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ABSTRACT

Designed for use in Pennsylvania secondary school science classes, this guide is intended to provide fundamental information in each of the various disciplines of the earth sciences. Some of the material contained in the guide is intended as background material for teachers. Five units are presented: The Earth, The Oceans, The Space Environment, The Atmosphere, and The Exploration of Space. The course is organized so that students proceed from the familiar, everyday world to the atmosphere and the space environment. Teaching geology in the fall takes advantage of weather conditions which permit field study. The purpose of the Earth and Space Science course is to encourage student behaviors which will be indicative of a broad understanding of man's physical environment of earth and space as well as an awareness of the consequences which could result from changes which man may effect. (PEB)

EARTH AND SPACE SCIENCE

A Guide For Secondary Teachers

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COVER PHOTOGRAPHS

Rocket Launch—The Apollo 15 Saturn V space vehicle carrying astronauts David R. Scott, Alfred M. Worden and James B. Irwin lifts off to the Moon at 9:34 A.M., EDT, July 26, 1971 from the Kennedy Space Center's Launch Complex 39A. NASA Photo.

Syncline—This striking example of a syncline is exposed along I-81 in Schuylkill County. Photo by W. Bolles.

Solar Eclipse—This photograph of a total solar eclipse was taken March 10, 1970 near Chesapeake, Virginia. Photo by W. Bolles.

Hailstone—Cross-section of a hailstone under polarized light. National Center for Atmospheric Research, Boulder, Colorado.

Catamaran—The Marine Science Consortium Catamaran operating out of Lewes, Delaware. Grant Heilman Photo.

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Preface

This teaching guide is not intended as a course of study to be taken by the teacher and taught to students, but rather, as a true guide which places emphasis upon the basic fundamentals in each of the various disciplines of the earth sciences. Some of the material in the guide is for the background information of the teacher and is not necessarily appropriate for secondary school students.

The committee which produced the guide feels that the Earth and Space Science course has been, and should continue to be, a course for all students. Throughout the guide every attempt has been made to indicate the relevance to man of the material being studied. The content of the course, however, must be adapted to the ability levels of the students if any semblance of interest in science is to be achieved. Nothing is ever gained by teaching a too rigorous course which is beyond the grasp of most students and then basing success on the fact that a high percentage of pupils are unable to pass the course.

Experience has shown that the grade placement of the Earth and Space Science course need not be fixed at any particular level. Schools have successfully taught the course as a preparatory offering, laying the foundation for more advanced courses, and as a terminal science course for the general student. A number of schools also offer Earth and Space Science II as an advanced course in the junior or senior year.

The order of the units may be varied at the discretion of the teacher; however, the sequence of the units in the guide is based upon the assumption that students should begin their study of the earth-space sciences with the familiar, everyday world which they see around them and then proceed to the less tangible areas of the atmosphere and the space environment. This procedure also allows the teaching of geology in the fall, which is the most desirable time for field trips; Oceanography next, in the hope that this rapidly developing and important discipline will be included instead of omitted as is often the case when it is scheduled last; astronomy in the winter, when darkness comes early and the familiar winter constellations are in the night sky; meterology in the spring, at a time when weather patterns show a great variety of changing conditions; and the exploration of space last because of its interrelationships with all the other earth sciences which have been previously taught.

Recommendations as to the time to be spent on any one unit would be extremely difficult due to the variation in length of class periods, the number of times the class meets per week, the extent of laboratory exercises, the ability levels of different groups of students and the training and interests of the teachers. It is strongly recommended, however, that no single discipline of the earth sciences be given a disproportionate share of time and that no discipline be omitted entirely. The quantity of material in the guide is such that only the most advanced classes will be able to proceed through all of it in a single school year. The teacher must exercise judgment as to what is essential with respect to the objectives of the course, for students of lesser ability. However, a portion of each of the units should be taught in each class.

There has been no attempt to approach the comprehensiveness of the materials produced by the National Science Foundation funded science projects such as PSSC, CHEMS, CBA, BSCS and ESCP. It is hoped, however, that this guide will suggest some additional activities and approaches which will make it a useful additional reference for both teachers and students as they explore the realm of the earth sciences.

John C. Pittenger

Introduction

GENERAL PURPOSE OF THE COURSE

The practical application of the basic concepts in the earth sciences is of vital importance to everyone if mankind is to continue to enjoy an environment which will sustain life on this planet. If man is to survive on earth, major problems such as air pollution, water pollution, thermal pollution, the disposal of industrial and human wastes, the proper handling of pesticides and wise conservation of natural resources must receive serious attention. All citizens must be aware of the necessity for directed scientific investigation of these problems if we are to solve, or alleviate, the conditions which, if permitted to continue, could mean the end of human life on the planet Earth.

With the increased exploration of space, and the placing of men on the moon, it has become vitally important that all students know more about the earth on which they live and the realm of space toward which their lives will become increasingly oriented.

The purpose of Earth and Space Science is to bring about those student behaviors which will be indicative of a broad understanding of man's physical environment of both earth and space together with an awareness of the consequences which could result from changes which man may effect.

THE SCOPE OF THE EARTH AND SPACE SCIENCES

Obviously, Earth and Space Science as a distinct discipline does not exist. The specific scientific fields of geology, oceanography, astronomy, and meteorology all deal so closely with the immediate physical environment of man that they readily lend themselves to an interdisciplinary course of study on the secondary school level. An excellent example of the interdisciplinary relationships would be the Hydrologic Cycle. Water from an ocean current (oceanography) is evaporated into the atmosphere (meteorology). Blown over the land the moisture laden air condenses, falls as rain, and in flowing in a stream to the sea, erodes the land (geology).

The earth and space sciences also rely heavily upon basic concepts of physics, chemistry and biology. In replacing general science this course places new emphasis upon the principles of the basic sciences. For example, the ability to identify fossils requires a knowledge of biology, meteorology is primarily concerned with the physics of the atmosphere and oceanography involves much chemistry, physics and biology as well as geology. In addition, the tremendous accomplishments of the space program show excellent interrelationships among all the scientific fields.

Teachers are urged to stress the interdisciplinary nature of the earth and space sciences to the best of their ability and to the degree that their students can understand these interactions. While student involvement is certainly recommended, caution is also suggested in regard to laboratory exercises that consume large amounts of time and have questionable educational outcomes.

The posing of pertinent questions, and the ensuing class discussion, also involves the student and is an excellent teaching method. The guide contains many questions which can be used to start students thinking and moving toward greater understanding of concepts they are studying. The questions are designed to arouse student interest by creating a desire to know more about their environment, as well as to increase their powers of observation.

As long as teachers must deal with wide range of student abilities the stimulation of interest is a prime concern. To achieve a degree of success the teacher may have to present a less quantitative, less complete, less integrated course. However, when a course is presented on too high a mathematical, conceptual or verbal level the interest of the student is quickly killed.

Another important phase of the course is field trips to localities of geologic interest, weather stations, observatories, planetaria and marine science centers. Such trips are extremely valuable in stimulating and maintaining student interest in addition to the experiences which result in greater understanding of a particular field of knowledge.

INDIVIDUAL AIMS OF THE COURSE

A. Teachers should insure that the basic principles of geology, oceanography, astronomy and meteorology are learned and the interrelationships of these fields understood.

B. Students should become aware of the intellectual challenge, and the demand for trained personnel, in various earth and space sciences.

C. Students should be guided toward applications of the concepts and principles learned to the interpretation of environmental problems and phenomena encountered in daily life.

D. Teachers should encourage students to go beyond memorized descriptions of phenomena and to probe for explanations.

E. Students should develop a general understanding of the vital economic and deep esthetic significance of their physical environment together with an attitude of responsibility for natural resource utilization and wise use of land.

F. Students should have the opportunity to work individually upon a problem which will give them experience in the utilization of the scientific method of problem solving.

G. Students should be made to realize that science is not a static body of knowledge, but is constantly changing as new facts are discovered.

APPROACH

The guide treats the areas of Earth and Space Science by beginning with the obvious and seeking answers through a series of pertinent questions. Emphasis is placed upon the relevance to man of the material being taught. This new format might be referred to as a "Man-Nature-Problem Solving" relationship. The observable phenomena and recognizable problems which confront man in his physical environment form the initial introduction and impart interest to the development of various topics throughout the guide. The student thus approaches this study at his or her own intellectual level of interest. The ability of the student should, in part, determine the degree and depth of refinement the teacher attempts to achieve in dealing with any particular topic.

When any new course is initiated, a phase of the development must include, on the part of the teacher, a review of the scope of the disciplines involved in order to decide what objectives should be developed and what useful information should be learned by the student. Once this is determined the most effective teaching methods must be decided upon. This guide is intended as an aid for teachers in the carrying out of the above processes.

The Earth

INTRODUCTION

The importance of other earth science fields and their interdisciplinary nature can be illustrated in many ways, one of which is weathering. This process not only involves geology with the parent material, but meteorology with the mechanisms of climate change and chemistry with the molecular changes that result in soil genesis.

Geology's importance to mankind is often overlooked in the teaching of this course, but it is so obvious and necessary that it should be brought to the students' attention whenever practical. How landforms and rivers often dictate transportation routes, how cities develop at junctions of these routes and near mineral resources, and how these mineral resources themselves affect man's daily life should be emphasized.

FIELDS OF STUDENT INVESTIGATION

The Landscape

Rocks and Minerals

Weathering

Mass Wasting

The Work of Ground Water

The Work of Streams

The Work of Glaciers

Structure of the Earth

The Geologic History of the Earth

Environmental Geology and Man

THE LANDSCAPE

It is possible to introduce students to geology in a number of different ways. Because the landscape and the landforms comprising it are the part of the earth most familiar to students, we suggest that the teacher use the different landforms students can see around them as the vehicle for introducing them to geology. The following sequence of questions about landforms leads from a description of what the student sees to a consideration of the geologic reasons for the difference between them. In this one example, many of the fields of geology are introduced.

Major Topics Explored

Surface of the Earth

Different Landforms

Landform Characteristics

Looking out the school room window or driving through the country, what does the surface of the earth look like?

Answers pointing out the irregularity of the surface of the earth should be encouraged; also, the idea that these irregularities give rise to landforms.

What different landforms have you seen locally or in travelling?

Students should give the names of a number of landforms such as hill, valley, plain, plateau, mountain, beach, or sand dune (see Plate 1-1). Definitions should be asked for. Clarity and precision of observation should be stressed as an important aspect of science. The location of different landforms should be emphasized.

Plate 1.1 Brush Valley in Centre County. Typical scene in the Valley and Ridge Physiographic Province.

How do landforms differ from one another? Are there different scales or magnitudes of landforms?

Through these questions, a realization that there is a great variation in the size of landforms from mountain chains, plains and plateaus on the one hand to valleys (Plate 1-2), individual hills, floodplains (Plate 1-3), or offshore bars on the other. The discussion should begin to move toward a consideration of the reasons for these differences.

Plate 1.2 Folded mountains at Cowans Gap State Park, Fulton County.

Plate 1.3 Appala: :n Plateau, Clearfield County, along Interstate 80.

Why do landforms differ from one another? Why is the surface of the earth not monotonously the same everywhere?

Since the answer to these questions is geological, the questions should lead directly to a consideration of the different fields of geology. Differences in the landforms are due to differences in:

a. Rock type—Mineralogy and Petrology

b. Active geological processes—Weathering, Mass Wasting, etc.

c. Rock structure—Structural Geology, Tectonics

d. Time—Historical Geology

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ROCKS AND MINERALS

Rocks and minerals are the building blocks of which the earth is constructed. The treatment of rocks and minerals in this section is in keeping with the treatment of the guide by beginning with the obvious and seeking answers through questions.

Major Topics Explored

- Rocks
  - Resistance
  - Composition
  - Texture
  - Methods of Formation
- Minerals
  - Properties
  - Structure
  - Benefits to Man

Why do rocks vary in resistance?

Every student either consciously or unconsciously has noticed that there are high places such as hills and mountains and low places such as valleys. A discussion based on this idea of uneven topography may be a way of drawing the student's awareness to the differences in the resistances of rock in particular, and to the differences in rock in general.

If the teacher wishes she or he may start with the following question:

Can you name some building material derived from rocks?

This introduction might be most appropriate in urban schools where the students are more familiar with buildings and their materials than they are with a scenic landscape. A class discussion on building materials will undoubtedly bring forth some of the following materials with their sources:

brick—clay and/or shale
glass—quartz sandstone (Plate 1.4)
cement—limestone
plaster—gypsum
steel—iron ore

Plate 1.4 High-silica sandstone being quarried for glass sand near Mt. Union, Huntingdon County.

building stones—limestone, granite, marble, quartzite (Plate 1.5)

Plate 1.5 Quartzite quarried for building stone at Avondale, Chester County.

The list can become lengthy and you may have to limit the discussion. It may be advisable to direct the discussion toward such materials as bricks and glass that are produced from silicates, as a lengthy treatment of the silicates is given in this section.

How do rocks differ?

There are numerous ways in which rocks differ from each other, and the way or ways in which the rocks in your particular locale vary would be a logical way to begin the study.

This might be a good time to conduct a field trip in which the students may collect local rocks to examine in the classroom. If a field trip is impractical, you might collect samples of local rock for the students to examine.

Hand lenses (3x to 10x) or low power microscopes (5x to 20x) would be beneficial for the students to examine the specimens. Through their own discovery, or through class discussion, the students should recognize differences such as color and texture.

Are all rocks formed in the same manner?

Either by independent study or class discussion the students should conclude that rocks are formed in different ways. The student should be made aware of the three methods of formation. The methods of formation along with representative rocks which the students might examine are as follows:

1. Sedimentary—formed from accumulations of sediments, both clastic and chemical.

   a. clastics: conglomerate, breccia, shale, sandstone, siltstone (Plate 1.6)

   b. precipitates and evaporates: limestone, halite and gypsum

   c. organic: coquina and coal (peat, lignite, bituminous)

   Film: EBF-AGI 16 mm. *Rocks that form on the earth's surface*

2. Igneous—formed from the cooling of a magma (melted rock).

   a. small crystal: rhyolite, trachyte, andesite and basalt

   b. large crystal: granite, syenite, diorite and gabbro

   c. combination of small and large crystals: any of the porphyrys

In addition to the above, samples of vesicular basalt, obsidian, tuff, scoria and pumice would help broaden the scope of discussion on the origin of these rocks.

Plate 1.6 Red conglomerate exposed in northeast corner of French Creek State Park, Chester County.

3. Metamorphic—formed from the heat and pressure that results from diastrophism and volcanism, without melting.

   a. banded: any gneiss (Plate 1.7)

   b. layer-like: any schist or phyllite (Plate 1.8)

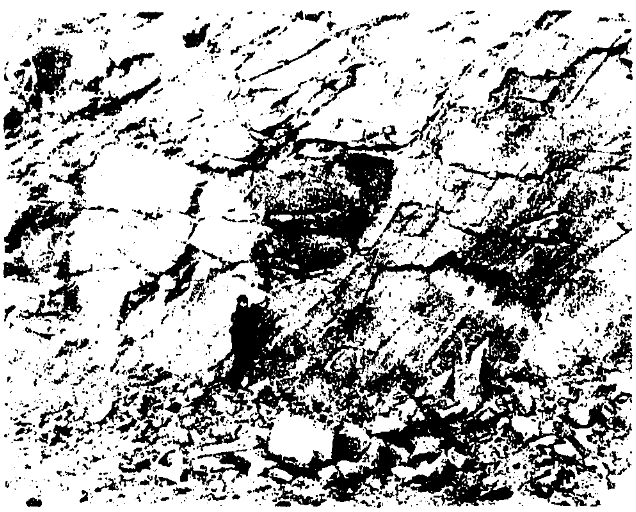

Plate 1.7 Gneiss quarried at Glen Mills, Delaware County.

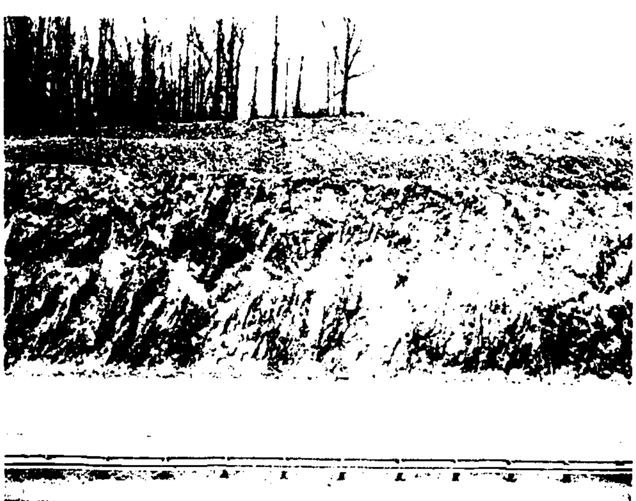

Plate 1.8 Schist in road cut along I-83, York County.

   c. uniform: quartzite and marble

   d. plate-like: slate

   e. organic: anthracite coal

   Film: EBF-AGI 16 mm. *Rocks that form underground*

A suggested method to introduce students into kinds of rocks would be to give the students a group of random rocks labeled with letters or numbers for ease in discussion. The students should then decide two things. One, what criteria should be used to separate them and two, which rock formed in a similar manner?

SUGGESTION: Another exercise in showing the relationship between rate of cooling and crystal size in igneous rocks is as follows:

Have the students place a small quantity of salol (phenyl salicylate) in a watch glass or other small container and heat the salol until it just melts. The student should then remove the container and let it cool at room temperature. In a few minutes crystals should be seen forming, if not, add a crystal or two of salol to the melt to start the action. After the first melt has crystallized, have the student remelt it as before only hasten the cooling by placing the container on ice water. The crystals from the first melt should be much larger than those from the second melt. This procedure can also be carried out in a Petrie dish on the stage of an overhead projector.

Are all rocks derived from the same materials?

When the students detect particles within the rocks that have different colors, sizes and shapes, it is hoped that they will conclude that these different appearing particles are composed of different materials. It should also be emphasized that composition is one of two main methods for classifying rocks.

How do these materials (minerals) differ from each other?

The learning of mineral properties may be accomplished by either having the students learn the properties from a text and then applying them to mineral samples, or by having the students study an assortment of minerals exhibiting numerous properties and identifying these properties for themselves, followed by class discussion to tie the loose ends together. For the identification of some of the common minerals through their properties, see the identification key on the following pages.

What produces different properties in minerals?

The students should not find it difficult to understand how chemical composition (different elements) can produce different properties in minerals. Molecular structure (how atoms fit together), however, may not be so obvious to them. The next four topics may be used, if desired, to help create an understanding of molecular structure.

Why use models?

Here is an opportunity early in the course to develop an appreciation for the usefulness of models (Fig. 1.1). Here in particular, models help us to visualize how atoms, that would otherwise be too small to see, fit together to form molecules.

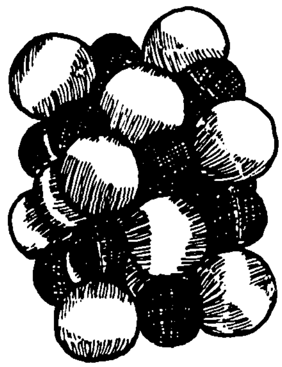

Figure 1.1
Halite crystal model.

Painting the spheres can be done simply by placing a number of spheres in an empty shoe box and spraying a light coat of paint onto the spheres. Next place the lid on the box and shake the contents. Remove the spheres for drying.

Why are different size spheres necessary?

Even though atoms are so small that they are measured in angstrom units, students should not be left with the idea that atoms are all the same size, or that because they are so small that any difference in size is meaningless. It is primarily this difference in size that dictates how the atoms will pack together.

Most minerals are silicates; what is a silicate?

Before discussing this topic, it might be advisable to review the states of matter with the students. The students may find it difficult to comprehend how oxygen, which they normally think of as a gas and a vital part of the atmosphere, can make up 46.6 per cent of the weight and 93.8 per cent of the volume of the earth's crust. Most of the minerals of the earth are silicates which accounts for the large percentage of oxygen present in the crust. Silicates are a large group of minerals that contain silicon and oxygen along with other elements in a variety of combinations. For this reason the molecular structure of the silicates is presented next.

How and why are silicates different from each other?

This topic can be presented either by a demonstration, in which you would have to proceed very slowly to insure student comprehension, or by permitting the students to work in groups of two or three. If sufficient time and materials are available the second method is recommended. Before beginning this exercise, the students should have a general knowledge of atomic structure and that bonding forces which hold atoms together are determined by the charge (valence) of the atoms and the distance between them, which is dictated by the size of the atoms. In assembling the different silicate models it should be stressed that the availability of silicon and oxygen will determine the structure of the minerals. As each model is made, *it should be brought to the attention of the students that some properties such as shape, cleavage and hardness are largely determined by the molecular structure.*

Probably the most logical place to begin constructing silicate models is with the silicon-oxygen tetrahedron (Figure 1.2). This molecule is the least complex of the silicates and can be represented by the mineral olivine. This mineral is typical of minerals that form under conditions of abundant oxygen. The oxygen spheres should be from three to four times larger than the silicon spheres. Four of the oxygen (larger) spheres will fit together nicely to give an external form of a tetrahedron, as shown in the figure below. By squeezing a silicon (smaller) sphere into the center of the tetrahedron, between the atoms of oxygen, a silicon-oxygen tetrahedron is produced. Since the silicon atom has a +4 valence and each of the four oxygen atoms has a –2 valence, the tetrahedron as a whole will have a –4 charge. This charge must be neutralized by cations that are available such as iron, magnesium, calcium, potassium, etc. The individual tetrahedron link together by sharing cations, and as a result *this group of silicates usually exhibits poor or no cleavage.* Because the oxygen atoms fit together so tightly in each tetrahedron, *this group also tends to have rather hard minerals.*

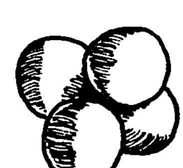

Figure 1.2 SiO_4 Tetrahedron.

If two similar tetrahedra are joined together by removing one oxygen from one of the tetrahedron and each of the tetrahedron share one oxygen atom, as shown in Figure 1.3, it becomes apparent that less oxygen atoms are required to produce a structure of this type. This type of silicate may be produced if oxygen atoms become less plentiful than in the previous type. This method of joining tetrahedra together results in a smaller unsatisfied charge in the molecule, thereby requiring fewer cations. Atoms may link together indefinitely to form a zig-zag pattern. Molecules formed this way are called single chain silicates, of which the pyroxene group of minerals is representative.

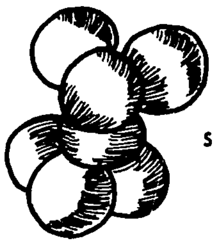

Figure 1.3
Single chain silicate.

Two single chains can be joined together, by further sharing, to produce a double chain (Figure 1.4). Double chains result in increased sharing of oxygen atoms thereby requiring less of them. As was pointed out before, the cation requirement is also reduced.

The mineral hornblende is typical of this group. *Looking at the models of these last two groups from each dimension gives a good impression of the crystal shapes and cleavage planes of these minerals.*

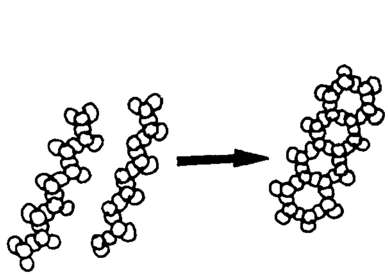

Figure 1.4 Single to double chain.

A lateral sharing of chains can be continued in two dimensions to produce sheets (Figure 1.5). No doubt many of the students will be familiar with the minerals of this group, which are the micas (Plate 1.9.). *The unusual cleavage of the micas should be easily understood from the sheetlike appearance of the model.* These sheets are held together so poorly by potassium ions that *the sheets can be peeled apart with a finger nail.*

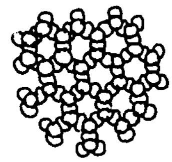

Figure 1.5
Sheet.

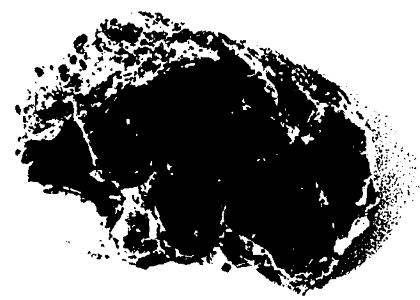

Plate 1.9 "Books" of muscovite; found near West Chester, Chester County.

Finally the point may be reached where all of the oxygen atoms are shared resulting in a stable mineral with no surplus charge to be satisfied with cations (Figure 1.6). In other words this mineral may be all silicon and oxygen. The cost representative mineral from this group is quartz which because of *its tight packing tends to be one of the most resistant minerals in nature* (Plate 1-10).

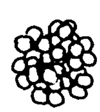

Figure 1.6
Complete sharing.

Plate 1.10 Quartz Crystals collected near White Haven, Luzerne County.

What relationship, if any, exists between the properties and molecular structure of minerals other than the silicates?

The dependency upon structure of some important properties such as crystal shape, cleavage and hardness as shown by the silicates, is also true for the other groups of minerals such as the sulfides, oxides, carbonates, sulfates, etc. Students should examine samples of halite, calcite, gypsum (selenite), fluorite and galena.

What benefits are derived from the knowledge of rocks and minerals?

If this unit were introduced as mentioned under the topic "Name some building materials derived from the rocks of the earth," then a summation based on this earlier discussion would complete the unit.

If any other method of introducing rocks and minerals has been used, it would be beneficial to enter into a discussion of the student's environment based on man's technology and use of earth materials. In addition to the minerals mentioned, other materials such as berylium, gold, silver, manganese, selurium and less common elements should be brought to the student's attention as they apply to space technology, communications, transportation and electronics.

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TABLE OF COMMON SEDIMENTARY ROCKS

	GRAIN SIZE	KIND OF FRAGMENTS USUALLY PRESENT	NAME
ROCK FORMED FROM FRAGMENTAL MATERIAL	Course (fragments easily visible)	Pebbles and boulders of hard, resistant rocks	CONGLOMERATE
	Medium (separate grains visible)	Quartz usually dominant, may have much feldspar, mica, and other minerals.	SANDSTONE
	Fine (separate grains not visible)	Chiefly clay minerals	SHALE
	MINERAL COMPOSITION :	CHEMICAL COMPOSITION	NAME
ROCKS FORMED FROM CHEM & BIOCHEM PRECIPITATES	Calcite (separate grains not visible)	Calcium Carbonate $CaCO_3$	LIMESTONE
	ROCKS FORMED FROM ORGANIC MATTER		COAL, LIMESTONE possibly some IRON ORE

TABLE OF COMMON METAMORPHIC ROCKS

	TEXTURE	MINERALS COMMONLY PRESENT	NAME
FOLIATED ROCKS	Medium-grained Uneven surfaces Grains visible	Mica or Hornblende Quartz Often Feldspar	SCHIST
	Medium-to-course Grained Banded Grains easily visible	Feldspar Quartz Mica or Hornblende	GNEISS
UNFOLIATED	Medium-to-course grained	Calcite	MARBLE
	Medium grained	Quartz	QUARTZITE

TABLE OF COMMON IGNEOUS ROCKS

CHEMICAL COMPOSITION	Silica High		Iron and Magnesium High	
COLOR	Light-colored Minerals Predominate		Dark-colored Minerals Predominate	
COURSE-GRAINED FINE	GRANITE RHYOLITE	DIORITE ANDESITE	GABBRO BASALT*	PERODITITE (very rare)
MINERAL COMPOSITION	QUARTZ	FELDSPAR		FERROMAGNESIAN MINERALS

IDENTIFICATION KEY FOR COMMON MINERALS

Group	Hardness	Cleavage	Properties	Mineral
NONMETALLIC DARK COLORED	Nail will not scratch. Scratches glass (hard).	Shows Cleavage or Parting	Black; pale green streak, hardness, 5-6; cleavage 2 surfaces almost at right angles	AUGITE (pyroxene)
			Black; pale green streak, hardness, 5-6; planes at about 60° and 120° cleavage 2	HORNBLENDE (amphibole)
			Light to dark gray; hardness 6; cleavage two directions almost at right angles. Sometimes shows *striations* on cleavage faces	PLAGIOCLASE
			Hexagonal (six-sided) crystals; hardness, 9: gray, brown, or blue-gray color,	CORUNDUM (corundum)
		No Cleavage	Red to red-brown; hardness, *6.5-7.5;* Equidimensional crystals	GARNET
	Nail will scratch. Does not scratch glass (soft)	Shows Cleavage	Cleavage faces visible. Resinous to adamantine luster; yellow-brown, hardness 3.5-4; streak-white to pale yellow	SPHALERITE
			Brown to black; *one perfect cleavage,* thin elastic plates	BIOTITE
			Dark green; one direction of good cleavage, flexible	CHLORITE
			Yellow-brown to dark brown, may be almost black: hardness, variable, streak-brown	LIMONITE
		No Cleavage	*Red* to red-brown streak; earthy appearance; red or silvery color	HEMATITE
			Hardness 5, hexagonal crystals with fused pyramid, vitreous luster green, brown, blue-purple color	APATITE
			Usually green or yellow green; *mottled* (spotted); dull luster; smooth to greasy feel on smooth surfaces, ranges from woody to asbestiform	SERPENTINE
			Black; octahedral crystals; *strongly magnetic; hardness, 6, black streak*	MAGNETITE
			Lead-pencil black; smudges fingers; hardness, 1, one direction of cleavage	GRAPHITE
			Brass yellow; hardness 3-6.5; cubic or octahedral crystals, black streak	PYRITE
	Black, green-black, or dark green streak		Greenish coppery-yellow, may be tarnished purple; hardness, 3.5-4; duller than pyrite.	

Italics = most diagnostic properties

METALLIC LUSTER			Shiny gray; very heavy; cubic/cleavage; hardness, 2.5; black streak (crystals and)	GALENA
	Yellow, brown, or white streak		*Copper color* and streak, tarnishes to green; H:3 high specific gravity, hackly fracture	NATIVE COPPER
	Nail will not scratch. Scratches glass (hard)	Has Cleavage	White or flesh-colored; 2 cleavage planes at right angles; hardness, 6	ORTHOCLASE
			Glassy luster; *transparent* to translucent; hexagonal (6 sided) crystals; hardness, 7; conchoidal fracture. Commonly milk white	QUARTZ
		No Cleavage	Glassy to sub-glassy luster; various shades of green and yellow; hardness, 6.5-7; sugary texture	OLIVINE
			White *to* gray; *conchoidal fractures* H:7 black variety called FLINT	CHERT
			Green or pale blue, six-sided (hexagonal) with flat termination, H:8	BERYL
NON-METALLIC, LIGHT COLORED			Colorless to white; salty taste; *cubic crystals and cleavage*	HALITE
			White, yellow, colorless; hardness, 3; *rhombohedral cleavage;* (3 directions, not at 90°); effervesces with dilute HCL	CALCITE
			White to transparent; hardness, 2. Small pieces are flexible. Some varieties may be transparent, or fibrous with silky luster	GYPSUM
			Green to white; *soapy feel;* hardness of *1*	TALC
	Nail will scratch. Does not scratch glass (soft)		Colorless to light *bronze;* transparent; in thin sheets which are very elastic; one direction of perfect cleavage	MUSCOVITE
			White, yellow, purple or green; *octahedral (8 sided) cleavage; hardness, 4*	FLUORITE
			Azure blue; H:3½-4. Effervesces with dilute acid	AZURITE
			Bright green. Effervesces with dilute acid. H:3½-4	MALACHITE

Italics = most diagnostic properties

WEATHERING

Weathering is an agent of landscape development. Weathering is regarded as a passive agent in that it does not provide a means of transport to distant places. The weathering processes (mechanical disintegration and chemical decomposition) act continuously on soils and bedrock that are close to the surface of the earth. The student should become familiar with the nature and role of weathering, types of weathering, and special cases of weathering.

Major Topics Explored

Evidence of Weathering
Types of Weathering–Mechanical Chemical
Soils

What is the most common evidence of weathering you see around the school or home?

The weathering processes may be thought of as the breaking up of hard strong bedrock into smaller *loose rocks* or *boulders* ranging in size down through the many size grades to sand and silt and finally to the size of chemical ions. The formation of *soil* over a parent bedrock is an example of this aspect of weathering.

Weathering may also involve the change in chemical composition of some minerals by the reaction of the mineral with acids and water. The change often results in the formation of new minerals that will remain stable without further change. The students may mention *rust* forming on iron as an example of this aspect of weathering.

What are some physical processes that exert mechanical stresses upon rock to break it?

These processes are the first breakdown of the bedrock into fragments.

A. *Frost Action*–Alternate freezing and melting of water in joint planes, bedding planes, foliation planes, and other openings in the rock constitute a strong mechanism of rock breakup because water expands when frozen approximately 10% (Fig. 1.7 and Plate 1.11).

Figure 1.7
Rock breakup by frost action.

Plate 1.11 "Joint-block separation" of sandstone at Hickory Run State Park in Carbon County.

B. *Wetting-and-Drying*—Clay minerals often swell considerably when wet causing many shales and other rocks containing clay minerals to disintegrate. Some shales break up into tiny pencil-like fragments (see Plate 1.13). This process is called "slaking". Soil cracks and mudcracks are formed in soil by this process.

Clay soils tend to expand or swell when wet and contract when dry.

C. *Volume Expansion*—This is the process of rock break up or rupture when it is relieved of the confining pressure of overlying rock (Fig. 1.8). In large diabase quarries in Pennsylvania the rock breaks loose in great slabs and sheets. Sometimes this happens with explosive force. Granite domes like the ones found in Yosemite National Park or Acadia National Park in Maine are excellent examples of rock sheeting. Forest fires also split rocks.

Plate 1.13 Shale "break-up" during weathering; exposure along Route 22 at Mt. Union, Huntingdon County.

Plate 1.12 Exfoliation of diabase boulders, Dauphin County.

Figure 1.8 Rock breakup by volume expansion (exfoliation).

D. *Tree or Root Wedging*—Roots exert pressure on the walls of cracks in soil or rock causing further break up (Plate 1.4).

These are all *Mechanical processes* of weathering.

Plate 1.14 Tree root wedging of diabase at French Creek State Park, Chester County.

Do you see any other results of weathering?

There are the *Chemical processes* of weathering.

A. *Hydration*—The chemical reaction of a mineral with water. One of the most common examples of this process in nature is the reaction of feldspars with water. Feldspars in granite in the presence of water will decay causing the rock to weaken and eventually disintegrate into individual minerals.

B. *Oxidation*—The chemical reaction of a mineral with oxygen. Ferromagnesian minerals in igneous and metamorphic rocks yield iron through the process of hydrolysis. The iron then combines with oxygen and water to produce the minerals hematite and limonite. The rusting of a nail is a common example of oxidation.

C. *Carbonation*—The chemical reaction of a mineral with carbonic acid. Carbonic acid decomposes many minerals but its effect with the carbonic rocks, limestone and dolomite, is most dramatic. Carbonic acid combines with calcium carbonate to form a highly soluble salt, calcium bicarbonate. The calcium bicarbonate is then carried away in solution. Deep ground water circulation allows carbonic acid to react with limestone or dolomite to produce a variety of features; caves, sinkholes, disappearing streams, etc.

Lab Investigation: Have students bring rock specimens to class, break them, discuss the difference between the fresh inner surface of the rock and the weathered outer surface. Diabase usually shows this weathered zone exceptionally good.

Films: *The Face of the The Earth* (EBF)
Wearing Away of the Land (EBF)

How deep are our soils? Does soil vary in thickness throughout Pennsylvania?

Before answering these questions, a general discussion of soil formation and soil profiles should take place. As the students become more familiar with the formation of soil from bedrock, the answers to these questions will become evident.

An excellent approach to this topic would be to locate an excavation or stream-cut bank where a typical soil profile exists. Show the students the four zones—Humus, Leached Zone, Subsoil (enriched) Zone, Weathered bedrock and the Unweathered bedrock (parent material)— or discuss whatever features are present and relate them to the typical profile (Figure 1.9).

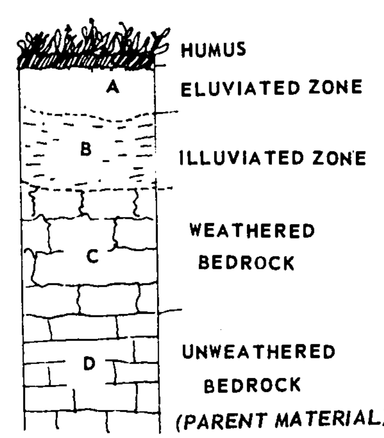

Figure 1.9 Typical Soil Profile.

Have the students bring in some soil samples. Examine these under a microscope. Ask them to distinguish the various components; humus, individual minerals, rock fragments, vegetation.

Have the students describe the overall characteristics of the samples and estimate where in the soil profile the sample came from.

What factors make soils different?

A. The *parent rock* adds different minerals to the soil; *i.e.* a schist will develop an overlying soil that is high in the mineral muscovite and/or biotote, a granite will impart excessive amounts of feldspar and quartz to a soil, a shale will develop a soil high in clay minerals and shale fragments, a sandstone will develop a soil that is high in quartz (sandy soil).

B. *Topography* affects soil characteristics. Well-drained soils occurring on slopes will be different from those that occur on uplands or valleys.

C. *Climate* affects the weathering of the parent rock and hence the formation of soils. Limestone in an arid climate weathers very little and the soil developed from limestone in an arid climate is thin and almost non-existent whereas a limestone in a semi-humid or humid climate weathers extensively and a thick, clayey soil is developed.

D. *Vegetation* adds to the soil decay products. As the amount of vegetation available increases, the amount of organic matter in the soil also increases, making the soil quite different from one without this material.

E. Time is a factor that is most important. The formation of a thick, rich soil takes considerable geologic time. This concept can be discussed here at some length.

The student should learn how the soil scientist classifies soils by the above factors. Any soil survey of Pennsylvania's counties will explain this classification and the soil groups present in our Commonwealth. The following soil surveys are available:

County	*Date*
Adams	1905
Armstrong	1939
Bedford	1913
Berks	1911
Blair	1917
Bradford	1913
Bucks	1946
Cambria	1917
Carbon	1962
Centre	1910
Chester-Delaware	1963
Clarion	1958
Clearfield	1919
Clinton	1966
Columbia	1967
Crawford	1954
Cumberland (Map)	1956
Erie	1960
Franklin	1938
Fulton	1947
Greene	1925
Huntingdon	1944
Indiana	1936
Jefferson	1964
Johnstown	1909
Juniata (Map)	1954
Lancaster	1959
Lehigh	1963
Lycoming	1928
Mercer	1919
Montgomery	1967
Montour-Northumberland	1942
Northampton	1966
Perry (Map)	1951
Potter	1958
Snyder (Map)	1957
Tioga	1929
Union	1946
Venango	1966
Washington	1966
Wayne	1938
York	1963

The answer to the question—*Does soil vary in thickness throughout Pennsylvania?*—now becomes evident. As each factor discussed above varies, so would the soil vary. The climate, rock type and time are probably the most important factors affecting the depth of weathering.

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MASS WASTAGE

Although most students in Pennsylvania are aware of erosional agents like rivers and wind transporting sediments and eroding the landscape, few realize the importance of mass wastage—the downslope movement of rock debris by gravity—in leveling the earth's surface.

Major Topics Explored

- Downslope Movement of Rock Debris
  - Slow
    - Creep
  - Fast
    - Rock falls
    - Slump
    - Landslides
- Mass Wastage Problems
  - Man's alternatives

Ask the class if they can think of any examples of this process at work.

Some may recall seeing signs saying "Caution Falling Rock", or noticed a slump of earth along a road cut or stream bank. They may have seen tilted fence posts on a steep slope or read about a recent landslide. A gross example of mass wasting was the downhill movement of parts of coastal California including houses into the Pacific Ocean in early 1969.

After discussing some of these examples, the teacher may ask, how can these movements be separated into categories or can these movements be separated into categories?

Hopefully the answer "slow" and "fast" will emerge. Under slow downhill movements in the latitude of Pennsylvania, the principle process is *creep* (Plate 1.15). This process accounts for the tilted fence posts, and slow downslope movement of stones in fields.

Plate 1.15 Classical example of "creep"; shale outcrop at intersection of Traffic Routes 230 and 72 in Lancaster County.

Fast movements include: *rock falls* forming talus piles at the foot of cliffs (Plate 1.16), *slumps* and *landslides* which may be mudflows if the moving material is predominantly fine grained and the moisture content is high (Plate 1.17).

What conditions favor mass wastage as against no downhill movement of weathered rock debris?

Steep slopes, a high moisture content in the weathered material, bedding planes tilted downhill beneath the regolith, and earthquakes are four favorable factors.

What can be done to halt this downhill movement or offer protection against it?

Along roads, the highway department at some places has built retaining walls, or planted vegetation whose roots stabilize the soil on steep road cuts.

Cliffs along highways are often cut back or terraced so that falling rocks will not drop onto the roadbed. Railroads erect fences along the tracks in rock gorges which turn the signals red stopping trains, if the fence is broken by falling rocks or a landslide.

In other cases, drainage pipes have been put into the moving mass to carry away the excess water, increasing the internal friction and stopping the movement.

For students wanting to pursue the subject further, college geology textbooks describe the great importance of this process in the Arctic where the frost action is more intense and permafrost (permanently frozen ground) underlies a thin thaw zone which in summer readily moves downhill. In Pennsylvania, Blue Rocks near U. S. Route 22 east of Hamburg and Hickory Run Boulder Field in Hickory Run State Park (Plate 1.18), Carbon County, are examples of arctic features of this type preserved from the time when the northern part of the state was being glaciated.

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Plate 1.16
Rockfall along Interstate 80 in Columbia County.

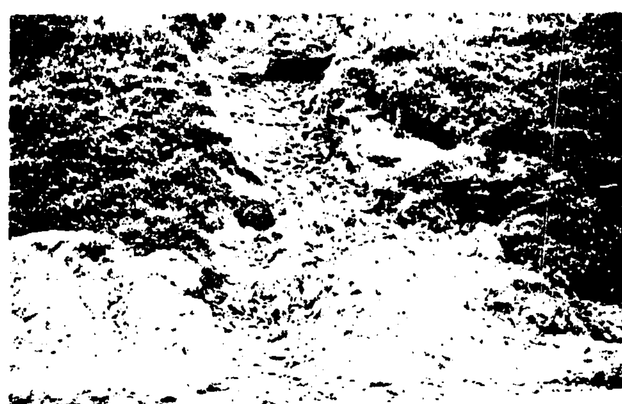

Plate 1.17
Landslide along Route 322 in Lebanon County.

Plate 1.18
Hickory Run Boulder Field, Carbon County.

THE WORK OF GROUND WATER

Did you ever look at a creek flowing along on a fine sunny day and wonder where the water comes from? You may answer that this water came from rain, but where has it been all the time since the last rain?

This water has been in the ground. It is thus necessary for the student to know how it got in the ground, how it moves from where it entered the ground to the place where it gets into the stream, how long it takes to travel from one place to another, and what landforms are the result of moving ground water.

Major Topics Explored

Infiltration and Runoff
Movement in Soil—Capillarity
Gravity
Aquifer—Depth
Water Table—Zone of Saturation
Ground Water Movement
Ground Water Quantity—Porosity
Permeability
Specific Yield
Artesian Water
Ground-Water Quality—Effects of Different Chemical Elements
Origin
Solution Features
Depositional Features
Man's Search for Water
Water in the Future

What is an aquifer?

When water strikes the ground, part of it sinks into the soil and part runs off the surface. The process of water sinking into the soil and rock is called *infiltration*. By taking this word, infiltration, apart we find that "filt" is similar to the word "filter" and that "in" means "into" or, in other words, the process is one of passing into. In this case, water passes into the rocks (Figure 1.10).

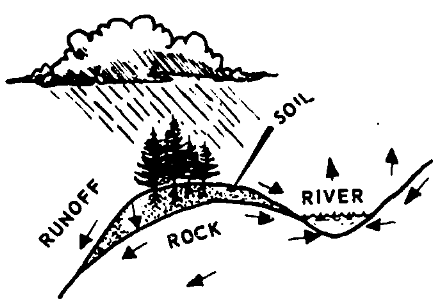

Figure 1.10 Precipitation-Runoff-Infiltration.

The movement of water within the rock involves two forces: *capillarity and gravity*. Both of these forces move water downward. Capillarity moves water downward into dry soil below the wetter portion, where the soil particles are very fine. However, where these particles are coarse, perhaps pebbles or large sand grains, water tends to move downward more or less freely through the spaces around the grains by gravity. The larger the spaces the more rapidly the water can move.

An aquifer is an underground zone or layer which is a relatively good source of water. An aquifer may be an underground zone of gravel and sand, a formation of sandstone, a zone of highly fractured rock, or a formation of cavernous limestone.

How deep will water go?

Water moves underground through pores, holes, and cracks which are often found in surface rocks. Many of these openings are the result of weathering of the rocks.

These cracks, seams, and minute spaces between particles of weathered rock become fewer and fewer as we go deeper in the earth. At varying depths, depending on rock types, these openings are no longer present except infrequently, and the movement of ground water does not exist.

Ground water may also occur at great depth in natural pore spaces between the grains of the rock itself. A common example of rock with natural pore space is sandstone. Porous rocks, through folding and other mountain building forces during geologic time, may occur many thousands of feet deep, but underneath these aquifers everywhere at some depth is rock that is impervious and watertight.

THE WATER TABLE

What is it? Where is it?

Rain falls on the surface of the ground and wets the soil and rock materials to varying depths depending upon the duration of precipitation. Somewhere at depth is an impervious base. Above this impervious base free water collects, and the top of this zone of free water (zone of saturation) is the water table (Figure 1.11). Do laboratory experiment on "Relationship of water table to unsaturated soil".

When the water table is high enough to emerge as a free water surface in a stream channel, the water in the channel flows.

In a humid climate there is enough precipitation to raise the water table high enough for even the

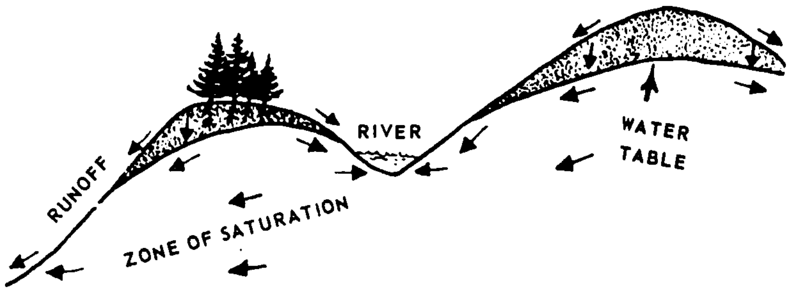

Figure 1.11 Hypothetical cross section showing the "zone of saturation" and "water table".

small rivulets and creeks to run water much of the year. In a dry climate, however, the small channels are dry between rains and only the large deeply cut river channels carry water the year around.

GROUND WATER MOVEMENT

Does ground water move?

The water table is seldom completely flat and horizontal but it is an undulating surface. The zone of saturation is continuous and has water in it that is constantly moving from the high places toward the lowest place. *Water underground flows downhill* (see Figure 1.13) in the direction which represents the steepest slope of the water surface.

