inset and the horizontal chart. Another means of representing a change in direction of vertical sections is by changing the direction of the plotted section on the page and utilizing projection techniques. This procedure, however, gets involved if the section changes direction

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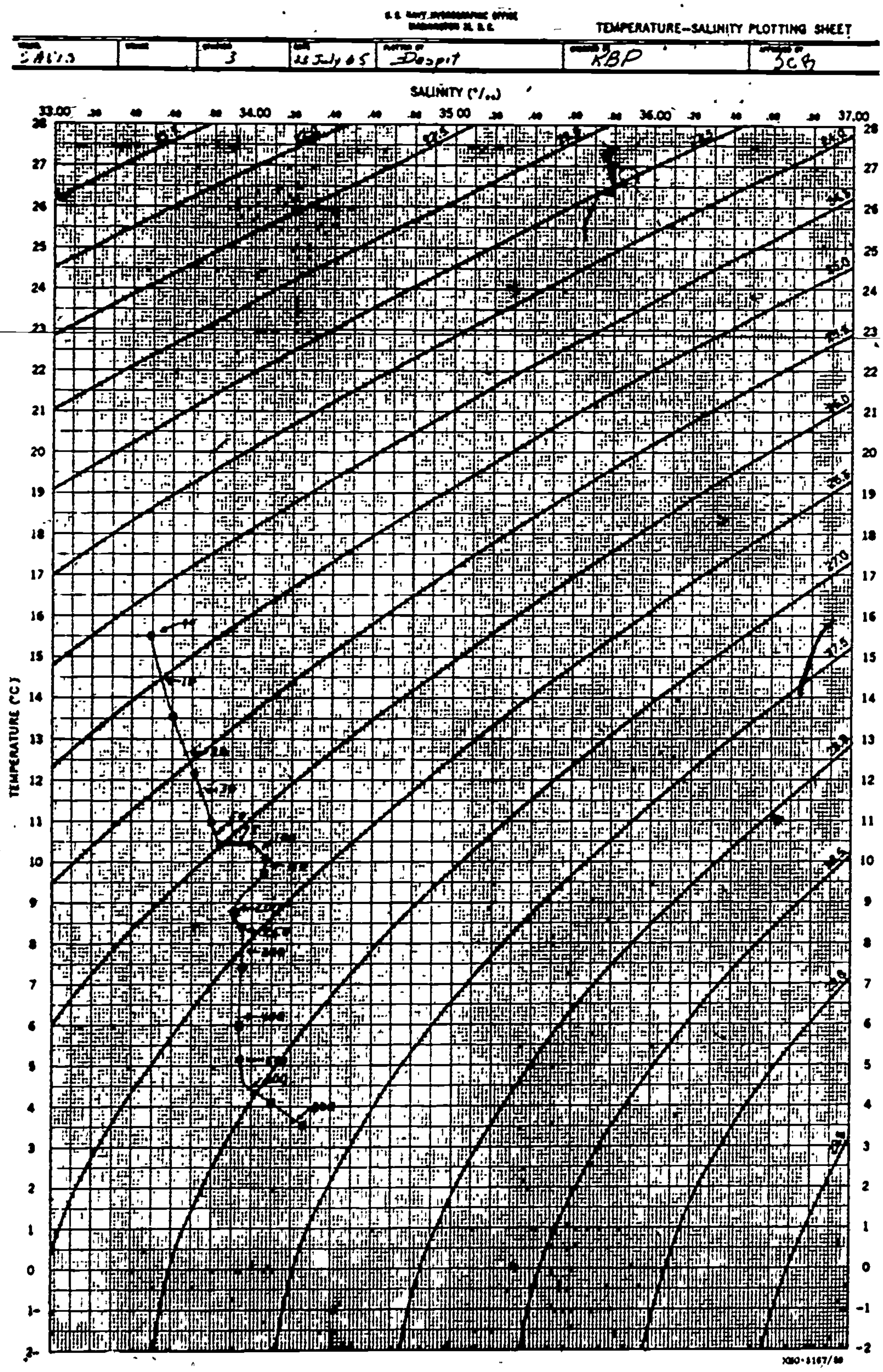


Figure 58.— Temperature-Salinity Plotting Sheet.