Many surface streams continue to flow even during long periods of dry weather. You will note, however, that the stream gets lower and lower as water in the ground is gradually drained away and the water table approaches a flat surface.

Surface streams are closely related to water in the ground. The water involved in both is the same, and they both have the same source.

To find out more about ground-water movement visit your local library and ask about your State Geological Survey Ground-Water reports. Talk to a local geologist and local well drillers to find out about ground-water conditions in your area. Laboratory experiment on "Movement of Ground Water" is also recommended.

How much water can be obtained from the ground?

A water table can be found anywhere at some depth underground, but it cannot tell us *how much* water can be obtained from the underground reservoir.

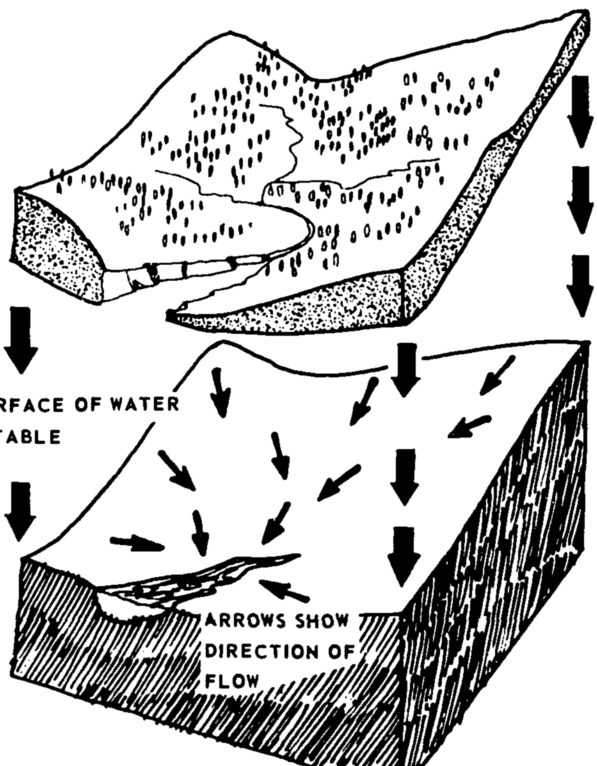

Figure 1.12 Ground water flows downhill.

LABORATORY EXPERIMENT

Relationship of water table to unsaturated soil

Fill any transparent container with sand. Slowly pour water into the container and observe the water being absorbed in the sand, seeping down through the spaces between sand grains until it comes to the watertight or impervious bottom of the container. (A blue coloring added to the water will help the students see the desired effects.) The sand becomes thoroughly moist before any free water collects at the bottom. As more water is introduced, a water surface rises until it reaches the surface of the sand.

At a point in time when the bottom half of the sand is saturated, the student can find the level of the free water surface by punching a trench across the sand with his finger. This trench will turn out to be partly filled with water, and the water level in the trench will be the same as the level of the free water surface throughout the sand. This level, or surface, is called the *water table*.

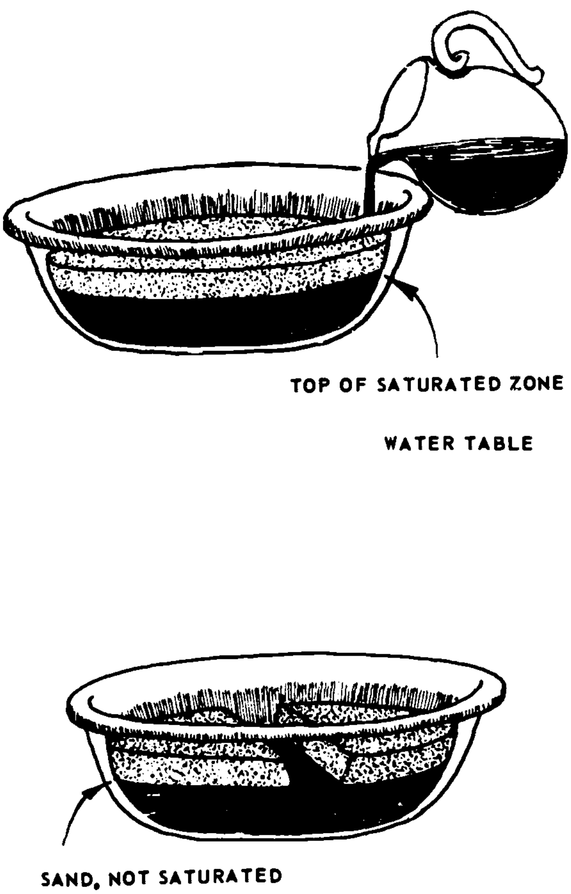

Figure 1.13
Relationship of water table to unsaturated soil.

LABORATORY EXPERIMENT

Movement of ground water

Ground water is the water that completely fills the pore spaces and other openings in soils and rocks beneath the surface of the earth. Replenished by rain and melting snow, it furnishes the flow in streams in dry-weather and is the perennial source of supply to springs and wells.

Ground water moves through the ground from areas of recharge to areas of discharge. Knowledge of the rate at which it moves is important to those interested in developing water supplies from wells. The rate of movement is governed by the hydraulic gradient or slope of the water table and by the permeability or capacity of the rock materials to transmit water. The permeability varies with the size and interconnection of pore spaces or openings in the water-bearing material, being higher for gravel than for sand or silt.

The relative permeability of different earth materials can be demonstrated with the apparatus illustrated in Figure 1.14, by separating sand into its grade sized with a set of sieves.

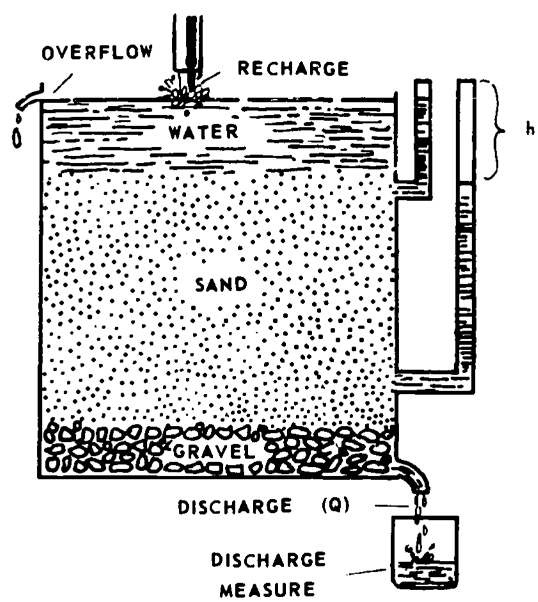

Figure 1.14
Relative permeability of different earth materials and the movement of water through each.

After the layers of gravel and sand have been placed in the container, fill the container with water and continue to introduce water (recharge) so that there is a continuous overflow. This maintains a constant pressure within the container. Measure the vertical distance (h) between the water surface in the two tubes at the side, and measure the volume of water discharged (Q) during a specific time interval (try 1 or 2 minutes). Next remove the sand and replace it with a finer sand or silt and again measure (Q) and (h) for the same time interval. A comparison of the quotients of Q/h will show the relative permeability of the two materials. Go through the same process using different mixtures of silt and sand of various sizes.

The pore space, cracks, and joints in the rock vary in amount (number) and size between different rock types. If we drill into a rock that has a great amount of pore space or many fractures that are saturated with water, then large amounts of water may be available to the well.

But if the rock has only a small amount of pore space or very few fractures, a well may become dry after only a small volume of water has been removed.

The *amount of pore space available* is one of two principal factors which determine whether one rock will be a good source of water for a well. This first factor is called *porosity*.

The second factor governing how a rock will act as a source of water is called *permeability*. This factor has to do with how readily the pores are able to transmit or allow the water to move. The pores must be large and connected so the water can flow; this rock then has a high permeability.

What is the meaning of artesian water?

Ground water under natural pressure is called artesian water. Not all artesian wells flow above the surface of the land. A well is an artesian one if its water rises above the aquifer from which the water comes. Figure 1.15 shows a sandstone aquifer coming out to the land surface at the top of a hill. Overlying this aquifer and shown on the three sides of the block diagram is a watertight layer of shale that confines the water in the sandstone aquifer. The water in this sandstone is under pressure. If a well is drilled at point A or B, water would rise in the well and might flow out onto the surface. This depends on the amount of pressure.

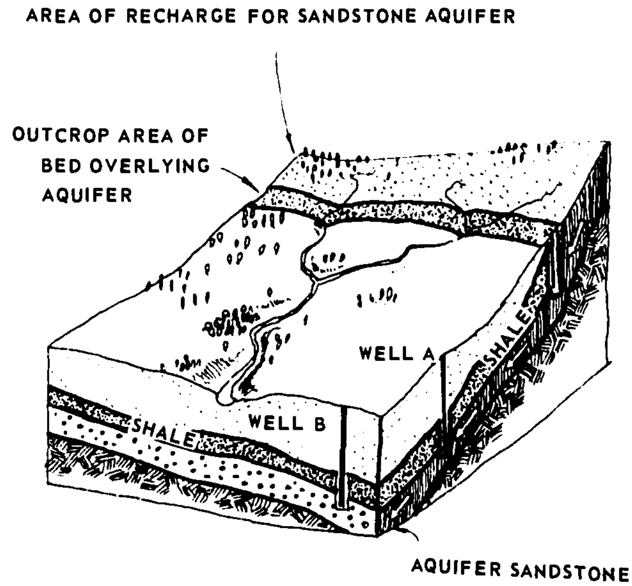

Figure 1.15 A Sandstone Aquifer under artesian conditions.

Is all ground water the same quality?

It is the dissolved chemical compounds called salts that give water its taste and that made it either hard or soft.

The chemical nature of water is important to man. We do not want the water we drink to taste salty or of sulfur or iron, nor do we want it to taste like distilled water. We also want it to be soft enough to lather easily.

The presence of calcium and magnesium compounds makes water hard because the *calcium and magnesium* combine with soap to form insoluble matter.

Sodium is an element that causes trouble on irrigated farms. Sodium salts tend to make a soil sticky when wet and to form clods when dry. It also affects plant growth in some cases.

Boron is one of several mineral constituents that is needed in very small amounts for plant growth. In large amounts boron is poisonous to plants.

Small amounts of *fluorine* in water tend to prevent cavities in children's teeth, but in excessive amounts it mottles and discolors the tooth enamel.

Salts in natural waters may be harmful or beneficial, and so it is important to know the amount and kind of salts in our water supply and how they affect the use of water.

What factors affect ground-water quality?

How do these salts get into our water?

Rainfall is nearly pure water. When rain strikes the ground it comes in contact with many kinds of soluble materials. Rocks are composed of minerals and given great amounts of time, much of these minerals are dissolved. The solvent action of the water is increased by the carbon dioxide absorbed from the air in the soil. *Many chemical elements are then taken into solution by the water moving through the rocks.*

LABORATORY EXPERIMENT

Water quality and its effect on aquatic life

Perhaps you have wondered how quality of water affects the growth of vegetable and animal life about us. It is known that aquatic life will remove the ions, that are essential to its growth, from solution. One interesting study is to observe the variations in chemical composition of aquatic plants grown in different kinds of water.

It is not difficult to determine the approximate chemical composition of water by using an inexpensive testing kit available from a chemical laboratory supply house. Elements such as calcium, magnesium, chloride, sulfate, nitrate, iron, and hydrogen-ion concentrations (pH) can be determined readily. Approximate sodium and potassium content can be determined by calculating the difference between total cations (metals) and total anions (nonmetals). Water could be obtained from two or three sources in your area, such as your city supply, a domestic well, or from the water supply of a nearby town. After the chemical content of water is determined, aquatic plants, obtained from an aquarium in a nearby store selling pet supplies, would be added to the water and allowed to grow for a period of several weeks. The containers, such as a large fish bowl or aquarium, should be covered with sheet polyethylene to prevent evaporation. After growing for several weeks, in full sunlight during the day and artificial light at night, samples of the aquatic plants from each type of water would be dried, weighed, burned, and the ash dissolved in water with the aid of a solvent such as nitric acid. The ion concentration of the chemical elements would again be determined. These results when compared with the chemical composition of the original plant will reveal the effects of the different kinds of water used.

Do the plants show chemical composition that relate to the amounts or kinds of ions in the water in which they grew?

The publications of the U. S. Geological Survey on the quality of river waters and public supplies are available to you in your State Library.

If facilities for chemical analyses are available, the studies could be expanded by adding 1 to 20 milligrams per liter of water of minor elements, such as boron, cobalt, or nickel, etc. This will determine the ability of the plants to use these chemical substances in their growth.

Some rocks are more soluble than others. Limestone and dolomite are very soluble, and when they are exposed to the action of moving water they dissolve and thus are a source of calcium and magnesium in the water. Solution of these carbonate rocks forms caves of which Indian Echo and Crystal Caves are examples of the fantastic shape and size which may result from solution.

Can you name some solution features produced by ground water?

Figure 1.16 will help to illustrate the features.

Sink (sink hole) any slight depression in the land surface, especially one having no outlet (see Plate 1.19); one of the hollows in a limestone region often connected to a cavern or subterranean passage so that water running into it is lost.

Cave a natural cavity, recess, chamber, or series of chambers and galleries beneath the surface of the earth.

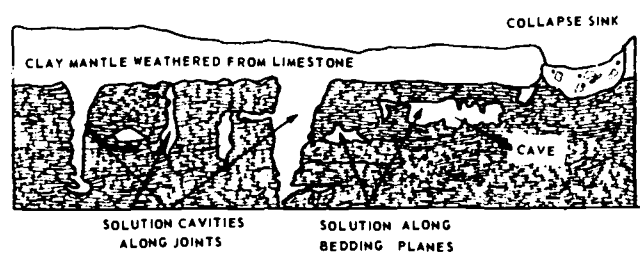

Figure 1.16 Generalized cross section through a limestone region.

Disappearing Stream a surface stream that disappears underground in a sink. (Plate 1.20 and 1.21)

Pennsylvania topographic maps illustrating solution features:

Mechanicsburg 7½″ map (sink holes)

Carlisle 7½″ map (sink holes)

Fleetwood 7½″ map (disappearing streams)

Norristown 7½″ map (sink holes, disappearing streams, "karst" topography)

Plate 1.19 Cross-section of sinkhole; exposed along I-80 in Centre County.

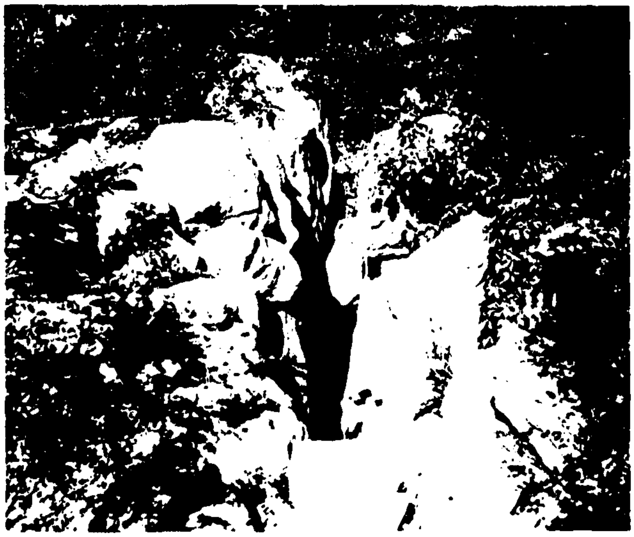

Plate 1.20 & 1.21 Solution along a joint plane in limestone, Cumberland County.

Can you name some depositional features produced by ground water in a cave?

Stalactite—a conical deposit of calcium carbonate, generally calcite or aragonite, hanging from the roof of a cave (Plate 1.22).

Stalagmite—a calcium carbonate ridge rising from a limestone cave floor, and formed by water charged with calcium carbonate dripping from the stalactites above. Stalagmites and stalactites often meet and then form a *column* from floor to roof (Plate 1.22).

Flowstone—deposits of calcium carbonate accumulated against the walls of limestone caves where water trickles from the rock and runs over a section of the wall or other irregularities. *Ribbons*, *sheets*, and *curtains* are variations of flowstone (Plate 1.23).

Helictites—are depositions of calcium carbonate that build out horizontally on the walls of the cave, or on the sides of stalactites and stalagmites. They represent deposition at the level of the water table, and hence formed when the water table was higher than its present level.

Plate 1.22 Stalactites, flowstone, ribbons, columns and stalagmites: *Indian Echo Cave, Dauphin County.*

Plate 1.23 Indian Echo Cave near Hummelstown, Dauphin County

WATER IN THE FUTURE

The demands on our ground-water supply are becoming critical in some areas of Pennsylvania and the nation, and this trend will continue. Urban expansion and industries using large quantities of water per employe will be discouraged from locating in water-poor areas through better urban and industrial planning. One of the greatest problems facing man in developing future water supplies is the increasing pollution of ground water.

Wise use of our water resources will be encouraged and eventually will be legislated. Much of Pennsylvania's surface water and some of her ground water is already controlled by local and regional regulations.

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THE WORK OF STREAMS

Rain water that does not evaporate or soak into the ground, combines with the ground water that comes to the surface in the form of springs, and drains off and flows to the sea. Springs and small rivulets join to form small streams, small streams join to form larger ones until they form rivers that flow into the sea.

Streams are probably the most important single agent in the modification of landscape throughout the world. Streams are responsible for the picking up and carrying materials that will abrade and modify the landscape as they are transported to the sea. They may deposit and re-transport materials numerous times during their journey to the sea. The shape of the streams is affected by the type and structure of the rock over which they flow, and also by the load which they carry.

Major Topics Explored

- Stream's Energy Requirements
- Stream Transport
  - Deposition
  - Abrasion
- Stream Features
  - Abraded Streams
  - Flood Plains
  - V-Shaped Valleys
  - Ox-Bow Lakes
- Stream Patterns
  - Meanders
  - Dendritic
  - Trellis
  - Radial
- Peneplantation

Why is it that one stream may be meandering back and forth across its channel whereas another stream is cutting deeply into a valley?

Anything moving possesses energy. It is this energy balance that is going to determine the ability of a stream to transport its materials. If the stream is flowing rapidly it will possess more kinetic energy and hence be capable of doing more work, thereby carrying larger particles and a larger total load. As long as the energy of the stream is equal to or greater than the energy necessary to move the load of the stream the stream will be relatively free of meandering. On the other hand if the energy is insufficient to transport the materials, then the stream will be forced to drop part of its load causing the stream to meander upon its deposited load with the increased possibility of flooding.

Why is it that some streams possess more energy than others?

There are two basic factors that influence the amount of energy a stream will possess. One is the volume, or rate of flow, of the water in the stream. A stream in which a large amount of water is flowing past a given point in a given unit of time, will contain more energy than a small stream having a trickle of water.

The other factor is the slope of the stream. The steeper the slope, the faster the water will move. Hence, the greater the kinetic energy the water possesses.

These factors can easily be discovered by the students or demonstrated by you in the classroom by using the following laboratory investigation or a modification of it. One other point should be kept in mind when drawing conclusions to this activity. The speed of the water is going to be affected by the cross-sectional shape of the stream bed. A stream with a small bed and a given quantity of water confined within the bed is going to be forced to flow more rapidly, than the same volume of water that is flowing in a larger stream channel.

If a stream does not possess sufficient energy to move materials, the stream will not be capable of cutting its channel; instead it will deposit or just barely transport the load that it is carrying. However, if the moving water possesses energy above that necessary to move the load, it will be capable of imparting some of this energy to the load which will abrade the sides and bottom of the stream. This action may cause downcutting and widening of the channel.

One of the best places to see an example of this cutting action is in the bed of a stream. The outside bank of the stream will usually be fairly steep and the deepest water will be closest to this bank. The inner bank of the bend will be gently sloping and probably contain sandy or fine materials that the stream deposited (see Figure 1.17). This asymmetrical method of lateral cutting can be described to Newton's law of motion which states that "an object in motion tends to stay in motion and in a straight line unless acted upon by an opposing force". When the stream bends, the water imparts energy to the outside bank causing most of the erosion to be performed there. The inner portion of the bank will possess the least energy and hence deposition will result.

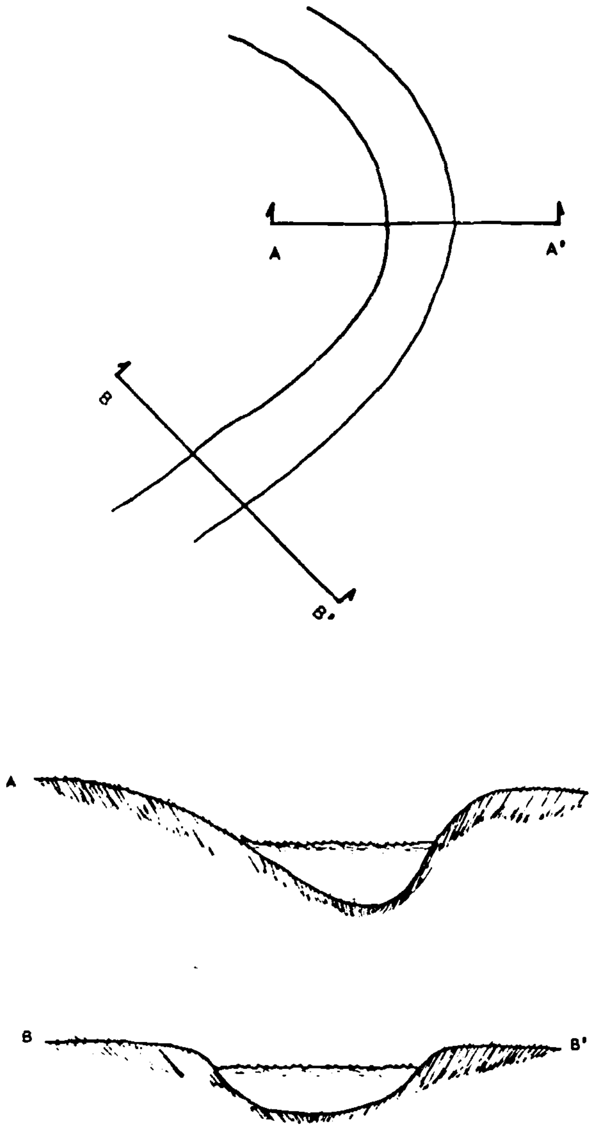

Figure 1.17 Bend in a stream showing differences in channel cross section.

LABORATORY EXPERIMENT

With the use of a semi-circular gutter spout or a stream table with a piece of plastic laid over a straight channel formed in the sand, the students can determine the relationship of the velocity of water to: 1) the stream and 2) the rate of flow of a stream. Pieces of cork or other small, light objects can be floated down the trough and timed over a measured distance to determine the speed of the water (distance ÷ time = speed).

For the first relationship the rate of flow of the water entering the trough must be kept constant and only the slope (angle of tilt) should be changed. At least two or three different slopes should be used to determine this relationship.

The influence of rate of flow to velocity can be determined on the same apparatus by keeping the slope constant and changing the rate of flow for each of two or three sets of trials. The easiest way to control the rate of flow is to run a hose from a faucet to the apparatus. If a faucet is not available, siphons can be used from a bucket to the trough. The rate can be controlled by the number of siphons in operation. *Caution:* the water level in the bucket reservoir must be kept constant or the pressure affecting the water through the siphons will vary.

The teacher should assure that the students can relate the *velocity* of a *stream* to its *kinetic energy* and hence, its ability to erode its banks or bed and to transport its load.

In comprehending the energy balance of a stream and its load, the shapes of the stream valleys and the streams themselves are better understood. A stream that possesses energy in excess of that necessary to carry its load, will be able to impart this energy into the load itself so that the stream bed may be cut down. As the stream bed is cut down, the valley walls will be steepened. Gravity and mass wasting will follow, continuously feeding more material into the stream so that the material may be picked up and carried further down stream. This will result in rather steep V-shaped valleys (see Figure 1.18A). When the gradient or slope of the stream is reduced, the stream will not cut down as fast as before and the valley walls will slowly diminish in steepness. In some textbooks, steep sided valleys are referred to as young river valleys. *Caution* should be exercised as these connotations only refer to the valley's present active state and not to its evolutionary stage.

As the stream gets closer to the sea, the slope of the stream becomes less and the load increases. The valley walls will be considerably wider and there may be a flood plain spreading over the valley floor (see Figure 1.18C). The flood plain is composed of sediments that the stream deposited during high water. As the stream overflowed its banks, the velocity of the water on the banks was suddenly reduced resulting in the deposition of sediments. This is typical of many large streams such as the Mississippi River and all those having a large volume fluctuation during the course of a year.

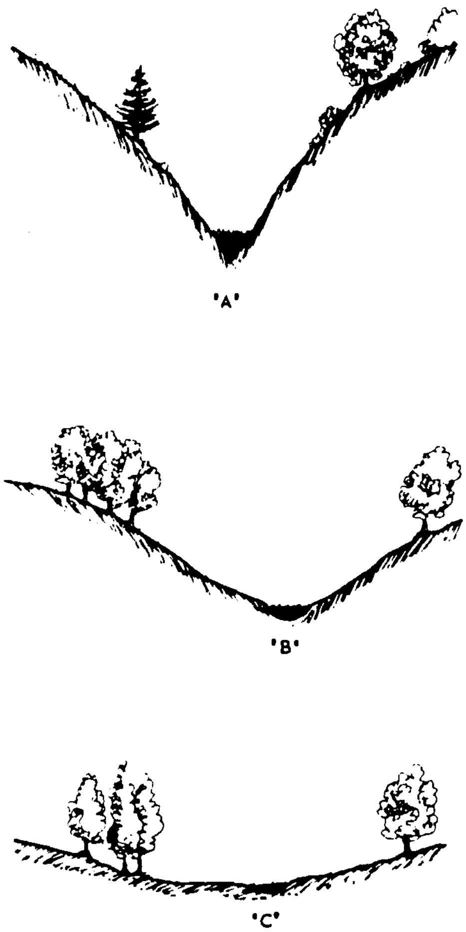

Figure 1.18 The energy balance of a stream is related to the shape of the stream valley.

A common misconception is that the water does most of the eroding. Actually most of the abrading down cutting in a stream is done by the load which the stream is carrying. The individual particles are constantly grinding away at the stream bed.

How far down a stream can erode its bed is controlled by its base level. That is, the lowest level to which a stream can cut its bed. The ultimate base level is sea level, however there are local base levels such as resistant ridges of rock cutting across a stream. Dams built by man and animals can produce local base levels, which actually halt downcutting above the point of the obstruction (see Figure 1.19). However, the rate of downcutting below a local base level is unaffected. Over an indefinite period of time, these local base levels will be destroyed by the downcutting below them; and weakening of the structure causing the upper local base level.

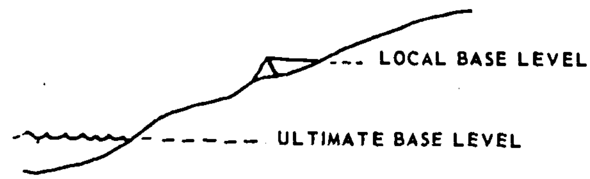

Figure 1.19 Local and ultimate base levels of surface streams.

How are materials transported in a stream?

Materials are transported basically in three ways. The largest particles will be rolled and bounced (saltated) along the bottom, depending upon their size and the available energy in the stream. Some materials will be small enough to be carried suspended in the water while certain other materials such as calcium carbonate, gypsum and other soluble minerals, may be carried as a dissolved load. The dissolved load must be deposited by chemical means whereas the deposition of the suspended and bed load is deposited by loss of energy.

The energy that a stream possesses will be reduced in proportion to the amount of sediment it is carrying, as some of the energy will be used in the transport of the load.

Once a particle has entered a stream it is not necessary that this particle make one continuous journey to the sea. It is likely that it will be carried more freely during periods of greater energy (periods of greater flow) and be dropped at a time when the energy decreases. A particle may remain practically stationary for a considerable length of time until the stream again acquires sufficient energy to pick it up and continue its journey toward the sea. This may result in a trip composed of many "ups and downs".

Where is the sediment (load) of a stream deposited?

The ultimate area of deposition in a stream is at its mouth. If the body of water into which the sediment is being deposited is relatively calm, a delta may result similar to that formed at the mouth of the Nile or Mississippi River. However, if there is a current in the receiving body of water, such as a long shore current, the sediments will be constantly carried away from the mouth of the stream and moved along the shore. This is one of the major sources of sand along our beaches.

A topographic feature similar to the delta and formed in a similar way is the alluvial fan, which is produced in arid regions by streams discharging their load on the valley sides as they emerge from adjacent mountains. The water generally spreads out and evaporates in a relatively short period of time allowing the sediments to accumulate to form fan-like features. They are fairly common in places like Death Valley.

What is a levee? What are natural levees?

As a stream overflows its banks, energy is suddenly reduced along the bank and a part of its load is dropped quickly, resulting in a natural wall or levee beyond the bank.

Sometimes flooding across meanders may result in a meander being cut off and the stream may actually change its course. When this happens the energy within the meander is curtailed and deposition begins within the isolated segment. When these segments are fairly recent they still contain water and are called ox-bow lakes. As time goes on these lakes fill in, leaving scars that are still evident in aerial photographs.

Do streams form a pattern?

It is possible to tell something about the structure of the underlying rocks from the pattern that the stream develops. As erosion takes place the stream may cut down into its bed. The stream should cut into the less resistant rocks more rapidly than into the more resistant rocks. Hence, if there is more than one rock type present, the rocks will probably have varying resistances and the streams will cut into them with varying degrees of rapidity.

If the layers are sedimentary and horizontal, the exposed layer will be basically of a homogeneous nature. In this instance the streams will not develop any particular orientation, instead the stream will flow in a random manner. The pattern produced by streams and their tributaries flowing in this manner is called dendritic (see Figure 1.20).

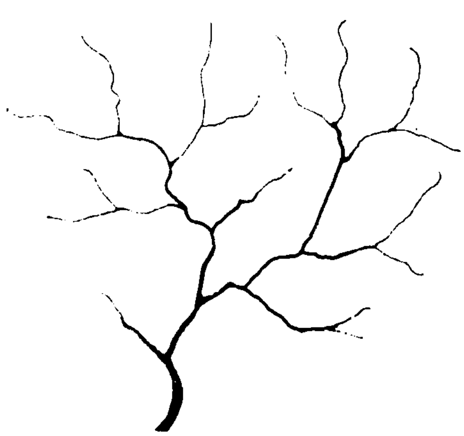

Figure 1.20 Stream pattern developed on sedimentary, horizontal rocks.

If there are tilted sedimentary rocks or other layers of tilted sedimentary rocks or other layers of tilted rock that would have varying resistances, the stream will develop in the least resistant layers producing valleys that are basically parallel to each other (see Figure 1.21). The long axis of the stream will parallel the rocks strata and the short segments will cut across the more resistant layers probably in zones of weakness such as major joint planes. A trellis pattern is developed.

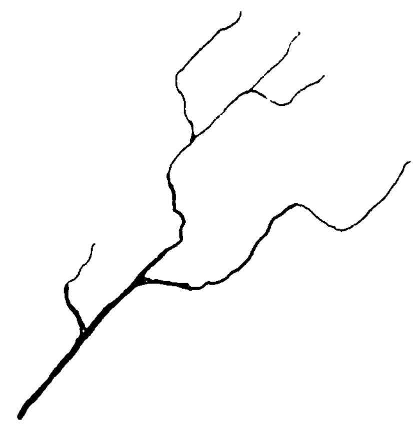

Figure 1.21 Trellis Stream pattern developed on tilted sedimentary rocks of varying resistance.

A structural dome (see Figure 1.22) will show itself readily as the streams radiate outward from the center. Sometimes the streams will follow a circular path as they encounter less resistant strata in the dome.

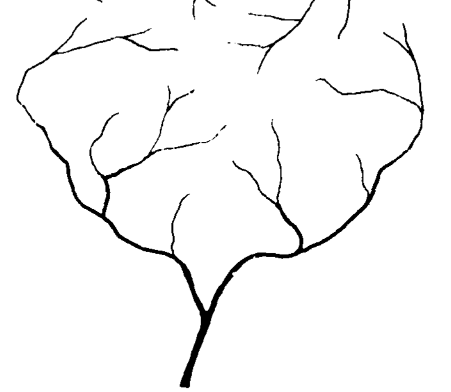

Figure 1.22 Stream pattern developed on a structural dome.

The joint structure of rocks can also influence a stream pattern. Joints and faults produce weak zones in the rock along which the streams tend to follow. The pattern may resemble the trellis as shown in Figure 1.21. If more than one set of joints are present, the angles formed by the stream bends may resemble the angles made by the joint sets.

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THE WORK OF GLACIERS

Glaciers today, except in high latitudes and at high altitudes, are of minor importance in the present-day shaping of the earth's topography, but those that existed during the Ice Age (Pleistocene Epoch) left their imprint upon millions of square miles of the earth's surface and thousands of square miles of northern Pennsylvania's surface.

About 10% of the earth's surface is covered by ice today. However, during the Pleistocene perhaps as much as 30% of the earth was covered by ice and snow.

The Pleistocene Epoch consisted of at least four glacial ages separated by interglacial ages of much greater duration. In the United States, each glacial period is named for the state where deposits of that period were first studied or where they are best exposed: from oldest to youngest: Nebraskan, Kansan, Illinoian, and Wisconsin.

Major Topics Explored

The Pleistocene Epoch
Evidences for Glacial Periods
- Topographic
- Weathering
- Radiocarbon Dating
- Interglacial deposits
- *Other Methods*

World-Wide Distribution of Ice and Snow
Theories of Glaciation
Formation and Movement of Glaciers
Glaciers in Pennsylvania
Effects of Glaciation Upon Man
Importance of Glaciation Relative to Man

How much temperature change would be required to cause ice sheets like the pleistocene to form again? (Not more than 9°C or 14°F). Is there any record of substantial temperature change during the last century?

Yes. According to the U. S. Weather Bureau records, the temperature increased 2 F between 1880 and 1950.

How do we know there were four glacial ages during the pleistocene?

Some of the evidence for distinguishing stages of glaciation include the following criteria:

1. *Topographic Evidence*—Wisconsin glacial topography is better defined and landforms possess better form than topography resulting from older glacial ages. The older deposits are more weathered, eroded, and many forms such as moraines are difficult to identify. Older deposits are also more patchy and not as uniform as the Wisconsin material.
2. *Weathering Phenomena*—Three methods of distinguishing glacial ages by using weathering phenomena include:
   a. comparing depths of leaching—older deposits show greater leaching depths of soluble minerals
   b. depth of oxidation—generally deeper in older deposits
   c. more rotted boulder, cobbles, and gravel in older deposits
3. *Radiocarbon Dating*—of organic material only applicable to later substage of the Wisconsin
4. *Interglacial Deposits*—Buried soils, peat, forests, loess, sands, outwash, and lake deposits found between two till deposits indicate multiple glaciation
5. *Other Methods*—pollen analysis and paleontologic evidence

What areas of the earth are covered by ice and snow today?

If we consult a world physical map or globe, we notice that snow and ice are found primarily on two continents, Antarctica and Greenland, and lesser and more restricted amounts in the mountainous areas of most continents (Alps, Himalayas, etc.). From this then we might divide our present day distribution of glaciers into two groups, namely, the continental glaciers or ice caps and the mountain or alpine type glaciers. The Arctic "Ice Cap" is merely frozen sea water.

How does ice in a glacier differ from ice on a pond and under what conditions do glaciers form?

Glacial ice is made from snow that has accumulated up to more than 100 feet thick, is packed tight, the air between the fallen snow flakes has been expelled, and has been recrystallized. Glacial ice forms when the annual snow fall exceeds summer melting, causing great thicknesses of snow to accumulate and be transformed into ice.

The *snow line* separates the zone of perennial snow and ice from lower altitude regions where the snow melts each year.

What is the altitude of the snow line?

It varies from sea level in the polar regions to approximately 30,000 feet between latitudes 20 and 30 (arid regions) to around 20,000 feet in the equatorial zone (tremendous snowfall compensates for higher temperatures).

> Note: At this point in the discussion it might be worthwhile to have students plot on a world outline map the distribution of ice and snow, the climatic elements (precipitation, temperature, wind and pressure patterns), and the patterns of oceanic circulation particularly in the ice cap regions (Greenland and Antarctica). After the patterns have been studied the question might be asked: *Why aren't there ice and snowfields in all similar areas of high latitude altitude?*
> The case of northern Canada being devoid of glaciers even though temperatures are cold enough can lead to a discussion of moisture, one of the primary requirements for glaciation.

What was the distribution of ice and snow during the Pleistocene?

Here we should begin to delimit our analysis of glaciation to North America, the United States, and Pennsylvania (see Figures 1.23 and 1.24). Many glacial maps (wall size) are available from most major map companies and smaller desk maps can be found in atlases and textbooks. From these sources students can plot the boundaries of Pleistocene glaciation. A detailed map of the glacial deposits of North America is available.

With additional map study the students can determine the directions of ice movement by mapping the end moraines and plotting the direction of glacial striae. From this work the student can see that the centers of ice did not originate in the high polar regions as might be expected, but did occur in the latitude of Hudson Bay (Laurentide Ice Sheet) and the mountainous region of western Canada Cordilleran Glacier Complex). When the magnitude of Pleistocene glaciation is fully realized, the teacher might ask the question: *What possibly could have caused this great extent of ice over North America less than 12,000 years ago?*

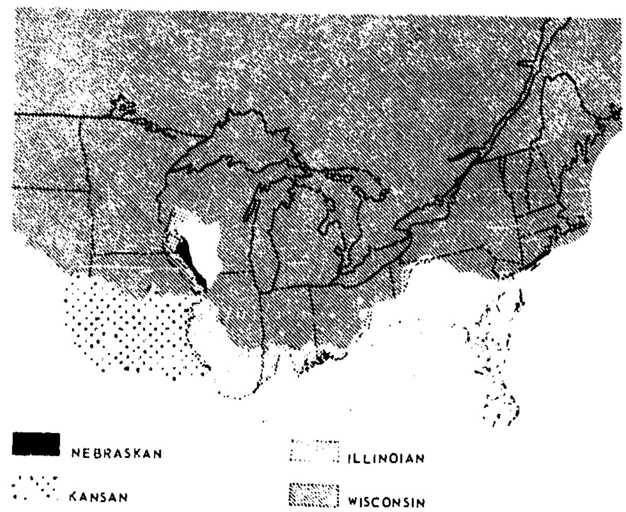

Figure 1.23 Areas of Eastern North America covered by ice invasions of the Ice Age.

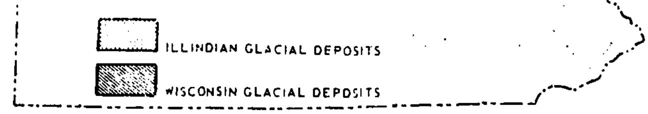

Figure 1.24 Areas of Pennsylvania covered by the Illinoian and Wisconsin ice advances.

Many hypotheses have been presented by geologists and meteorologists concerning the cause of glaciation. The classification of such hypotheses can be divided into two groups, geologic and astronomic.

Geologic Theories	*Astronomic Theories*
uplift; highlands	earth-sun relationships
volcanic dust; shutting out solar radiation	variations in solar output
continental drift	
polar wandering	

Plate 1.24 Marshalls Creek Mastodon bones *insitu* before being removed from John Leap's peat bog one mile northwest of Marshalls Creek, Monroe County. The skeleton is partially exposed with foot rule near center of photo. Rear limb bones—bottom of photo, pelvis—center; with the vertebrae, ribs and front limb bones at the top of the photo. The skull and mandible were removed before the photo was taken. The exceptionally large bone at the bottom center is the left femur. Radiocarbon date for Marshalls Creek Mastodon was 12,000 years before present. *Photo courtesy of Pa. Historical & Museum Commission.*

Whatever the real cause of glaciation the climatic elements must be considered in a search for the answer. More snow must fall than melts so moisture becomes a critical factor. Glacial temperatures on the other hand do not call for drastic changes over present temperature ranges but cooler summers seem almost a necessity since the snow must be retained throughout the year.

Remember also that the glacial periods were followed by warmer interglacial episodes thus adding greater complexity to the problem. For any logical hypothesis must explain the occurrence of the four glacial and three interglacial stages. It is on this point that many theories break down with insufficient data to explain the waxing and waning glacial cycles.

How does a glacier form and move?

Glaciers originate in snowfields where yearly accumulation is constantly building up. The lower limit of the snowfield is marked by the snowline. As the snowfield thickens the older snow becomes more compacted into névé through transformation of snow into ice. This transformation is similar to the changes that take place when sediments are altered into sedimentary rocks. Stratification is evident in the intermediate stage, often called firn, since compaction increases the density of the snow through the expulsion of air.

Also aiding in the crystallization of snow is the process called sublimation and recrystallization. It seems a critical thickness of the snowfield is needed before these processes can fully operate. This is thought to be about 150 feet thick.

Glacier movement is not very dramatic, typically only a few inches per day. A glacier moves down the slope by gravity as does a stream with the greatest velocity being reached toward the center and near the top of the ice advance. It seems that two types of movement are evident in glacier although there is much debate concerning glacial advance.

One type is a fracture and shear (fault) type motion occurring primarily in the upper zone of movement (100 to 200 feet thick) where there is a gliding and melting-refreezing of crystals. Here the ice reacts as a brittle substance.

A second type of movement is encountered at greater depths where the ice under great pressure from overlying material will flow by plastic yield like toothpaste being squeezed from a tube. As a result of the differential movement taking place between these two zones (upper brittle zone and the lower plastic zone) the upper zone fractures giving rise to faults and crevasses.

What effects did the moving ice have in Pennsylvania?

Although mountain glaciation was active in the western United States, northern Pennsylvania was covered by continental ice sheets moving southward from Canada. These moving ice masses dragged along beneath them a mass of fragmented rock which smoothed and scratched (striated) the mountain tops they crossed and widened and deepened valleys they occupied.

As they melted, they left a thick accumulation of glacial drift (rock debris) in the valleys and thin deposits on the uplands. There depositional features are the most obvious glacial features of the Pennsylvania landscape in northern counties. Some of this rock debris was laid down directly by the ice while others was deposited by meltwater streams which transported glacially eroded debris from within or beneath the ice.

The most prominent ice formed landscape features are called moraines, consisting usually of ridges of unsorted till extending across the landscape. North of the glacial border there are also areas of low hummocky ground moraine, made of till (Plate 1.25).

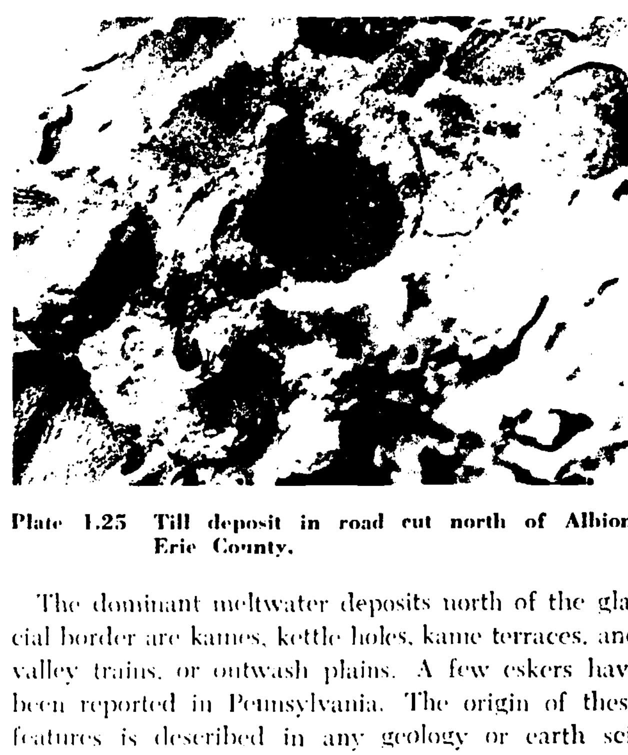

Plate 1.25 Till deposit in road cut north of Albion, Erie County.

The dominant meltwater deposits north of the glacial border are kames, kettle holes, kame terraces, and valley trains, or outwash plains. A few eskers have been reported in Pennsylvania. The origin of these features is described in any geology or earth science textbook. Below are listed a series of topographic maps illustrating glacial features found in Pennsylvania.

An excellent description of glaciation in Pennsylvania has been published by the Pennsylvania Geological Survey, Harrisburg, "Pennsylvania and the Ice Age", by V. C. Shepps, Educational Series #6, 1966. Other booklets on glaciation in Pennsylvania published by the Pennsylvania Geological Survey are: Bulletin G-7, "Glacial Deposits Outside the Wisconsin Terminal Moraine in Pennsylvania" and Bulletin G-9, "The Geomorphology of the Wyoming-Lackawanna Region".

Feature	*U. S. Geological Survey Topographic Quadrangle Map*
END MORAINE	Sandy Lake 7½′ Pocono 15′ Bangor 15′, just north of Bangor along the base of the mountain
VALLEY TRAIN	Brodheadsville 7½″, Pohopoco Creek valley floor Pittston 7½′, Wyoming Valley floor Milford 15′, along Delaware River valley as terraces Beaver Falls 7½′, terraces along Beaver River especially at Koppel
LAKE DEPOSITS	Cambridge Springs 15′, flat valley bottom north of Cambridge Springs on lake deposits Swanville 7½″, beach ridges just about 700 and 750 foot contour lines; lowest is beach of ancient Lake Arkona; highest is beach of Lake Maumee
KAMES	Conneaut Lake 7½′, east of Conneaut Lake; east of West Vernon; and west of Stony Point—north of Jackson Run Milford 15′, just south of Milford at the valley edge, base marked by 500 foot contour line
ESKERS	Mercer 15′
KETTLE LAKE	Conneaut and Harmonsburg 7½′ quadrangles, Conneaut Lake and Clearwater Lake are kettle lakes Cambridge Springs 15′ Edinboro Lake is a kettle lake Brodheadsville 7½′, small lakes in valley of Pohopoco Creek are kettle lakes
DRUMLINS	Wattsburg 7½′, spoon-shaped hills are drumlins. Note also lineated topography; This has been called in other areas "corrugated topography" because of its resemblance to corrugated cardboard

Can You Name One Or More Glacial Lakes In Pennsylvania? (see Figure 1.25)

OTHER EFFECTS OF GLACIATION

1. *Eustatic Change of Sea Level*—Many estimates have been made of how much sea level has risen (interglacial) or fallen (glacial) during the Pleistocene Epoch but the most popularly quoted figure seems to be about 300 feet.

   Topics for investigation:

   Strandlines, glacial terraces (Atlantic coast), drowned valleys, effects on plant and animal life.

2. *Drainage Change*—Many drainage modifications occurred throughout the Pleistocene as meltwaters from the glaciers flowed away from the ice fronts. Four major existing river systems were greatly influenced by and show dramatic effects of glaciation; Missouri River, Ohio River, Mississippi River, and Columbia River.

Topics for investigation:

Teays River Valley, "through valleys", Columbia Plateau scablands, River and associated terraces.

3. *Glacio-Lacustrine Features*—It is undoubtedly true that glaciation has been responsible for the formation of more lakes than all other geomorphic processes combined (Thornbury, 1954). The origin of glacial lakes is very complex and diversified. Glacial lakes form as a result of damming by moraines, ice blocked basins, glacial scouring, deposition of till, kettle lakes, and where topography slopes toward an ice sheet, to mention a few.