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PHYSICAL AND CHEMICAL DATA FORM
FOR OCEANOGRAPHIC STATIONS

NATIONAL OCEANOGRAPHIC DATA CENTER
WASHINGTON D C 20390

| 3 | 1 | | | 4 | 2 | 5 | 4 | - | N | 1 | 6 | 7 | 1 | 0 | - | W | | | | 6 | 5 | 0 | 7 | 2 | 3 | 2 | 3 | 3 | | | | 0 | 0 | 3 | 4 | 7 | 5 | 5 | 0 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

| 1 | 6 | | | | | 0 | 8 | 2 | | 0 | 8 | 0 | 9 | 3 | 1 | 3 | 1 | 9 | 0 | 1 | 7 | 0 | X | 5 | 6 | 8 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

COUNTRY: USA
INSTITUTE: NAVOCEANO
VESSEL: DAVIS

| | | | | | |
|---|---|---|---|---|---|
| 240 | 0000 | 1549 | 3349 | | 3 |
| | 0008 | 1550 | 3349 | | |
| | 0012 | 1356 | 3360 | | |
| | 0025 | 1213 | 3371 | | |
| | 0042 | 1096 | 3380 | | |
| | 0063 | 1043 | 3384 | | |
| | 0083 | 1042 | 3399 | | |
| | 0125 | 1008 | 3407 | | |
| | 0166 | 0974 | 3406 | | |
| | 0207 | 0875 | 3391 | | |
| | 0248 | 0841 | 3395 | | |
| | 0331 | 0742 | 3395 | | |
| | 0415 | 0598 | 3394 | | |
| | 0499 | 0516 | 3394 | | |
| | 0674 | 0408 | 3410 | | |
| | 0866 | 0352 | 3426 | | 3 |

Figure 59.— Physical and Chemical Data Form for Oceanographic Stations.

NODC STATION DATA

| REFERENCE | | SHIP CODE | LATITUDE ° ' 1/10 | LONGITUDE ° ' 1/10 | [illegible] | MARSDEN SQUARE | | STATION TIME (GMT) | | | YEAR | ORIGINATOR'S | | DEPTH TO BOTTOM | MAX DEPTH OF SAMPLES | WAVE OBSERVATIONS | | | | [illegible] | CLOUD CODES | | | NODC STATION NUMBER |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | [illegible] | | | | | 10° | 1° | [illegible] | DAY | HR 1/10 | | CRUISE NUMBER | STATION NUMBER | | | DIR | HGT | PER | SEA AMT | | TYPE | AMT | | |
| 31 | 589 | CD | 4254 N | 16710 W | | 161 | 27 | 07 | 23 | 233 | 1965 | | 003 | 4755 | 09 | 08 | | | 2 | X5 | 6 | 8 | | 0003 |

| WATER | | WIND | | BAROMETER (mbs) | AIR TEMP °C | | VIS. CODE | ADD'L OBS. | SPECIAL OBSERVATIONS |
|---|---|---|---|---|---|---|---|---|---|
| COLOR CODE | TRANS. (m) | DIR. | SPEED OR FORCE | | DRY BULB | WET BULB | | | |
| | | 08 | S09 | 313 | 19 | 17 | 6 | 16 | |