Topics for investigation:

Varve deposits, History of the Great Lakes, The Finger Lakes, Lake Agassiz, Lake Souris.

4. *Pluvial Climates in Arid Regions*—Pluvial climates characterized by increased rainfall and decreased evaporation that affected nonglaciated areas during the Pleistocene.

During the glacial periods large sections of western United States were covered with extensive lakes while in the interglacial ages the land became arid and shrinkage of the lakes took place.

Topics for investigation:

Lake Bonneville (Great Salt Lake), Lake Lahontan, Lake Russell, Dead Sea.

5. *Migrations of Plants and Animals*—There is much evidence throughout the Pleistocene Epoch of repeated mass migrations of plants and animals as the climate fluctuated from glacial to interglacial stages.

All living species, both plant and animal, have certain climate tolerances within which they can live and reproduce. Certain plants and invertebrates whose tolerances are highly restricted by the critical factors of moisture and temperature provide rather accurate indications of past climatic patterns. From these paleoclimatic studies paleontologists have pieced together rather clear evidence of large population shifts correlating with the shrinking and expanding of the glaciers.

Topics for investigation:

Trace the evolution and migratory routes of the horse, camel, rhinoceros, elephant, carnivores, and primates; land bridges; carbon 14 dating; biotopes; pollen analysis; oxygen-isotope ratios.

6. *Other Topics for Investigation*
   a. Periglacial phenomena
   b. Pre-Pleistocene glaciations
   c. Periodicity of climatic change
   d. Distribution of loess and eolian deposits
   e. Effect of glacial loads on the earth's crust
   f. Contemporary deglaciation

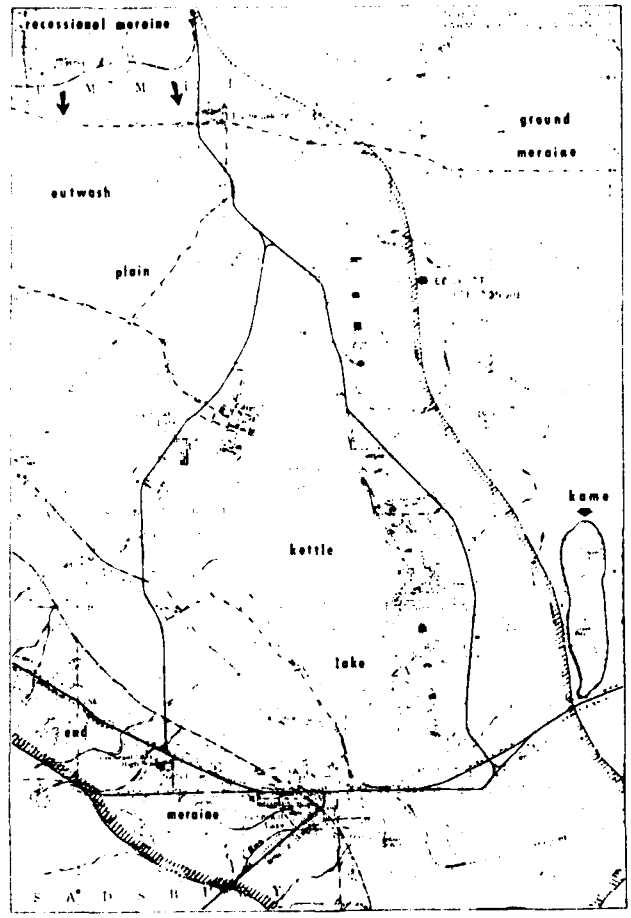

Figure 1.25 Glacial deposits in the Conneaut Lake area.

Plate 1.26 Glacial lake deposit adjacent to I-80 in Monroe County.

Plate 1.27 Kames north of Waterford, Crawford County. Looking east from Route 19.

Plate 1.28 View of Conneaut Lake from gravel pit in kame east of the lake.

Of what practical importance to man have been glaciers and glaciation?

Glaciers eroded and deposited large amounts of rock debris filling in valleys, displacing streams, and creating unique landforms. These deposits by glaciers are important sources of sand and gravel for road building and fill as well as prime underground storage areas for ground water.

In addition, the study of minerals in glacial drift has revealed buried mineral deposits crossed by the ice.

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STRUCTURE OF THE EARTH

Major Topics Explored

Principles of structural geology
Structural axioms
Tectonics
Practical applications of structural geology

What is structural geology?

Most of the surface of the earth is covered by layers of sedimentary rocks. In a few areas such as Central United States the sedimentary rocks are mostly flat lying. However, here in the East, particularly in the Appalachian Provinces, we find these rock layers contorted into many shapes. These rocks have been subjected to many forces that have drastically altered them from their original horizontal attitude.

Through observation and measurement the structural geologist attempts to reconstruct partially eroded and often puzzling geometric rock forms. From a study of the existing evidence, he tries to draw a three dimensional picture of the area. This drawing illustrates each layer's position in time and space and each layer's relationship to the entire sequence of rock he is studying.

Structural geology is important to man in locating valuable mineral deposits and is a necessary tool in understanding earth history.

TEACHING STRUCTURAL GEOLOGY

An analysis of earth structures involves an understanding of forms and three dimensional spacial relationships. Erosion has modified and altered almost all original rock structures so that the problem is first to identify and recreate the original structures in their proper perspective.

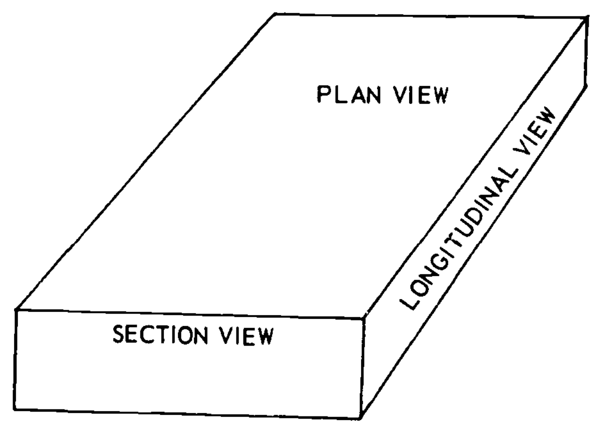
The next few pages provide a set of axiomatic statements regarding common structural and stratigraphic relationships appearing frequently in the earth's crust and depicted on geologic maps and cross-sections.

Structural geology may be taught by presenting the student with this series of axioms and related block diagrams

When the student becomes familiar with these axioms, he will be able to interpret almost any geologic map and cross-section.

Before you engage in any structural analysis of the following diagrams, the student should become familiar with a few general mapping terms and symbols.

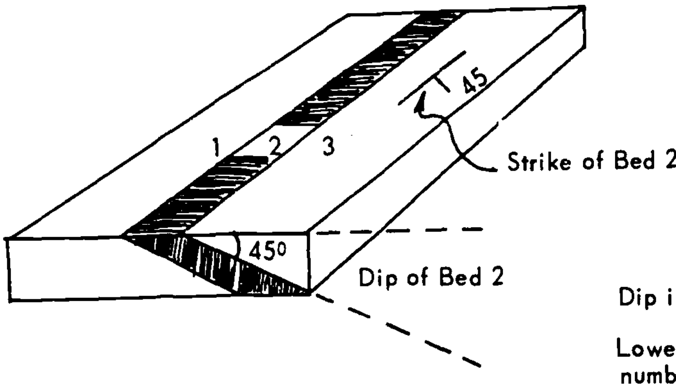
BLOCK DIAGRAM



Plan View: A top view of the view you would get if flying over the structure looking down on it.

Section View: A side or structure view looking into a cut of the block.

Longitudinal View: A view along the side of the block at a right angle to the section view.

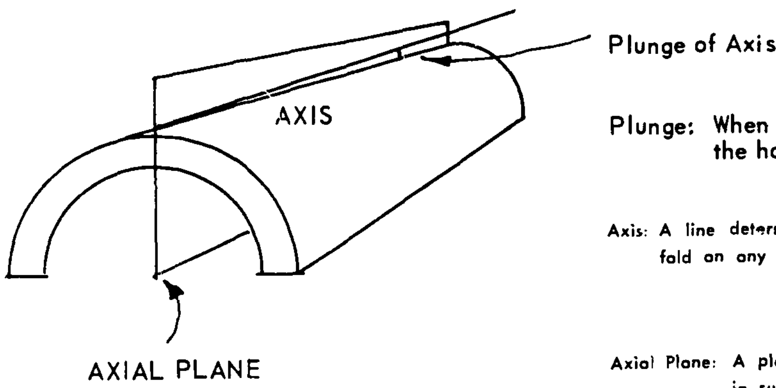


Strike: The compass direction of a horizontal line formed by the intersection of a rock surface with a horizontal plane.

Dip: The acute angle measured between a rock surface and a horizontal plane.

Dip is always measured at a right angle to the strike.

Lowered numbered (1) rock units are older than higher numbered (3) units, and so on. This numbering system is important later when the student is studying the axioms.



Plunge: When the axis of a fold is tilted from the horizontal plane.

Axis: A line determined by the intersection of the two limbs of a fold on any given bed at the crest or trough.

Axial Plane: A plane that intersects the crest or trough of a fold in such a manner that the limbs of the fold are more or less symmetrically arranged with reference to the axial plane.

Geologic Map Symbols

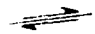
BEDDING

- Strike and dip of beds (number indicates dip in degrees)
- Strike and dip of overturned beds
- Strike of vertical beds
- Horizontal beds

FOLDS

- Anticline, showing trace of axial plane and bearing and plunge of axis.
- Syncline, showing trace of axial plane and bearing and plunge of axis.
- Overturned anticline, (no plunge of axis)
- Overturned syncline, (no plunge of axis)

Faults

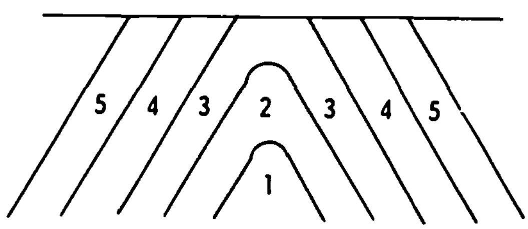

Fault, showing relative movement

High angle fault, movement – U, up, and D, down (plan view only)


Thrust or reverse fault, barbs on side of upper plate shows direction of dip. (plan view only)

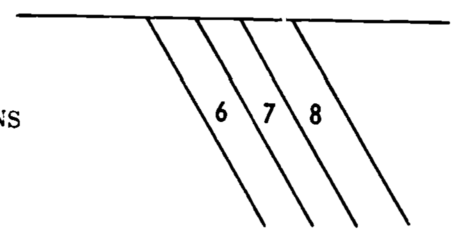
STRUCTURAL AXIOMS ON FOLDED BEDS

1. IN A NORMAL SEQUENCE OF ROCKS OLDER BEDS DIP TOWARD (UNDER) YOUNGER BEDS.



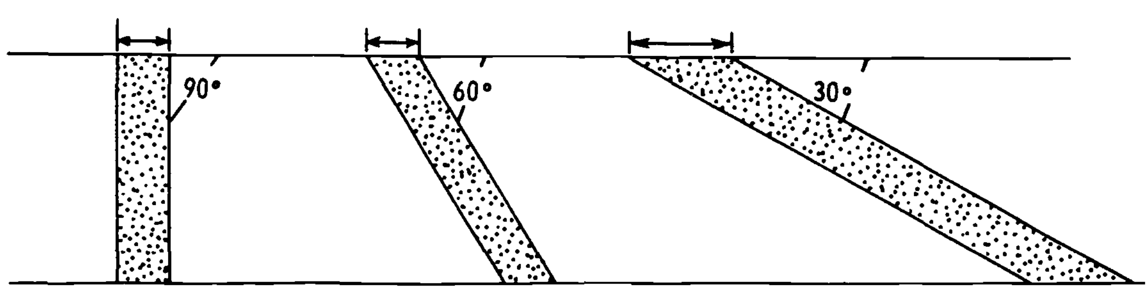
CROSS SECTIONS

YOUNGER →



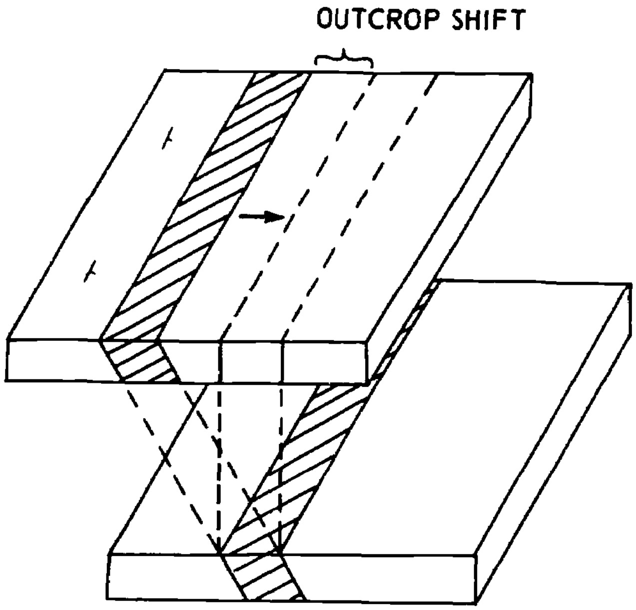
OUTCROP WIDTH

2.



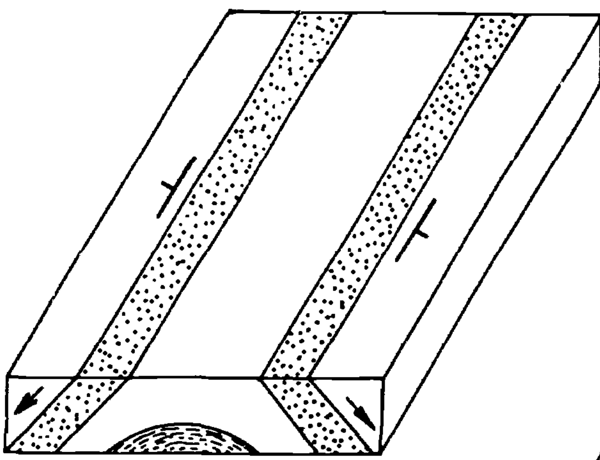
THE OUTCROP WIDTH OF A BED IS INVERSELY PROPORTIONAL TO ITS DIP.

3.



THE OUTCROP PATTERN OF DIPPING BEDS MOVES IN THE DIRECTION OF DIP AS EROSION OCCURS.

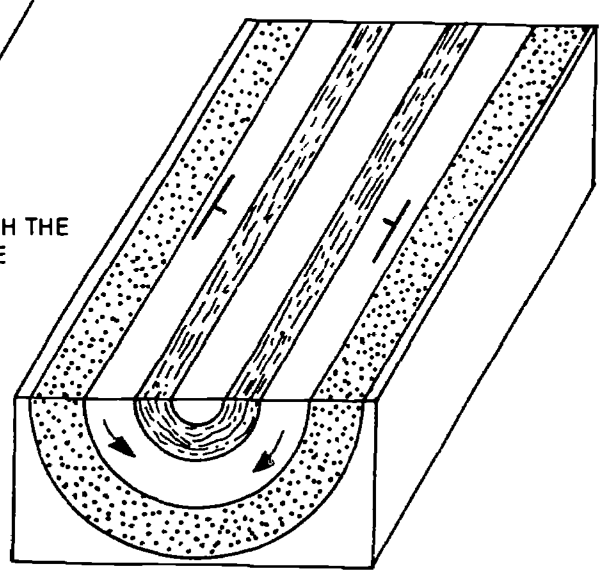
4.



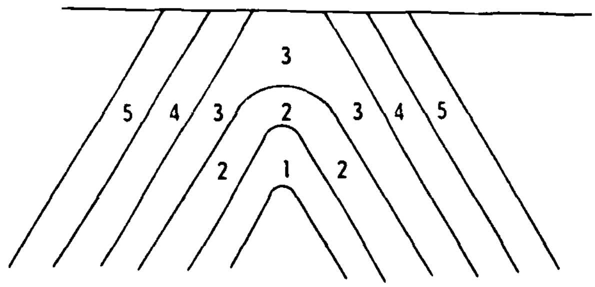
ANTICLINES ARE FOLDS IN WHICH THE ROCK LAYERS DIP AWAY FROM THE AXIS.

SYNCLINES ARE FOLDS IN WHICH THE ROCK LAYERS DIP TOWARD THE AXIS.

5.



6. OLDER BEDS ARE EXPOSED IN THE CENTER OF AN ANTICLINE.



7. YOUNGER BEDS ARE EXPOSED IN THE CENTER OF A SYNCLINE.

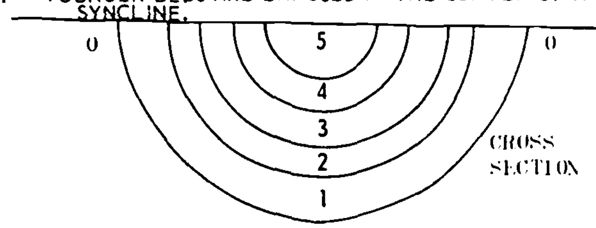
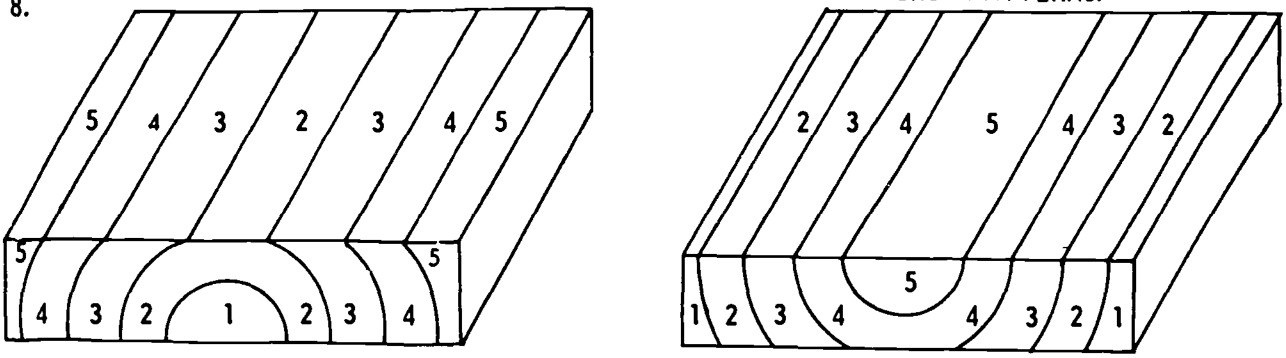


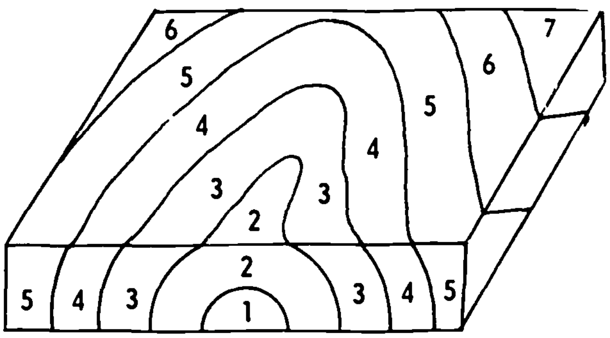
Plate 1.29 Plunging anticline of Pocono standstone, northern Dauphin County.

Plate 1.30 Syncline in southern Anthracite Field of Schuylkill County.

8. FOLDS WITHOUT PLUNGE HAVE STRAIGHT AND PARALLEL OUTCROP PATTERNS.

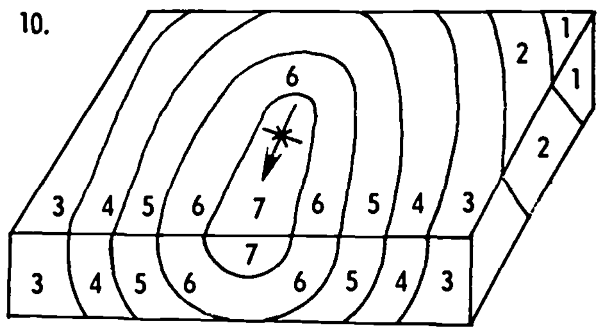


9.



PLUNGING FOLDS HAVE HORSESHOE OR OR CURVED OUTCROP PATTERNS.

10.

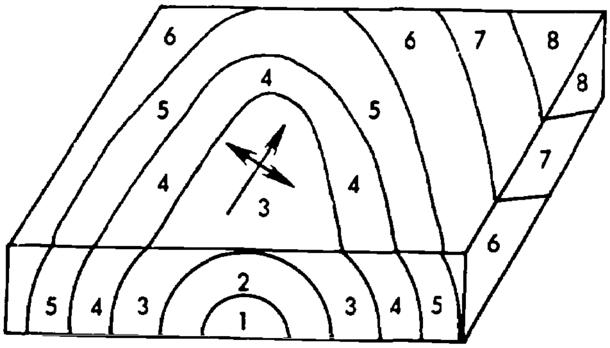


THE DIRECTION OF PLUNGE IN A SYNCLINE IS TOWARD THE OPEN END OF THE CURVED OUTCROP PATTERN.

Plate 1.31 Anticline in Catskill Formation, Carbon County.

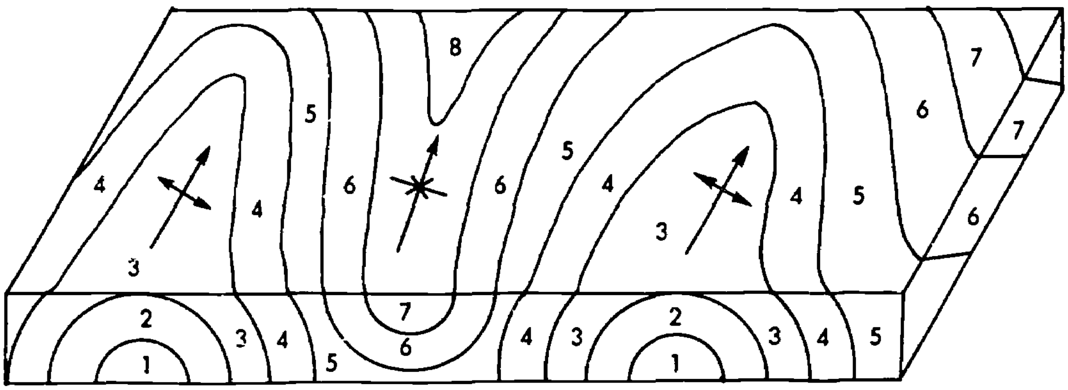
Plate 1.32 Overturned folds in Eshleman's Quarry, Lancaster County.

11.



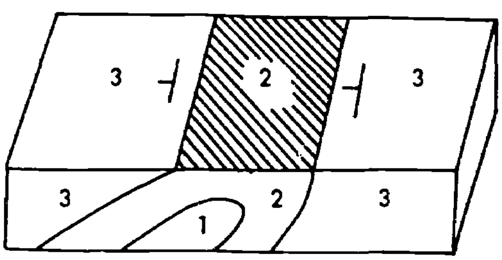
THE DIRECTION OF PLUNGE IN AN ANTICLINE IS TOWARD THE CLOSED END OF THE CURVED PATTERN.

12.



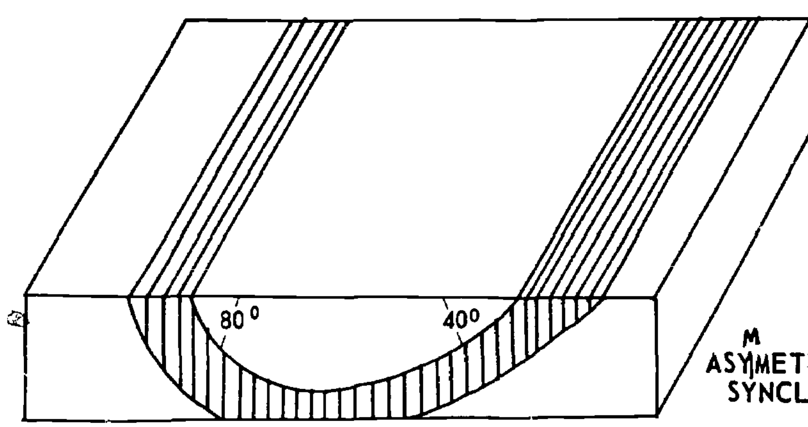
ALTERNATING PLUNGING ANTICLINES AND SYNCLINES OUTCROP IN A Z-SHAPED PATTERN.

13.



WHEN THE LIMBS OF THE FOLD ARE DIPPING IN THE SAME DIRECTION, THE FOLD IS OVERTURNED.

14.

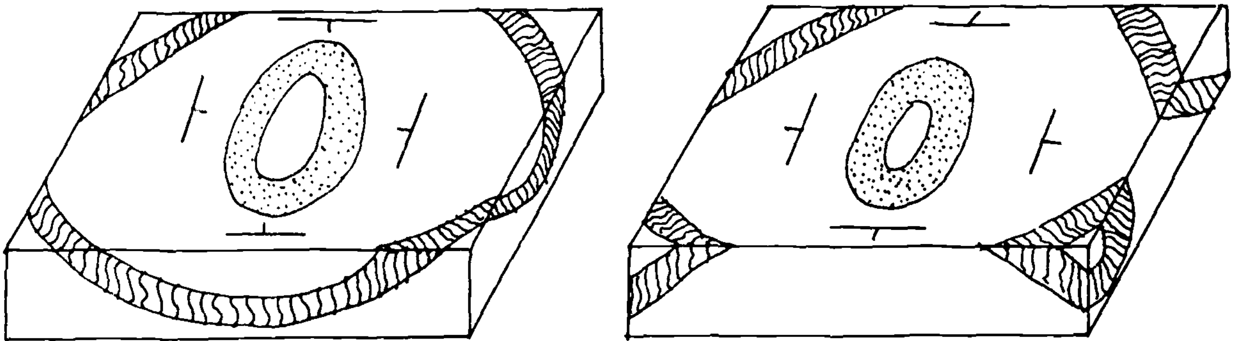


ASYMMETRICAL SYNCLINE

IF ONE LIMB OF A FOLD DIPS MORE STEEPLY THAN THE OTHER, THE FOLD IS ASYMETRICAL.

WHEN THE ERODED OUTCROP FORMS A CIRCULAR PATTERN THE STRUCTURE IS A DOME IF THE DIP IS AWAY FROM A COMMON CENTER; AND A BASIN IF THE DIP IS TOWARD A COMMON CENTER.

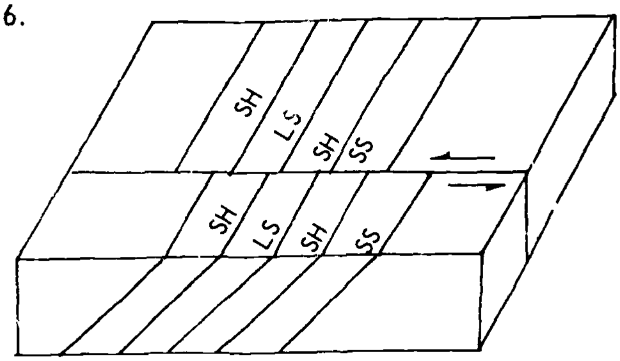
5.



BASIN DOME

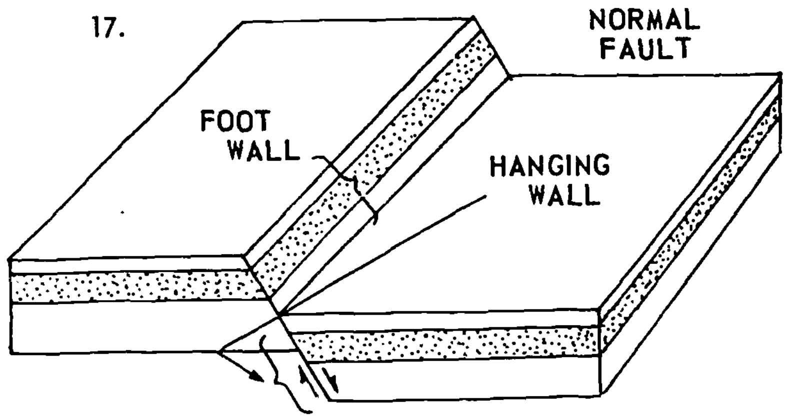
STRUCTURAL AXIONS FOR FAULTED ROCKS

6.



INTERRUPTED OUTCROP PATTERNS MAY INDICATE A FAULT.

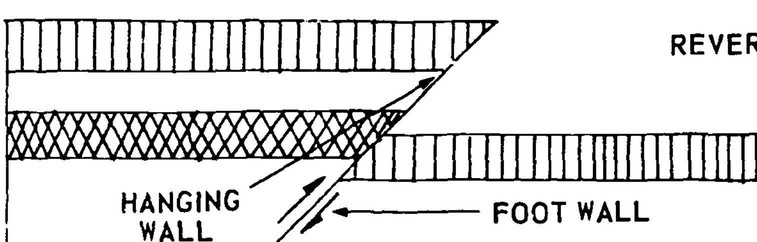
17.



THE HANGING WALL APPEARS TO HAVE MOVED DOWNWARD IN A NORMAL FAULT.

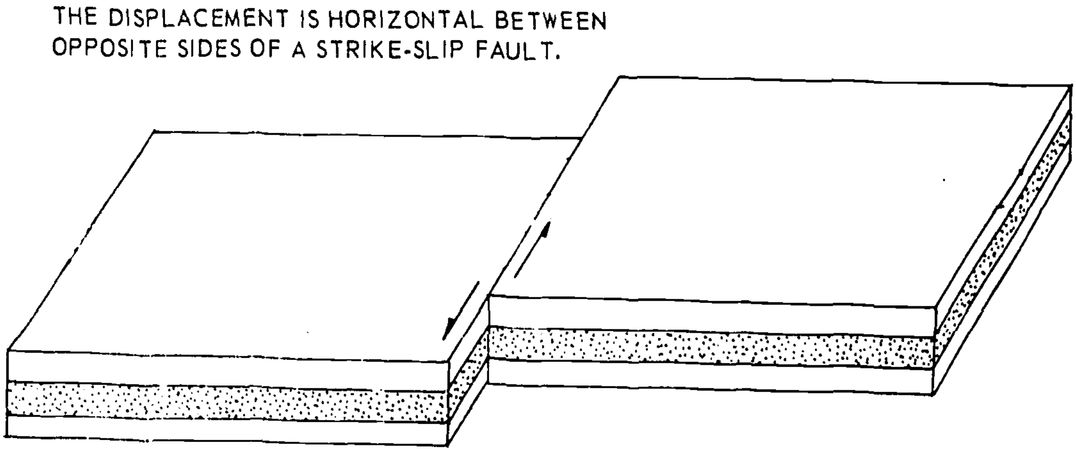
THE HANGING WALL APPEARS TO HAVE MOVED UPWARD IN A REVERSE FAULT.

18.

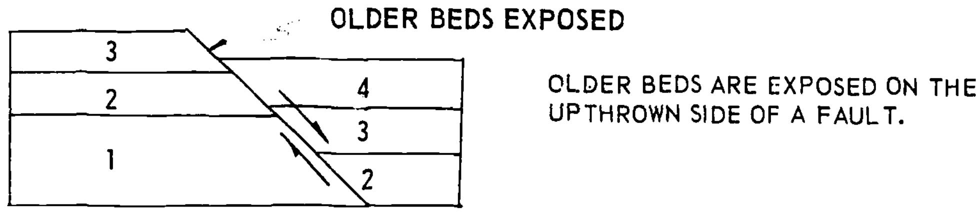


REVERSE FAULT.

19



20.



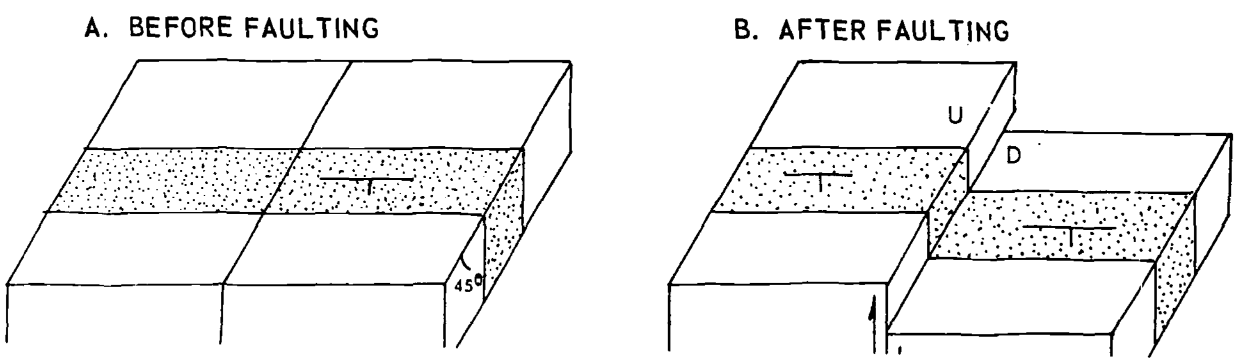
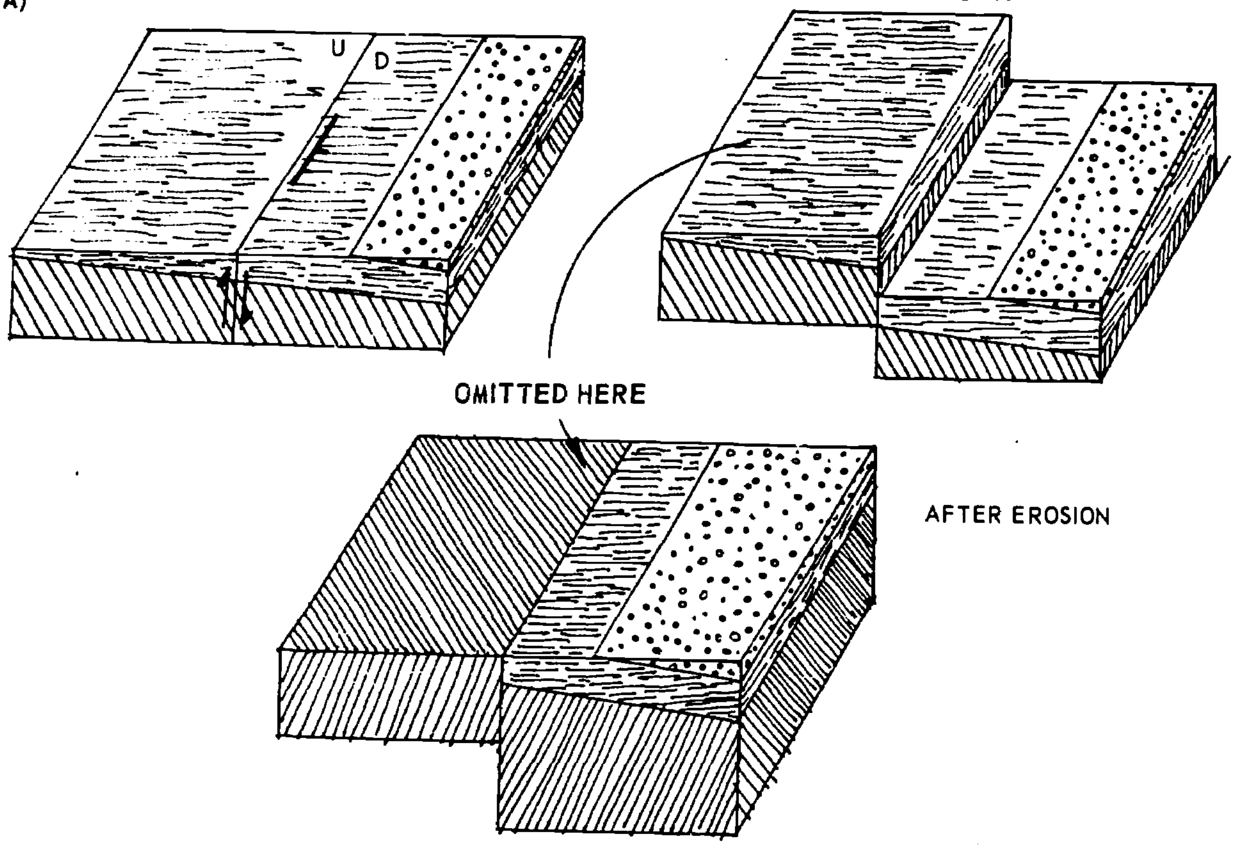


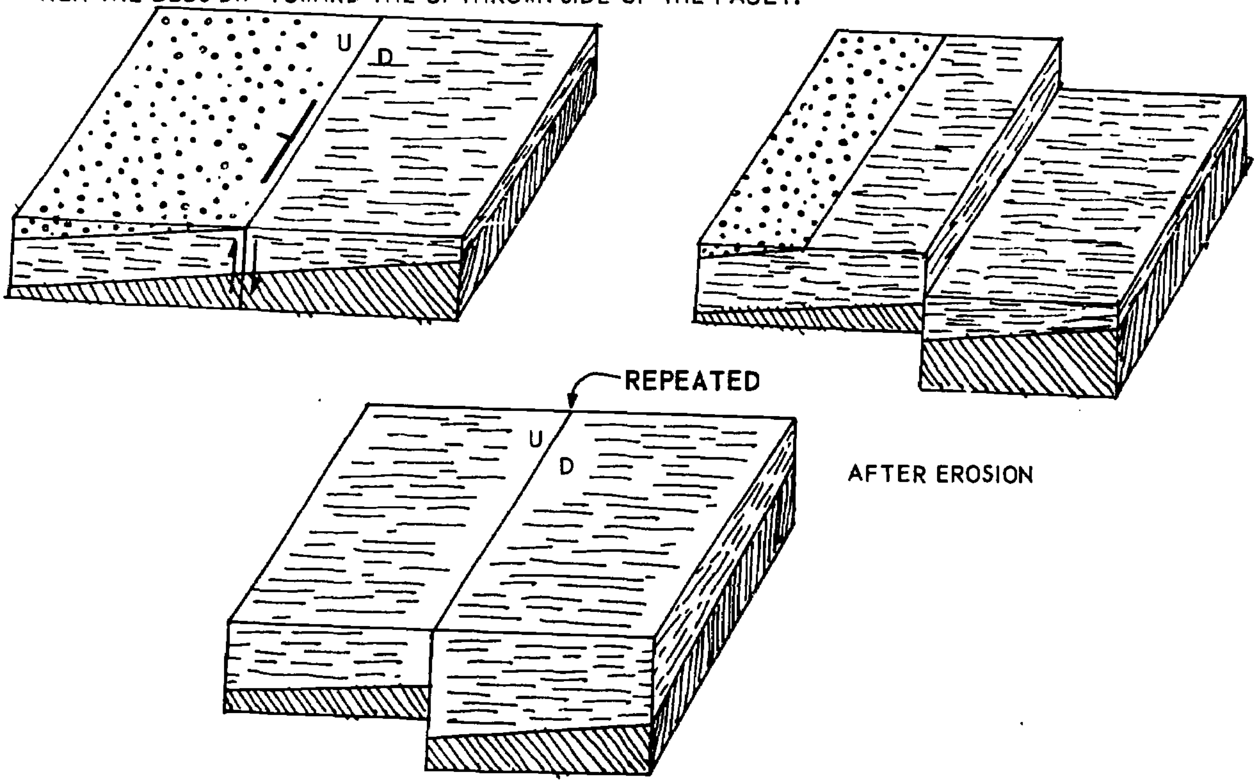
Plate 1.33 *Normal fault.*

Plate 1.34 **High-angle reverse fault, exposed along Interstate 81 near Hazleton, Luzerne County.**

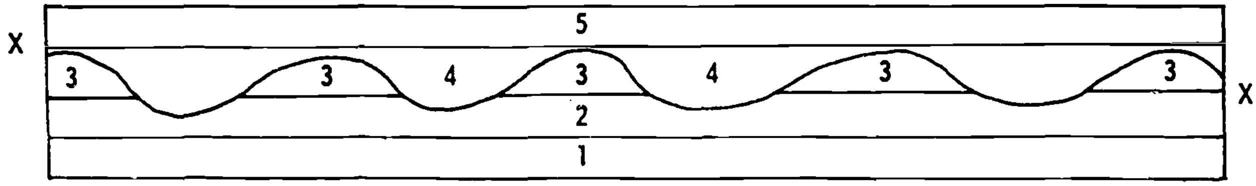
22. (A) WHEN THE FAULT LINE AND STRIKE OF THE BEDS ARE PARALLEL, SOME OF THE BEDS MAY BE MISSING WHEN THE DIP OF THE BEDS ARE TOWARD THE DOWNTHROWN SIDE OF THE FAULT.



(B) WHEN THE FAULT LINE AND STRIKE OF THE BEDS ARE PARALLEL, SOME OF THE BEDS MAY APPEAR TWICE WHEN THE BEDS DIP TOWARD THE UPTHROWN SIDE OF THE FAULT.

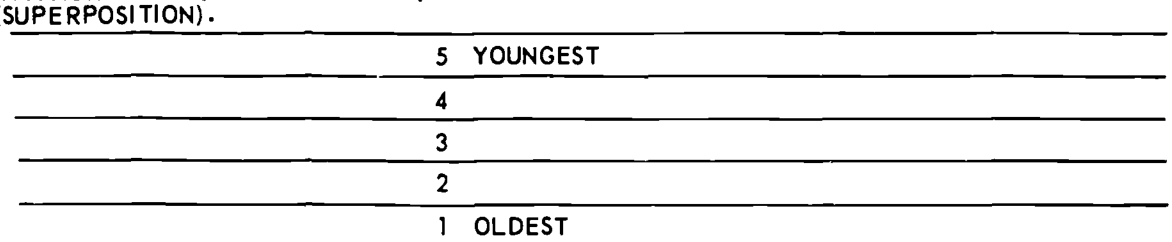


23. A SURFACE OF EROSION OR NONDEPOSITION THAT SEPARATES YOUNGER ROCKS FROM OLDER ROCKS IS CALLED AN UNCONFORMITY.

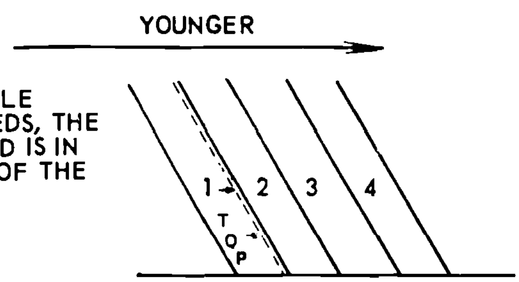


X–X' = UNCONFORMITY

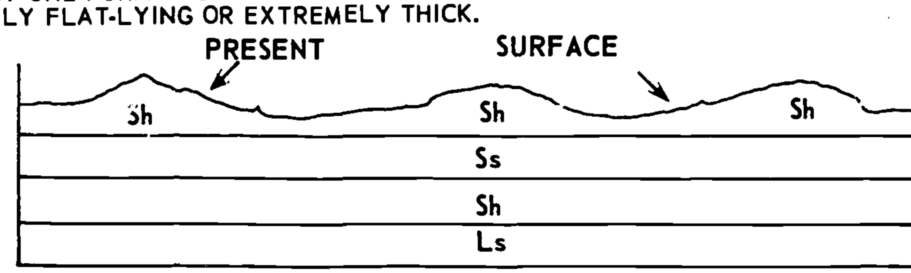
24. IN A NORMAL SEQUENCE OF ROCKS, THE YOUNGEST BEDS ARE TOWARD THE TOP OF THE SEQUENCE (SUPERPOSITION).



25. IN A COMFORMABLE SEQUENCE OF BEDS, THE TOP OF EACH BED IS IN THE DIRECTION OF THE YOUNGER BED.



26. WHEN ONLY ONE FORMATION OUTCROPS OVER A FAIRLY EXTENSIVE AREA, THE BEDS ARE RELATIVELY FLAT-LYING OR EXTREMELY THICK.



27. A PERIOD OF DIASTROPHISM IS YOUNGER THAN ANY OF THE BEDS THAT SHOW ITS EFFECTS.

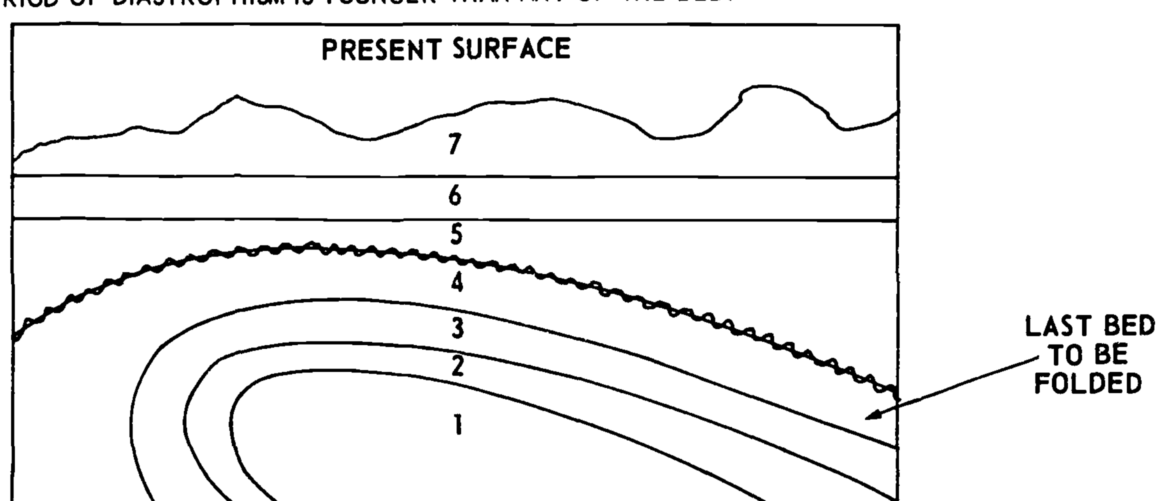
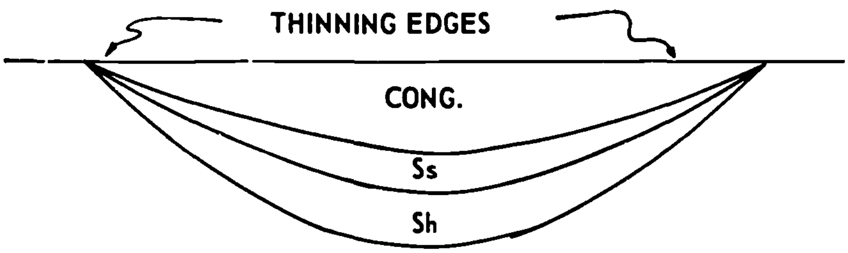


Plate 1.35 Unconformity between Triassic red sandstones (top) and Beekmantown dolomite (bottom).

Plate 1.36 Unconformity between Ordovician Martinsburg shale (left) and Silurian Tuscarora quartzite (right).

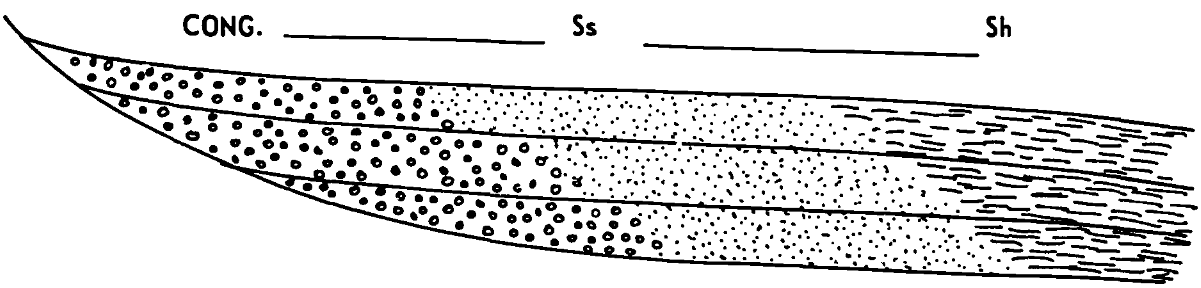
28.



A SEDIMENTARY ROCK LAYER MAY CHANGE IN CHARACTER (FACIES) LATERALLY AS A RESULT OF THE NATURE OF THE DEPOSITIONAL ENVIRONMENT (I.E. THINNING OF ROCK ON EDGES OF A BASIN).

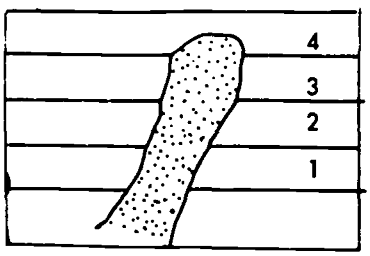
CONFORMABLE IN AGE AND POSITION

29.



IN THE CASE OF A PINCH-OUT OF BEDS ALONG THE MARGINS OF A DEPOSITIONAL BASIN, TWO DIFFERENT ROCK UNITS (I.E. SANDSTONE AND SHALE) MAY BE CONFORMABLE IN AGE AND POSITION.

30. A FAULT, INTRUSION, OR UNCONFORMITY IS YOUNGER THAN ANY ROCK THAT IT CUTS.

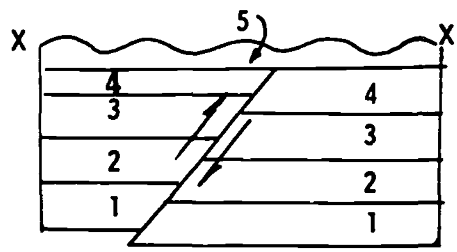


PROBLEM

GEOLOGIC COLUMN

DIKE
4
3
2
1

ANSWER



PROBLEM

GEOLOGIC COLUMN

X-X
5
REV. FAULT
4
3
2
1

ANSWER

Now that we have studied "structural geology", what is "tectonics"?

Tectonics deals with major structures in the earth's crust and the forces involved in the shaping of the continents and ocean basins. It is therefore a phase of structural geology dealing with the largescale framework of the earth's crust.

Advances in tectonics depend on a knowledge of the geological structures of large regions. There have been great advances in this scientific area but many problems go unanswered because of insufficient geologic and geophysical data. As a result, the science of tectonics deals mostly with speculations rather than scientific fact. This field is wide open for personal theorizing and interpretation.

The following outline is provided for the teacher as a guide to stimulate class discussion and student investigation of some of the most interesting and contemporary topics of earth tectonics.

1. *Continental Drift*—The Theory of Continental Drift was first formalized by Alfred Wegener, an Austrian meteorologist in 1912. He envisioned a single vast continent consisting of all dry land (Pangaea). During late Mesozoic time the landmass broke up and began drifting into the present positions of the existing continents. Today there is renewed interest in the drift concept as a result of recent studies in convectional currents and paleomagnetism.

Suggestions for study

a. A good way to introduce the topic of continental drift is by observing the shapes of the continents on a world map and literally fitting the continents together (i.e., South America fits into Africa).
b. Investigate Wegener's Theory of Continental Drift.
c. Investigate evidence in support of continental drift (i.e., paleomagnetism, Paleozoic glaciation, fossils, paleoclimates).
d. Investigate evidence against the theory of continental drift (i.e., Gondwanaland, fossils, etc.).

2. *Convectional Currents*—The possibility of convectional currents in the earth's mantle have led to many exciting and interesting controversies regarding their relationship to mountain building, continental drift, isostasy, and others. This convectional movement is analogous to the movement of water when heated in a beaker. In each convection cell, the semi-liquid material of the mantel rises in the middle, curves outwards to the sides, and descends along the outer edges. The currents normally occur in pairs so that where two cells upwell and diverge the crust is under considerable tension and the basic material of the mantle is displaced upward toward the crust. Where the cells converge and descend the crust is dragged downward under compressional forces.

Suggestions for study

a. Investigate nature of the material in the earth's mantle.
b. On a world relief map attempt to locate possible sites of converging and diverging convectional cells.
c. Investigate convectional cell theories (i.e., Grigg's, Pekeris, etc.).
d. Demonstrate convectional movements using different mediums (i.e., water, glycerin, etc.).
e. Investigate the time factor and cyclic occurence of convectional cells.

3. *Sea Floor Spreading*—Recent geological evidence has indicated that mid-oceanic ridges are marked by normal faulting, high seismic activity, high heat flows, and an absence of a sharp Mohorovicic discontinuity.

The Mid-Atlantic Ridge could represent an area of upwelling mantle and divergence of a paired convectional cell system. In this way, the normal faulting and horizontal extension of the ridge at right angles to its length is brought about. Surveys in Iceland show that the country is being pulled apart at the rate of about 3.5 meters per year per kilometer of width. The Atlantic continents thus move apart as new oceanic crust forms.

There seem to be enough areas of folding and compression at and near the borders of continents to compensate for the expansion postulated at the mid-oceanic ridges. Perhaps in these zones of compression the convection current is descending.

4. *Isostasy*—The Theory of Isostasy from the Greek "equal standing" states that different portions of the earth's crust are in balance or equilibrium as a result of difference in mass and specific gravity. Gravity surveys have proven that mountain masses do not exert as much gravitational attraction as they should if they were loads resting on a uniform crust. One feasible explanation of this phenomena is that the mountains are buoyed up by a more dense plastic layer beneath the mountain masses. A mountain system such as the Himalayas rises over five miles above sea level. To compensate for this excess

volume the lighter sialic layer of the crust is thicker than the more dense simatic layer. Thus the mountains have roots of lighter material extending deeply into the crust. Conversely, if surface features have negative topographic expression the sialic layer is thinner and the simatic layer proportionately thicker.

Suggestions for study

a. Investigate the different theories of isostasy (i.e., Pratt, Airy).
b. Investigate the nature of the earth's crust.
c. Investigate the forces involved in the establishment of isostasic equilibrium (internal and external).
d. Terminology: geoid, spheroid, gravity anomaly, plumb line, sial, sima.
e. Demonstrate isostasy by floating materials of different densities in different mediums.

5. *Fold Mountains and Geosynclines*—Most of the major mountain systems of the world such as the Rockies, Appalachians, Alps, Andes, and Himalayas are examples of folded type mountains consisting of anticlines and synclines that are commonly faulted. Folded mountains contain all types of rocks with various fossil assemblages but the common element of all folded mountains is that they contain extremely thick deposits of shallow water sedimentary rock strata. Since these strata are not typical of deep ocean sediments another explanation is required for their accumulation, namely a geosyncline. A geosyncline is defined as a large linear-shaped trough continuously downwarping while contained sediments are accumulating.

Below is a partial list of generalizations regarding geosynclines:

a. Geosynclines form during sedimentation rather than afterwards.
b. Geosynclines commonly occur along the margins of continents.
c. Subsidence of the crust in a geosyncline must be related to internal forces underneath.
d. A geosyncline is a mobile belt.
e. Geosynclines represent surface expressions of deep crustal structures.

Suggestions for study

a. Investigate the various theories of geosynclines (i.e., Hall, Dana, Kay).
b. What was Appalachia?
c. Geosynclinal terminology: miogeosyncline, eugeosyncline, Craton, tectonic lands, foreland, hinterland, shield.
d. Map the past and present positions of geosynclines and look for correlations between them and mountain systems.
e. Explain how mountains can form from geosynclinal basins. Crustal shortening?
f. Investigate other types of mountain building (i.e., fault, block, volcanic, upwarped).

6. *Oceanic Features:* Island Arcs—A system of arcuate-shaped volcanic ridges rising from the ocean floor and separating shallow seas from the open ocean. Among them are the Circum-Pacific belt of islands such as the Aleutians, Japan, Philippines, etc.

   Deep Sea Trenches—Long narrow depressions typically over 20,000 feet deep with steeply sloping sides typically found adjacent to and on the ocean side of the island areas. Many of the ocean depths represent areas of negative gravity anomalies or portions of the earth's crust that are deficient in mass due to an excess of light crustal rocks pulled down to great depths.

   Ridges and Rises—Ridges are narrow steep-sided submarine masses elevated high above the ocean floor. Rises are large, broad topped swells rising from the ocean floor and sometimes appearing above the surface as islands (Azores). The rises frequently represent positive gravity anomalies, an indication that the denser rocks of the lower crust are closer to the surface than usual.

Suggestions for study

a. What is the relationship of the oceanic features and gravity anomalies to convectional currents?
b. Map the position of Island Arcs, Trenches and Ridges and study their geographic distribution.
c. What is the relationship of earthquakes and volcanoes to Island Arcs and Trenches?
d. Taking into consideration all of the above structural features (one to five), list the correlations and discrepancies that exist among them.

The following texts provide additional information concerning the list of topics discussed under this heading and should provide greater understanding without getting into the technological and quantitative aspects of tectonics.

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Hodgson, J. H. (1964), *Earthquakes and Earth Structure*, Gordian Press, S. I., N. Y.

King, C. A. M. (1961), *An Introduction to Oceanography*, McGraw-Hill.

Menard, H. W. (1964), *Marine Geology of the Pacific*, McGraw-Hill.

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Can you name some practical applications of structural geology?

How can a knowledge of structural geology help man?

The structural geologist is concerned with many man-related activities which might be interesting for the student to investigate. Below are some suggested questions and topics for student involvement:

1. How does man locate oil deposits? Ore deposits? etc.

Oil being lighter than water tends to migrate upward through rock pores as a result of buoyancy. When the passage of oil is halted, usually because of contact with an impermeable rock layer, the oil begins to accumulate to form economically significant deposits called oil traps.

Some of the most common types of oil traps (Figure 1.26) are produced by folding and faulting of rock layers. Anticlines and domes represent common types of structural traps in which the oil will migrate up-dip along the limbs of the fold and form a pool in the crest of the fold beneath the impervious caprock. An oil trap can also be produced through faulting by bringing a reservoir rock in juxtaposition with an impermeable bed thus producing an oil pool adjacent to the fault plane.

2. Coal mining problem—How might structural geology be used in coal mining?

One of the cheapest and most desirable methods of coal mining in the United States is by open pit strip mining where a large scoop is employed to remove the undesirable overburden (soil and rock) and mining the coal with a power shovel. In order to mine coal by this method the geologist must be concerned with both the economic and geologic aspects of the deposit.

The amount of overburden to be removed before stripping operations can be carried out is an economic factor that must be considered since it is a cost factor in any mining operation. If the overburden removal cost exceeds the value of the coal the company would "be in the red". Frequently coal beds are found to be slightly dipping which presents the problem of determining the depth of the overburden to be removed and still operate with a profit (overburden/-coal ratio). As the scooping operations continue down dip the amount of overburden increases and at some point the removal of the overburden (cost) will exceed the value of the coal (earning.)

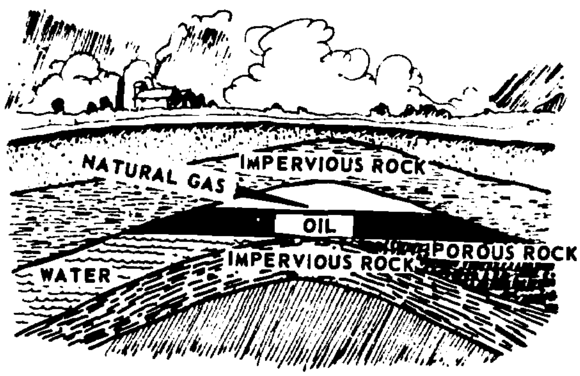
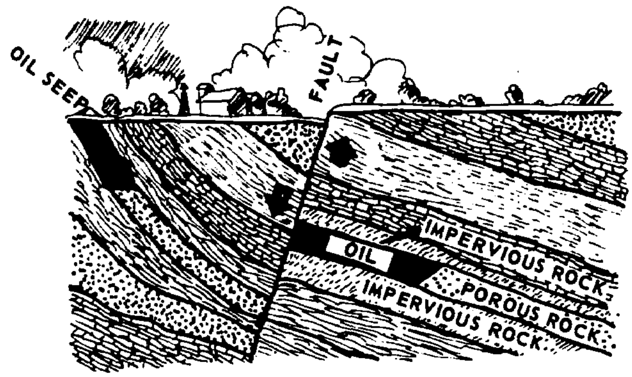


Figure 1.26 (A) The Dome Trap. Oil and gas are often found in folds in rock strata. Oil "floats" above the denser water. Gas, less dense than oil, is present above the oil.



(B) The Fault Trap. When a fault occurs, movement takes place. If oil-bearing rocks are present, oil is trapped by impervious rock present at the other side of the fault.

Example

A coal bed 5 feet thick strikes north-south and dips 10 west. The top of the bed outcrops along the eastern edge of the property owned by the mining company. The coal can be strip mined at a profit as long as the overburden/coal ratio does not exceed 20:1. How far west can stripping operations be profitably carried? (See Figure 1.27.)

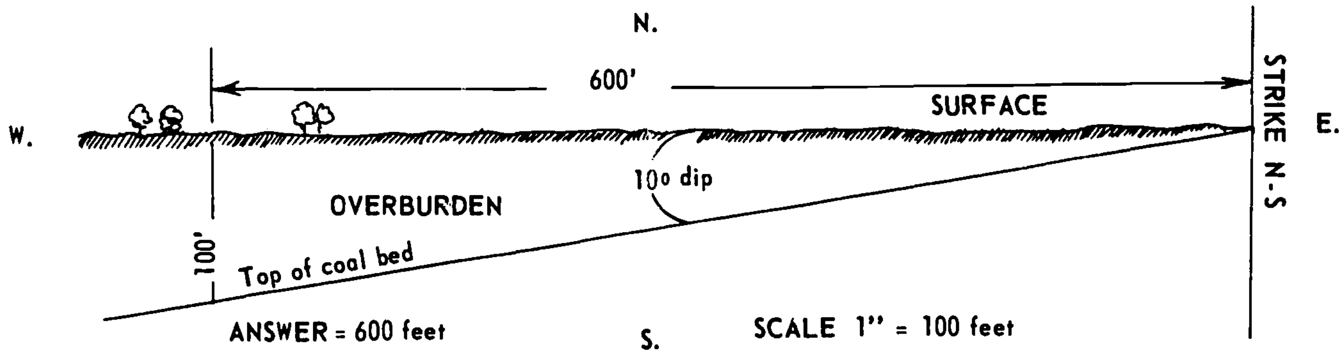


Figure 1.27 Graphic solution to mining problem.

3. **Can you name other ways structural geology helps man?**

There are many, but the following questions and topics will point out some of the more important.

a. What is the relationship of rock structure to ground water, artesian springs, city water supplies?
b. Why is a knowledge of rock structure important in the construction of highways, dams, airfields, and housing developments?
c. Examine selected ore deposits in the United States and study their structural implications and significance of the deposits.
   (1) Mesabi Range, Minnesota (iron)
   (2) Keweenaw Peninsula, Michigan (copper)
   (3) Black Hills, South Dakota (gold)
   (4) Salt domes, Gulf of Mexico (salt)
   (5) Oil fields, Gulf Coast
d. How does geologic structure influence and control the evolution of landforms?
e. Study the topography that developes upon folded and faulted rocks. Consult "Principles of Geomorphology", by W. D. Thornbury, 2nd Edition, John Wiley and Sons, 1969. Also consult U. S. G. S., "Set of One Hundred Topographic Map Series".

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THE GEOLOGIC HISTORY OF THE EARTH

The students should be familiar now with the more important geologic features and with the physiographic aspects of the United States and Pennsylvania. At this point, the teacher may turn to a discussion of how these features came to be.

Major Topics Explored

Measuring geologic time
Uniformitarianism
Methods of unraveling the past
Geologic time scale
Geologic history of Pennsylvania
The fossil record

Can Anyone Tell Us How We Might Measure Geologic Time?

Relative Time—whether one event in the history of the earth came before or after another event.

Absolute Time—whether a geologic event took place a few thousand years ago, a billion years ago, or at some specific date in geologic history.

Absolute Time

1. *Radioactivity*—The nuclei of certain elements spontaneously emit particles, and in so doing produce new elements. This process is known as radioactivity.

   Uranium 238 (U^{238}) will yield helium and lead as end-products. The rate at which U^{238} decays is constant, unaffected by any known physical or chemical agency.

   The rate at which a radioactive element decays is expressed in terms of its *half life* (time required for half of the nuclei in a sample of the element to decay). The half life of U^{238} is 456 x 10^9 years, which means if we start with an ounce of U^{238} there will be only half an ounce left after 4,560 million years.

   Potassium-Argon is more simple and reliable than U^{238}. Potassium becomes argon, by one transformation. Half life is 1 billion, 310 million years.

   Rubidium-Strontium—the half life of Rb^{87} is about 6 billion years and is useful in old rocks.

   Carbon 14—Neutrons from outer space (cosmic rays) bombard nitrogen and knock a proton out of the nitrogen. Carbon 14 combines with oxygen to form a special carbon dioxide $C^{14}O_2$, which circulates in the atmoshpere and eventually reaches the earth's surface, where it is absorbed by living matter. It has been found that the distribution of carbon 14 around the world is almost constant. Its abundance is independent of longitude, latitude, altitude, and the type of habitat of living matter. There is, then, a certain small amount of carbon 14 in all living matter. And when the organism, whether it is a plant or animal, dies its supply of carbon 14 is, of course, no longer replenished by life processes. Instead, the carbon 14 with a half life of about 5600 years, begins the change back to N^{14}. The longer the time that has lapsed since the death of the organism, the less the amount of carbon 14 that remains. By comparing the amount present (i.e. in a buried piece of wood or a bone), with the modern abundance a value is worked out for the amount of C^{14} remaining.

   This isotope can be used only for organic material that is 50,000 years old or younger.

2. *Sedimentation*—Absolute dates for some sedimentary rocks can be established by determining the rate at which they were deposited. Certain sedimentary rocks shows a succession of thinly laminated beds. Various lines of evidence suggest that in some instances at least, each of these beds represents a single year of deposition. So by counting the beds, we can determine the total time it took for the rock to be deposited.

   Varve—a pair of thin sedimentary beds, one coarse and one fine. In glacial lake areas (best examples in Scandinavian Countries) where in summer lakes were not frozen, and water turbulent, finer particles are held in suspension while heavier particles settled out and are light colored. In winter, lakes are frozen so that finer particles now settle out and are of darker color. Both layers represent a year's deposit (lamination).

3. *Growth Rings on Trees* (Dendrochronology) Oldest tree (Sequoia) dated 4600 years.

4. *Retreat of Falls*—Niagara Falls—Falls cutting back about 3 feet per year. Has cut back 7 miles. About 12,000 years when ice covered area and with retreat falls started cutting.

5. *Salt in Salt Lakes*

Relative Time

1. *Law of Superposition*

   If a series of sedimentary rocks has not been overturned, the topmost layer is always the youngest and the lowermost is always the oldest.

2. *Correlation of Sedimentary Rocks*
Since we cannot find sedimentary rocks that represent all of earth time neatly arranged in one convenient area, we must piece together the rock sequence from locality to locality.
3. *Physical Correlation*
   a. "Walking out the Beds" geologic mapping out of surface outcrops.
   b. Lithologic Similarity rocks with identifiable characteristics such as color, texture, etc. can be correlated.
   c. Sedimentary Features - mudcracks, ripple marks, worm borings, concretions, and nodules.
   d. Topographic Expression--forming ridges, depressions, valleys, (see Plate 1.1).
   e. Heavy Minerals--(garnet, magnetite, rutile--minerals high in specific gravity). Traces are too small to see in the field. Must be examined in the lab by dissolving samples.
   f. Cross-cutting relationships--a rock is younger than any rock that it cuts across.

Paleontologic Methods

1. Index Fossils--requirements: short life span, wide distribution, easily recognized, moderately abundant, well preserved. Example: Fusulina--Penna. Period.
2. Similarity of Fauna—If you have 25 to 40 per cent of all species in two rock layers, this method is practical.
3. Mid-point Ranges—must have large fauna, 50 species or more.
4. General Faunal Succession—The broad over-all evolutionary development has resulted in the major groups of organisms reaching the scene of their developments in different periods of time.

Other Methods of Relative Dating

Electric Well Logging—measures resistance of flow of current through rocks.

Radioactivity Well Logging—Uses neutron curve, reflects amount of hydrogen in rock.

Caliper Logs--size of hole variations measured.

Drilling Time Lag—How many feet drill through in given period of time.

Have you ever thought that the geologic processes we see in action today were active throughout geologic time?

Geologists feel that this is a true assumption and have been able to decipher geologic history in this way. By studying present-day processes which produce sediments, transport them, deposit them, and solidify them into rocks, we can learn how sedimentary rocks were formed in the past. Thus the old saying, *The Present is a Key to the Past.*

What is historical geology?

Historical geology is the study of the history of the planet Earth. It is the study of the development of the physical world, its life forms and its past natural environments.

How does the geologist decipher the history of the Earth?

The historical geologist performs duties very similar to that of a detective solving a crime. He begins by gathering all of the available facts (as seen in the rock and fossil record); he then begins to work backward piecing together all the possible events that could have occurred; takes into consideration all available clues and finally arrives at a correct or near correct solution.

What is a fossil?

A fossil is the evidence of a once-living organism (plant or animal) preserved in rocks. Fossils range in size from microscopic single-celled organisms to structures as large as dinosaur skeletons.

A fossil need not be a whole animal; broken fragments or naturally separated pieces are also fossils. In fact, many types of animals and plants are rarely found as complete specimens. Most plants are made up of many easily separated pieces such as seeds, leaves, stems, and branches. Many animals have bony skeletons held together by fleshy material; decay of the fleshy material allows the hard parts to be scattered by various natural processes.

How do fossils form?

Certain types of environments are conducive to the preservation of organic materials. Those conditions that typically favor preservation include: 1) *hard parts* such as bones, shells, teeth, scales; 2 *quick burial* such as in sand, mud, quicksand, volcanic ash, snow burial.

Marine environments represent the best regions for preservation of fossils. Marine life is abundant and sedimentation is rapid and constant. The best records of past life are therefore derived from rocks that represent past oceanic environments.

What are the different types of preservation?

Petrifaction refers to the hard parts of fossils that change to stone. This process is accomplished by:

1. *Permineralization*--If the original structure is porous, as bones or shells, mineral matter may be added from underground water to fill up the voids without altering the original substance.

This makes objects more compact and protects them from air and solutions that would destroy them.

2. *Replacement*—The substitution of mineral matter from ground water for the original organic material. Silica or calcite replaces original cell structure retaining the internal parts of the animal (see Plate 1.37).

Plate 1.37 Pyritized gastropod fossil.

3. *Distillation* (Carbonation)—The volatile (gaseous) elements of organic material are distilled away leaving a residue of carbon on the fossil.

Other Methods of Preservation

1. Burial in quicksand, peat bogs, and asphalt bogs.
2. Burial in caves and underground caverns.
3. Quick freeze burial in avalanches of snow and ice.
4. Falls of volcanic ash.
5. Burial by dry wind-blown sands in deserts.
6. Preservation in amber (particularly insects).

Fossil Terminology

External Mold—An impression of skeletal hard parts in adjoining rock, showing the shape of the outer sides of the hard parts; formed by the close packing of sediments around the preserved hard parts.

Internal Mold—Impression of skeletal parts in adjoining rock revealing the form of the inner surfaces.

Imprint—A very thin mold lacking any evidence of original organic material.

Cast—Filling mineral matter of a cavity formed by the solution and removal of skeletal hard parts by ground water.

Track—Individual impression made in soft sediment by the foot or locomotory appendage of an organism. Commonly produced by vertebrates.

Trail—Marks produced by organisms lacking discrete feet moving through soft sediment; commonly produced by invertebrates.

Burrow—Cavity produced in soft sediment by organic activity such as in feeding or habitation.

Boring—Cavity produced in hard sediment or other material by organic activity usually for the purpose of habitation (see Plate 1.38).

Coprolite—Undigestible residue that has passed through the alimentary canal of an organism and preserved in sediment.

Gastrolith—Small polished stones found in the stomachs of dinosaurs—used in their digestive processes.

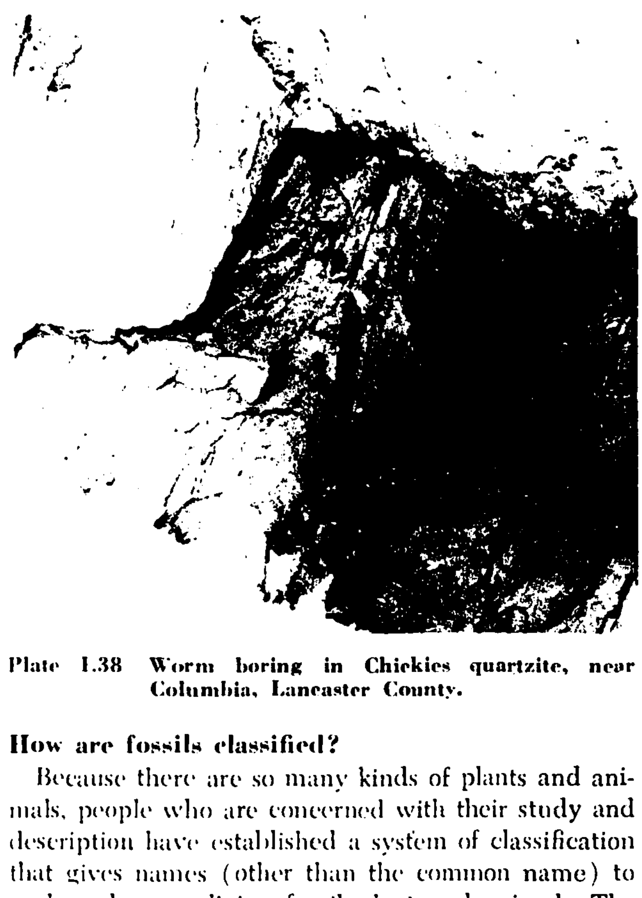

Plate 1.38 Worm boring in Chickies quartzite, near Columbia, Lancaster County.

How are fossils classified?

Because there are so many kinds of plants and animals, people who are concerned with their study and description have established a system of classification that gives names (other than the common name) to each and every living fossil plant and animal. The most commonly used name in scientific writing which concerns animals and plants is the generic and specific name. For example, you may be familiar with the scientific name for man, which is Homo sapiens, or of the scientific name for dogs, which is Canis familiaris. The first name is the genus, the second name is the species. Homo sapiens refers to all men; to refer to an individual it is the custom to use a familiar name such as John Jones. Referring to dogs, we might call an individual Fido.

What do fossils tell us and of what value are they?

1. Record of life from age to age.
2. Sea animals found on land tell us where sea originally was.
3. Tell former existence of land-ridges (elephants found in N. A. after they developed in Eurasia).
4. Evidence of climatic changes.
5. Tell us evolutionary steps in different species.
6. Index Fossil provides us with a chronology.
7. Economic value in locating oil deposits.
8. Dispersal of plants and animals in the past.
9. Aesthetic value.

Can you name some of the methods or features we use in deciphering the past?

1. *The Rocks*—Rocks can be the pages of our geologic history book. The composition and characteristics of the rocks give us clues as to conditions of the environment at th time rocks were formed. Some examples follow:
   a. Basalt = a volcanic environment.
   b. Black shale = a reducing environment on the sea floor.
   c. Red sandstone = a strong oxidizing environment, probably a land surface exposed to the atmosphere.
   d. Coal = a subtropical climate suitable for the development of swamp forests.
   e. Coral limestone = clear, warm, shallow seas.
   f. Gneiss = dynamic change involving heat and pressure.
2. *Information from a sequence of beds of rock.* Clues derived from a sequence of beds have been studied in detail under a previous section on the structure of the Earth.
3. *Fossils.*
4. *Structural features.* Folds and faults indicate periods of mountain building, unconformities represent periods of erosion or non-deposition, dikes show a cross-cutting relationship with rocks—indicating the dike is younger than the rock it cuts across. These features have been discussed in detail in the section on the Structure of the Earth.

THE GEOLOGICAL HISTORY OF PENNSYLVANIA

PRECAMBRIAN HISTORY

Very little is known about the Precambrian history of Pennsylvania because of the scarcity of the rock record. Precambrian rocks are found in parts of southeastern Pennsylvania. These rocks seem to indicate that almost one billion years ago this part of the State was the scene for volcanic activity in the form of extrusive lava flows. A few explosive volcanoes probably existed also as indicated by limited exposures of volcanic breccias and tuffs found in the area of South Mt.

PALEOZOIC HISTORY

During much of Paleozoic time the general relations of land and sea in the eastern part of the United States were nearly opposite to those of today. Southeastern Pennsylvania was then part of the border of a great, eastward-extending, continental land mass, Appalachia, composed of Precambrian metamorphic and igneous rocks. Its western shore crossed southeastern Pennsylvania; and, westward thereof, a vast sea spread into the interior of North America. Along the coast of Appalachia in Cambrian time were sandy beaches (see Plate 1.39). Farther out from shore (to the west) were laid down muds and limy oozes. In Ordovician time the sea spread farther eastward, overwhelming the earlier Cambrian beaches and covering many of the areas of ancient crystalline rocks of Appalachia (see Plate 1.40). Thousands of feet of lime carbonate now seen in the great limestone valleys were deposited. The limy beds were followed by hundreds of thousands of feet of mud destined to become shale and, in part, the slate of eastern Pennsylvania. The Ordovician ended in time of change. The ancient land rose and the seas withdrew northwestward. The Ordovician and Cambrian sediments were squeezed by a force exerted from the southeast. The shales, limestones and sandstones suffered changes and, in the east, were folded. Upon these beds were spread a thousand or more feet of debris washed into the borders of the sea from the newly raised land to

Plate 1.39 Cambrian cryptozoons found in the Millbach Formation near the village of Sheridan, Lebanon County.

Plate 1.40 Ordovician starfish fossil from Swatara Gap, Lebanon County, in the Martinsburg Formation.

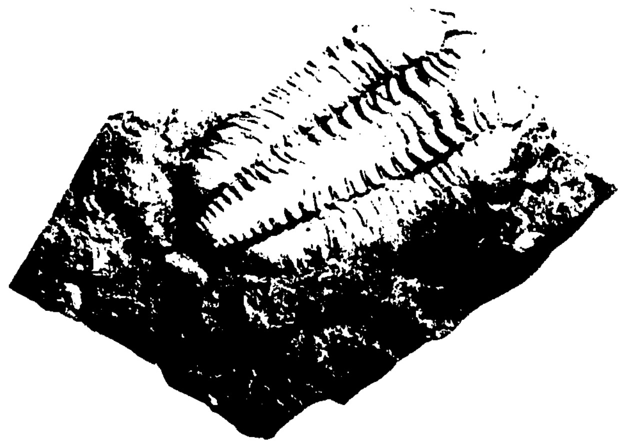

Plate 1.42 Silurian trilobite from the Rose Hill Formation. Perry County.

the east. These coarse sediments became the Silurian sandstones and conglomerates of Kittatinny Mountain and other ridges of central Pennsylvania (see Plate 1.41 and 1.42). After the first uplift comparative quiet continued during Silurian and Devonian times. Much of southeastern Pennsylvania probably remained dry land, while over the rest of the state a thick succession of sandstones, shales and an occasional thin limestone accumulated.

Most of these beds formed in shallow water. Because their aggregate thickness is thousands of feet, we *assume that the ocean bottom gradually subsided* as the sediments accumulated.

Plate 1.41 Geologic Time sign located near Mt. Union, Huntingdon County.

Toward the end of the Devonian came renewed uplift of the eastward land-mass, Appalachia, so that the quickened (steepened) streams of that region, flowing westward to the interior sea, carried in a tremendous quantity of material which brought the ocean bottom up to sea level and created much dry land (see Plate 1.43). The coarse-grained sediments of this time formed massive sandstones that later became the basis of our mountains and the high plateaus of *northern Pennsylvania. During the Mississippian Period* that followed, the seashore extended across western Pennsylvania so that most of the deposits were laid down upon a broad coastal land area. This deposition was interrupted by long periods in which part or all of the state was subject to erosion. Then came the coal beds of the Pennsylvanian and Permian Periods, with most of the state alternately just at or a little above or below sea level, so that cycles of beds were repeated many times (see Plate 1.44). Part of the time vast swamps spread over the state and later became coal beds.

The Appalachian Revolution closed the Paleozoic era and great pressure from the southeast folded the *thousands of feet of rocks* as one might wrinkle a pile of blankets by pushing on one end. At the southeast, the rocks were pushed into an indescribable jumble; between Harrisburg and Altoona, great folds miles high were formed. This folding left some rocks of central Pennsylvania standing more or less vertically.

Here and there the folds broke and one side was shoved across the other side. In western Pennsylvania folding became gentle and died out.

Plate 1.43 Devonian Fossils.

MESOZOIC HISTORY

When the pressure was relieved, the crust at the east under the old land mass collapsed or subsided to form a long trough across southeastern Pennsylvania. Into this fault-cut lowland streams brought sediments, which piled up thousands of feet in thickness in Triassic time. Eventually, outpourings of lava cut through these strata, forming the trap rocks of southeastern Pennsylvania.

For a long time after the folding, Pennsylvania was part of a great land mass slowly wearing down. At first, during the Triassic and Jurassic periods, the land mass included most of North America. In Cretaceous time the edges of this land mass subsided and sediments were deposited on its eastern and southern edges. Whether any of Pennsylvania was at one time covered by such sediments is not certain. Probably as sinking took place on the edges there was some uplift in the center.

CENOZOIC HISTORY

Cretaceous time, the last of the Age of Reptiles, was followed by the Tertiary Age of Mammals. During most of this time, Pennsylvania was probably a land of low relief, rising steadily as the edges of the land mass still subsided, and received sediments of Tertiary Age to the east and south. Only small traces of these sediments remain in Pennsylvania, capping the divides in the Philadelphia area.

In late Tertiary time the streams began to deepen their channels. Uplift centered across the State in a north-south line through Altoona. As uplift and channel sinking continued, the belts of softer rocks were etched out into valleys. The main streams kept their courses down the slopes of the rising land, cutting deep notches across the harder strata. During the

Plate 1.44 Pennsylvanian fern fossils from the Southern Anthracite Field, Schuylkill County.

process, a struggle between different streams for supremacy set in, some streams being favored by shorter distance to the sea, or in having fewer or narrower hard strata to cross. As a result, the whole system of drainage has been modified. Regions of both folded and flat-lying rocks, through uplift and erosion, have been carved into mountains and valleys, plateaus and ravines. The final result is the surface of today, with flat-topped mountains cut by deep, picturesque water gaps, and deeply dissected areas of generally accordant upper level. In the last minute of geologic time, as it were, ice which had been accumulating in Labrador and west of Hudson Bay, advanced to cover large areas in the northeastern and northwestern parts of the state, widening some valleys, filling others with debris, leaving a mantle of till over the whole surface, and forming moraines and other hilly deposits where the edge of the ice stood still for a time. Many changes in drainage occurred and when the ice melted and retreated, choked valleys created lakes, and streams diverted from their former channels often produced waterfalls (Figure 1.28).

GEOLOGIC TIME SCALE

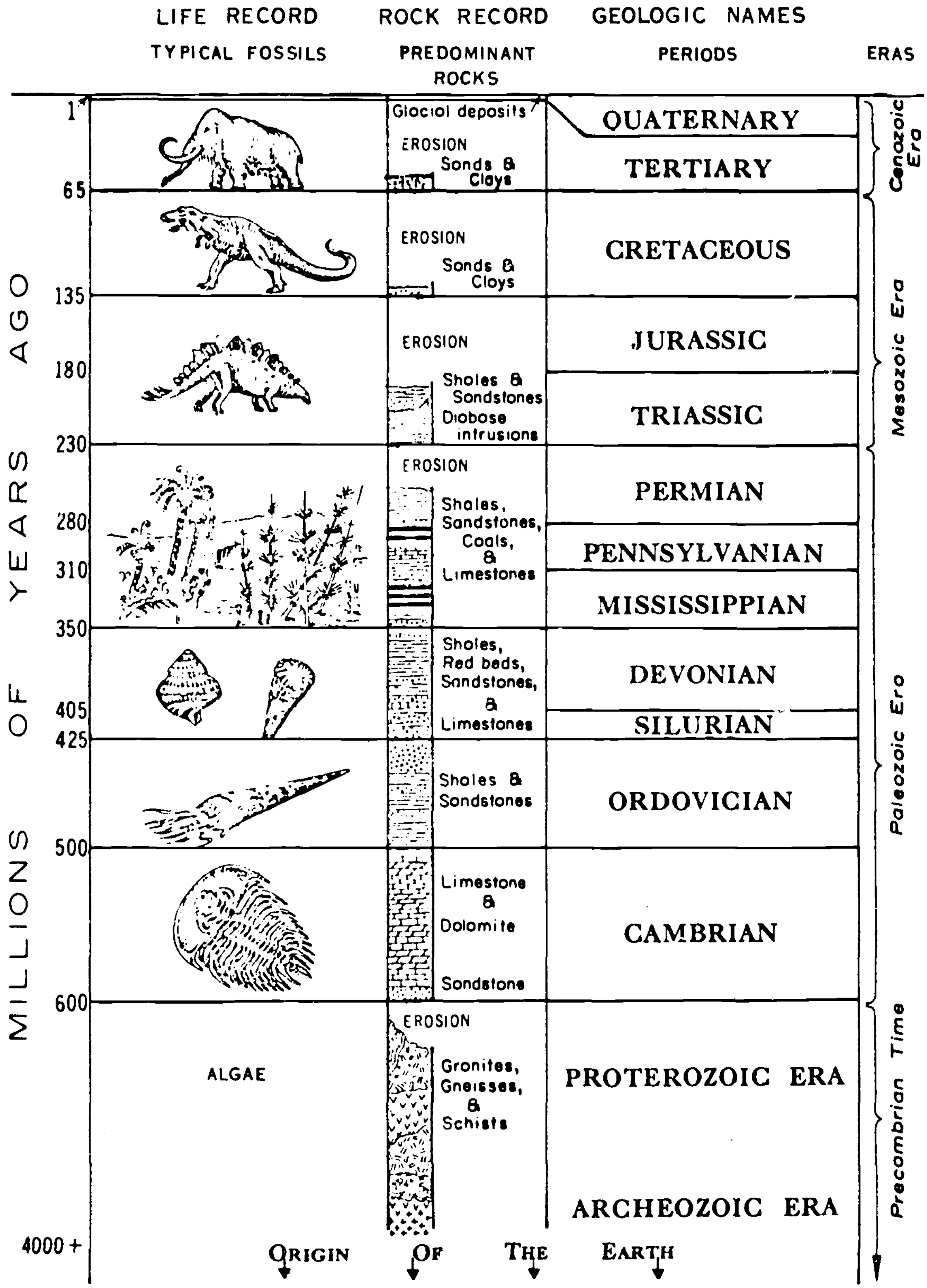

Figure 1.28

Laboratory Exercise: A problem in the identification and interpretation of folds and faults might be introduced here to help the students interpret the geologic history of an area. The students should be asked to list the steps in the geologic history of the region described in Figure 1.29.

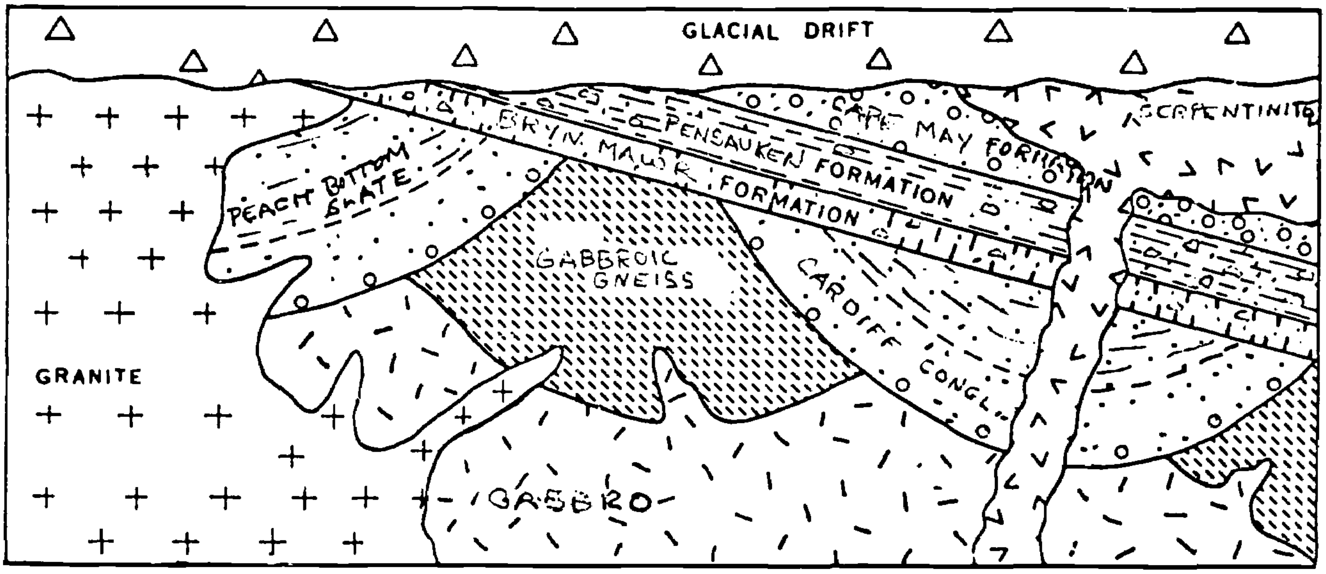

Figure 1.29 A Hypothetical Cross-section Through Southeastern Pennsylvania.

Answer: The following is a list of the geologic formations and events from oldest to youngest stating the criteria used to determine each relationship.

1. The Gabbroic Gneiss is the oldest of all the rocks: it is older than the gabbro because the gabbro intrudes the gabbroic gneiss.
2. The gabbro is older than the Cardiff Conglomerate because of the law of superposition.
3. Erosion is older than the Cardiff Conglomerate because of the unconformable relationship between the gabbro, the gabbroic gneiss, and the Cardiff Conglomerate.
4. The Cardiff Conglomerate is older than the granite because the conglomerate is intruded by the granite.
5. The Cardiff Conglomerate is also older than the Peach Bottom Slate because of the law of superposition.
6. The Peach Bottom Slate is older than the granite also because it too is intruded by the granite.
7. Folding of the originally flat-lying Cardiff Conglomerate and Peach Bottom Slate formations.
8. The granite is older than the Bryn Mawr Formation because it does not intrude it but younger than the folding and the slate conglomerate formations because it intrudes them after they were folded.
9. Erosion is older than the Bryn Mawr Formation because of the unconformable relationship between this formation and the granite.
10. Bryn Mawr Formation is older than the Pennsauken Formation because of the law of superposition but younger than the granite because the granite does not intrude it.
11. The Pennsauken Formation is older than the Cape May Formation because of the law of superposition but younger than the Bryn Mawr Formation because of the same law.
12. Cape May Formation is older than the serpentinite because the serpentinite intrudes it but younger than the Pennsauken Formation because of the law of superposition.
13. Tilting of the originally flat-lying Bryn Mawrs, Pennsauken, and Cape May Formations.
14. Serpentinite is older than the glacial drift because the serpentinite does not intrude the drift but is younger than the Cape May Formation and the tilting because it intrudes the tilted Cape May Formation.
15. Erosion is older than the glacial drift because the drift is deposited upon the eroded surface of many of the formations and it is younger than the serpentinite because the serpentinite is also eroded.

Students should learn how to interpret the geologic history from a geologic map and legend. This is especially true of each school's area. Students should be encouraged to investigate the structure and geologic history of the rocks near their school and home.

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ENVIRONMENTAL GEOLOGY AND MAN

Major Topics Explored

- Definition of Environmental Geology
- Importance of Environmental Geology to Man
- Usefulness of Environmental Geology to Man
- Environmental Geology Factors
  - Topography
  - Water Resources
  - Engineering Characteristics of Rocks
  - Mineral Resources

What is environmental geology?

Environmental Geology is the application of geologic principles to the wise use and improvement of man's environment.

By the late 1960's the interrelationship of *topography, soil, rock, water resources*, and *mineral resources* was considered in evaluating any portion of *our natural environment*. The application of all geologic principles to the wise use, as well as improvement of this environment, became known as "Environmental Geology".

Today the geologists can and should make a significant contribution to the general over-all wise utilization and improvement of man's total environment. They are making this new discipline function in all segments of our society; metropolitan areas, the suburbs, rural areas, and even in remote mountain areas. They are combining their talents with those of other scientists, sociologists, architects, and community planners to build for the future.

Why is environmental geology important?

In the very near future, an *increased population will accelerate land utilization* and the people-to-land ratio will compound man's problems and his wise use of the land.

The need for ground water will grow throughout the world, especially in those areas where surface water is in short supply or where space and economic limitations prevent development of surface water storage.

The costs of construction in or on rock are directly related to the strength of the rocks, relative saturation by ground water, weathering characteristics of the rocks and other geologic criteria. If a foundation fails, these costs soar.

The stability of slopes cut into rocks for highways and other engineering structures is a very important element in considering feasibility and the economics of a project.

It has been estimated that in Pennsylvania alone, 12 million residents produce and discard 60,000 tons of solid waste a day. The safe disposal of this solid waste is a problem for every community. The better the community understands its geologic environment, the more assured it is of proper solid waste management.

Tunnels through mountains or under rivers, soaring bridges or towering dams reflect the role of geology in determining their safe location, design, and construction.

Safety consciousness is particularly important in communities where pressure and competition for land has resulted in construction on unstable slopes, in known landslide areas, over active faults, and in flood plains.

How may environmental geology be used?

A thorough understanding of the topography allows a high, scenic vista overlooking an urban area to be used for something appropriate and not for a junk yard. A detailed flood-plain map and report spells out the danger of locating a housing subdivision on a flood plain and properly advises its use for agriculture or recreation.

Certain rock units are very susceptible to rock falls and landslides. Before and during the excavation for highways, schools, and other large buildings, geological studies are needed. The conclusions and recommendations developed by the geologist are utilized by the engineer in the design of the road or building.

Environmental geology can be utilized to solve existing problems concerning man-made features or natural features or to rehabilitate additional land that is presently unsuitable. This may involve the restoration of abandoned coal mine strip pits thereby releasing waste land for recreational or other use as well as abating water pollution. Special hazards such as landslides and land subsidence can be recognized and alleviated or eliminated. It may mean the use of abandoned quarries for sanitary landfills, swim clubs, or for a thousand and one other uses.