| [illegible] (1/10) | CAST NO | CARD TYPE | DEPTH (m) | T °C | S ‰ | SIGMA—T | SPECIFIC VOL. ANOMALY—X 10^5 | ΣΔD DYN. M. X 10^3 | SOUND VELOCITY | $O_2$ ml/l | $PO_4$—P µg-at/l | TOTAL—P µg-at/l | $NO_2$—N µg-at/l | $NO_3$—N µg-at/l | $SiO_4$—Si µg-at/l | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | STD | 0000 | 1549 | 3349 | 2472 | 0032319 | 0000 | 15071 | | | | | | | |
| 240 | | OBS | 0000 | 1549 | 3349 | 2472 | | | 15071 | | | | | | | |
| 240 | | OBS | 0008 | 1550 | 3349 | 2472 | | | 15073 | | | | | | | |
| | | STD | 0010 | 1444 | 3355 | 2500 | 0029741 | 0031 | 15040 | | | | | | | |
| 240 | | OBS | 0012 | 1356 | 3360 | 2522 | | | 15012 | | | | | | | |
| | | STD | 0020 | 1263 | 3367 | 2546 | 0025378 | 0059 | 14983 | | | | | | | |
| 240 | | OBS | 0025 | 1213 | 3371 | 2558 | | | 14967 | | | | | | | |
| | | STD | 0030 | 1172 | 3374 | 2568 | 0023234 | 0083 | 14954 | | | | | | | |
| 240 | | OBS | 0042 | 1096 | 3380 | 2587 | | | 14930 | | | | | | | |
| | | STD | 0050 | 1070 | 3382 | 2593 | 0020962 | 0127 | 14922 | | | | | | | |
| 240 | | OBS | 0063 | 1043 | 3384 | 2599 | | | 14915 | | | | | | | |
| | | STD | 0075 | 1042 | 3394 | 2607 | 0019632 | 0178 | 14918 | | | | | | | |
| 240 | | OBS | 0083 | 1042 | 3399 | 2611 | | | 14920 | | | | | | | |
| | | STD | 0100 | 1028 | 3403 | 2617 | 0018782 | 0226 | 14918 | | | | | | | |
| | | STD | 0125 | 1008 | 3407 | 2623 | 0018209 | 0272 | 14915 | | | | | | | |
| 240 | | OBS | 0125 | 1008 | 3407 | 2623 | | | 14915 | | | | | | | |
| | | STD | 0150 | 0995 | 3406 | 2625 | 0018093 | 0317 | 14915 | | | | | | | |
| 240 | | OBS | T0166 | 0974 | 3406 | 2628 | | | 14909 | | | | | | | |
| | | STD | 0200 | 0887 | 3392 | 2631 | 0017545 | 0407 | 14881 | | | | | | | |
| 240 | | OBS | T0207 | 0875 | 3391 | 2633 | | | 14877 | | | | | | | |
| 240 | | OBS | 0248 | 0841 | 3395 | 2641 | | | 14872 | | | | | | | |
| | | STD | 0250 | 0839 | 3395 | 2641 | 0016686 | 0492 | 14871 | | | | | | | |
| | | STD | 0300 | 0784 | 3395 | 2649 | 0015961 | 0574 | 14859 | | | | | | | |
| 240 | | OBS | 0331 | 0742 | 3395 | 2655 | | | 14847 | | | | | | | |
| | | STD | 0400 | 0619 | 3394 | 2671 | 0013901 | 0723 | 14810 | | | | | | | |
| 240 | | OBS | 0415 | 0598 | 3394 | 2674 | | | 14804 | | | | | | | |
| 240 | | OBS | T0499 | 0516 | 3394 | 2684 | | | 14785 | | | | | | | |
| | | STD | 0500 | 0515 | 3394 | 2684 | 0012723 | 0856 | 14784 | | | | | | | |
| | | STD | 0600 | 0447 | 3403 | 2699 | 0011342 | 0977 | 14774 | | | | | | | |
| 240 | | OBS | T0674 | 0408 | 3410 | 2708 | | | 14771 | | | | | | | |
| | | STD | 0700 | 0397 | 3412 | 2711 | 0010204 | 1084 | 14771 | | | | | | | |
| | | STD | 0800 | 0364 | 3421 | 2722 | 0009244 | 1181 | 14775 | | | | | | | |
| 240 | | OBS | T0866 | 0352 | 3426 | 2727 | | | 14781 | | | | | | | |

Figure 60.— Computer listing of oceanographic station data with template.

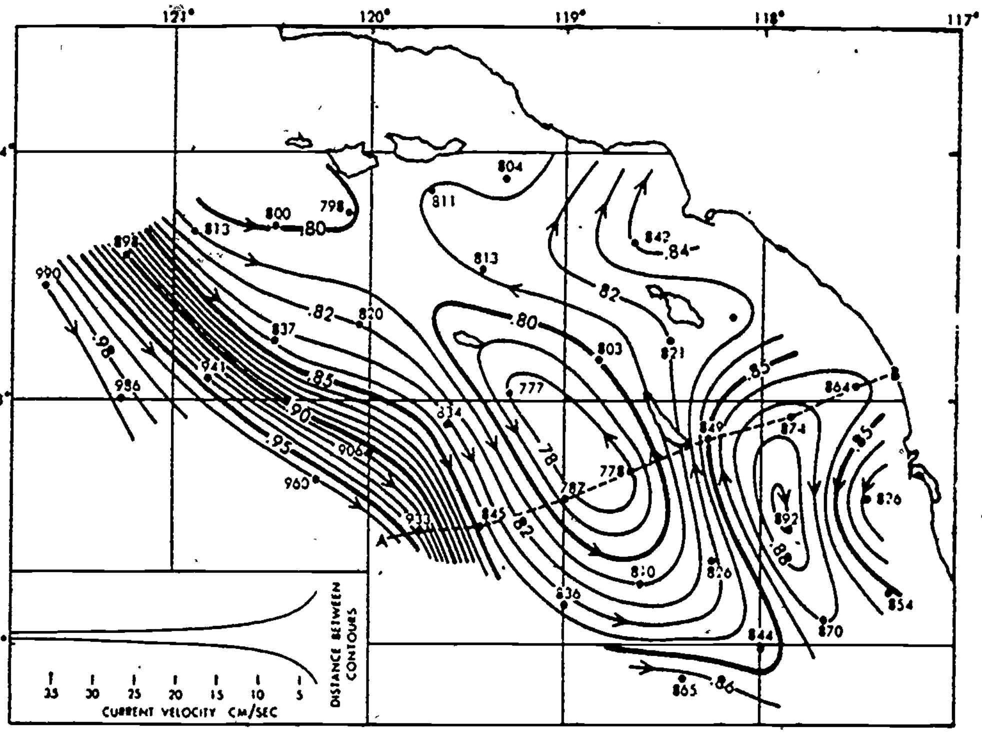


Figure 61.— Contours of dynamic height anomalies (dynamic meters) for surface over 500 decibars. Current direction is indicated by arrows on contours; velocity, by contour spacing using scale at lower left.