In many urban areas it is important that the locations and depths of subsurface coal mine workings be accurately known to insure that certain precautions are taken in industrial site selection. Construction with proper modifications may then be made in these potentially hazardous subsidence areas.

The quantity, quality, and immediate availability of local industrial mineral deposits should be considered by the community. The nearby extraction of construction minerals has a definite effect on the community's appearance, future growth, and cost of building programs.

Sinkholes may occur wherever limestone and dolomite are the bedrock. Sinkholes have been known to rob creeks of their water, destroy farm and commercial land, damage buildings, and endanger lives. All construction contemplated in the limestone-dolomite areas should have extensive foundation studies made prior to building in order to eliminate possible failures and added costs.

ENVIRONMENTAL GEOLOGY FACTORS

Topography

Natural features are probably the most stable part of our total environment, since the social and economic aspects of it are changeable and subject to the moods and desires of society. The only hope is to be good managers of our own actions by living in harmony with your natural environment.

Slope maps are extremely useful to the builder, construction engineer, planner and others. The construction, economics and engineering feasibility of certain projects may be strongly dependent upon the degree of slope in a particular area. On-lot sewage disposal may be adversely affected by steep slope conditions. Some local governments have already developed on-lot sewage ordinances where slope conditions play a major role in determining the acceptability of a soil for the disposal of sewage.

A topography map is used in the determination of the slope of the land. Slope may be computed directly from the topographic map by noting the relationship between vertical elevation and horizontal distance. A *slope map* may be drawn showing areas of equal ranges of slope in percent.

Flood plains, or areas adjacent to streams which are subjected to flooding by periodic high water flowing in the stream bed, are important to the farmer, builder and flood control engineer as well as the planner. Land use for a flood plain area is usually limited because of the public safety factor and the economics of property loss during flooding. If a flood plain area is to be utilized for construction, agriculture or recreation it should be recognized and developed accordingly.

Flood plain topography may be obtained by inspection of a topographic map. A *flood plain map* may easily be constructed by outlining known flood areas on a topographic map and noting the high-water elevations and the frequency of flooding to these elevations.

WATER RESOURCES

It is estimated that by the year 2000, withdrawal of surface water will total 900 billion gallons per day or about 80 percent of available stream flow. In order to meet this demand, storage facilities will have to increase and be located in strategic places. In addition, the use of ground water will increase and artificial recharge of subsurface aquifers will be widespread.

Surface Water

Our supply of surface water may seem relatively constant over a long period of time, but this supply is subject to sharp curtailment, yearly by drought; or for extended periods of time by pollution.

The first key to good water management is the collection of specific data on the surface water. Surface water data is published annually in two volumes; Water Resource Data for Pennsylvania—Part 1. *Surface Water Records*, and Part 2. *Water Quality Records*. The information contained in these two volumes may be used in three principal ways: 1) the calculation of discharge or total volume of surface water available in a specific area, 2) determination of water quality in reference to use of water and potential health hazards of water, and 3) in the determination of flood frequency and flooding potential of a stream.

Ground Water

The reserves and quality of ground water present in the rocks are important. This vast, relatively untapped water supply is a valuable asset to a community that anticipates population and industrial growth.

Every region, and each rock formation within the region, have special characteristics that must be defined that will ultimately provide the clues to the quantity and quality of ground water available.

ENGINEERING CHARACTERISTICS OF ROCKS

Most construction takes place on or into rock. Where structures are placed and how they are designed, built, and maintained should depend in part on the engineering characteristics of the surrounding rocks.

How will the rocks involved react when they are wet or dry, when they freeze and then thaw, when the dip of the rocks is flat, gentle or very steep, or when they are subject to earthquakes or large-scale subsidence?

Few who travel through the white-tiled tunnels along the Pennsylvania Turnpike and on soaring bridges over the Allegheny and Delaware Rivers realize how the details of geology affected the location, design, and construction of these engineering works.

Excavation of Rocks

Certain characteristics of rocks relate to their ease of excavation. The degree of weathering, the mineral composition of the rock, the structure of the rock mass, and the porosity—permeability of the rock all contribute to the degree of difficulty involved in excavating it (Plate 1.45).

Plate 1.45 Excavation for I-80; Juniata Formation exposed west of the Loganton Interchange in Union County.

Based on these same rock characteristics (degree of weathering, mineral composition, structure, and porosity-permeability), the geologist is able to predict the relative drillability of a rock unit, thereby allowing others to better estimate time and costs of drilling operations.

Foundation Conditions

Again, certain rock characteristics are essential in determining the stability of any foundation. The depth to bedrock, estimates of volumes and direction ground-water movement, location and depth to water table, strength of the rocks, degree of weathering, and composition of the rock are critical aspects to be considered in a foundation site elevation (Plate 1.46).

Plate 1.46 Sinkholes encountered in building Interstate 80 in Centre County.

Rock lithology, structure of the rock mass (description and orientation of bedding, joints, and faults), quantity and direction of ground-water flow, plus other minor geological factors contribute to the development of a stable or unstable rock mass on any man-made slope (Plate 1.47).

A detailed geological investigation is important in determining the stability of the rock mass about to be altered by man.

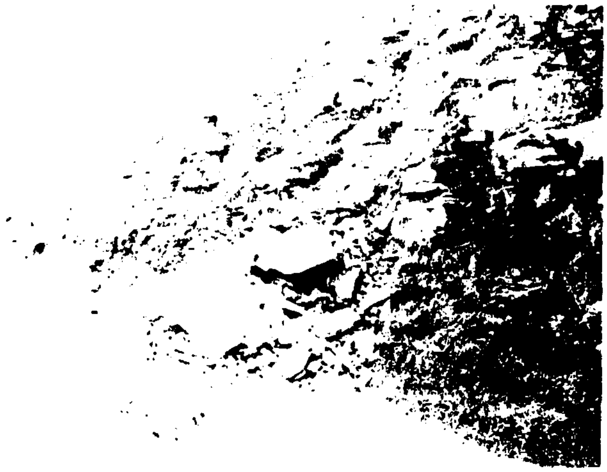

Plate 1.47 Rockfall in sandstones and siltstones near DuBois, Clearfield County.

Subsidence

The location of deep and surface, inactive and active, mines is important to those concerned with the subsidence of surface construction, water pollution abatement, and a continuing supply of fresh surface and ground water in areas where mining has or is prone to take place.

It is particularly vital to know the types of mined minerals, the composition of the waste rock stored at mined sites, the quality of the water in strip pits, the possibility of strip pit leakage to surface and ground water reservoirs, and the roof thickness over the mined-out areas.

Solid Waste Disposal

Solid waste disposal is one of the principal concerns facing the municipal official and the planner of today (Plate 1.48).

All sanitary landfill operations must conform to certain standards set by the Pennsylvania Department of Health. Permit applications must contain a topographic map of the proposed fill and adjacent area. In addition to the topographic information, the operator of the landfill must include a soils, geologic and groundwater report of the characteristics of the proposed site with his application.

Plate 1.48 Well-managed sanitary landfill, Dauphin County.

The environmental geologist with his experience in physiography, general geology, ground-water availability, and the engineering characteristics of rocks, is ideally suited to the investigation and evaluation of possible sanitary landfill sites. Recognizing that the safe disposal of this solid waste is a problem for every community, the geologist and the community working together to better understand the natural environment will assure a wise solid waste management program.

MINERAL RESOURCES

In earlier years the most valuable mineral resources extracted were metals, but in recent time industrial (*nonmetallic*) *minerals* have greatly increased in importance. The current gross value of all industrial mineral products annually exceeds that of metallic ores.

These industrial mineral resources consist of solids such as coal, limestone, sandtone, and shale, or liquids such as oil, or gases as in the case of natural gas. Most of these deposits are abundantly distributed but their value often depends on the ability to use the raw material near its source.

The full utilization of all mineral resources should be considered in developing a community's economy and oftentimes consideration should be given to actually promoting this utilization (Plate 1.49).

A *mineral resource map* as produced by a geologist, defines the exact limits of the mineral deposit as well as its exact location within a political area. This map, with a descriptive legend, describes the rock formations of the area in detail and points out those formations most likely to be of value to the community and what their potential use may be.

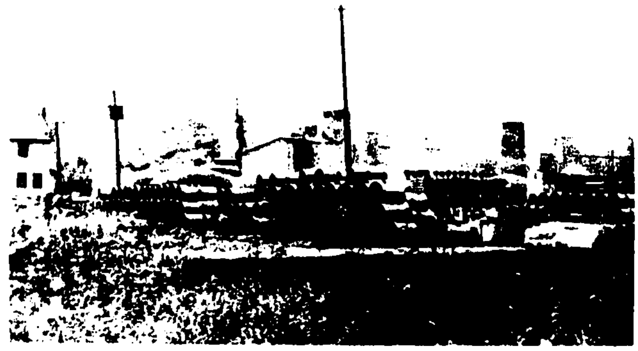

Plate 1.49 A) High-calcium limestone quarry near Palmyra, Lebanon County.

B) Clay tile products and ovens located near excellent source of shale raw material at Brockway, Jefferson County.

Mineral Extraction and Urbanization

It is important to know the reserves of any given mineral deposit. If these reserves are not known, urban and suburban developments may be allowed to expand to the very limits of active quarrying and before the community realizes it, the operation must close. This closing of a mineral producing operation not only means the loss of valuable minerals, but also a loss of construction materials to the community, possible loss of jobs and revenue to the area, and higher costs for the same materials from farther away.

One answer to the growing shortage of land is multiple use wherever possible. Mineral deposits can be quarried; the land can then be made available for industrial parks, housing developments, recreational sites, or just plain greenspace.

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The Oceans

INTRODUCTION

Oceanography is one of the most active fields of scientific exploration at the present time. Foremost among the agencies engaged in investigating the problems of the oceans and estuaries are the U. S. Coast and Geodetic Survey and the U. S. Naval Oceanographic Office.

Oceanography is not itself a science. It is the application of the basic sciences to the study of the marine environment. Since this is the case, there are four branches: 1) *geological oceanography* which ranges from studying the origin of the ocean basins through the origin of sea floor landforms to interpreting the past history of the oceans and estuaries and their fauna and flora from the sediments on their floors; 2) *physical oceanography* involving studies of the temperature and circulation of oceanic waters; 3) *chemical oceanography* which involves the analysis of sea water to determine its mineral content and salinity; and 4) *biological oceanography* which focuses on the organisms inhabiting the water, their primary productivity, etc.

The study of the oceans is one of the best integrators in the Earth Sciences because much that is taking place in the oceans is related to meteorology, astronomy and geological processes on the land. For example, the relation between oceanic currents, such as the Gulf Stream, and the planetary wind system; the fact that the air is the medium whereby water is transported from the oceans to the land; the correlation between the amount of solar radiation received and the salinity of the sea water; the coastal changes wrought by marine erosion; the relation between temperature and organic life in the water; and the changes in sea level brought about by glaciation and deglaciation show that none of the earth sciences is a field of study unto itself but is related to all of the other sciences.

FIELDS OF STUDENT INVESTIGATIONS

Oceanographic Surveying and Research at Sea
Waves, Tides and Oceans
Geology of the Oceans
Physical Properties of Sea Water
Chemistry of Sea Water and Its Importance to Man
Biological Oceanography
Conservation and the Importance of the Sea to Man

OCEANOGRAPHIC SURVEYING AND RESEARCH AT SEA

Three quarters of the Earth is covered by water, *why is so much more known about the land than the oceans?*

Major Topics Explored

Oceanographic vessels
Instrumentation

Difficulties of man exploring the ocean to any depth have hampered exploration of the seas. Scuba divers and hard-hat divers can penetrate only shallow depths, submarines a little deeper and specially designed vessels like *bathyscapes* have reached 13,284 feet. These vessels can descend to the deepest parts of the ocean but their lateral mobility is very limited.

For the most part, special instruments must be used to explore the oceans and most of this exploration is carried out from an ocean-surface research ship. *Nansen bottles* are used to bring up water samples. *Special thermometers* take ocean temperature measurements. *Echo-sounders* record depth data. *Submarine cameras* take ocean bottom pictures. *Coring tubes* and *scoops* are used for gathering sediment samples and now *special drills* are operated from ships or drilling platforms to bring up cores of sediment and rock from the sea floor.

In general, however, gathering data about the oceans is more difficult and costly than studying the continents and hence much more has been learned about the land.

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WAVES, TIDES AND CURRENTS

To begin a discussion about the oceans, we suggest that teachers ask: *How many of the students have ever seen the ocean?* and ask those who have: *What did it look like?*

Descriptions will almost certainly include waves, maybe tides and perhaps the color of the ocean.

Major Topics Explored

- Waves
  - Definition
  - Surface waves—origin and characteristics
  - Breakers and surf
  - Destructive waves
- Tides
  - Tide-producing forces
  - Astronomical tides
  - Meteorological tides
  - Tidal bore
- Currents
  - Large scale currents
  - Currents related to the distribution of density
  - Effects of winds on currents
  - Tidal currents

What causes waves at sea?

Oceanic water is almost always in motion. Waves are formed by the wind blowing on the surface of the water. When a rope attached to a post at one end is held in your hand and snapped, a wave pattern moves along the rope. Another example of waves may be seen when you drop a stone in a pool of water. So it is in deep water, the wave pattern moves along the surface but the individual water particles tend to move in a circular pattern, forward on the crest of the waves, backwards in the troughs.

What causes the height of waves?

The height of waves depends on the wind velocity, its duration, the water depth and the distance over which it blows (fetch).

What causes the surf or breakers?

As a wave approaches the shore, the water depth becomes less which tends to push the wave height upward until the top falls forward forming a breaker. The water in the breaker crashes downward and rushes up on the beach.

What is a riptide and what do you do if caught in one?

Sometimes, when many large waves in close succession break on a beach, so much water accumulates on the beach that it gathers into a single stream, usually narrow, and moves out to sea through the incoming breakers. Riptides are capable of carrying swimmers one-quarter of a mile offshore. If a swimmer feels himself in a riptide, he should swim parallel to the shore and, since the current is usually narrow, will soon find himself out of its dangerous path.

What are "tidal waves"?

"Tidal waves" (tsunamis), or extremely high destructive waves, are not connected with tides but are usually caused by the shock of a submarine earthquake or landslide. They move at high speeds sometimes up to 450 mph and reach heights in funnel shaped bays of as much as 200 feet above sea level.

What causes tides in the oceans?

Everyone who has spent time on a beach along the East Coast has noticed the twice daily movement of the water's edge between *high* and *low tide*. This movement is due to the gravitational attraction of the moon and sun on the waters of the earth. The highest tides, "spring tides" occur when the moon is new and the sun and moon are located on the same side of the Earth. "Neap tides", which have less range, occur when the Earth is at right angles to the moon and sun. *Tidal currents* are very strong where the ebbing and flooding tides enter and leave lagoons behind *barrier beaches* by the way of narrow inlets.

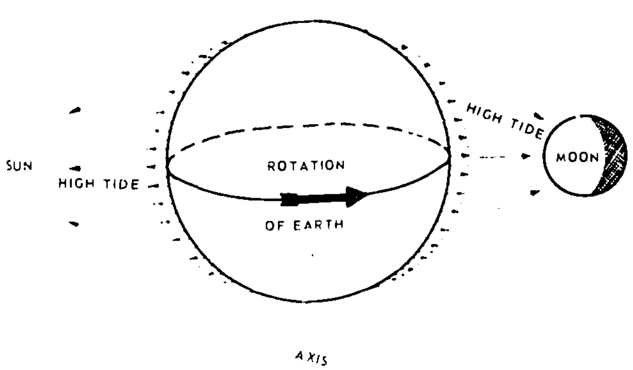

Figure 2.1 **High and low tides are due to the gravitational attraction of the moon and sun on the waters of the earth.**

What moves the gulf stream and other oceanic currents?

Most of the students should be aware of the Gulf Stream located off the east coast of the United States. For the most part it is a very shallow current (1,000 feet deep) moved northeast across the Atlantic Ocean by the prevailing westerly winds which blow toward the southeast. There is in general a movement of warmer water from the equatorial regions toward the polar regions where this water is cooled and becomes denser. The water then sinks and returns southward along the ocean bottom. This denser water carries life-giving oxygen to great depths.

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GEOLOGY OF THE OCEANS

How does man explore the ocean bottom?

Formerly water depths were determined by dropping a sounding line with a lead weight on the end. Now it is determined by continuously recording *echo sounders* which measure the time it takes for sound waves to travel from the hull of a ship to the sea floor and back; converting this time into water depth. Many continuous depth profiles across all the oceans have been made by this method.

Major Topics Explored

Nature of the Sea Floor—Old ideas and recent discoveries

Methods of measuring and representing relief

Sediments in the ocean

The mantle and crust under the ocean

What does the bottom of the ocean look like?

Topographic profiles of the sea floor made by echo sounders show that virtually all the landforms found on the continents also occur beneath the sea. In other words there are plains, plateaus, mountains, valleys, basins, volcanoes and many other topographic features. Of special interest are the deep narrow *trenches* in different parts of the oceans where the earth's crust is unstable. Flat-topped *seamounts* rising from the sea floor some 5,000 feet below sea level are also of special interest.

The *Mid-Atlantic Ridge* is a mountain chain running down the middle of the Atlantic Ocean between North and South America on one side and Europe and Africa on the other. The Azores and Iceland are parts of this ridge that extend above sea level.

What are continental shelves?

Bordering the east coast of North America and other continents are submerged portions of the continental margin. In the Atlantic Ocean bordering the United States, the *continental shelf* is a thick accumulation of sediments derived from the land. Off the coast of New Jersey, it is about 80 miles wide and the water depth at the outer margin is only 600 feet. Extending to the true floor of the *ocean basin* from the edge of the continental shelf is the *continental slope.* These slopes average about 400 feet per mile extending to a depth of 6,000 feet. Off the coast of Great Britain, the slope drops sharply from 650 feet to 13,120 feet. The average depth of the oceanic basins is approximately 12,000 feet.

What are submarine canyons and how did they form?

Cut into the continental slope are steep-sided canyons with depths up to several thousand feet and features resembling subareial stream canyons. Some originated as broad valleys on the continental shelf and extended onto the ocean basin floor. Some, such as the Hudson Canyon, appear to be related to the Hudson River of the North American continent (see Figure 2.2). Others seem to have no relation to present continental rivers. Three theories of origin are currently being given serious consideration but all have drawbacks.

1. They were cut subaerially when the shelves and slopes stood higher, after which there was subsidence of the outer edge of the continents.
   Objection: This theory requires too much subsidence.
2. They were cut subaerially during lower periods of sea level and connected with the trapping of large quantities of water on the continents.
   Objection: Sea level probably only fell 500 feet.
3. They were cut by submarine currents carrying silt and clay turbidity currents.
   Objection: Silt and clay are weak cutting tools.

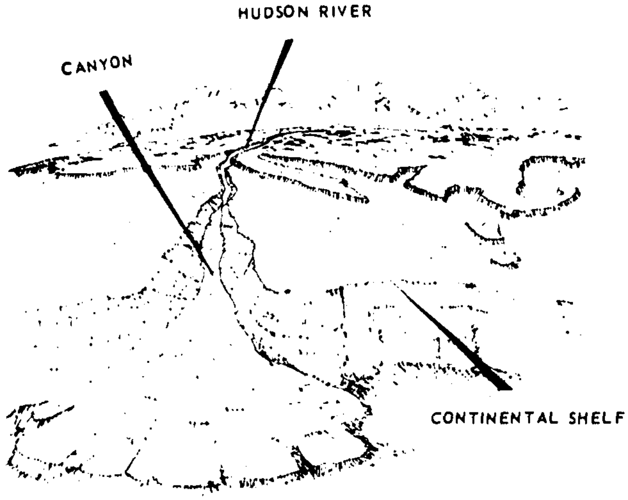

Figure 2.2 Submarine canyon cut into the continental shelf at the mouth of the Hudson River.

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PHYSICAL PROPERTIES OF SEA WATER

Major Topics Explored

- Measured properties
  - Temperature
  - Salinity
  - Pressure and color
    - Methods of measurement
    - Units
    - Range in the sea

Why is the ocean blue?

Not all sea water is blue. Sea water may be various shades of brown, green or brownish-red. The blue of the sea is caused by scattering of sunlight by tiny particles suspended in the water. Blue light, of short wave length, is scattered more effectively. Green water is commonly seen near coasts. This color is caused by yellow pigments, often from microscopic floating plants, being mixed with blue water. Other microscopic plants may color the water brown or brownish-red.

Oceanographers record the color of the ocean by comparison with a series of bottles of colored water known as the Forel scale.

Where is the hottest ocean or portion of ocean?

The hottest ocean area is the Persian Gulf, where water temperatures at the surface exceed 90°F. in the summer months. A unique hot, salty area has recently been discovered in the Red Sea, where oceanographers of the Woods Hole Oceanographic Institution recorded a temperature of 132.8°F. at a depth of 2,000 meters. The reason for these extreme temperatures is unknown.

How salty are the oceans and which is the saltiest?

Salinity in the open ocean ranges from 3.3 to 3.7%. Oceanographers express salinity in parts per thousand. The average is about 35 parts per thousand. The Atlantic Ocean is the saltiest with 37.5 ppt in the northern subtropical region. The Arctic and Antarctic waters are the least salty.

What is the pressure at the deepest part of the ocean?

The pressure at the deepest part of the ocean is close to seven tons per square inch, almost 1,000 times the atmospheric pressure on the earth's surface.

At a depth of 3,000 feet a pressure of 1,350 pounds per square inch is sufficient to squeeze a block of wood to half its volume so that it will sink.

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THE CHEMISTRY OF SEA WATER AND ITS IMPORTANCE TO MAN

The chemical composition of sea water varies but on the average 100 pounds of sea water yields when dried approximately three and one-half pounds of minerals, some of which are very useful to man. The commonest dissolved substances are sodium chloride (sources of table salt and a chemical compound for chemical industries), magnesium chloride, magnesium sulfate (source of much of the earth's supply of magnesium), calcium sulfate (source of gypsum or "plaster"), calcium carbonate (source of lime) and magnesium bromide (source of bromide).

Major Topics Explored

Composition of sea water
Dissolved solids

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BIOLOGICAL OCEANOGRAPHY

Major Topics Explored

Seaweed
Plankton
Bioluminescence
Deep Scattering Layer
Dangerous and Toxic Organisms

Is a seaweed a weed? What is it and how does it grow?

Plants as useful as seaweed can not be considered weeds because weeds are commonly defined as wild plants that are useless, unsightly and have no economic value. Seaweed is used as a food by millions of people, as fertilizers, medicines, source of iodine and ingredients used in the preparation of bread, candy, canned meat, ice cream, jellies and emulsions (see Figure 2.3).

Attached seaweeds grow only along the narrow border near shore. Growth is depth limited to the depth of penetration of natural sunlight.

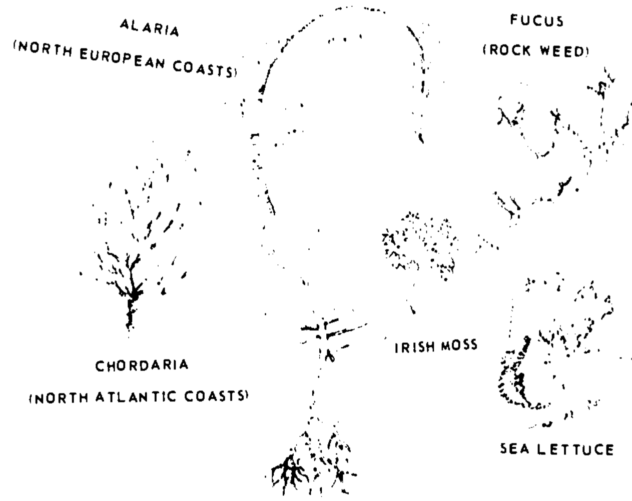

Figure 2.3 Types of seaweed.

What is plankton?

Plankton includes all sea animals and plants too small or weak to attach themselves. They drift with the currents. The plants are known as phytoplankton and the animals as zooplankton. Both are important food sources for other marine life (see Figure 2.4).

Phytoplankton, mostly diatoms, use the nutrient salts and minerals in the sea water as food. They, in turn, are food for many animals, which are themselves part of the "food chain".

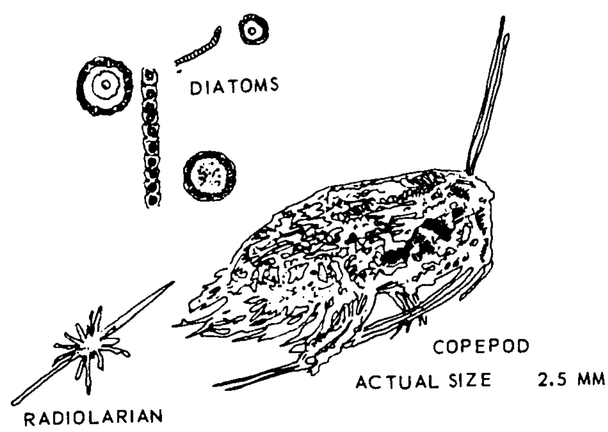

Figure 2.4 Plankton.

What are algae?

Algae are primitive plants ranging in size from a single cell to the giant kelps, which grow to a length of 100 feet. Algae are dominant in the sea. Algae do not need roots because they live in a solution of nutrients and the whole plant can absorb water and nutrients from this solution. Some algae have blades that resemble leaves, but these are extensions of the plant body and are not the primary site of photosyntheses as in land plants.

Algae in the open ocean are generally one-celled forms and are limited to the lighted zone (surface to approximately 600 feet). These algae are extremely numerous and are referred to as the "grass of the sea" because they are the very beginning of the food chain in the sea.

What is green scum?

The green scum on ponds and slow-flowing rivers is formed by floating green and blue-green algae and a tiny flowering plant called duck weed. The duck weed and floating green algae do not live in sea water, but the blue-green algae do. These blue-green algae have a sticky covering and form slimy films on rocks and pilings. Mermaid's Hair, a large blue-green algae, forms thick feathery coverings on rocks and boat bottoms.

Is life found at all depths in the ocean?

This question was settled for all time in 1960 when Piccard and Walsh reported a flatfish at a depth of 35,800 feet. From the porthole of the bathyscaph TRIESTE they observed a fish about one foot long and six inches wide swimming away (see Figure 2.5).

What is bioluminescence?

Bioluminescence is light produced by living organisms, both animals and plants. Thousands of species of marine animals produce bioluminescence. Various jellyfish and related animals produce some form of light. These displays are seen most commonly in warm surface waters. Although most of the organisms are small, there are such immense numbers present that brilliant displays occur when the waters are disturbed by the passage of a ship at night.

At ocean depths where light does not penetrate, there are strange looking luminescent fishes. However, there is an unanswered question concerning the purpose of lights on marine animals. Some creatures have well-developed eyes but no light to enable them to see in the dark. Others have brilliant light organs but are too blind to see. The exact purpose of these lights is unknown.

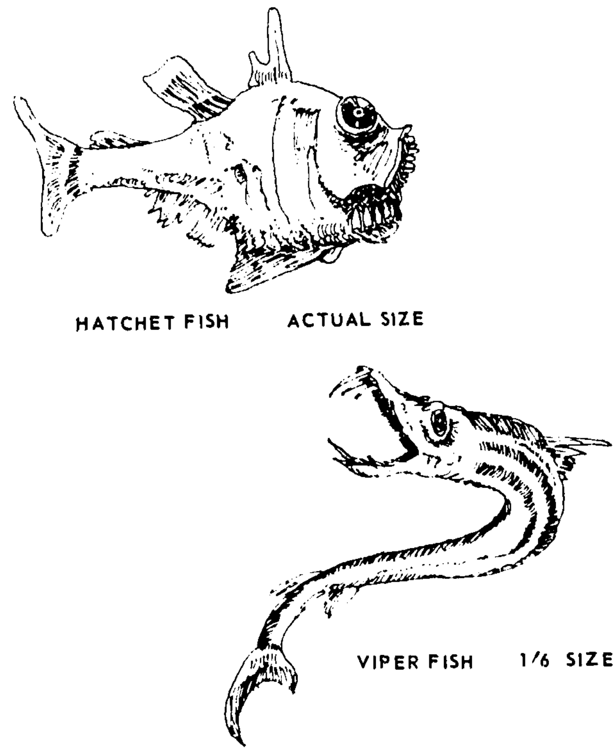

Figure 2.5 Extremely deep-water forms of fish life.

Are there really sea monsters?

Although we discount the *fabled* sea monsters, we have not yet explored the ocean thoroughly enough to say with absolute certainty that there are no monsters in the deep.

Scientific observations and records note that giant squids with tentacles 40 feet long live at 1,500 feet and that sizable objects have been detected by explosive echo sounding at greater depths (see Figure 2.6).

Oar fish 40 to 50 feet long also have been observed. In recent years, Danish oceanographers have studied large eel larvae that would grow to 90 feet if their growth rate is the same as eels of other species.

Have you ever heard of the DSL in the ocean?

The deep scattering layer (DSL) is a widespread layer of living organisms that scatter or reflect sound pulses. During the day, this layer has been reported at depths of 700 to 2,400 feet but most often between depths of 1,000 and 1,500 feet. At night, the layer moves to or near the surface. The types of organisms making up the deep scattering layer are still not known definitely. Attempts to collect and photograph the organisms have been inconclusive.

Figure 2.6 Scientists have not yet explored the ocean thoroughly enough to say with absolute certainty that there are no monsters in the deep.

The DSL produces a phantom bottom or echograms, which probably accounts for the charting of nonexistent shoals in the early days of echo sounders.

What types of organisms, other than sharks, are potentially dangerous to man?

The most dangerous sea animal other than sharks is probably the barracuda. Its usual length is only four to six feet, but it is aggressive, fast and armed with a combination of long canines and small teeth.

The killer whale is potentially more dangerous than either sharks or barracudas although no authentic records of deliberate attacks on man exists. This whale measures 15 to 20 feet and hunts in packs. It attacks seals, walruses, porpoises and even other whales.

The moray eel, which is as long as ten feet, lurks in holes in coral reefs and may bite divers if disturbed.

The octopus is probably overrated as a villain because of his evil looks; nevertheless, its bite is poisonous. The giant squid has been known to pull man beneath the water to his death. The Portuguese man-of-war has tentacles up to 50 feet long with stinging cells which are painful to a swimmer brushing against them.

There is a large group of animals dangerous to swimmers or waders who step on them. These include the sting ray, stonefish, zebra fish, toadfish and many others.

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CONSERVATION AND THE IMPORTANCE OF THE SEA TO MAN

1. It is now believed that large quantities of petroleum are stored in the sediments of the continental shelves.
2. Nodules containing the important element, manganese and small amounts of cobalt, nickel and silver are found on some parts of the sea floor and are expected to be located by submarine photography and mined by giant vacuum cleaners.
3. As processes for desalting sea water more economically become available, an unlimited amount of fresh water will become available for coastal cities.
4. With the population of the world due to double in the next 35 years, increasing efforts will be made to extract more food from the sea. Only a few of the edible fish are now being consumed. Consumption of fish in the U. S. is rather low, averaging only 11 pounds per person per year. In contrast, the consumption of fish in Japan is seven times as great per person.
5. Seaweed is being increasingly gathered and pressed into a substance called "algin" which is used in cosmetics, textiles, paper, ink, drugs, chocolate milk, jellies and jams.

The sea as a major avenue of transportation, a source of recreation, and a controller of climate on Earth should not be underestimated.

Major Topics Explored

Food from the sea
- Fish and shellfish farming
- Fish protein concentrate
- Comparison of U. S. with other countries in fish catch and consumption

Fresh water from the sea

Recreation

Extracting natural resources from the sea and sea bottom

Offshore oil production

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Periodicals, Journals, Newsletters

The periodicals and newsletters listed below:

(a) are industrial or sales organizations, inhouse journal

(b) contain popular non-technical articles on marine science

(c) have occasional articles, technical or popular, in marine science

It may be advisable to write for a sample copy of a publication to determine whether or not it fits the needs of the local situation, prior to paying a subscription fee. Some are free.

Sea Secrets, International Oceanographic Foundation, 1 Rickenbacker Causeway, Virginia Key, Miami, Fla. 33149 free 12/year

The Seahorse, Oceanographic Engineering Corp., Hydro Products Division, P. O. Box 10766, San Diego 10, Calif. free 4/year

Naval Oceanographic Newsletter, U. S. Naval Oceanographic Office, Washington, D. C. free, limited distribution, irregular

Newsletter, National Oceanographic Data Center, Washington, D. C. 20390 free 10/year

Sea Frontiers, International Oceanographic Foundation Institute of Marine Science, 1 Rickenbacker Causeway, Miami, Fla. 33149 $6.00 6/year

Davy Jones Newsletter, Edgerton, Germehausen & Grier, Inc., 160 Brookline Avenue, Boston 15, Mass. free irregular

Maritimes, University of Rhode Island, Graduate School of Oceanography, Wakefield, Rhode Island. free, limited distribution 4/year

Under Water Naturalist, American Littoral Society, Sandy Hook Marine Laboratory, Highlands, New Jersey $5.00 to members, 4/year

Ecology, Ecological Society of America, Duke University Press, Durham, N. C. 27706 $6.00 4/year

The Progressive Fish-Culturist, U. S. Dept. of the Interior, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, D. C. 20402 $1.00 4/year

National Geographic, National Geographic Society, 17th and M Streets N.W., Washington, D. C. 20036 $6.50 12/year

Natural History, The American Museum of Natural History, Central Park West at 79th Street, New York, N. Y. 10024 $7.00 10/year

Environmental Science & Technology, American Chemical Society, 1155 Sixteenth St. N.W., Washington D. C. 20036 $7.00 12/year

Scientific American, Scientific American, Inc., 415 Madison Ave., New York, N. Y. 10017 $7.00 12/year

Frontiers, The Academy of Natural Sciences of Philadelphia, 19th and The Parkway, Philadelphia, Pa. 19103 $2.50 5/year

Turtox News, General Biological Supply House, 8200 South Hoyne Avenue, Chicago, Ill. 60620 free

Carolina Tips, Carolina Biological Supply Co., Burlington, N. C. 27215 free 10/year

National Wildlife, National Wildlife Federation, Membership Services, 1255 Portland Pl., Boulder, Colo. 80301 $5.00 6/year

Skin Diver, Skin Diver Publications, Lynwood, Calif. $5.00 12/year

Films, Lab Supplies, Audio-Visual Materials

Cuzon du Rest, R. P. (1969), *Films on Oceanography*, U. S. Naval Oceanographic Office, Catalog Series Publ. C-4; Available from the Superintendent of Documents, Gov't Printing Office, Washington, D. C. 20402

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The Space Environment

INTRODUCTION

The astronomy section of this teaching guide is intended neither as a textbook nor a detailed course outline to be closely followed in the teaching of Earth and Space Science in the secondary schools. It is hoped that some of the material will enable the teachers to enrich their own program with topics and approaches that prove to be of significant and meaningful value to the student. Much of the content cannot be found in a single text and some of the content does not appear in textbooks at all. Also, much of the material is presented as background information for the teacher and is not intended to be taught to secondary students unless they happen to be at a very advanced level and/or show an unusual interest and aptitude.

Teachers are urged, wherever possible, to include occasional evening observing sessions in their instructional program or to at least explain to their students how they themselves can organize their own observing program. In order to do this successfully the teacher must be able to predict where and when a celestial object can be located. The material on celestial coordinates is therefore included for the primary benefit of the teacher and it is not suggested that this is suitable material for inclusion in an astronomy unit at the secondary school level, although the above average student might be able independently to read and comprehend this material from this guide or introductory astronomy texts written on the college level.

The construction of a starfinder is a relatively simple project that can be undertaken by students and teachers alike and does not require a considerable understanding of coordinate systems. The use of setting circles on telescopes is another useful tool in locating celestial objects which does not require complete comprehension of coordinate systems. With the simple and inexpensive starfinder described in this guide it is possible to locate with considerable accuracy any object in the sky and also to predict positions of objects at some future time.

Few teachers realize how much astronomy can be taught by the use of a celestial globe. Photographs of two types of celestial globes are included together with instructions for setting up and using them. Students should be encouraged to experiment with these globes on their own.

Some of the simple shadow stick experiments described herein may be carried out by individual students and reported on in class. The more interested and capable students might be encouraged to design and construct a sundial for their particular latitude. Assistance in calculating angles can be obtained from a mathematics teacher in the school; otherwise it is not a very difficult project.

It is vital in carrying out the experiments and projects suggested that the student should feel the effort necessary is worthwhile and that the exercise will produce significant results so far as he is concerned. Wherever possible a question should be drawn from the student on the basis of his own observations. In lieu of this, a question can be posed by the teacher, however, in either case the activity *should be performed to answer specific questions.*

Since most schools have a telescope, or are planning to acquire one, a short list of Objects for Telescopic Observation is included. Brief instructions are also given for setting up and using an equatorially mounted telescope. While alt-azimuth mounted telescopes require less time to set up they are not recommended because of the difficulty encountered in keeping objects within the field of view. Since the most frequently asked question in regard to a telescope is, "What is the power of the telescope?", a section describes telescopic powers and gives hints on what to look for in purchasing an instrument.

The remainder of the guide includes reference material for teacher use. It may be possible to organize all, or part of, the course around a central theme, or problem. One such example might be the problem of determination of stellar distances, both galactic and extragalactic. This has been and still is one of the major problems in astronomy. An approach such as this leads naturally into the study of apparent and absolute magnitudes, stellar spectra, the Hertzsprung-Russell diagram, the period-luminosity relation, the velocity-distance relation and finally cosmology and cosmogony. It must again be emphasized that while not all of this material can be taught at the secondary level with every group it is mentioned here for the benefit of the teacher who wishes to increase his own background knowledge in this area.

FIELDS OF STUDENT INVESTIGATION

The Earth in Motion
The Moon
The Solar System
The Nearest Star—Our Sun
Aspects of the Sky
The Stars
The Milky Way
The Universe

ENVIRONMENTAL EFFECTS OF EARTH MOTION

Major Topics Explored

- The Effects of Rotation
- The Effects of Revolution
- The Sun Centered Solar System
- Causes of the Seasons
- The Precessional Effect
- The Different Kinds of Days
- Solar vs. Sidereal Time

How is our environment affected by the motions of the earth?

The primary motions of the earth which have a direct effect upon our daily lives and our environment are rotation and revolution. Precession and nutation will be mentioned for their long range effects.

The Effects of Rotation

What is rotation and how does it affect us?

The earth rotates upon an axis which is inclined 23½° from the vertical with respect to the plane of its orbit. This spinning of the earth, at a speed of about 1000 miles per hour at the equator, results in day and night which gives us the time interval of a day. The Foucault pendulum provides evidence for this motion as opposed to the contrary assumption that it is the sun and stars moving around the earth. Star trail photographs also show the effect of the rotation of the earth (See Plate 3.1).

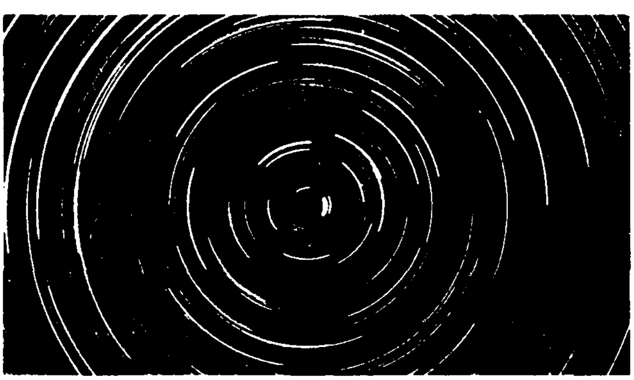


Plate 3.1 Six hour time exposure showing the effect of rotation of the earth.

Another effect of the rotation of the earth is expressed in Ferrel's Law. Commonly known as the Coriolis effect it describes the deflection of winds to the right in our hemisphere and to the left in the southern hemisphere. If it were not for this deflection, winds would blow directly into a low-pressure region and not produce the cyclonic circulation which results in hurricanes, tornadoes, and lesser storms. The deflection caused by the rotation of the earth is also responsible for the major wind belts which are a prime factor in the world climates.

The rotation of the earth also tends to hurl matter into space, thereby causing a reduction in gravity as one moves from the poles to the equator. This motion also gives an increased boost to rockets launched with the rotation of the earth and were it not for problems of logistics the ideal launch site would be at the equator to utilize the 1000 miles per hour speed boost of the earth's rotation.

The Equatorial bulge is also attributed to the rotation of the earth and may be illustrated by rotating a "centrifugal" hoop to note the oblate shape as speed increases.

The Effects of Revolution

What is revolution and how does it affect us?

Revolution is the orbital motion of the earth about the sun. The journey of the earth around the sun, at a speed of 75,000 miles per hour, is the basic time interval we know as a tropical year as 365 days 5 hours 48 minutes 46 seconds. For most purposes the year can be expressed as 365¼ days.

Based on observable evidence it can be argued that the sun is revolving around the earth. We can only "prove" that the earth revolved if we are willing to accept certain postulates. If we accept Newton's laws of motion then the earth must revolve around the sun. The assumption that the earth is not revolving around the sun becomes difficult to explain on the basis of stellar parallax as the closer stars shift their position among the more distant background of stars when we observe them from different parts of the earth's orbit. The aberration of starlight also indicates a moving earth.

The skies also change from season to season as the earth revolves around the sun; however, if the celestial sphere were rotating the same change would be apparent.

THE SUN CENTERED SOLAR SYSTEM

Did man always believe the sun was the center of the solar system?

No. Ptolemy, in about 140 A.D. worked out a geometrical representation of the motions of the planets with considerable accuracy. This was done with the earth as the center of the solar system. To solve the problem of retrograde planetary motion (where the planet appears to reverse its direction temporarily) he devised a complicated system of epicycles in which the planet revolved around its own orbit. This representation of the solar system lasted almost 1400 years until Copernicus advanced his unorthodox and heretical idea that the sun was the center of the solar system.

Causes of the Seasons

Does the revolution of the earth around the sun cause the seasons?

No, not primarily, at least not seasons as we know them. If the axis of the earth were vertical to the plane of its orbit there would probably be seasonal change only on the basis of latitude and not in connection with the revolution of the earth around the sun.

The earth is nearly 3 million miles closer to the sun in the winter so distance cannot be the reason for seasonal change.

Without the 23½° tilt of the earth's axis, seasons as we know them would not exist.

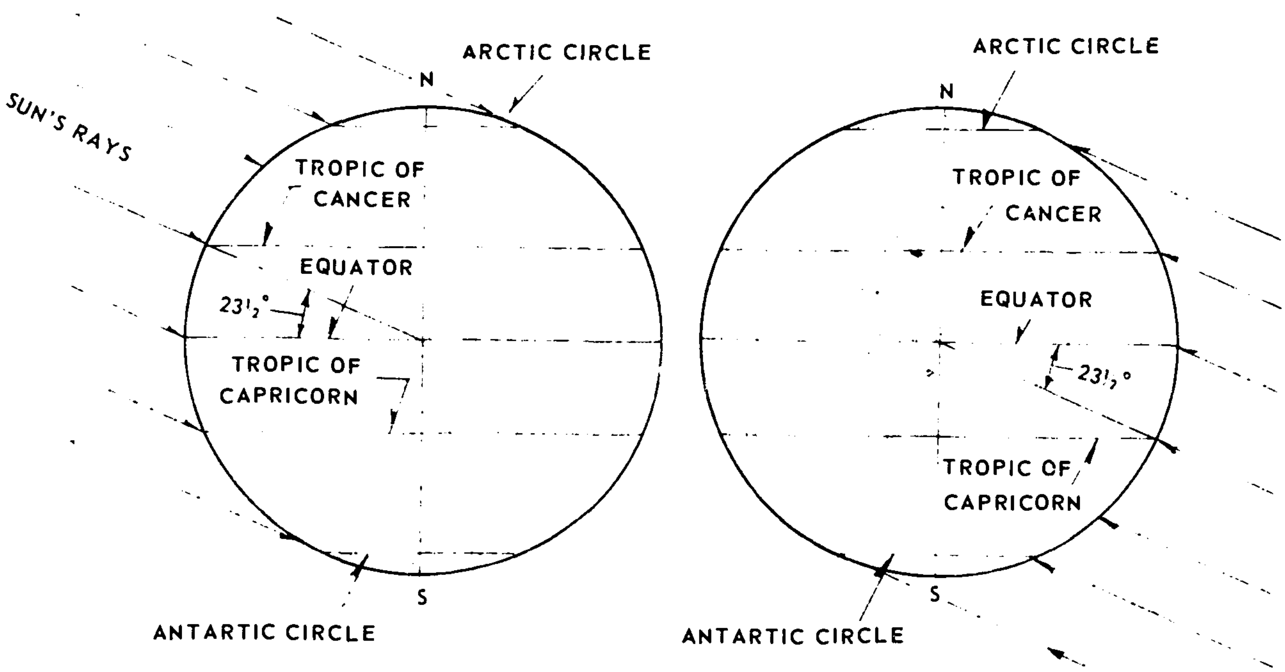
How does the tilt of the earth's axis cause the seasons?

Because of the tilt of the earth's axis there is a position along the orbital path when the north point of the axis is inclined most toward the sun. This takes place on June 22nd (summer solstice, see Figure 3.1) and the rays of the sun shine down on the northern hemisphere most directly. To a person at latitude 23½° N the sun appears directly overhead. The line indicating this latitude on a map is called the Tropic of Cancer. Figure 3.1 also shows that the rays of the sun shine 23½° past the north pole so that all areas within this area, that is 66½° N latitude or greater have sunshine for 24 hours (Midnight sun) on June 22nd, the first day of summer in the Northern latitude. On this date the sun is as far north as it will get. The 66½° N latitude line is called the Arctic Circle.

The summer situation is reversed six months later, on December 22nd, when the earth is opposite the summer solstice position. Now at the winter solstice it is the Arctic Circle that has a 24 hour night and the Antarctic Circle has the 24 hour day or midnight sun. At latitude 23½° S, the Tropic of Capricorn, the sun is directly overhead at noon. The Northern Hemisphere is having winter while it is summer in the Southern Hemisphere. Refer to figure 3.2. At this time we are having short days and long nights as less than half of the Northern Hemisphere is lighted. The combination of short days and very oblique rays from the sun result in less heat being absorbed by the earth and our cold winter season results.

As seen in figure 3.3 there are two positions of the earth along its orbit, each midway between the summer and winter solstices, where the sun appears to be in the direction of the equator. On these days the axis of the earth is tilted neither toward nor away from the sun. Every place on the earth receives 12 hours of sunlight and 12 hours of darkness because exactly half of both the hemispheres are lighted by the sun. These points, where the sun appears directly

THE PLANET EARTH



THE EARTH ON JUNE 22   THE EARTH ON DECEMBER 22

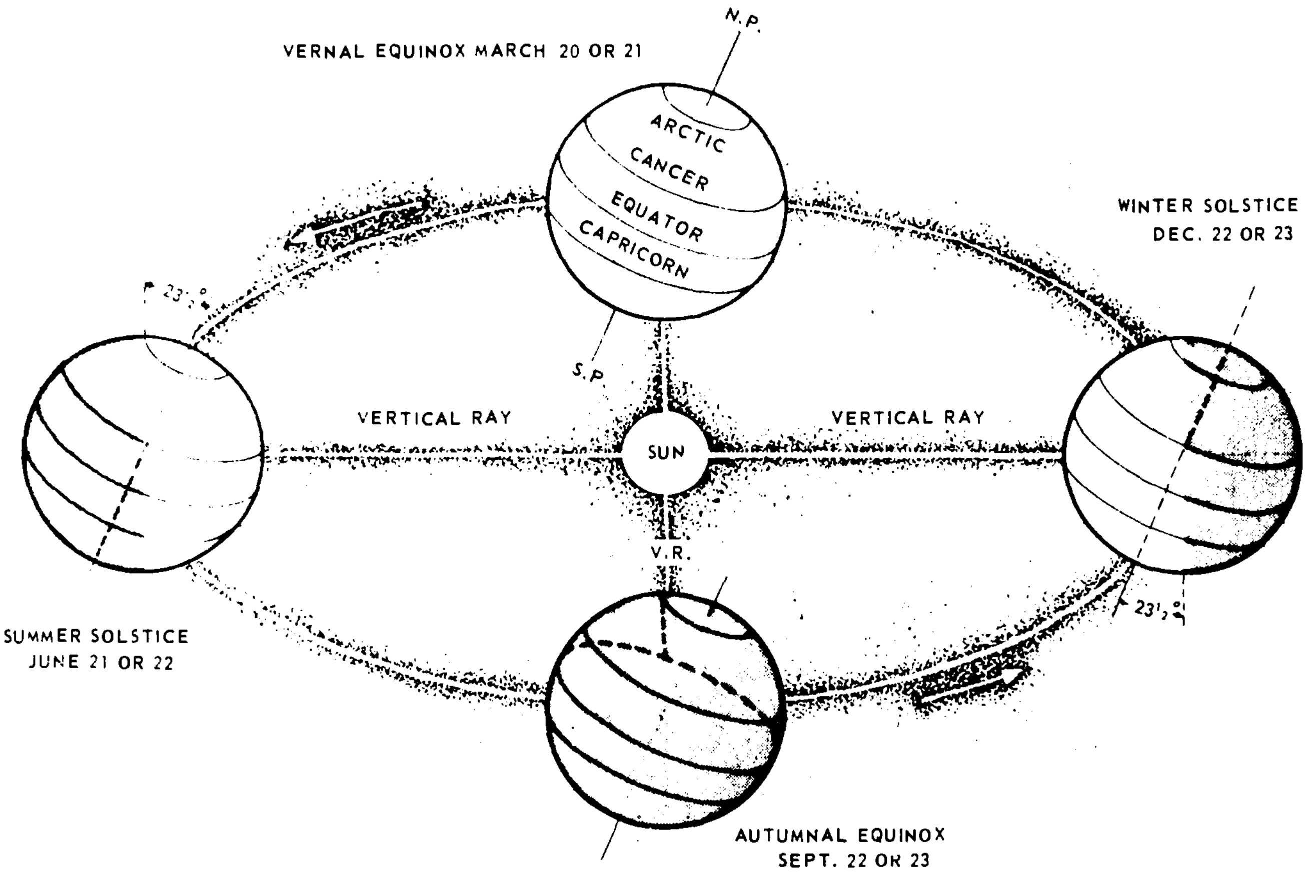


Figure 3.3

overhead at the equator are called the vernal (spring) equinox and the autumnal (fall) equinox. Equinox means "equal night".

If we are closest to the sun in winter, and at this time the Southern Hemisphere is having summer, does this distance factor make their summer warmer than ours?

Although one might expect the Southern Hemisphere seasons to be more severe, both summer and winter, the larger sea area and other topographical features have a greater effect on their seasons than the earth's distance from the sun.

Since the earth receives a maximum amount of solar energy on June 22nd why is this not the hottest day of the summer?

The amount of heat received by the earth is called its insolation. Although the insolation is greatest on the first day of summer, and decreases thereafter, you must remember that from the preceding winter the Northern Hemisphere has cooled considerably and has received large amounts of snow and ice. During spring the insolation increases and as the snow deposits slowly melt the hemisphere gradually warms up. This gradual warming up process continues until the portions of the earth that have the greatest effect upon the climate of a region have thawed out as much as they are going to. This warming up continues past the date of the summer solstice and usually occurs for us in August.

Likewise, the coldest part of the year is not at the winter solstice, even though this is the time of least insolation, because the land and ocean areas, having retained some heat from the previous summer, are still cooling down. They generally reach their lowest temperatures by the end of January.

The Precessional Effect

What effect has precession upon our daily lives?

Precession has virtually no effect upon us due to the extremely long time, 25,800 years, that it takes to complete one cycle. It is a motion comparable to the wobble of a spinning top. The gyration of the earth's axis causes the north celestial pole to describe a circle on the celestial sphere (see figure 3.4). This will, in 12,000 years, cause the bright star Vega to become the pole star. A change in our seasonal constellations will also result. Orion, a winter constellation for the twentieth century, will be visible in the summer sky 13,000 years from now. This will not

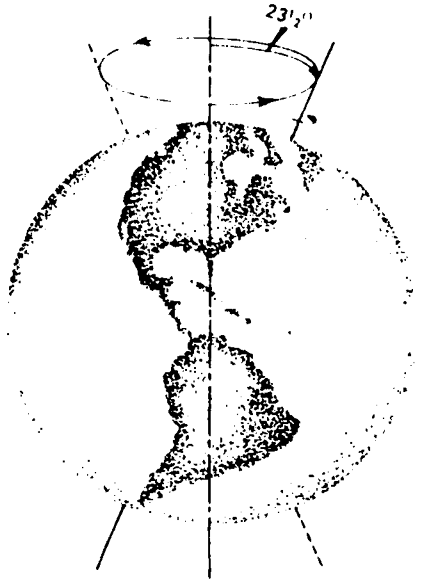


Figure 3.4 Precession of the Earth's axis.

affect our seasons, only the constellations will change.

The cause of this motion is due to the gravitational attraction of the sun and the moon upon the equatorial bulge of the earth, which is 27 miles greater than its polar diameter, as they try to pull it into line with the plane of the ecliptic. As you have seen the earth's equator and thus its equatorial bulge, is inclined 23½° to the plane of the earth's orbit.

The Different Kinds of Days

Although the day has been defined as one rotation of the earth, aren't there different kinds of "days"?

There are different kinds of days; however, all are based on the rotation of the earth. The difference results in what object you select as your reference point.

Using the sun as a reference point we have the "solar day" which is the interval from one Noon (sun on celestial meridian) to the next, or from one sunrise to the next. This unit of time proves to be of unequal length and does not represent a complete rotation of the earth. No watch can keep solar time. A study of figure 3.5 will show why this variation exists. Let us start our solar day when the earth is at position A, with the sun on the meridian (noon) of an observer at point N on the earth. Since celestial distances are so great it can be assumed that all parallel lines will point to the same spot on the celestial sphere; therefore, if line AS is extended points to the same location as line BC among a star on the celestial sphere.

After the earth has made one rotation in respect to the star (position B) the same star will be on the

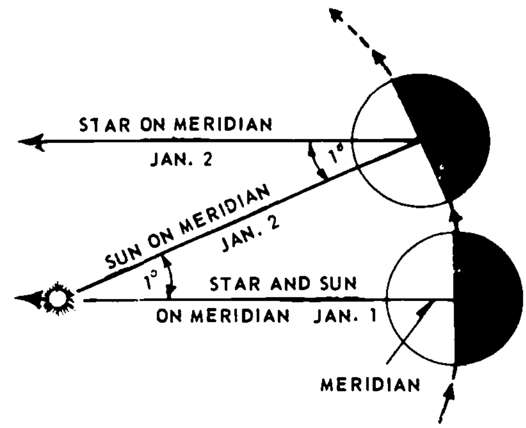


Figure 3.5 Diagram illustrating solar versus sidereal day.

local meridians for an observer at N. However, because the earth has moved along its orbit from point A to B while it rotated, the sun is not yet on the observer meridian, but is still slightly to the east. At this point the earth has completed one "celestial day" (sidereal day), but to complete a solar day it must turn one degree more to bring the sun again above the same meridian.

In other words, a solar day is slightly longer (approximately 1 degree) than a complete rotation of the earth with respect to a star. A year having about 365 days and a circle having 360 degrees the daily motion of the earth in its orbit is roughly one degree. This one degree angle, ASB, is the same as the alternate interior angle, SBC, over and above the 360 degrees through which the earth must turn to complete a solar day making its total solar revolution 361 degrees. Because it takes the earth about four minutes to turn through one degree a solar day is, therefore, about four minutes (3^m 56^s) longer than a sidereal day.

A solar day is longer than a sidereal day by one part in 365. In units of solar time, one sidereal day is exactly 23 hours 56 minutes 4.091 seconds. The period of rotation of the earth with respect to the stars is exactly 23 hours 23 minutes 4.099 seconds.

The sidereal clock, used by astronomers, is regulated to run 3 minutes 56 seconds faster per day than an ordinary clock. Thus the gain of sidereal clock in the period of a mean solar year will amount to 24 hours. On about September 22nd, the sidereal clock and a mean solar clock will be in agreement. From this date one can estimate his local sidereal time corresponding to a given time zone to within a few minutes. Local sidereal time is the local hour angle of the vernal equinox.

Our daily lives are regulated by the sun, not the vernal equinox; therefore, for the vast majority of people sidereal time is of little value or interest. Since the position of a star in the sky with respect to the observer's meridian is directly related to the sidereal time, every observatory maintains clocks which read sidereal time. For a further discussion of its use in locating celestial objects see the section on Determination of Local Sidereal Time and Directions for Using the Starfinder in the Teacher reference section at the back of this guide.

Solar vs. Sidereal Time

If the orbital velocity of the earth varies in accord with Kepler's Second Law, wouldn't this affect the length of a solar day?

The solar day does vary in length by a few seconds and these accumulate to several minutes after a few days. After the invention of accurate timepieces it became necessary to abandon the apparent solar day as the fundamental unit of time. Otherwise, all clocks would have to be adjusted to run at a different rate every day.

Our clocks today keep mean solar time which is an average length of the apparent solar day. In other words, mean solar time is just apparent solar time averaged out to be uniform.

The difference between the two can accumulate to about 17 minutes and is called the equation of time. Due to the irregular rate of apparent solar time the relation to mean solar time may be ahead of or behind mean solar time. When the equation of time is positive it is ahead of mean solar time. The equation of time is often plotted on globes of the earth as a nomogram, shaped like a figure 8 and located in the region of the South Pacific Ocean.

Since each location along any east-west line would actually have a time that is unique to their location, how is this regulated?

The time we have on our watches is the local mean time of the central meridian of whatever time zone we are located in. Eastern Standard time is the local mean time of the 75th meridian.

How is daylight saving time worked out?

So that we may make maximum use of the amount of sunlight during our working hours most states, as well as many foreign nations, established the practice of daylight saving time. We simply agree that on the last Sunday in April at 2:00 a.m. the clocks are set ahead one hour. This first day has only 23 hours; however, the "lost" hour is regained in a 25 hour day when we set our clocks back one hour. Thus, on a summer evening when it would normally grow dark at 8:00 p.m. standard time, it is light until 9:00 p.m. daylight saving time. It is not practical to retain this system in winter for if the clock remained ahead one hour in December it would still be dark in many parts of the country at 7:30 a.m. when most people are on their way to work.

Since there are solar and sidereal days it would seem that there should be different months and even years. Are there?

Yes, however, the term used for a complete revolution of the moon about the earth, with respect to the sun, is 29½ days and is called a synodic month.

The period of revolution of the moon about the earth with respect to the stars is 27⅓ days and is the sidereal month.

In regard to years there are three kinds of years. The period of revolution of the earth around the sun with reference to the stars is called the sidereal year and is 365 days 6 hours 9 minutes 10 seconds or 365.2564 mean solar days.

The period of revolution of the earth with respect to the vernal equinox, that is, in respect to the beginning of the various seasons, is called the tropical year. Its length is 365 days 5 hours 48 minutes 46 seconds or 365.242119 mean solar days. Our calendar is based upon this year so that it keeps in step with the seasons.

The anomalistic year is the third type of year and consists of the interval between two successive perihelion passages of the earth. Its length is 365 days 6 hours 13 minutes 53 seconds or 365.2596 mean solar days.

This differs from the sidereal year because the major axis of the earth's orbit revolves due to perturbations caused by the other planets.

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THE MOON

Major Topics Explored

- Origin of the Moon
- Physical Characteristics of the Moon
- Measuring the Distance to the Moon
- Moon Brightness
- Rotation and Revolution
- Eclipses
- Tides
- Phases

What is the origin of the moon?

The best estimate of the origin of the moon at the present time, prior to the analysis of lunar material brought back to earth by the Apollo 11 and 12 Missions, is that it formed from the condensation of the same material that formed the earth and the other planets.

What physical characteristics are known about the moon?

The following table gives the physical characteristics of the moon:

Physical Characteristics	*Compared to the Earth*
a. size–2159.81 miles in dia.	about $\frac{1}{4}$
b. shape–Prolate spheroid (football) long axis pointed toward earth	oblate spheroid
c. shape of orbit–ellipse	ellipse
d. Mass–8.1×10^{19} tons	$\frac{1}{81}$ of 6.6×10^{21} tons
e. surface gravity–$\frac{1}{6}$ of earth	1
f. velocity of escape–$1\frac{1}{2}$ miles per sec.	about 7 miles per second
g. atmosphere–trace	abundant
h. mean distance from earth–238,857 miles from center of earth to center of moon, · 1 mile	

How is the distance to the moon measured?

The most accurate distance determination has been made by using a laser. The interval of time between the instant a laser beam is broadcast to the moon and the instant it is reflected back can be determined to within a few millionths of a second. The distance is the speed of the laser (speed of light) multiplied by half the time required by the round trip.

Students may do a simple experiment which will allow them to calculate the diameter of the moon if the mean distance from the earth to moon is known. Hold a round pencil of diameter d (inches) in line of sight with the moon and measure the distance x (inches) from the eye to the part of the pencil closest to the eye when the moon's disk is just eclipsed. If D is the diameter of the moon in miles the equation

$$\frac{d}{x} = \frac{D}{239{,}000}$$

can be solved for D.

Why does the moon appear so bright?

While the moon is the brightest object in the sky it absorbs most of the sunlight it receives, reflecting only a small part toward the earth. If the moon could reflect all the light it receives it would appear 14 times as bright as it does now. The fact that it is the closet neighbor we have makes it appear so bright.

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What are the basic motions of the moon?

The moon revolves around the earth from west to east in a period of $27\frac{1}{3}$ days. Since this takes place while the earth is revolving around the sun, the moon also revolves around the sun. The plane of the moon's orbit is inclined 5 degrees to the plane of the earth's orbit around the sun. This will be shown to be of great importance later in explaining how eclipses occur.

The period of rotation of the moon is the same as its period of revolution–$27\frac{1}{3}$ days. This is the same as saying that it makes a complete rotation on its axis in the same time as it revolves once around the earth. The result is to have the same side of the moon facing the earth at all times.

Actually we can see approximately 59 per cent of the surface of the moon due to its rocking motions or librations.

What part does the moon play in producing eclipses?

An eclipse occurs when either the earth or moon encounters the other's shadow in space. Usually the shadow cast by the earth or moon falls upon no other natural body in space; however, should the moon pass into the shadow of the earth a lunar eclipse results (see figure 3.6). This takes place during the full moon phase and to cause a total lunar eclipse the moon must pass completely into the shadow of the earth.

The shadow cast by the earth or moon consists of a completely dark inner cone called the umbra and a semi-darkened surrounding cone called the penumbra. When the moon passes completely into either the umbra or penumbra the eclipse is total. In this case if the moon does not enter the umbra it is known as a penumbral eclipse. If the moon does not completely enter the penumbra it is a partial lunar eclipse.

A lunar eclipse can be viewed by all persons who are located on the night side of the earth. For this reason a large number of people have seen eclipses of the moon.

Since the path of the moon around the earth is tilted five degrees to the plane of the earth's orbit around the sun the moon does not pass into the shadow of the earth at each full moon phase.

How are solar eclipses caused?

During a total solar eclipse, the umbral portion of the shadow of the moon touches the earth. This can happen only during the new moon phase. The moon completely covers the sun. (See figure 3.7 and Plate 3.2.) Only those people within the narrow band of

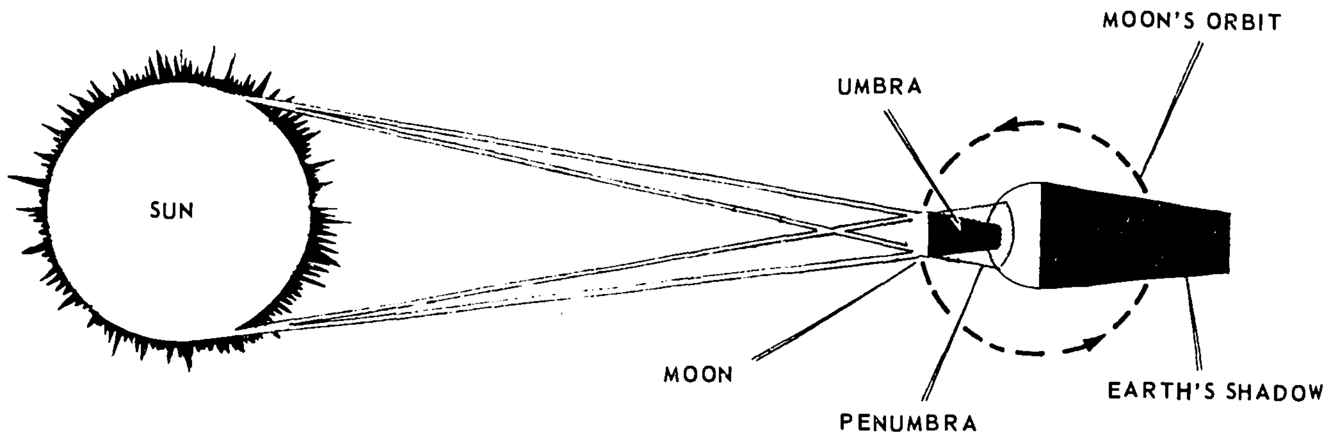

Figure 3.6 Lunar Eclipse.

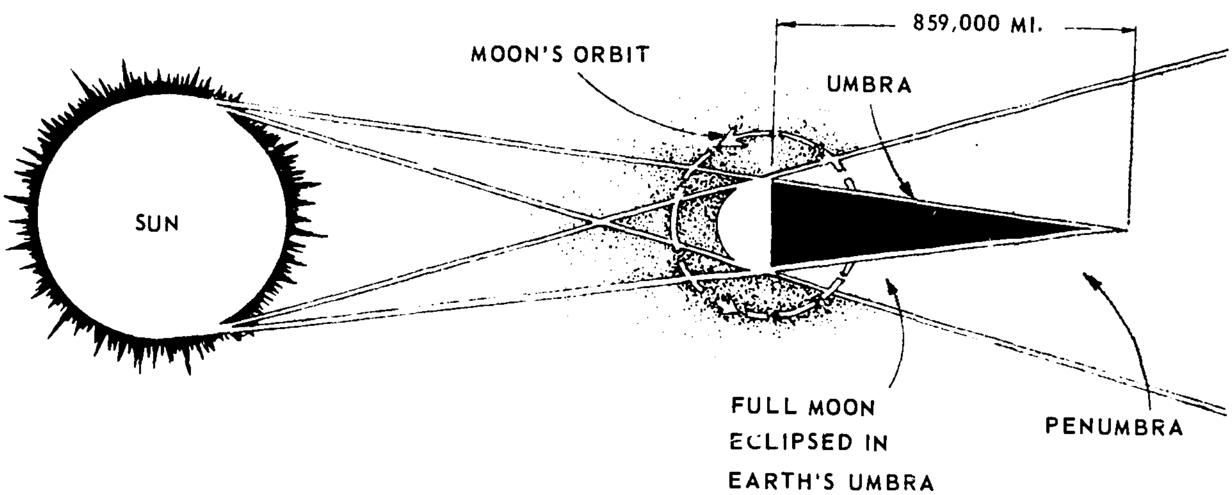

Figure 3.7 Solar Eclipse.

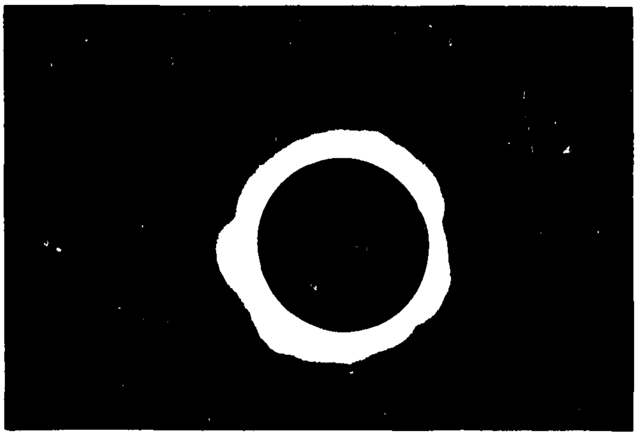

Plate 3.2 Solar Eclipse of March 10, 1970.

the umbral shadow will see a total eclipse of the sun. The last total solar eclipse visible from the continental United States was March 7, 1970 and the next will not be until 1979. Only those people within the narrow band of the umbral shadow which will cross the state of Washington will be able to witness totality. Less than 1% of the total population of the earth have seen a total eclipse of the sun.

Those people outside of the path of the umbra, and still within the path of the penumbra, would witness a partial eclipse. The motion of the moon in its orbit and the rotational speed of the earth combines to move the shadow across the surface of the earth at a speed such that totality never lasts more than 7 minutes at any given location.

How does the moon affect the tides on the earth?

The mutual gravitational attraction between the earth and the moon causes the water on the earth to be pulled toward the moon. This tidal bulge is a direct result of the moon's gravitational attraction. (See figure 3.8.)

A tidal bulge is also produced on the opposite side of the earth. This is generally explained as being caused by the lessened gravitational pull on the water on the far side which permits the force caused by the rotation of the earth to move the water outward from the surface. There are two tidal bulges: a direct tide on the side facing the moon and an opposite tide on the side facing away from the moon.

These tidal bulges follow the moon as it moves around the earth and, combined with the rotation of the earth, produce two high tides every 24 hours and 50 minutes.

Why doesn't the sun produce an affect upon the oceans of the earth?

The gravitational attraction of the sun does raise tidal bulges in the oceans of the earth. These tides are very small because the gravitational attraction of the sun is quite weak because of its great distance from the earth.

Twice each month the sun and the moon are in a direct line with the earth (at full moon and new moon) and their forces combine to produce unusually high tides called spring tides. The word "spring" bears no relation to the season of the year. (See figure 3.8.)

During the first and last quarter phases of the moon, the sun and moon are at right angles to each other so that their gravitational forces are not combined. At this time their gravitational forces are minimal and unusually low tides are produced which are called neap tides. (See figure 3.9.)

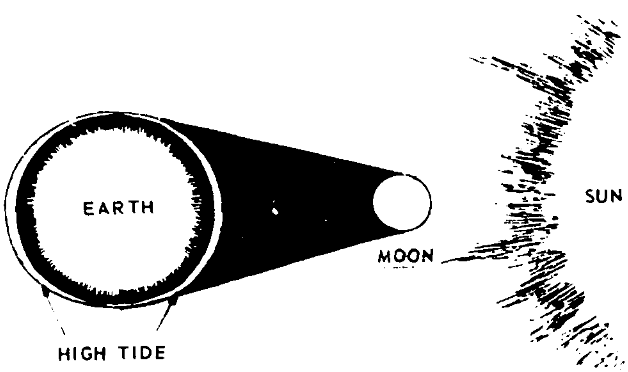

Figure 3.8 High Tides.

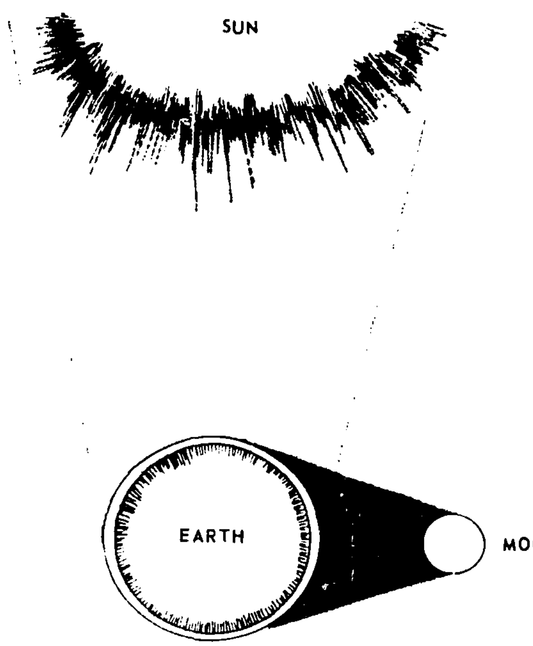

Figure 3.9 Neap Tides.

How are the different phases of the moon produced?

If the moon produced light of its own it would appear as a full moon at all times. Since the moon, like the earth, produces no light of its own what we see is the area lighted by the sun. Because it is approximately spherical in shape the sun can only illuminate one-half of the moon at any one time. The revolution of the moon around the earth and its own rotation serve to cause the lighted half to change constantly. The varying amount of the moon's light half that can be seen from the earth we have called its phases. (See figure 3.10.)

From new moon to full moon takes approximately two weeks and the amount of lighted half which we see is increasing. The moon is said to be waxing. From full moon to new moon again takes approximately two weeks and the lighted half which we are able to see is decreasing. The moon is said to be waning.

At new moon the entire unlighted half of the moon is facing the earth and we see nothing. At the crescent phases only a small edge of the lighted half can be seen. At the quarter phases the side of the moon facing the earth is half lighted. At the gibbous phases only a dark crescent remains unlighted. At full moon the entire side facing the earth is lighted.

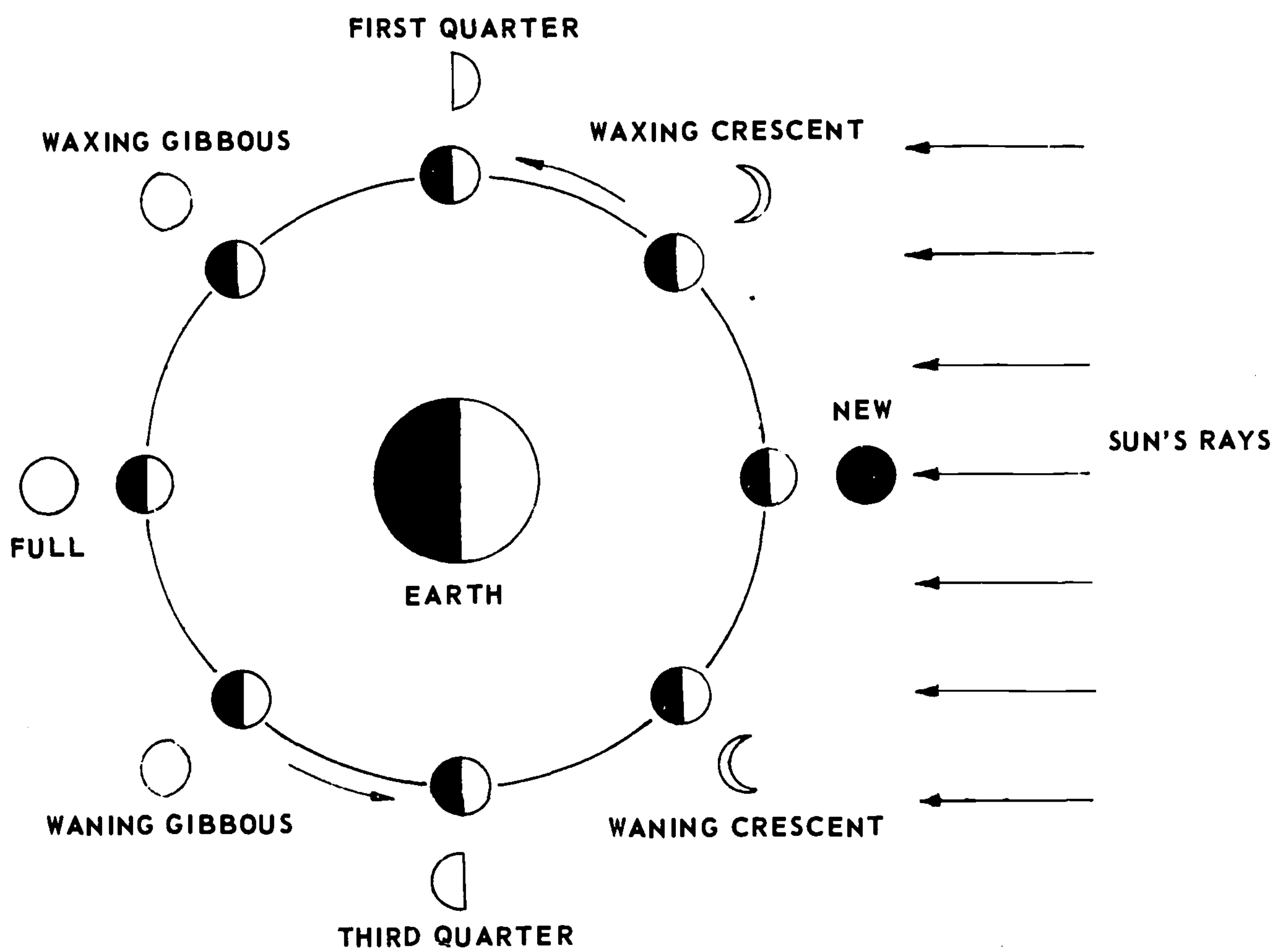

Figure 3.10 Phases of the Moon.

THE SOLAR SYSTEM

Major Topics Explored

- Members of the Solar System
  - Sun
  - Planets and Their Satellites
  - Comets
  - Asteroids
  - Meteoroids
  - Dust and Gas
- Planetary Orbits
- Life on Other Planets
- Origin of the Solar System

What determines whether an object is a member of our solar system?

When one considers the mass of the sun compared with the mass of the solar system, it practically is the solar system. The sun comprises 99.86% of the mass of the group of objects over which it has direct gravitational control. All such objects are members *of the solar system.*

Most of the material of the solar system which is not part of the sun itself, 0.135% of the system's mass, is concentrated in the planets. The nine known planets include Earth, the five planets known to the ancients: Mercury, Venus, Mars, Jupiter, and Saturn; together with the three which have been discovered since the invention of the telescope: Uranus, Neptune, and Pluto.

In addition to the sun and planets, what else does our solar system contain?

Other than the sun and the planets the next most prominent members of the solar system are the satellites. Mercury, Venus, and Pluto have no known satellites. Jupiter has twelve, Saturn ten, Uranus five, Neptune and Mars each have two, and Earth one. This gives a total of 32 tiny bodies which revolve about their parent planets. They range in size from roughly 5 miles in diameter (Phobos of Mars) to 3000 or 3500 miles in diameter (Titan of Saturn). They are all dead, airless worlds except Titan, which has an atmosphere of the same poison gases found on its parent planet, Saturn. The satellites comprise 0.0004% of the mass of the solar system.

Next in order of mass in the solar system are the comets. More than a thousand have been observed and an average of five to ten are discovered telescopically each year. Most of the newly discovered comets have orbital periods of thousands and even millions of years and have never been observed before in recorded history.

The orbits of comets are very elongated ellipses and they spend most of their time in the part of their orbit that is very far from the sun. As a comet approaches the sun, it warms up and some of the particles vaporize to form a cloud of gas or coma around the swarm of particles. The particles and surrounding coma comprise the head of the comet. When within a few astronomical units from the sun, the pressure of the sun's radiation (solar wind) forces particles and gases away from the head to form a tail which always points away from the sun. The head of a comet may be from 10,000 to 100,000 miles across and the tail may extend millions of miles. The mass of a typical comet is thought to be less than a billionth—perhaps less than a trillionth—that of the earth, therefore, they are extremely flimsy entities. Little is known about their origin although it has been hypothesized that there may be a vast cloud of a hundred billion or so comets surrounding the sun at a distance of trillions of miles. Comets are estimated to comprise 0.0003% of the mass of the solar system.

Next in order of decreasing mass are the minor planets, also called either asteroids or planetoids, which are orbiting the sun between the orbits of Mars and Jupiter. Most of them are invisible to the naked eye; however, tens of thousands of them are probably large enough to observe with existing telescopes. Ceres, the largest minor planet, has a diameter just under 500 miles. Most are only a mile or so in diameter. These minor planets make up approximately 0.0000003% of the mass of the solar system.

Approximately of equal mass with the minor planets are the meteoroids. These very tiny particles, too small to observe as they travel in their orbits, only make their presence known when they collide with the earth's atmosphere, heat up by friction, and vaporize. The luminous vapor produced looks like a star moving across the sky, hence the name "shooting star". The correct term is meteor.

The total number of meteoroids that collide with the earth's asmosphere has been estimated at 200 million during a 24 hr. period.

Should a meteoroid enter our atmosphere it becomes a meteor and should this meteor survive its flight and land upon the earth's surface it is then called a meteorite. The largest known meteorites have masses of about 50 tons. Most are the size of small pebbles. One of the most famous meteorite craters in this country is the Barringer Crater in Arizona.

The final, and most tenuous part, of the solar system is the interplanetary medium. It makes up less than 0.0000001% of the mass of the solar system and is the part about which we know the least. The two components of the interplanetary medium are the interplanetary dust and the interplanetary gas.

The interplanetary dust might be considered as a sparse general distribution of micrometeorites throughout the solar system, or at least throughout the main disc that contains the orbits of the planets. The effect of these particles can be seen on a dark, clear night as a faint band of light circling the sky along the ecliptic. This band of light is brightest near the sun and can be seen best in the west a few hours after sunset or in the east a few hours before sunrise. At times it can be seen as a complete band across the southern sky and because it follows the ecliptic or zodiac it is called the Zodiacal light. Spectrographic analysis indicates it to be reflected sunlight and on this basis it is assumed to be due to the reflection from microscopic solid particles.

Some of the Zodiacal light from regions near the sun has characteristics which indicate it comes from atoms or electrons of gas. This suggests the presence of interplanetary gas spread throughout the solar system. Evidence in favor of this conclusion also comes from space probes which have contained instruments to measure rapidly moving atoms and charged atomic particles. Further support comes from high altitude rockets carrying cameras which can photograph in the far ultraviolet region of the spectrum. These photographs show a point illumination apparently emitted by hydrogen gas high in the atmosphere or in interplanetary space. Finally, the tails of comets indicate the presence of a gaseous medium producing a drag upon the tails as they move through space.

The density of the interplanetary medium is probably not less than a hundred or so atoms per cubic inch and not in excess of a few thousand per cubic inch. This is a much more nearly perfect vacuum than can be produced in any terrestrial laboratory.

Planetary Orbits

Why do planets in a solar system travel in orbits about the sun?

Johannes Kepler in 1619 first defined three rules, based on the observation of Tycho Brahe, which describe planetary behavior. Kepler's three laws summarized are:

First Law: Each planet moves around the sun in an orbit that is an ellipse with the sun at one focus. (The planet's distance from the sun is, therefore, changing constantly.)

Second Law: (The Law of Areas) A straight line joining a planet and the sun sweeps out equal areas in space in equal intervals of time. (This means that the orbital velocity of a planet is constantly changing and when a planet is at perihelion (point of its orbit closest to the sun), it travels fastest; when it is at aphelion (point of its orbit farthest from the sun), it travels slowest.

Third Law: For any planet the ratio of the cube of its mean distance from the sun to the square of its period of revolution is equal to that ratio for any other planet. This simple algebraic expression can be used to determine the period of Jupiter if its distance is expressed in astronomical units as t 5.6 A.U.:

Earth		Jupiter
$1^3/1^2$	$=$	$(5.2^3/p^2)$

The cube of 5.2 being 140.6 the period of Jupiter should be the square root of 140.6, or just under 12 years. This agrees with observational evidence.

What keeps the planets in their orbits?

Although Kepler's three laws describe planetary motion they do not explain why planets maintain relatively fixed orbits. It remained for Newton in 1687 to explain this question with the formulation of his Law of Universal Gravitation which states: Every molecule of matter in the universe attracts, and is attracted by, every other molecule. The force of this attraction depends upon the mass of the particles and the distance between them.

This is expressed mathematically as $F = G \dfrac{m_1 m_2}{d^2}$.

The force, F is between two bodies of masses m_1 and m_2, and separated by a distance of d. G is a number called the "constant of gravitation" whose value has to be determined experimentally by the laboratory measurement of the attractive force between two material bodies. Stated another way the force of attraction between any two objects in space varies directly as the product of their masses, and inversely as the square of the distance between them.

The gravitational attraction between the sun and the planets results in the orbital motion of the planets about the sun.

While it should be noted that Newtonian mechanics had to be corrected in relation to the theory of relativity and the quantum theory, we should not jump to the conclusion that Newton was wrong. Natural laws are the means by which science attempts to describe nature, not explain it. The laws of Newton do an excellent job of describing a wide range of phenomena; however, it is a mistake to apply them to situations that are outside their range of validity. The laws of science give us a model of the universe and as long as their model accurately describes nature, it is not an incorrect one. The simple Principles of Newtonian mechanics are within the grasp of most high school students and give an amazingly accurate representation of most natural phenomena to the degree that they serve their purpose well.

Life on Other Planets
Is there life on other planets?

While we cannot rule out the possibility of life processes which are unknown to us we have no evidence for their existence and, therefore, must confine our speculation to those conditions under which known life forms can exist.

Only the planets Venus, Earth, and Mars have conditions under which we could even remotely imagine life to exist.

Among the countless billions of stars in the universe we have no reason to assume that there are not a large number of planets, and that some of these planets would have conditions approximating those on earth. We can only speculate on whether life abounds in the universe, or is unique to the earth.

Origin of the Solar System
How did the solar system form?

A great many theories have been advanced to try to explain the origin of the solar system. Most of them can be classed into two general categories (1) Chamberlin, Moulton, Jeans, and Jeffreys were among those who postulated that a passing star pulled material out of our sun from which the planets were formed; (2) Kant, and later Laplace, suggested that the sun and planets formed from the same cloud of cosmic gas and dust.

Most modern theories favor the second mechanism chiefly because of the expected rarity of such a close stellar encounter and also because all the planets revolve in the same direction with orbits in nearly the same plane.

One can speculate that the original cloud of matter that formed the solar system was much larger than the orbit of the most distant planet. It also must have had a slight rotation. As this cloud contracted, it rotated faster and faster to conserve angular momentum. Most of the entire mass contracted to form a dense core which became the sun. A small fraction of the material, in the form of a disk, was left behind to form the planets and their satellites.

A mechanism by which the planets were formed was suggested by C. F. Von Weizsacker in the mid 1940's, later modified by Kuiper, and is known as the protoplanet hypothesis. According to this theory the protoplanets were condensations that developed in the rotating disk. The planets formed in the denser portion of these condensations and the satellites from smaller sub-condensations.

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THE NEAREST STAR—OUR SUN

Major Topics Explored

- Physical Characteristics
- Composition
- Determination of Composition
- Expected Life of Sun
- Nuclear Energy Production

How does it compare physically with other stars?

Essentially, our sun is a yellow star, average in all characteristics. It is 860,000 miles in diameter with a mass of 333,420 earth-masses. The volume of the sun is more than 1 million times the earth's volume. The composition of the sun is approximately 90% hydrogen and 6% helium with the remaining 4% being made up of the remaining 64 of the 92 natural elements which astronomers have identified as existing on the sun. Pressure at the center reaches millions of tons while the interior temperatures reach 25 million degrees Fahrenheit. The surface of the sun averages 10,000 degrees F. except for sunspots which are approximately 7,000 degrees F.

What does the sun look like to the astronomer?

Seen with the proper equipment many features of the sun which are invisible to the naked eye are present. What appears to us as the surface of the sun is the photosphere. This is the level at which the sun becomes opaque. (See Figure 3.11.) As a precaution one should not look directly at the sun at any time, especially with binoculars or a telescope, even if filters are used. The amount of heat absorbed by filters has been known to crack them, and if this should happen while observing, blindness could result. The only safe means of viewing the sun with a telescope is by projecting the image upon a surface.

Dark blotches which appear on the photosphere are severe "storms" called sunspots. The number of sunspots seen varies regularly over a period of 11.1 years. At maximum sunspot activity streams of charged particles (probably protons) are ejected which are believed to be responsible for the "magnetic storm" which interrupts radio transmission and produces auroral displays here on earth.

The next layer outward is the chromosphere which prior to the invention of the coronograph could be seen only during a total solar eclipse. This reddish colored zone is about 5000 miles thick with a rather indistinct upper boundary.

The outermost layer identified by astronomers as part of the solar atmosphere is the corona which extends at least a million miles beyond the photosphere. This pearly-greenish layer has a temperature of at least a million degrees Kelvin; however, it must be understood that because of the low density of the

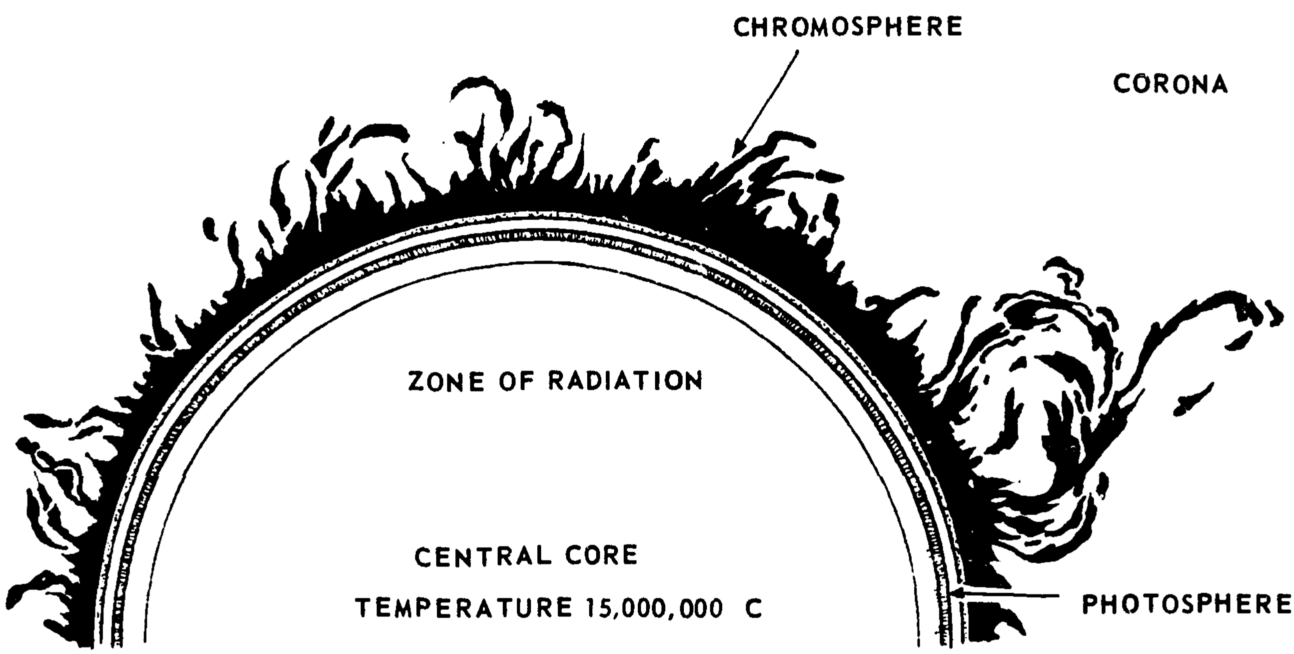

Figure 3.11 Layers of the Sun.

corona it does not contain much active heat despite the high temperature.

By what means does the astronomer determine the composition of the sun?

The French philosopher, August Comte, published a book in 1835 in which he stated that while astronomers could determine "the shapes, distances, sizes, and motions" of planets and stars, "whereas never, by any means, will we be able to study their chemical compositions (as) their mineralogic structure . . ." Astronomers proved him wrong.

It had long been known that colors were produced when white light was passed through a prism but prior to Newton it was thought that the glass produced the color. Newton used a prism to produce a spectrum and then recombined the various colors by reflecting them by mirrors upon a screen. When recombined, the result was white light which indicated that the glass prism had not caused the colors, but had only separated them out from white light.

To Newton the solar system appeared as a band of colors; however, in 1802, William Wollaston observed several dark lines running across the solar spectrum. He explained these lines as boundaries between colors. Later, in 1814-15, Joseph Fraunhofer made a more careful examination of the solar spectrum and found 600 such dark lines. Of these 600 lines, he noted the specific positions, or the wavelengths, of 324 of them. To the more pronounced of the lines he assigned letters of the alphabet increasing from the red to the violet end of the spectrum. Today several of these lines in the solar spectrum are still referred to by the letters assigned them by Fraunhofer.

The full significance of the Fraunhofer lines was not understood until in 1862 several scientists, Sir George Gabriel Stokes in Cambridge, Anders Jons Angstrom in Upsala, and Bernard Leon Foucult in Paris had noticed that the D line, which was an especially pronounced double line in the yellow section of the solar spectrum, could be produced by heating sodium. Did this mean that there is sodium in the sun? In giving an affirmative answer to this question an absolutely undreamed of possibility became a reality: chemical analysis of a body from a distance of 93 million miles.

The spectroscope, a device which separates white light into various colors, was further refined and development of special analysis was perfected by Gustav Adolf Kirchoff and Robert Wilhelm Bunsen.

The spectra of stars gives us such information as temperature, pressure, the presence of particular elements and their relative abundance, radial velocity, rotation, turbulence, the presence of magnetic fields, and the existence of shells of ejected gases.

As a basic introduction to spectroscopy students should observe various light sources, such as Geissler tubes which show emission lines. A simple shoe box spectroscope can be constructed for this purpose. (See figure 3.12.) Inexpensive hand spectroscopes are available from scientific supply houses at low cost.

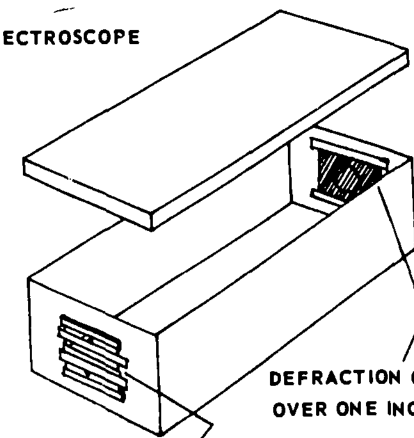

Figure 3.12 Shoe Box Spectroscope.

How long will the sun continue to provide the energy needed for life in our solar system?

Some astronomers place the age of the sun at 5 billion years and estimate that it will last approximately an equal length of time.

Our sun and the vast majority of other stars are in a "steady state". This is to say that they are neither expanding nor contracting. A condition of equilibrium exists so that all forces are balanced and at each point within the star the temperature, pressure, density, etc. are being maintained at constant values. Basically the tremendous gravitational force which tends to collapse a star is exactly balanced by a force from within.