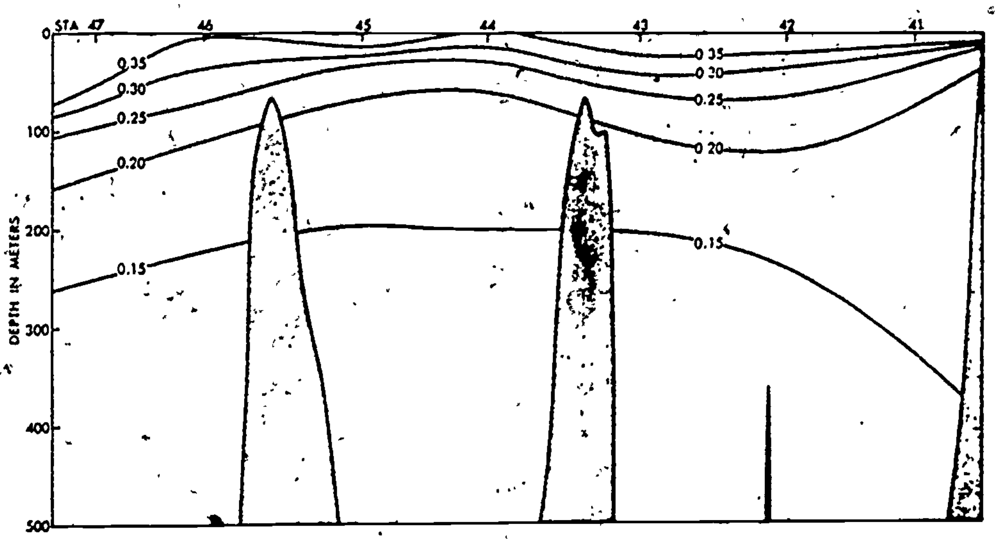


Figure 62.— Vertical section of $10^5\delta$.

several times. In illustration of the vertical section, figure 62 shows isopleths of constant specific volume anomaly, $\delta$, plotted along the section marked A—B on the chart of dynamic topography, figure 61. Figure 63 shows isotherms in the same section.

Both sections in figures 62 and 63, as well as figure 61, are based upon the same group of serial observations, and therefore must be drawn in such a way as to be consistent. This fact is obvious where the distribution of a single variable, such as pressure, is illustrated in more than one way. It is less obvious where the distributions of different variables from the same data are illustrated, and it is therefore important to bear in mind the relations between variables. As has been shown above, the slopes of isobaric surfaces are closely related to the distribution of mass.

Surfaces of constant value of all the mass variables slope in the same direction in the sea, and, except for $\sigma_t$ which represents density reduced to a common pressure, form a single family of surfaces. However, specific volume and specific volume anomaly increase upward; density and $\sigma_t$ increase downward. Since the mass field is largely dependent upon temperature, isothermal surfaces tend to slope in a similar manner, and currents may usually be deduced from charts of isotherms.

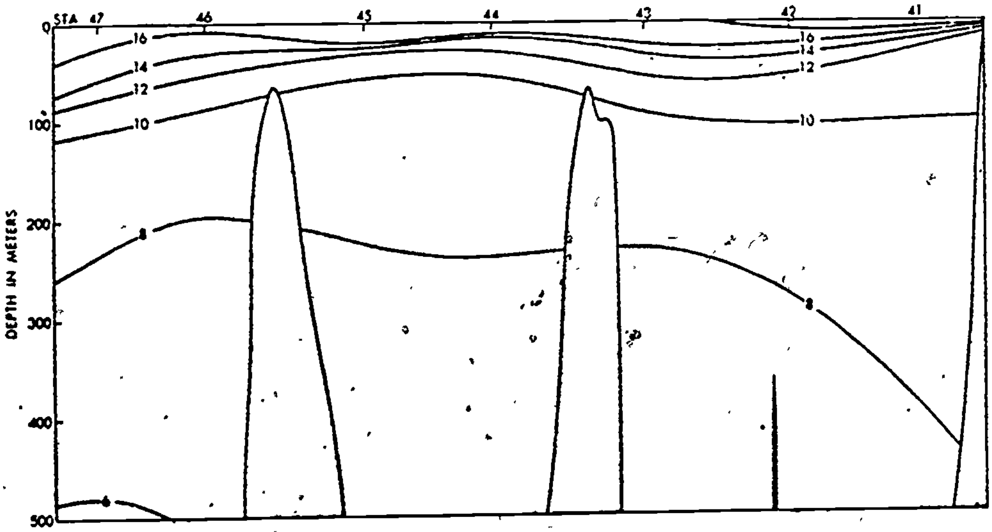


Figure 63.— Vertical section of temperature.