Nuclear Energy Production

The temperature which exists in stars are such that all chemical elements are vaporized to gases. The energy production from within the sun, which serves to support the weight of the surrounding gases, comes from two different series of nuclear reactions. In either, hydrogen is eventually changed to helium under the conditions prevailing in stellar interiors. The carbon cycle involves collisions between the nuclei of hydrogen and carbon. In successive collisions with hydrogen nuclei (protons), a carbon nucleus is built up into nitrogen and then into oxygen, which in turn disintegrates back into a carbon nucleus and a helium nucleus.

The other nuclear reaction is the proton-proton chain. Protons collide directly to form, first, deuterium nuclei (heavy hydrogen) which, after further collisions with protons are transformed into nuclei of a light form of helium. These light helium nuclei collide with each other to form ordinary helium.

It is believed that in the sun and other less luminous stars, the proton-proton chain accounts for most of the nuclear energy, while in more luminous stars the carbon cycle is the most effective means.

These nuclear reactions occur deep in the interior of a star and produce mostly electromagnetic radiation at very short wavelengths—in the form of X-rays and gamma rays. Before this energy reaches the surface, it is absorbed and reemitted by various atoms a great number of times. By the time the original X-rays and gamma rays reach the surface of the sun they have been converted to the photons of lower energy and longer wavelength which we actually observe leaving the star.

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ASPECTS OF THE SKY

Major Topics Explored

- Locating Celestial Objects
  - Coordinate Systems
    - Horizon System of Coordinates
    - Equator System of Coordinates
  - Using a Celestial Globe
  - Construction of a Starfinder
    - Directions for using a Starfinder
  - List of the Brightest Stars
  - Starfinder Experiments
- Shadow Stick Astronomy
- The Use of Telescopes
  - Some Celestial Objects for Telescopic Observation
- Design of a Sundial
- Telling Time by the stars in the Northern Hemisphere
- Role of the Planetarium
- Using the Classroom as a Planetarium

Locating Celestial Objects

To locate an object on the celestial sphere, the astronomer must know his location, the local sidereal time, right ascension and declination of the object. It is probably not wise to teach the intricacies of the coordinate systems to the average student, but a knowledge of sidereal time will enable the student and teacher to use a starfinder and a celestial globe in identifying stars and constellations. The use of the setting circles on a telescope also requires some knowledge of coordinate systems. Planetarium teachers must also be familiar with locating objects in order to set up their equipment properly. A complete description of coordinate systems, celestial globe, and starfinder follows.

COORDINATE SYSTEMS

Horizon Systems of Coordinates
(Refer to Celestial Sphere Diagram)

By the celestial sphere we mean the whole sky, or the imaginary surface on which the stars, planets, etc., seem to be located. The center of this sphere is the center of the earth. Because the earth is so small in proportion to the size of the sphere, we usually consider the center of the earth to be at the same point as the observer.

In the horizon system of coordinates, the point on the celestial sphere directly overhead the observer is the zenith. (See figure 3.13.) The point directly below is the nadir. These points may be located precisely by means of a plumb line. The great circle on the celestial sphere, midway between the zenith and nadir with the observer at its center, is called the astronomical horizon. A great circle starting at the zenith, passing through an object and the nadir, is called a vertical circle and is perpendicular to the astronomical horizon.

The coordinates of an object in the horizon system of coordinates are azimuth and altitude. The astronomer usually measures azimuth from the north point on the horizon, eastward around the horizon circle, to the point where the vertical circle through the star meets the horizon. Thus the east point on the horizon circle has an azimuth of 90°, the west point, 270°. The symbol for azimuth is Z_n. Starting on the horizon, the angular distance measured upward along the vertical circle, passing through the star to the star itself, is called the altitude of the star. Thus a star midway between zenith and horizon would have altitude 45°. Objects below the horizon may be specified to have negative altitudes. The symbol for altitude is h.

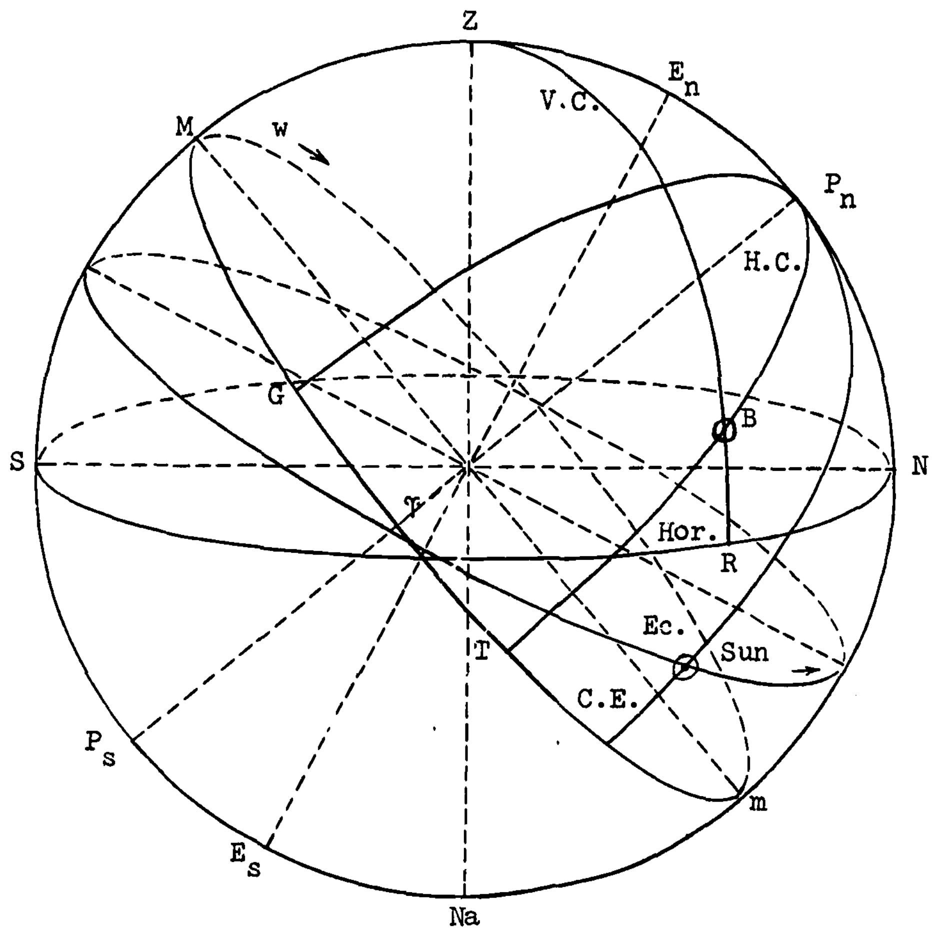


Figure 3.13 CELESTIAL SPHERE

Latitude of observer equals the elevation of P_n or P_s

L.S.T.	Mm♈	L.H.A.	MmT
R.A.	♈ T	Azimuth	NR
Dec.	TB	Altitude	RB

(Note: the arcs, as indicated above, are for this sketch only)

Abbreviations

Z	zenith	♈	first point of Aries (vernal equinox)
Na	nadir	P_nG	Greenwich meridian
E_n	north ecliptic pole	P_nZMP_s	observer's meridian (upper branch)
E_s	south ecliptic pole	Hor.	celestial horizon
P_n	north celestial pole	Ec.	ecliptic
P_s	south celestial pole	C.E.	celestial equator
N	north point of horizon	L.H.A.	local hour angle
S	south point of horizon	L.S.T.	local sidereal time
V.C.	vertical circle	T	foot of hour circle through B
H.C.	hour circle	R	foot of vertical circle through B
B	celestial body	w	westward direction along C.E.

Figure 3.13 Celestial Sphere.

Since each person, in effect, carries his own zenith and horizon around with him, altitudes and azimuths of objects will not be the same at all points on the earth's surface. This is a disadvantage; but when the horizon system of coordinates is used in conjunction with the equator system of coordinates, it will be very useful in describing the position of an object.

Equator System of Coordinates

In the equator system of coordinates (refer to figure 3.13), those points where the earth's axis prolonged intersects the celestial sphere are called the north and south celestial poles. The celestial equator, a great circle on the celestial sphere, is midway between the poles and may be thought of as the projection of the earth's equator onto the celestial sphere. Looking down on the celestial equator from the north celestial pole, we shall define a clockwise direction to be a westward direction. A great circle drawn on the celestial sphere from pole to pole and passing through an object is called an hour circle. This hour circle intersects the celestial equator at right angles.

The apparent path of the sun, called the ecliptic, intersects the celestial equator at two points, called the vernal equinox and the autumnal equinox. The plane of the ecliptic makes an angle approximately 23½° with the plane of the celestial equator. The symbol ♈ on the diagram denotes the vernal equinox. Location of the vernal equinox will be discussed under sidereal time.

The coordinates of an object in the equator system of coordinates are right ascension and declination. The right ascension of an object is the angular distance or length of arc measured from the vernal equinox eastward along the celestial equator to the foot of the hour circle passing through the star, from 0° to 360° or, as usually expressed, in time units of 0^h to 24^h. Here 1 hour corresponds to 15°. We shall denote right ascension by the letters R.A. Starting at the celestial equator, the angular distance measured along the hour circle passing through the object to the object itself is called the declination of the object. Stars north of the celestial equator have their declinations marked N or +; those south have their declinations marked S or –. We shall abbreviate declination by dec.

Latitude of the Observer Equals the Elevation of P_n or P_s

$\measuredangle L = \measuredangle E$, i.e., latitude of the observer is equal to the elevation of P_n. The polar axis and the line of sight from the observer to P_n may be considered to be parallel (intersecting at infinity). Refer to figure 3.14.

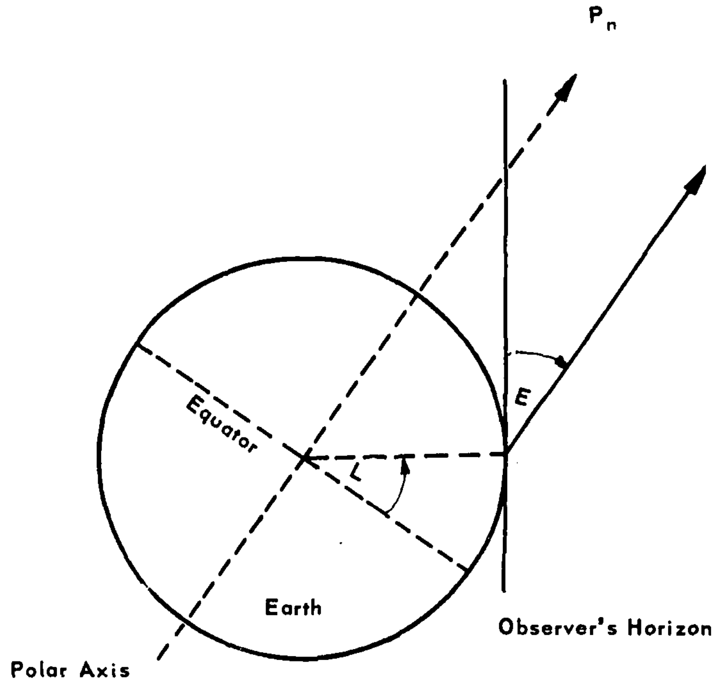


Figure 3.14 **Diagram indicating that the altitude (in degrees) of the north celestial pole, Pn, above the observer's horizon is equal to the observer's latitude.**

Sidereal Time

The upper branch of the observer's meridian is that half between the poles which contains the zenith; the lower branch is the opposite half. In the diagram of the celestial sphere, the upper branch is the arc P_nZP_s.

The local hour angle (L.H.A.) of an object is measured along the celestial equator from the upper branch of the observer's meridian (M) westward to the foot of the hour circle through the object.

The local sidereal time (L.S.T.) is the local hour angle of the vernal equinox. Thus the local sidereal time serves to determine the position of the vernal equinox on the celestial equator. Refer to figure 3.13.

Determination of Local Sidereal Time

A. See table giving approximate L.S.T. for 75° W. longitude at 7 p.m., E.S.T. (See "Directions for Using the Starfinder.") Correct for your longitude. If you are east of 75°, add the difference between your longitude and 75° to the given figure. If west of 75°, subtract the difference.

B. A sidereal clock gains approximately 3^m56^s daily over an ordinary clock. When it is midnight, i.e., 0^h for an observer on or about September 22, it is also 0^h sidereal time since the vernal equinox is on the observer's meridian. From this data one can estimate the L.S.T. corresponding to a given time zone to within a few minutes.

C. Accurate determination of L.S.T. (to within 1 second)
   1. Select your zone time so that Z.T. ± Z.D. = G.M.T. = 0^h.
      Note: G.M.T. = U.T. (Universal Time).
      Add the Z.D. (the integer number of hours the central meridian of your zone is from the Greenwich meridian) if you are in west longitude; otherwise, subtract.
   2. In the American Ephemeris and Nautical Almanac for the year in question, find the G.S.T. corresponding to the G.M.T. of 0^h and date. (G.S.T. = Greenwich hour angle of the vernal equinox, or H.A. of First Point of Aries.)
   3. From the G.S.T. subtract your precise longitude if you are in west longitude; otherwise, add. You now have the L.S.T. corresponding to the Z.T. in step 1. Correct for passage of time, and remember to add 10^s additional for each hour of time past the given Z.T. The reason for this is that a sidereal clock gains 3^m56^s each day over an ordinary clock.

Example: Location: F. & M. Observatory, Lancaster, Pa., Lat. 40° N., Longitude $5^h\ 05^m\ 20^s$ W.
Date and Time: Nov. 10, 1969; Z.T. $19^h\ 30^m\ 00^s$

Z.T.	$19^h\ 00^m\ 00^s$	Nov. 10, 1969
Z.D.	5	
U.T. = G.M.T.	$00^h\ 00^m\ 00^s$	Nov. 11, 1969
G.S.T.	$03^h\ 19^m\ 51^s$	(From Ephemeris for Nov. 11, 1969)
Longitude	05 05 20	(Subtract)
L.S.T.	$22^h\ 14^m\ 31^s$	(Corresponds to Z.T. 19^h in Lancaster on Nov. 10)
	30^m	
	05^s	(Gain of Sidereal clock in 30^m)
L.S.T.	$22^h\ 44^m\ 36^s$	(Corresponds to Z.T. $19^h\ 30^m$ in Lancaster on Nov. 10)

To illustrate the use of coordinate systems in describing the position of an object, let us consider an example. (See figure 3.15.)

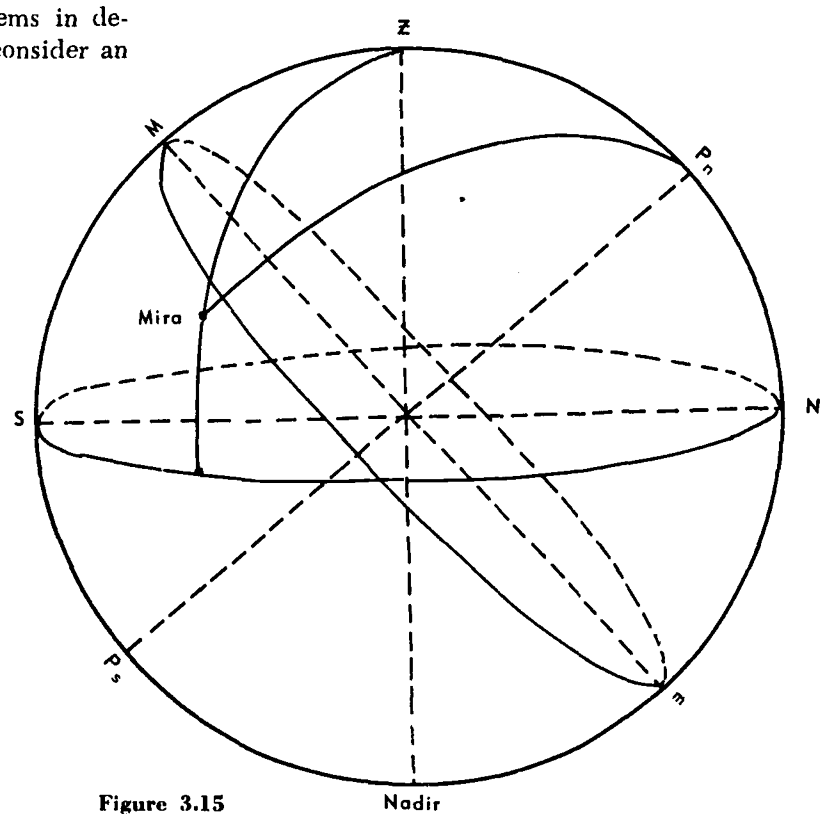


Figure 3.15

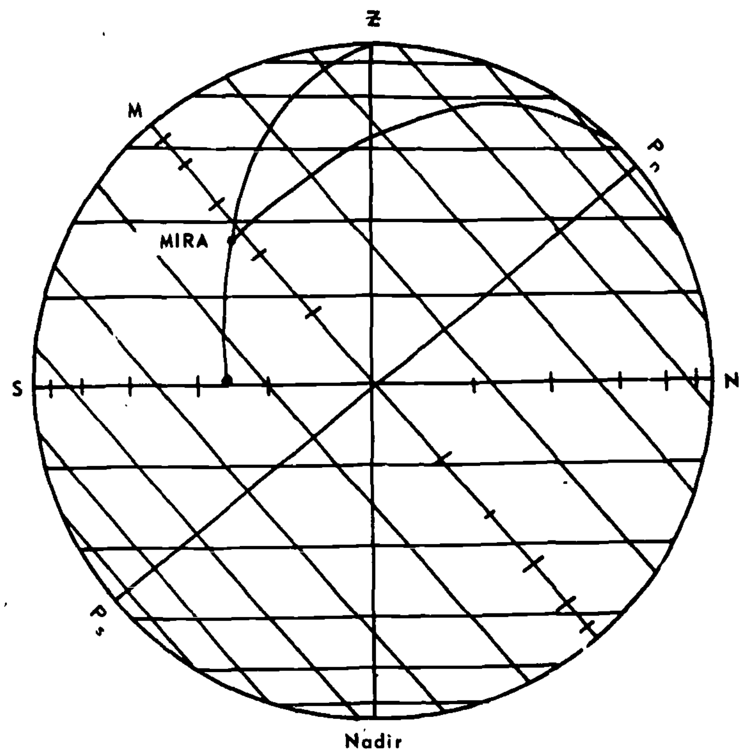


Figure 3.16

Example: Where would you look for the variable star Mira at the F. & M. Observatory, Lancaster, Pa., Lat. 40° N., Longitude $5^h\ 05^m\ 20^s$ W. on Nov. 10, 1969 at $19^h\ 30^m$ zone time?

We obtain the following information

R.A. (Mira)	$02^h\ 17^m8$
Dec. (Mira)	-03° 07′
L.S.T. (as previously calculated)	$22^h\ 44^m\ 36^s$
L.H.A. = L.S.T. - R.A. =	$20^h\ 26^m\ 48^s$
Estimated Azimuth (Z_n) =	120°
Estimated Altitude (h) =	20°

Reasonable estimates of the azimuth and altitude of the object may be made very quickly for a properly oriented celestial globe. (See page 97.)

Much better estimates of Z_n and h may be made from a diagram similar to Figure 3.16. Such diagrams are easily prepared and reproduced. First, elevate the pole to your latitude. On this diagram you are viewing the celestial equator and the celestial horizon edgewise. Using the horizon line S-N as a base line, then later the equator line M-Q, construct angles at 15° and mark points on the circumference of the circle. Connect points on opposite sides of the zenith-nadir line with lines parallel to the horizon line, then do the same for the equator line. Similarly, hour markings are obtained on the celestial equator. Distances between parallel lines represent 15° of arc in each case.

For estimation purposes, the same precision is now obtained whether the object is on the front or on the back of the sphere.

From this diagram we obtain Z_n = 115°, h = 25°; our estimates are probably not in error by more than a few degrees at most.

Franklin and Marshall College Observatory
Lat. 40° 03′ .15 N. Long. 76° 19′ .97 W.

Object: MIRA

Z.T.	19 -00 -00	Date: Nov. 10, 1969
Z.D.	05	
G.M.T.	00 -00 -00	Date: Nov. 11
G.S.T.	3 -19 -51	(Ephemeris)
λ (-)	05 -05 -20	
L.S.T.	22 -14 -31	for 19^h
Corr.	30 -05	
L.S.T.	22 -44 -36	
R.A.*	2 -17 -48	
L.H.A.	20 -26 -48	
Dec.* (-)	03° 07′	
Azimuth	115° (Z_n)	
Altitude	25° (h)	

USING A CELESTIAL GLOBE

A celestial globe is a small model of the celestial sphere and can be oriented to show the sky as seen by an observer at any point on the earth for any given time. One must imagine that he is at the center of the globe and looking out at the constellations and the several thousand stars positioned on its surface. The moon, planets and comets are not marked because their positions are not fixed in the sky pattern. The celestial globe can show only the fixed stars.

Globes are of two types—one is transparent showing the earth at the center and the stars on the larger spherical surface; the other is opaque. The Farquhar Transparent Globe (Plate 3.3) is made by the Farquhar Co., 5007 Warrington Avenue, Philadelphia, Pennsylvania 19143. The opaque model (Plate 3.4) is made by the Denoyer-Geppert Co., 5235 Ravenswood Avenue, Chicago, Illinois.

The celestial globe is perhaps the most useful single device ever devised for showing the apparent movements of the celestial objects. One can determine the positions of objects (azimuth and altitude) by use of it without becoming involved in complicated mathematics. Therefore, every science classroom should have one or more models for study and demonstration purposes.

The globe (Plate 3.4) is mounted on an axis of rotation which passes through the north and south celestial poles. This axis is supported at its ends by a bronze ring called the meridian ring.

The celestial equator is the great circle of the celestial sphere midway between the celestial poles and is the projection of the earth's equator onto the celestial sphere. Similarly the plane of the earth's orbit is pro-

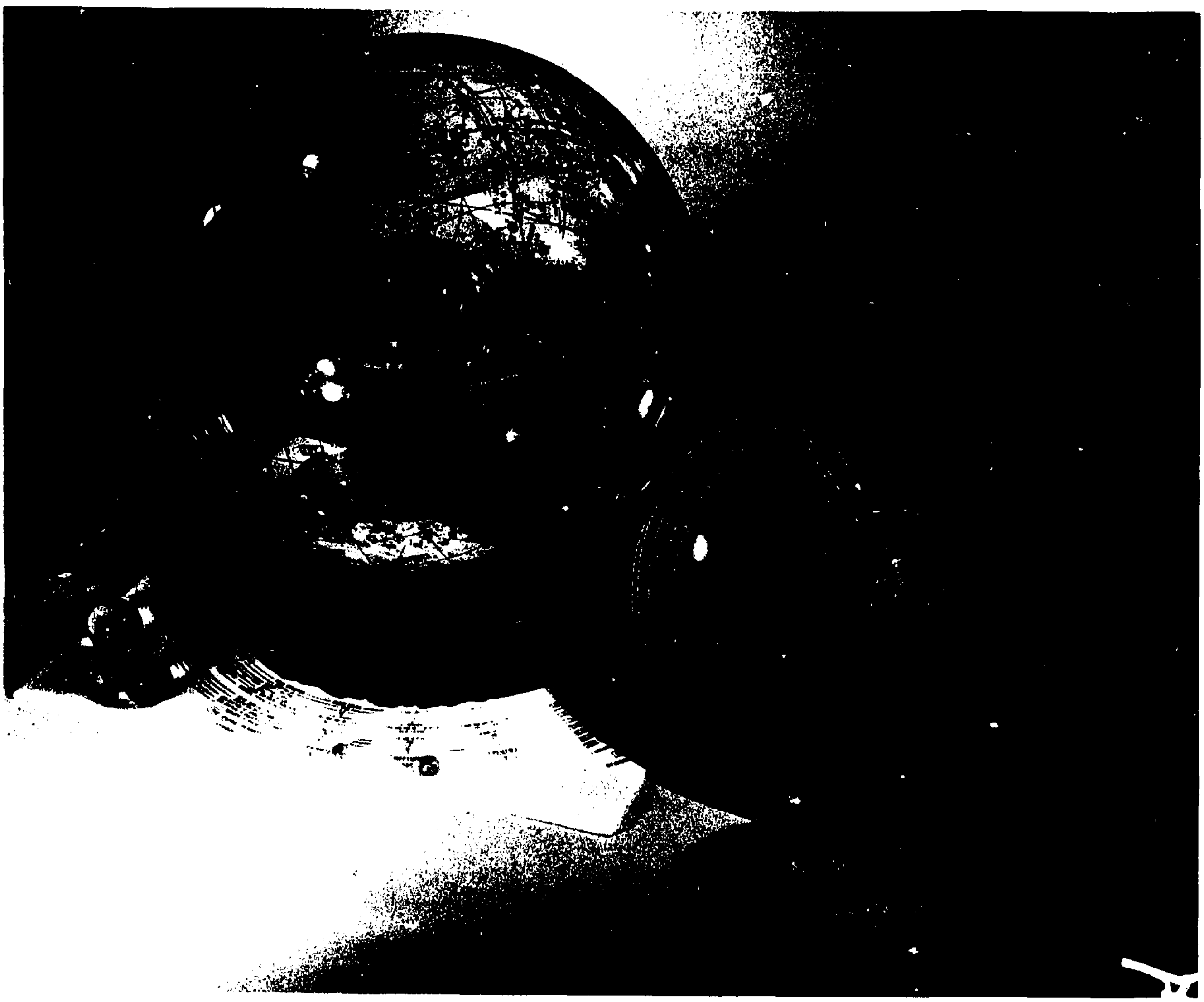


Plate 3.3 Transparent Celestial Globe and Solar System Model.

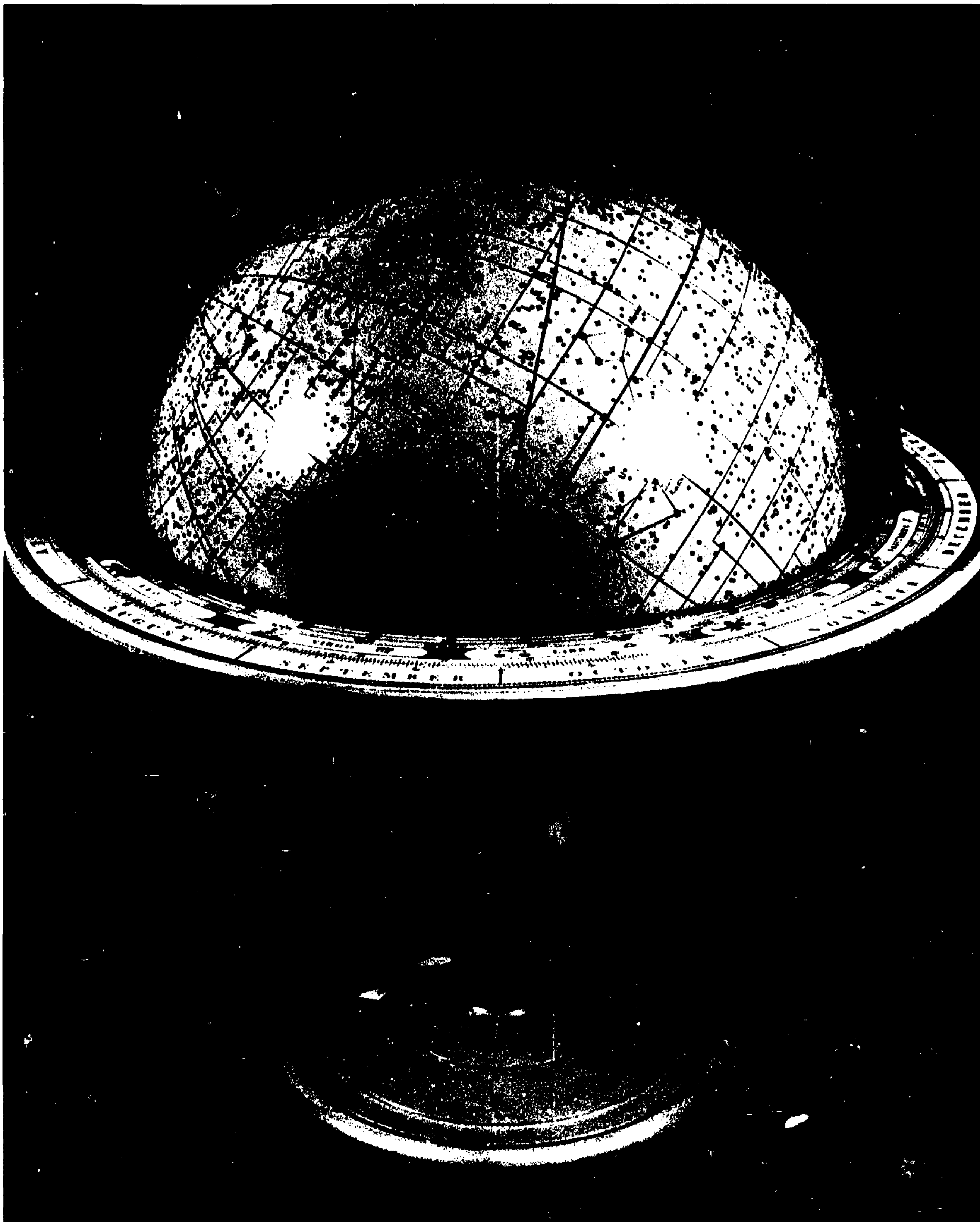


Plate 3.4 Opaque Celestial Globe.

jected onto the celestial sphere and forms another great circle called the ecliptic inclined 23½° to the plane of the celestial equator. (The earth's axis is tilted from the vertical by this amount.) The ecliptic marks the apparent path of the sun with respect to the background stars. As the sun moves on the ecliptic from south declination to north declination, the intersection marks the position of the vernal equinox (0^h) indicated by the symbol for Aries (♈) and occurs around March 21. The ecliptic is marked from 0° to 360° and the longitude of the sun may be read directly on this circle.

Twenty-four circles of right ascension (R.A.) pass through the poles with right ascension increasing eastward from ♈ along the celestial equator. Parallels of declination are drawn for every 10°; 0° to 90° N. and 0° to 90° S. Thus we can estimate the approximate right ascension and declination of a star shown on the globe. The bright star Sirius (α Canis Majoris) has R.A. = 6^h44^m, Dec. = –16°41′.

The meridian ring is supported in a horizontal wooden ring (Plate 3.3) which is graduated from 0° at the north point, eastward to 360° or, from 0° at the south point, westward to 360°. This is the horizon circle. The azimuth Z_n (sometimes Z_s) of any object on the globe is determined from the scale on the horizon circle ring.

A graduated, flexible scale, when held at the zenith and an edge allowed to pass through the star, represents a vertical circle and the altitude of the object can be read directly from this scale. Where the flexible scale intersects the celestial horizon will be the azimuth reading.

To rectify (orient) the globe for latitude and time, we do the following:

(1) Because the elevation of the visible celestial pole is numerically equal to the latitude of the observer, turn the vertical bronze meridian ring until the arc between the horizon of the globe and the pole equals the latitude.

(2) For the given date and zone time calculate the local hour angle of the vernal equinox, i.e., the right ascension of the observer's meridian, hence the globe may be rectified by merely rotating it until the reading on the celestial equator under the bronze meridian ring equals the local sidereal time.

With the globe now oriented for latitude and time and also turned so that the north point of the horizon is facing north, everything above the horizon circle is in the observer's sky at that instant. Rotating the globe will clearly indicate which constellations and stars are circumpolar and therefore never set.

Celestial globes generally come with manuals and detailed explanations. However, if one understands the basic concepts of coordinate systems and the steps taken in rectifying the globe for latitude and time, he or she can write their own manual and develop simple, but constructive exercises for students to perform. Or, after having given a few basic instructions on the use of a globe, the instructor might turn loose several of the better students to discover for themselves facts and principles about the objects in the sky from a study of the globe.

Example: Where would you look for the star Sirius on February 1, 1972 at 19^h E.S.T. in latitude 40° N. and longitude 76° W.?

Answer: Azimuth = Z_n = 135° (Southeast)
Altitude = h = 22°
(L.S.T. = 3^h42^m).

CONSTRUCTION OF A STARFINDER

Starfinders, similar to that pictured in Plate 3.5 have been constructed by several hundred Earth Science Teachers at NSF Institutes held at Franklin and Marshall College in recent years. They are inexpensive to make (approximately 30¢ exclusive of circular level) and they are simple to use in locating rather precisely any celestial object at any given time. Dimensions of the various components listed below are not critical except for the triangular block where the acute angle at the right (where the line is drawn on the edge of the block) should be numerically equal to your latitude. Thus if your latitude is 40°N, the triangular block will have angles 40°, 50°, 90°. For latitude 42°N, the appropriate angles are 42°, 48°, 90°. The base of the triangular block shown is 3¼ and is glued to the hardboard base piece which is 5" x 3" x ⅛". See figure 3.17.

The ¼" hole in the rectangular base piece is for tripod mounting with a nut holding the Starfinder to the tripod. Any tripod used for photographic work will do though other mounting arrangements may be devised.

A hole 1¼" deep should be drilled at right angles into the triangular block and a ¼" dowel stick inserted and glued as shown. Shaving a flat on a portion of the dowel stick will enable it to enter the triangular piece more readily since air will not be trapped. The part extending from the triangular piece should remain round.

The rectangular block 3³⁄₁₆" x 2⁵⁄₁₆" x ¾" has a ¼" hole drilled 1¼" deep with center approximately 1¼" from the right end. This piece when on the dowel should appear as in figure 3.18 with about ⅛" separation between the two blocks. If the hole in the rectangular block is drilled about ¹⁄₆₄" larger than the supposed ¼" dowel, the rectangular block will likely turn about the dowel without binding or excess looseness. Otherwise it may be necessary to sand lightly that portion of the dowel extending from the triangular block.

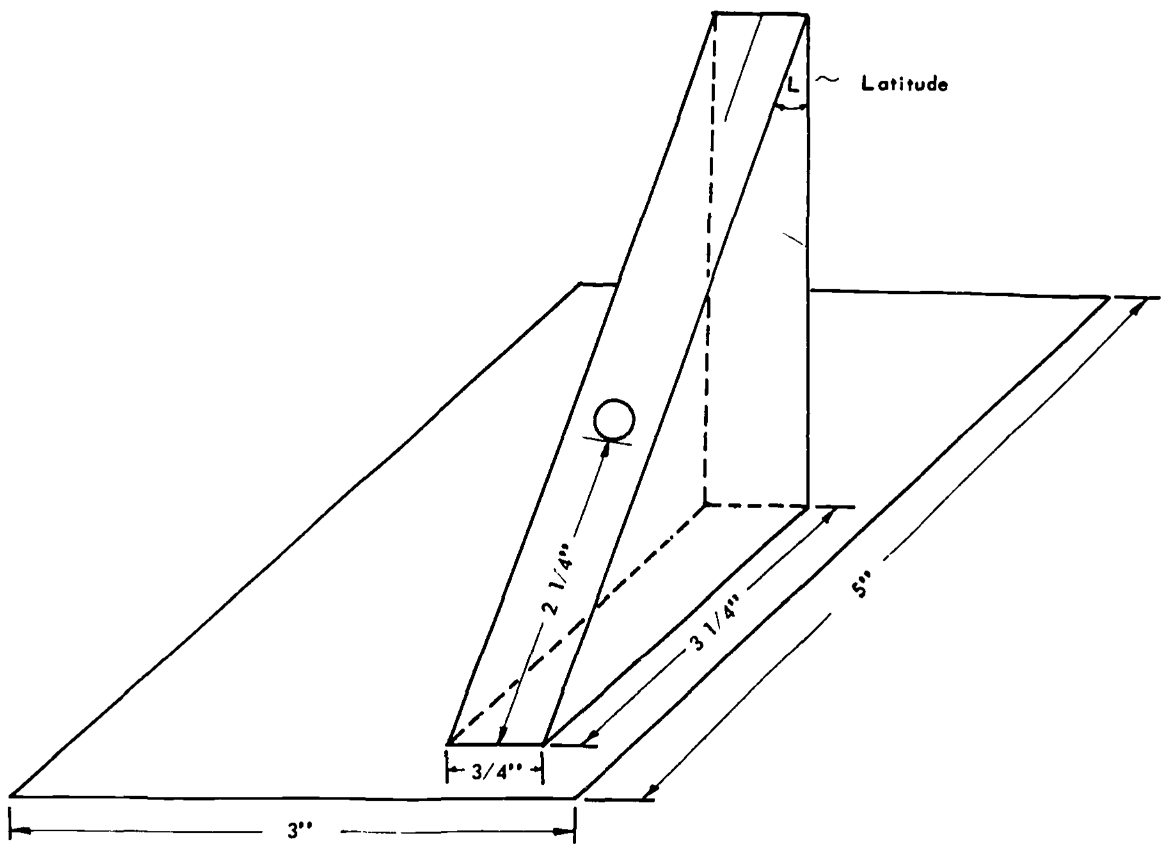


Figure 3.17 Construction of triangular block and base of starfinder.

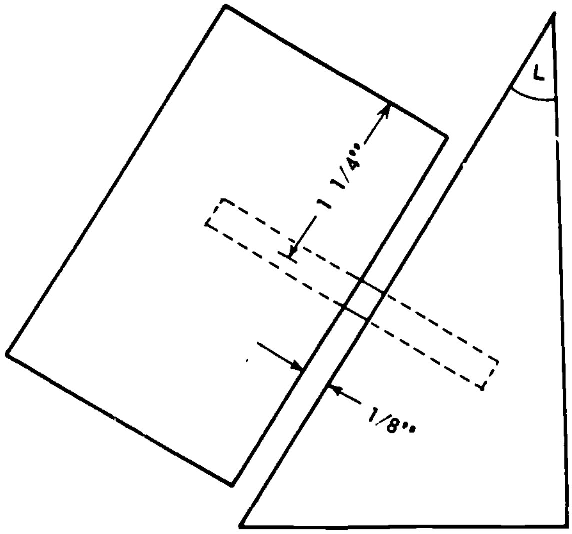


Figure 3.18

Construction of rectangular block joined to triangular piece by ¼" dowel.

The semicircular declination dial has the same dimensions as the rectangular block above it and may be made by laying a piece of stiff but thin cardboard of appropriate size on the template provided and marking off the divisions as shown on figure 3.19 with a sharp #2 pencil.

The circular dial of similar material is 4" in diameter. Lightly draw two concentric circles near the rim to simplify the task of making uniform markings. Punch a ¼" center hole, then place the cardboard circle on the template and mark off the divisions with a sharp #2 pencil. The use of a small amount of Plasti-Tak to hold the cardboard pieces on the templates will simplify the marking process and the plastic compound is easily removable afterwards. A simple ¼" centerpunch can be made from a few inches of ¼" round steel—your shop teacher can do this for you on a lathe in a few minutes.

The clear plastic piece is plexiglass and is 4¾" x ¾" x ⅛" with a small crosspiece 1" x 3/16" glued with Duco cement at right angles to the axis and about ⅞" from the square end. Cut and drill the plexiglass while the gummed paper is still on it. Then peel and smooth the edges by rubbing on a piece of sandpaper laid on a flat surface. With a needle scribe a ½" central line on one side of the plexiglass about 1½" from the hole, i.e., opposite where you will be reading declination on the semicircular dial. Fill in with dark ink and wipe. The small plastic crosspiece and this inked line will be on the same side of this plexiglass viewing tube holder.

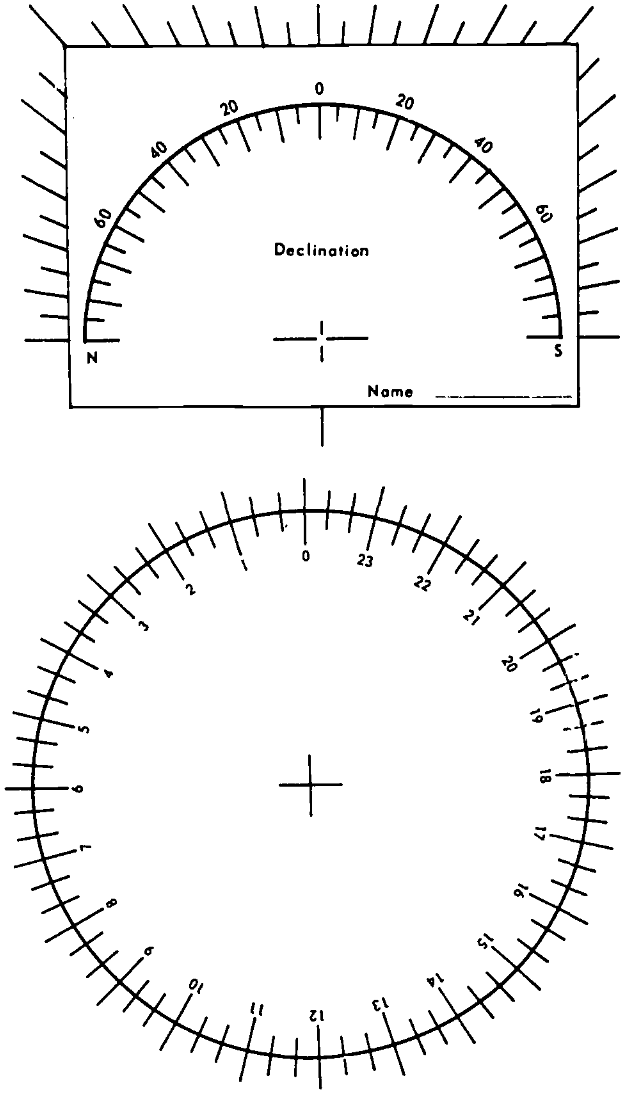


Figure 3.19

Template for declination and right ascension dials.

The aluminum viewing tube, 4" long and ½" outside diameter, is held against the edge of the small plastic piece by a rubber band, as shown. At 0° declination, the viewing tube should be parallel to the rectangular block immediately below it. To eliminate internal reflections in the tube either coat the inside of the aluminum tube with black paint or insert a cylinder of black flock paper made by rolling a 4" x 1⅝" piece around a pencil and inserting into the aluminum tube.

A cardboard pointer 1½" x ¾" is cemented to the under surface of the declination block (see Plate 3.5) and is used for reading right ascension on the circular dial. A circular level may be purchased for less than a dollar and may be cemented, if desired, at the front left of the base piece.

¾″ white pine or other wood is suitable for the project and variations on the above design may easily be made. The only critical measurements are the angles on the triangular block. If the starfinder is made with reasonable care and used according to the following instructions, the desired object will appear near the center of the field of the viewing tube. Modern telescopes operate by the same set of principles as this starfinder which will locate objects either visible or invisible to the naked eye. See Plate 3.6 for Starfinder Parts and Plate 3.5 for the completed Starfinder. Figure 3.19 is the template to be used for the right ascension and declination dials.

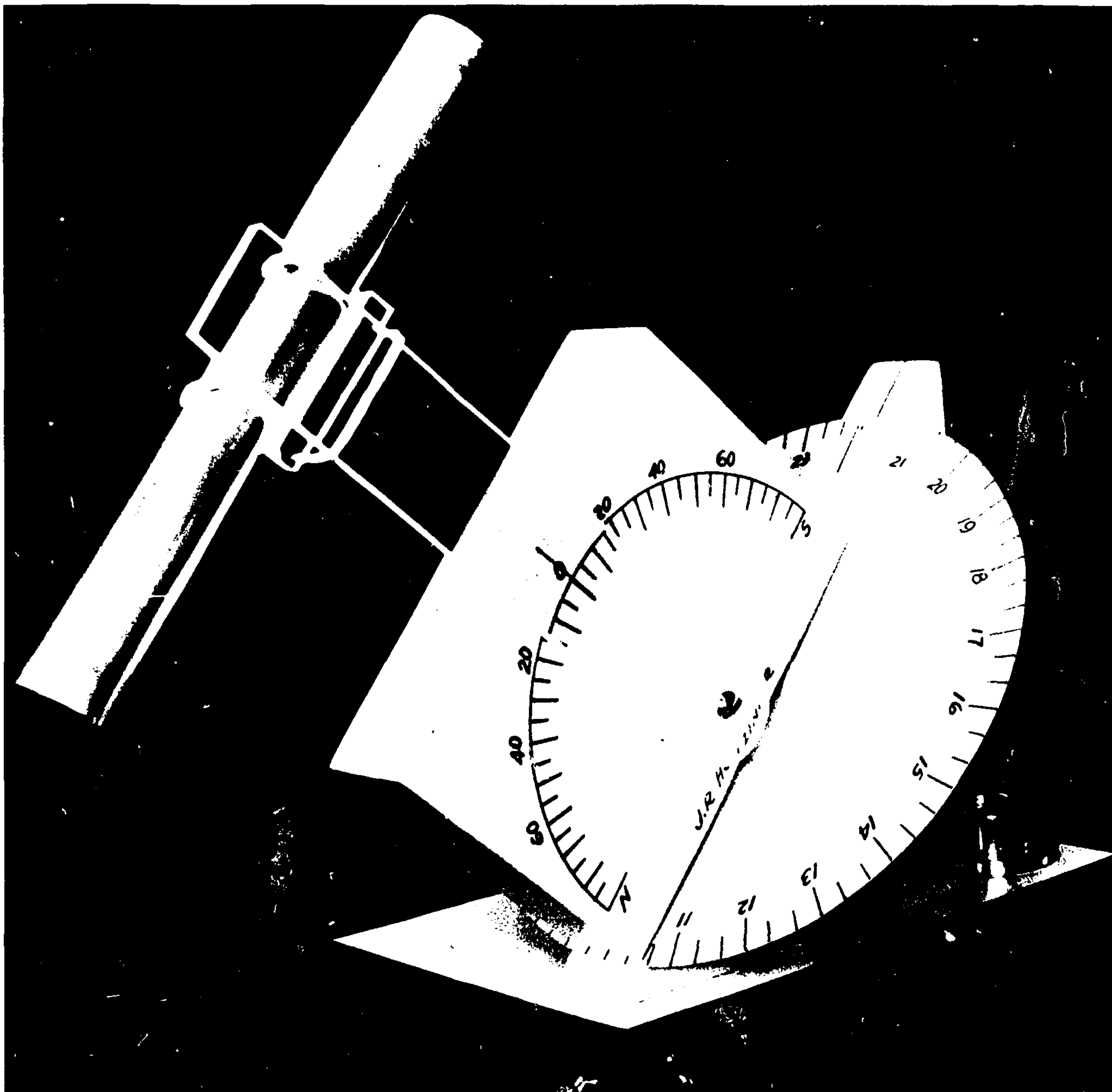


Plate 3.5 The Completed Star Finder Model.

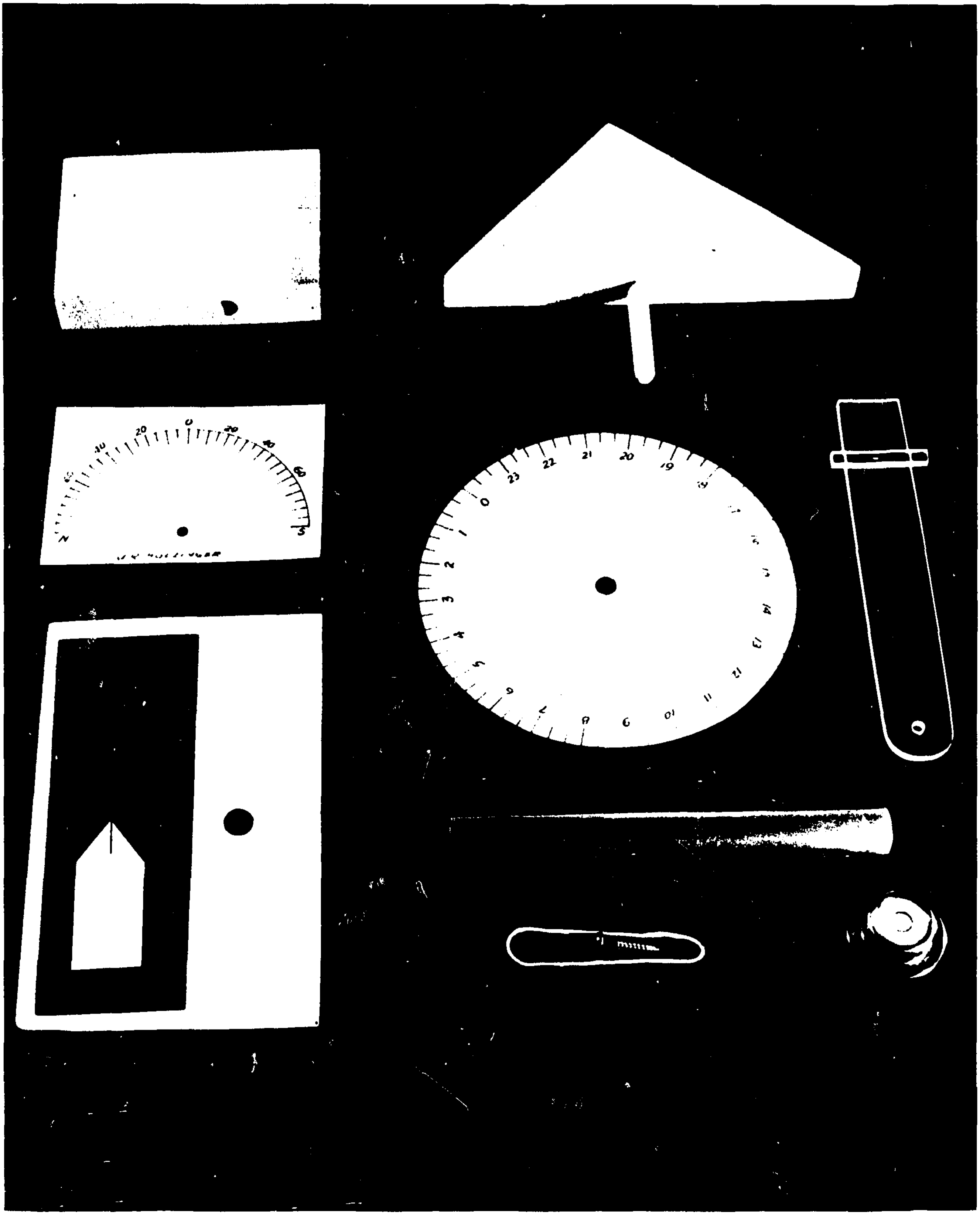


Plate 3.6 The Component Parts of the Star Finder Model.

Directions For Using The Starfinder

In using the Starfinder (and modern telescopes) we need, in addition to right ascension and declination, local sidereal time (L.S.T.). The meaning of L.S.T. and L.S.T. calculations have been treated in detail in the section on Celestial Coordinates, but the following table (for any year) may be used by anyone whether or not he has a full understanding of the subject. Longitude corrections are simply made—see examples.

Approx. L.S.T. at 19^h (7 p.m. E.S.T.) in Longitude 75° W.

		hrs. min.			*hrs. min.*
January	1	1 – 44	July	1	13 – 38
	15	2 – 39		15	14 – 33
February	1	3 – 46	August	1	15 – 40
	15	4 – 42		15	16 – 35
March	1	5 – 37	September	1	17 – 42
	15	6 – 32		15	18 – 37
April	1	7 – 39	October	1	19 – 40
	15	8 – 34		15	20 – 36
May	1	9 – 37	November	1	21 – 43
	15	10 – 32		15	22 – 38
June	1	11 – 39	December	1	23 – 41
	15	12 – 35		15	0 – 36

Because a sidereal clock gains nearly 4^m daily over an ordinary clock, add 4^m for each day past the 1st or 15th of the month.

Example 1

What is the approximate L.S.T. in longitude 78° 15′ W. on April 4 when the zone time is 22^h (E.S.T.)?

April 1	L.S.T.	$7^h\ 39^m$	for 19^h, Long. 75° W.
Correction (3 days)		12^m	
April 4	L.S.T.	$7^h\ 51^m$	for 19^h, Long. 75° W.
Hrs. past 19		3^h	
April 4	L.S.T.	$10^h\ 51^m$	for 22^h, Long. 75° W.
Long. difference (3° 15′)		13^m	(subtract)
April 4	L.S.T.	$10^h\ 38^m$	for 22^h, Long. 78° 30′ W.

Example 2

What is the approximate L.S.T. in longitude 73° 30′ W. on June 6 when the zone time is $22^h\ 30^m$ (10:30 p.m.)?

June 1	L.S.T.	$11^h\ 39^m$	for 19^h, Long. 75° W.
Correction (5 days)		20^m	
June 6	L.S.T.	$11^h\ 59^m$	for 19^h, Long. 75° W.
Hrs. past 19		$3^h\ 30^m$	
June 6	L.S.T.	$15^h\ 29^m$	for $22^h\ 30^m$, Long. 75° W.
Long. difference (1° 30′)		6^m	(add)
June 6	L.S.T.	$15^h\ 35^m$	for $22^h\ 30^m$, Long. 73° 30′ W.

Conversion of Arc to Time

Arc	Time
15°	1^h
1°	4^m
15′	1^m
1′	4^s
15″	1^s

Mount the Starfinder on a tripod or base and adjust to a level position by use of a circular level. Compute the local sidereal time (L.S.T.) corresponding to your standard time. Set the sidereal time on the circular dial opposite the line drawn on the triangular block. Note that each small division on the dial represents 20 minutes of time.

Select a bright star that you know. Obtain its right ascension (R.A.) and declination (Dec.) from the list of brightest stars on page 105 or from some other source such as a star chart, a celestial globe, or an ephemeris. A plus sign (or no sign) with the declination means north declination; a minus sign denotes south declination.

Set the R.A. of the star on the instrument by turning the pointer attached to the rectangular block to the appropriate figure on the circular dial (the circular dial has already been set to the L.S.T.). Move the plastic piece to the appropriate declination figure on the semicircular dial.

Now turn the entire instrument (but not the tripod) until the star can be seen through the viewing tube. Lock the instrument in this position. The Starfinder is now oriented and you have a true north-south line. To locate other objects, set the sidereal time, the right ascension and declination of the object on the instrument. With a little practice, after the finder is oriented, it will take only a few seconds to locate an object. Note: Bright objects appearing in the sky but which are not on the list of brightest stars are probably planets.

TEACHER NOTES

LIST OF BRIGHTEST STARS

STAR		*Position* R.A. h	m	*1970* Dec °	′	*Mag (visual)*
α Andromedae		00	06.8	+28	55	2.06
β Cassiopeiae		00	07.6	+58	59	2.26
α Phoenicis		00	24.8	–42	28	2.39
α Cassiopeiae		00	38.8	+56	22	2.16
β Ceti		00	42.1	–18	09	2.02
γ Cassiopeiae A		00	54.9	+60	33	2.13 v
β Andromedae	(Mirach)	1	08.0	+35	28	2.02
α Eridani	(Achernar)	1	36.6	–57	23	0.51
γ Andromedae		2	02.1	+42	11	2.14
α Ursae Minoris	(Polaris)	2	02.5	+89	08	1.99 v
α Arietis		2	05.5	+23	19	2.00
ο Ceti A	(Mira)	2	17.8	– 3	07	2.0 v
β Persei	(Algol)	3	06.0	+40	50	2.06 v
α Persei		3	22.2	+49	45	1.80
α Tauri A	(Aldebaran)	4	34.2	+16	27	0.86 v
β Orionis A	(Rigel)	5	13.1	– 8	14	.14 v
α Aurigae	(Capella)	5	14.5	+45	58	0.05
γ Orionis	(Bellatrix)	5	23.5	+ 6	19	1.64
β Tauri		5	24.4	+28	35	1.65
δ Orionis		5	30.5	– 0	19	2.20 v
ε Orionis		5	34.7	– 1	13	1.70
ζ Orionis AB		5	39.2	– 1	57	1.79
κ Orionis		5	46.3	– 9	41	2.06
α Orionis	(Betelgeuse)	5	53.5	+ 7	24	.41 v
β Aurigae		5	57.3	+44	57	1.86
β Canis Majoris		6	21.4	–17	56	1.96
α Carinae	(Canopus)	6	23.3	–52	41	–0.72
γ Geminorum		6	36.0	+16	26	1.93
α Canis Majoris	(Sirius)	6	43.8	–16	41	–1.42
ε Canis Majoris		6	57.4	–28	56	1.48
δ Canis Majoris		7	07.2	–26	21	1.85
η Canis Majoris		7	22.9	–29	14	2.46
α Geminorum A	(Castor)	7	32.7	+31	57	1.97
α Canis Minoris	(Procyon)	7	37.7	+ 5	18	0.37
β Geminorum	(Pollux)	7	43.5	+28	06	1.16
ζ Puppis		8	02.5	–39	55	2.23
γ Velorum A		8	08.6	–47	16	1.88
ε Carini		8	21.9	–59	24	1.97
δ Velorum AB		8	43.9	–54	36	1.95
λ Velorum		9	06.9	–43	19	2.24
β Carinae		9	12.9	–69	36	1.67
ι Carinae		9	16.3	–59	08	2.25
α Hydrae		9	26.1	– 8	32	1.98
α Leonis	(Regulus)	10	06.8	+12	07	1.36
γ Leonis AB	(Algieba)	10	18.3	+20	00	1.99
β Ursae Majoris		11	00.0	+56	33	2.37
α Ursae Majoris AB		11	01.9	+61	55	1.81

STAR		Position R.A. h	m	1970 Dec °	′	Mag (visual)
β Leonis	(Denebola)	11	47.5	+14	44	2.14
γ Ursae Majoris		11	52.2	+53	52	2.44
α Crucis A		12	24.9	−62	56	1.39
α Crucis B		12	24.9	−62	56	1.86
γ Crucis		12	29.5	−56	57	1.69
γ Centauri AB		12	39.9	−48	48	2.17
β Crucis		12	46.0	−59	32	1.28
ε Ursae Majoris		12	52.7	+56	07	1.79
ζ Ursae Majoris	(Mizar)	13	22.7	+55	05	2.26
α Virginis	(Spica)	13	23.6	−11	00	.91 v
η Ursae Majoris		13	46.4	+49	28	1.87
β Centauri AB		14	01.7	−60	13	0.63
θ Centauri		14	04.9	−36	14	2.04
α Bootis	(Arcturus)	14	14.3	+19	20	−0.06
α Centauri A		14	37.6	−60	43	0.01
β Ursae Minoris		14	50.8	+74	16	2.04
α Coronae Borealis	(Gemma)	15	33.4	+26	49	2.23 v
α Scorpii A	(Antares)	16	27.6	−26	22	0.92 v
α Trianguli Australis		16	45.5	−68	59	1.93
ε Scorpii		16	48.2	−34	15	2.28
λ Scorpii		17	31.6	−37	05	1.60
α Ophiuchi		17	33.5	+12	35	2.09
θ Scorpii		17	35.2	−42	59	1.86
κ Scorpii		17	40.4	−39	01	2.39
γ Draconis		17	55.9	+51	29	2.21
ε Sagittarii		18	22.2	−34	24	1.81
α Lyrae	(Vega)	18	35.9	+38	45	0.04
σ Sagittarii		18	53.4	−26	20	2.12
α Aquilae	(Altair)	19	49.3	+ 8	47	.77
γ Cygni		20	21.1	+40	09	2.22
α Pavonis		20	23.3	−56	50	1.95
α Cygni	(Deneb)	20	40.4	+45	10	1.26
ε Pegasi A		21	42.7	+ 9	45	2.31
α Gruis		22	06.3	−47	07	1.76
β Gruis		22	40.9	−47	02	2.17 v
α Piscis Austrini	(Fomalhaut)	22	56.0	−29	47	1.19

Useful Adjuncts to the Starfinder

1. The Observer's Handbook (1970). The Royal Astronomical Society of Canada, 252 College Street, Toronto 2B, Ontario, Canada. Price: $1.50. Excellent.
2. An excellent book for the amateur is Norton's Star Atlas which includes maps and data on 9000 stars, clusters, nebulae, etc.
3. The American Ephemeris and Nautical Almanac (Government Printing Office) gives positions for planets, stars, moon, sun, etc. for any particular year.

Interesting Starfinder Experiments

1. If your starfinder is aligned north-south, it is easy to determine L.S.T. Pick a star that you recognize in the sky. Set its declination on the instrument and move the rectangular block until you can observe the star through the viewing tube. Now turn the circular dial until the R.A. of the star is under the cardboard pointer. Read the L.S.T. opposite the line on the triangular block.
2. If your starfinder is aligned north-south and you observe, for example, a star that is due south (on the meridian), then at this instant, L.S.T. = R.A. You have the R.A. of the star from your tables, hence you know the L.S.T.

   This is the principle of the transit instrument such as is used by the U. S. Naval Observatory. They obtain L.S.T. in this way, then convert it to mean time. You can get the National Bureau of Standards WWV Fort Collins, Colorado time signals on 2.5, 5, 10, 15, 20, 25 megahertz; CHU Ottawa, Canada time signals on 3330, 7335, 14670 kilohertz.
3. You can obtain approximate right ascensions and declinations of visible objects. Align the instrument and set the L.S.T. Then for any object which can be seen in the viewing tube, you can read off its right ascension and declination on the appropriate scales. Indeed, you can identify a fairly bright star in this way. In the List of Brightest Stars, the stars are arranged in increasing order of right ascension. Match with appropriate declination and magnitude, and your identification is complete.
4. You are somewhere in North America on June 8, 1972 with a Starfinder designed for use in Latitude 40° N., a copy of the American Ephemeris and Nautical Almanac (or equivalent information) and a radio capable of picking up time signals. You wish to determine your latitude and longitude approximately. Assume that you have previously determined a north-south line by the sun-shadow method described on page 110 under "Shadow Stick Astronomy."

Set up the Starfinder in the north-south direction. Set L.S.T. = 0^h, R.A. = 0^h. Select a star that you know which is slightly east of the meridian, say α Lib (Zubenelgenubi) whose R.A. = $14^h49^m12^s$ and Dec. = −15°52′, but do not make these settings. Suppose a time signal is received indicating that it is 22^h40^m Central Time and that 48^s later you judge that the star is on the meridian, i.e. due south. You read the angle θ = 26°29′ on the starfinder when the star is due south. See figure 3.20.

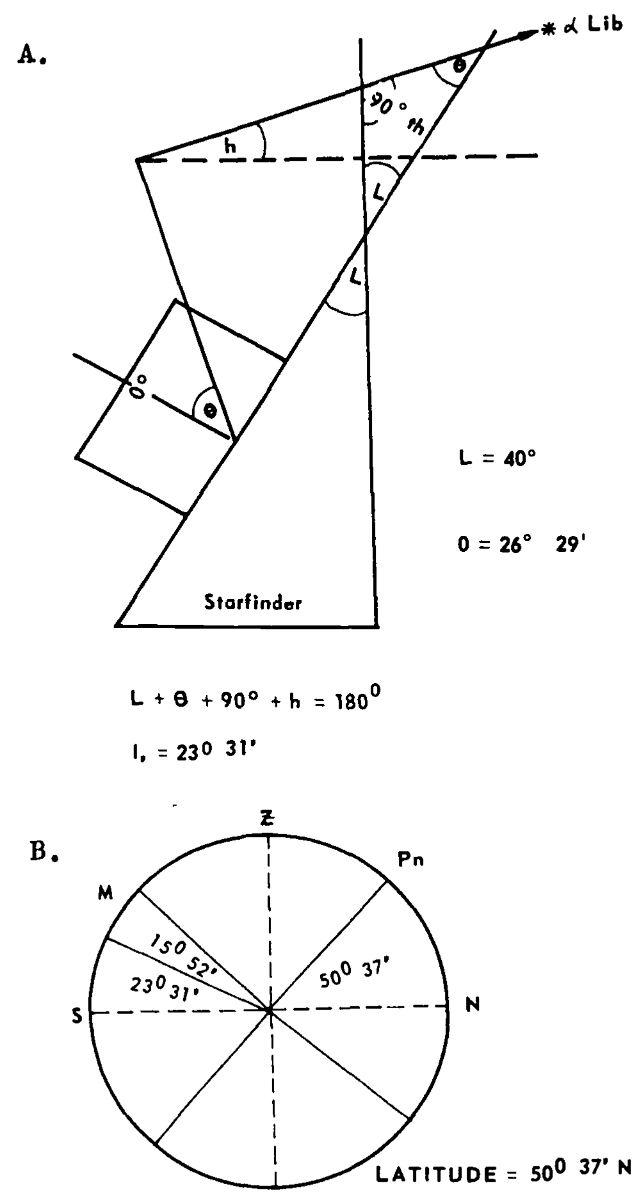


Figure 3.20 Calculation for Latitude.

Calculation for Longitude

When a star is on the meridian, R.A. = L.S.T. From the Ephemeris we determine that the Greenwich Sidereal Time (G.S.T.) is $17^h 09^m 42^s$ corresponding to 0^h Greenwich Mean Time (G.M.T.), June 9, 1968. Since Central Standard Time was mentioned, we can calculate the Greenwich Mean Time.

Z.T.	$22^h\ 40^m\ 00^s$	June 8, 1968	
Z.D.	6^h		
G.M.T.	$4^h\ 40^m\ 00^s$	June 9, 1968	
G.S.T.	$17^h\ 09^m\ 42^s$ for 0^h G.M.T.		June 9, 1968
Correction for $4^h 40^m$ and Sidereal Clock gain	$4^h\ 40^m\ 94^s$ (includes 48^s)		
G.S.T.	$21^h\ 51^m\ 16^s$ for $4^h 40^m$ G.M.T.		June 9, 1968
R.A. = L.S.T.	$14^h\ 49^m\ 12^s$		
	$7^h\ 02^m\ 04^h = 105°31'$ W.		

In summary, our latitude is 50°37′ N. and our longitude is 105°31′ W. We are at Moose Jaw, Saskatchewan, Canada!

Note: Precise determination of longitude and latitude is somewhat more involved than the above procedure suggests. The use of a Starfinder which is a relatively crude instrument, does not justify the high degree of precision indicated in the above calculations.

TEACHER NOTES

SHADOW STICK ASTRONOMY

Introduction

By observing the length and direction of the shadow cast by a vertical stick of known length, we can make some simple and also some rather sophisticated astronomical measurements during the course of a year or part of a year.

What is a Shadow Stick?

For our purposes a shadow stick is an object, say a thin pole 3′ to 6′ in length and pointed or rounded at the upper end, placed vertically in level ground. Or we may use a board, say 16″ x 8″, on which is erected an upright thin post 3″ to 5″ in height. The post (gnomon) should be perpendicular to the board and the board should be provided with screws for leveling. (See figure 3.21.)

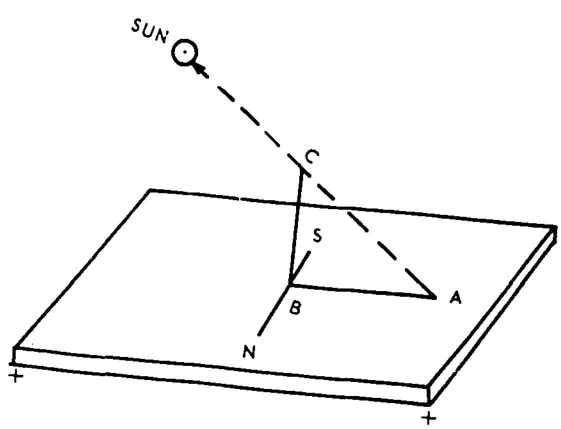


Figure 3.21

Classroom construction of a shadow stick board.

What are some Shadow Stick experiments?

1. Determination of a north-south line or the local meridian.

   At an hour or two before noon (no watch is required), mark the end of the shadow on the ground. Using the distance from the base of the stick to this point as radius, draw a circle around the base of the stick. Some time past noon the tip of the lengthening shadow will again be on the circle. Bisect the angle formed by the two shadow points and the base of the stick to get the north-south line. A perpendicular to this line will mark the east-west directions.

2. Determination of Local Apparent Noon (Noon by the true Sun).

   When, during the day, the sun's shadow is the shortest or the shadow falls along the north-south line, is the instant of apparent noon. At apparent noon the sun's altitude is maximum for that day. Draw a triangle similar to triangle ABC in the previous figure and measure angle A with a protractor. This is the maximum altitude of the sun for that day. Indeed, the altitude of the sun at any time during the day can be determined by this method.

3. Determination of Local Mean Time (L.M.T.) and Zone Time (Z.T.).

   From the American Ephemeris and Nautical Almanac one can obtain the Equation of Time (Eq.T.) for each day of the year—or see the Equation of Time sheet with the material in this Guide on "Construction of a Sundial". The local apparent time (L.A.T.) at apparent noon is 12^h.

   Now L.A.T. – L.M.T. = Eq.T. and since we have the Eq.T., we can solve for the local mean time. Let $\Delta\lambda$ represent the difference between your longitude and the longitude of the central meridian of your time zone. Then Z.T. $\pm \Delta\lambda =$ L.M.T.

   If you are west of the central meridian, subtract; otherwise add in order to solve for Zone Time.

4. Determination of the Summer and Winter Solstices.

   The shortest noonday shadow occurs on June 21 when the sun has maximum altitude for the year. This is the date of the summer solstice. The shadow, at noon, is longest on December 22, the winter solstice.

5. Finding the Dates of the Equinoxes.

   When the shadows at sunrise and at sunset lie along the east-west line, you have the dates of the equinoxes. The vernal equinox occurs on March 21 at which time the declination of the sun is 0°.

6. Determination of Latitude.

   At the time of the vernal equinox or 6 months later at the time of the autumnal equinox, find sun's noon altitude, i.e. measure angle A in the figure. The complement of this angle is the latitude. If one knows the declination of the sun at other times, latitude is determined from the maximum altitude by the formula

   Latitude = 90° – (Altitude – Dec. of Sun).

7. Finding the Declination of the Sun.

   If we have a scale on which the zero point is noon altitude of the sun at the time of an equinox, the measured angle each noon thereafter will be the declination of the sun north or south of the celestial equator.

8. Finding the length of the Solar Year.

Determine the number of days from summer solstice to summer solstice.

9. Measuring the Angle Between the Planes of the Ecliptic and the Celestial Equator (Obliquity).

The value of the maximum or the minimum declination is the obliquity of the ecliptic.

10. Approximate Longitude.

See example 4 on the use of a Starfinder. L.A.T. at noon altitude of the sun is 12^h. With Eq.T. one can get L.M.T. With the aid of the radio time signal we can calculate G.M.T. (Greenwich Mean Time). If λ is longitude, L.M.T. $\pm \lambda =$ G.M.T. If L.M.T. is less than G.M.T., use the plus sign, indicating that λ is west longitude.

11. Determination of the Time of Day.

To determine the time of day (Zone time) when the sun is not at noon altitude and using a vertical stick is a rather involved problem; it is much easier to use a sundial specially designed for your particular latitude. (See Design of a Horizontal Sundial.)

Consider the following problem: On October 20, 1966 a pointed 4″ dowel stick was carefully placed in a vertical position facing an east window in Stahr Hall at Franklin and Marshall College. The shadow length cast by the Sun was approximately 6.06″. On that day the R.A. of the Sun was approximately 13^h38^m and the declination approximately $-10°15'$. What was the time of day?

The calculated zone time was 9^h58^m, the actual time at which the shadow-length was measured was 10^h00^m.

TEACHER NOTES

THE USE OF TELESCOPES

Types

Optical telescopes are of two types, refractors and reflectors. The refractor (lens type) was probably invented in 1608 by Hans Lippershey. In the following year Galileo constructed a model that he used for astronomical observations. The reflecting (mirror type) telescope was invented by Newton about 1670 and avoided the chromatic aberration that plagued the single lens objective of the refractor.

Power of a Telescope

The most frequently asked question at an observatory is "What is the power of the telescope?" A brief but meaningful answer is difficult to give; there are at least three powers of a telescope which are important to an observer. They are:

(1) Light Gathering Power (L.G.P.)

The brightness of an image is proportional to the area of the objective lens or mirror. Thus the 200-inch mirror of the Hale telescope on Mt. Palomar will give an image 400 times as bright as a 10-inch mirror. We say that the light gathering power of the 200-inch is 400 times the light gathering power of the 10-inch mirror. To see or photograph very faint stars a large aperture is necessary.

$$\frac{\text{L.G.P. } (200'')}{\text{L.G.P. } (10'')} = \frac{\text{Area } (200'')}{\text{Area } (10'')} = \frac{\pi.100^2}{\pi.5^2} = \left(\frac{100}{5}\right)^2 = \left(\frac{200}{10}\right)^2 = 400$$

(2) Magnification

This is the power that probably intrigues the questioner. The magnifying power of a visual telescope is the number of times the telescope increases the apparent diameter of an object as compared with the naked-eye view. To obtain magnifying power, divide the focal length of the Objective (mirror or lens) by the focal length of the eyepiece. Since telescopes frequently have a number of eyepieces to select from, one can choose the magnification he needs for his purpose. If the objective lens of a telescope has a focal length of 10 ft. (120 inches) and the eyepiece is of focal length ½", then the magnification will be 240 diameters.

There is a practical upper and lower limit to magnification which is a function of the diameter of the objective. The upper limit is about 50 times the aperture in inches because of the spreading of light by magnification; indeed one does not use high magnification unless seeing is steady. Should there be appreciable turbulence in the atmosphere making the image appear unsteady at low magnification, using higher magnification will only magnify the effects of turbulence as well. A power less than 3 times the aperture in inches is unsuitable also because the beam of light entering the eye is then larger than the widest opening of the lens of the eye. With a 6" telescope, the useful magnifying powers range from about 18 to 300, but one would seldom use these extreme values. Probably 100 would be a more useful figure for many purposes. Magnification is useful when studying the moon and certain of the planets, but no amount of magnification with most instruments will show the real disk of a star. Increased magnification decreases the size of the field of view and also diminishes somewhat the brightness of the object. An astronomical telescope inverts and reverses from left to right, equivalent to a rotation of 180 in the plane. (See figure 3.22.)

Figure as Seen with Naked Eye

The same Figure as seen through an Astronomical Telescope

Figure 3.22
Diagram showing inversion and lateral reversal of a telescopic image.

(3) Resolving Power

Images of stars are spread by diffraction with disks surrounded by fainter concentric rings. Two stars which are closer together than the diameter of the brighter portion of the diffraction disk cannot be separated (resolved) by any magnification. The resolving power of a telescope is a function of the aperture, a, in inches of the objective, also the wavelength, λ, of the light involved. The minimum angular separation, d, in seconds of arc, of the stars which can just be resolved or seen as two stars rather than one is given by

d (Seconds of arc) = 1.03 x 206,265 (seconds) x $\frac{\lambda \text{ (inches)}}{a \text{ (inches)}}$. For visual telescopes, $d = \frac{4.56}{a}$ seconds. Thus a 10″ telescope has a resolving power of $\frac{4.56}{10} = .456''$. For the eye alone the formula does not hold because of the relatively coarse structure of the retina of the eye. Resolving power is seriously limited when seeing conditions are poor.

Limiting magnitudes for a given Instrument

The limit of brightness for the unaided eye is about the 6th magnitude, i.e., under ideal seeing conditions (time of new moon, clear sky, no city lights, etc.) one can see stars of the 6th magnitude and brighter. Note: The brighter the object, the lower the magnitude number.

The light gathering power of a telescope depends upon the square of its aperture. It is generally assumed that under good conditions a 9th magnitude star can be seen visually with a telescope of 1-inch aperture. Let D_k be the diameter of a given objective and LGP_k the light gathering power of this objective. Then

$$\frac{LGP_k}{LGP_1} = (2.512)^{m-9} = \frac{D_k^2}{D_1^2} \text{ where } D_1 = 1, \text{ the}$$

diameter of the 1″ objective. (See discussion of magnitudes in this Guide.)

Taking the logarithm of both sides of

$$(2.512)^{m-9} = \frac{D_k^2}{1^2},$$

we have

$$.4(m-9) = 2 \log D_k$$

and $$m = 9 + 5 \log D_k.$$

For a 10″ objective, m = 14, i.e., the faintest stars that can be seen visually are 14th magnitude objects. for the 200″ telescope, m = 20.5. Throughout we assume good seeing conditions.

Types of Mountings

Basically, telescope mountings are of two types; equatorial and alt-azimuth. The former is preferable in that tracking an object is much simpler since a sidereal drive unit can be used; also locating an object is easier with setting circles.

With the equatorial instrument there are two axes of rotation for the telescope tube: a polar axis which is elevated to the latitude of the observer and about which the telescope turns with the passage of time; the other is the declination axis. Initially it takes somewhat longer to set up the equatorial instrument, but locating and observing objects is greatly facilitated. The alt-azimuth (generally less expensive) instrument can be set up quickly. No leveling or orientation is required, but objects may be difficult to keep in the field of view.

Orienting an Equatorial Telescope

One orients an equatorial telescope as he would a Starfinder (see section on Starfinder). The Starfinder is designed for a particular latitude whereas the polar axis of the equatorial instrument must be elevated to the latitude angle of the observer. Leveling must be accomplished and orientation made on Polaris (easiest) or on some other known star. Declination may be set directly, but rather than setting local sidereal time (L.S.T.) and right ascension (R.A.) separately, the difference between the two, L.S.T. − R.A. = L.H.A. (local hour angle), will probably be the setting to use on the polar axis setting circle. Add 24^h to the L.S.T. if necessary in order to make the subtraction.

Purchasing an Instrument

For school use an equatorially mounted 6″ portable reflector with setting circles and sidereal drive unit and costing \$200-\$300 would probably represent the minimum in acceptable instruments. A 6″ permanently mounted refractor with setting circles, sidereal drive and other accessory equipment could cost \$6000 or more. Generally, the larger the instrument the less portable it becomes and setting up time will probably be increased. Smaller, less expensive refractors, may also be suitable for school use.

Questar, a small but excellent instrument is priced from \$800 up. Other telescopes of various types, sizes, and prices are regularly advertised in Sky and Telescope Magazine—your library should subscribe to this popular, but excellent journal.

When choosing eyepieces for use with your instrument, it is better to choose those giving low or moderate magnification; those with high magnification are seldom used.

Some Celestial Objects For Telescopic Observation

R.A.	1970 Dec.	
00-23.1	64 00	Nova 1572 Cassiopeiae (Brahe)
00-41.1	41 07	M31 Andromeda Nebula
01-40.3	51 25	M76—nebula
01-52.1	19 09	Gamma Arietis—double star
02-02.0	42 12	Gamma Andromeda—gold and blue double
02-17.8	-03 07	Mira, o Ceti—variable star
02-16.9	57 01	H33—cluster
02-20.3	56 59	H34—cluster
02-26.6	67 16	Iota Cassiopeiae—triple
02-40.3	42 37	M34—loose cluster
03-06.0	40 50	Beta Persei—Algol ("The Demon Star"), variable
03-45.3	24 02	Pleiades cluster
03-53.0	-03 02	32 Eridani—topaz and green double
04-04.8	62 15	485 Camelopardalis—relatively fixed double
05-26.6	35 49	M38 Auriga—cluster
05-32.7	22 00	M1 Crab Nebula in Taurus
05-34.4	37 08	M36—cluster
05-33.9	-05 57	The trapezium in Orion, open cluster
05-33.8	-05 25	M42 The Great Nebula
05-37.0	-02 35	Sigma Orionis—multiple
05-50.4	32 32	M37 Auriga—cluster
05-53.5	07 24	Betelgeuse—Alpha Orionis, variable
06-07.0	24 21	M35 Geminorum—open cluster
06-22.1	04 36	8 Monocerotis—yellow and blue double
06-45.8	-20 42	M41 Canis Major—cluster
07-32.7	31 58	Castor—double
07-40.4	-14 45	M46 Puppis—cluster
07-40.5	-18 08	H64—planetary nebula
08-38.4	20 06	M44 Praesepe (The Bee-Hive), cluster
08-45.2	28 53	Iota Cancri—double
09-53.1	69 12	M81—spiral nebula
09-53.6	69 50	M82—spiral nebula
10-18.3	20 00	Gamma Leonis—double
11-13.1	55 11	M97 (The Owl Nebula), planetary
12-17.5	47 28	H43 spiral nebula
12-40.1	-01 18	Gamma Virginis—binary double
12-49.3	83 34	1694 Camelopardalis—pale yellow and lilac double
12-54.6	38 29	Corcaroli—double
12-55.3	21 51	M64 (Black-eye Nebula)
13-22.7	55 05	Mizar—naked eye pair with Alcor
13-28.6	47 21	M51 (Whirlpool Nebula)
13-40.8	28 32	M3—globular cluster
14-43.7	27 12	Epsilon Bootis—yellow and blue double
15-17.0	02 12	M5—globular cluster
16-27.6	-26 22	Antares—red and green double
16-40.6	36 31	M13 Herculis—cluster

R.A.	1970 Dec.	
17-13.3	14 26	Alpha Herculis—orange and green double variable
17-16.2	43 11	M92—globular cluster
17-38.1	-32 12	M6—cluster
18-00.6	-23 02	M20—nebula
18-01.8	-24 23	M8 cluster and nebula
18-19.1	-16 12	M17 (horseshoe or Omega Nebula)
18-23.3	58 47	39 Draconis—triple
18-34.5	-23 57	M22—cluster
18-43.6	39 37	Epsilon Lyrae—double-double
18-49.5	-06 19	M11—fan shaped cluster
18-52.5	33 00	M57 (Ring Nebula)
19-29.5	27 54	Beta Cygni—yellow and blue double
19-58.3	22 38	M27 (Dumb-bell Nebula)
20-44.9	16 01	Gamma Delphini—double
21-02.5	-11 30	Saturn Nebula, planetary
21-04.8	38 33	61 Cygni—double
21-28.6	12 02	M15—globular cluster
21-31.9	-00 58	M2—globular cluster
22-13.8	49 44	H75—cluster
22-28.1	58 16	Delta Cephei—long period variable
23-24.5	42 22	H18—planetary nebula

DESIGN OF A SUNDIAL

If the instructor has included a unit on time in the astronomy program, some members of his class may be interested in constructing a horizontal sundial. The construction of a sundial for a particular locality is dependent on the latitude of the observer. The fundamental formula of spherical trigonometry together with the latitude of the observer, 40° in the example, are used in the design. (See figure 3.23.) The accompanying diagram (figure 3.24) is self-explanatory.

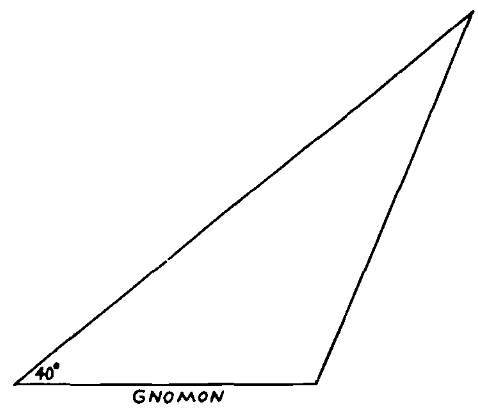


Figure 3.24 (A)

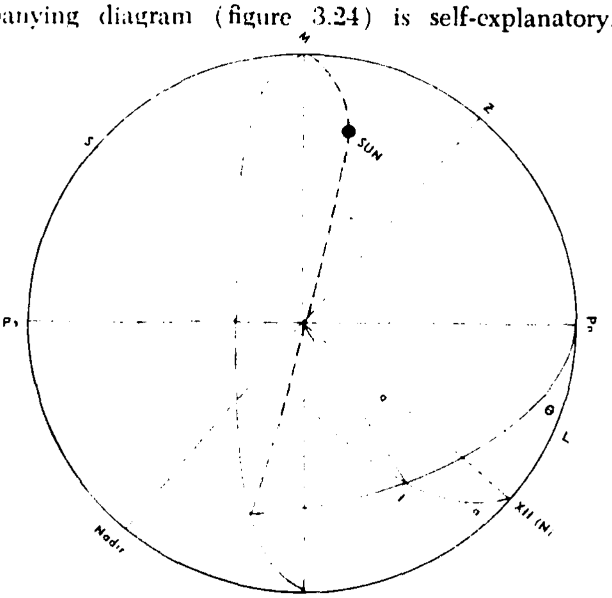
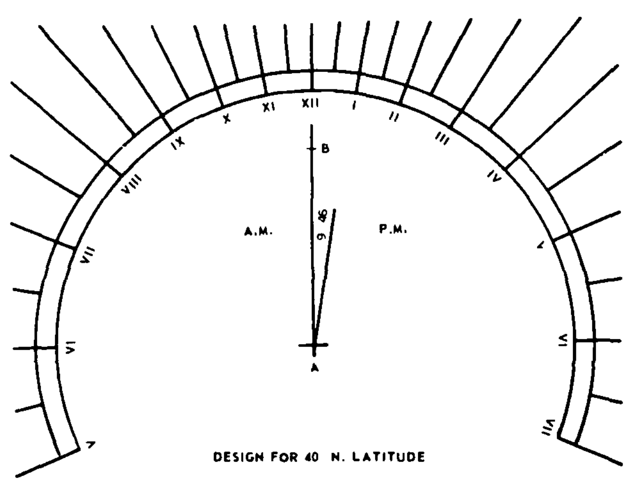


Figure 3.23



The gnomon is mounted perpendicular to the plane of the dial at the positions A and B. The dial may be constructed of heavy cardboard, and small strips of wood may be glued to the dial along the line AB to support the gnomon in a vertical position.

When completed, the dial may be mounted on a tripod, if desired, leveled with a circular level, and oriented with the gnomon or XII o'clock on the dial pointing true north. Orientation may be accomplished in the following manner:

Suppose the Z.T. is 10^h on September 25. The corresponding L.M.T. in Lancaster, for example, is 10^h minus $5^m = 9^h\ 55^m$, since we are approximately 5^m (actually $5^m\ 20^s$) west of the 75th or central meridian on which our zone time is based. From the table we find that the Equation of Time is 8^m for the given date. Then L.A.T. = L.M.T. + Eq.T. or L.A.T. = $10^h\ 03^m$ corresponding to the given Z.T. and date. Turn the dial on the tripod until the shadow cast by the gnomon shows approximately $10^h\ 03^m$. The dial is now oriented.

In using the dial, after it has been leveled and oriented, read the dial time (L.A.T.). Now use the formula L.A.T. – L.M.T. = Eq.T. to obtain L.M.T., which is the mean solar time for your particular meridian. Compute the number of minutes between your meridian and the central meridian of your time zone. If you are west of the central meridian, add this difference to the L.M.T. to get Z.T. or correct watch time which is the time of the central meridian; otherwise, subtract this quantity.

Four times a year the clock and the sundial agree exactly; but the sundial—now going a little slower, now a little faster—will be sometimes behind, sometimes before the clock. The greatest accumulated difference will be about 16^m for a few days in November, but on the average considerably less. Those days on which the two agree are April 15, June 15, September 1, and December 24.

Calculations for construction of a Horizontal Sundial

From the equations

$$\cos a = \cos b \cos L + \sin b \sin L \cos \theta$$
$$\cos b = \cos L \cos a + \sin L \sin a \cos 90°$$

it can be shown that

$$\tan a = \tan \theta \sin L$$

a: Dial angles measured from XII o'clock, clockwise and counterclockwise.

θ: Half hours and hours in degrees measured along the celestial equator. Equal arcs on the celestial equator do not project into equal arcs on the celestial horizon.

L: Latitude of the observer.

θ	sin L = sin 40°	tan θ sin L	∠ a (see diagram)
7½°	.6428	.0847	4° 50′
15 °	.6428	.1722	9° 46′
22½°	.6428	.2662	14° 55′
30 °	.6428	.3712	20° 22′
37½°	.6428	.4932	26° 15′
45 °	.6428	.6428	32° 44′
52½°	.6428	.7797	37° 57′
60 °	.6428	1.113	48° 04′
67½°	.6428	1.552	57° 13′
75 °	.6428	2.399	67° 22′
82½°	.6428	4.883	78° 26′
90 °	.6428	not defined	90° 00′
97½°	.6428	–4.883	101° 34′
105 °	.6428	–2.399	112° 38′

The Equation of Time in Minutes

L.A.T. – L.C.T. = Eq.T.

Day of Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	– 4	–14	–13	–4	3	2	–3	–6	0	10	16	11
4	– 5	–14	–12	–3	3	2	–4	–6	1	11	16	10
7	– 6	–14	–11	–2	3	2	–5	–6	2	12	16	9
10	– 8	–14	–10	–1	4	1	–5	–5	3	13	16	7
13	– 9	–14	–10	–1	4	0	–6	–5	4	14	16	6
16	–10	–14	– 9	0	4	0	–6	–4	5	14	15	4
19	–11	–14	– 8	1	4	–1	–6	–4	6	15	15	3
22	–12	–14	– 7	1	4	–2	–6	–3	7	15	14	2
25	–12	–13	– 6	2	3	–2	–6	–2	8	16	13	0
28	–13	–13	– 5	2	3	–3	–6	–1	9	16	12	–2

Example: On Nov. 21 in Lancaster we place an upright stake in the ground; and, when the shadow is due north, we decide to go home for lunch. At what time did we leave? The answer is noon apparent time; but, if standard time is desired, we proceed as follows:

L.A.T. – Eq.T. = L.M.T.

$12^h\ 00^m - 00^h\ 14^m = 11^h\ 46^m$

L.M.T. + $\Delta\lambda$ = Z.T.

$11^h\ 46^m + 00^h\ 05^m = 11^h\ 51^m$ (E.S.T.)

$\Delta\lambda = 5^h\ 05^m\ 20^s - 5^h\ 00^m\ 00^s$ (for Lancaster) $\Delta\lambda \approx 05^m$.

L.A.T. Local Apparent Time. True sun time or sundial time.
L.M.T. Local Mean Time. Time by the mean sun.
Eq.T. Equation of time, given in minutes.

TELLING TIME BY THE STARS IN THE NORTHERN HEMISPHERE

The star Polaris is near the North Celestial Pole, and a line drawn from Polaris through β Cassiopeiae (figure 3.25A) very nearly passes through the vernal equinox. If we take Polaris as the center of the 24 hour clock, β Cassiopeiae on the rim of the clock will circle Polaris counterclockwise in a sidereal day of 24^h (figure 3.25B). We measure the local sidereal time from the upper branch of the observer's meridian westward (counterclockwise) to the line joining Polaris with β Cassiopeiae. By definition, L.S.T. is the local hour angle of the vernal equinox.

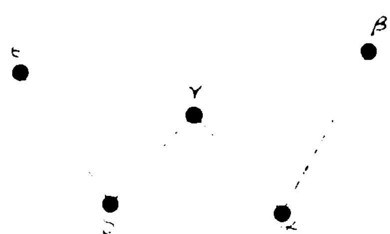
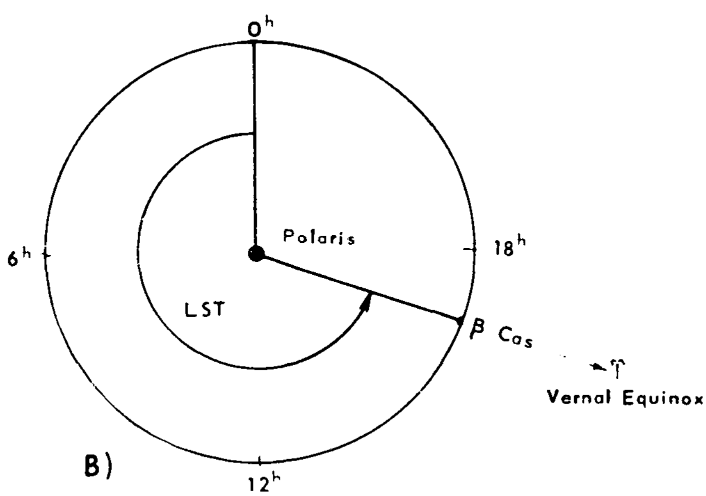


Figure 3.25 A) The constellation Cassiopeia with the member stars named.



B) Diagram showing Beta Cassiopeiae as it would appear to circle Polaris counterclockwise in a sidereal day of 24 hours.

With a bit of practice, one can make a reasonable estimate of the L.S.T. on any clear evening by observing Polaris and β Cassiopeiae. If a better estimate is desired, a dial approximately 7″ in diameter with a ½″ hole at the center may be cut out of cardboard and calibrated, as shown in figure 3.26.

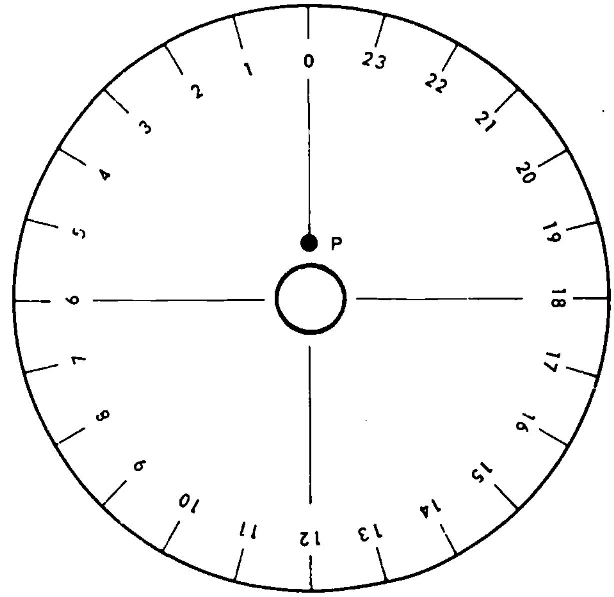


Figure 3.26 Diagram showing a dial which may be cut from cardboard to better estimate the position of Beta Cassiopeiae in telling time by the stars.

At the point P on the dial, a string somewhat longer than the radius of the dial may be attached and a small weight added at the free end; this serves as a plumb line.

Holding the face of the dial toward you, sight Polaris through the ½″ hole. 0^h should be at the top, 12^h at the bottom directly behind the weighted string, and the plane of the dial should lie in the plane of the celestial equator. Now move the dial toward or away from you until Cassiopeiae appears on the rim of the dial. The position of β Cassiopeiae on the rim gives the L.S.T.

We can now convert the observed L.S.T. to L.M.T., and then to Z.T., if we know the date. On or about September 22, the L.S.T. and the L.M.T. for the observer will be the same, but thereafter the sidereal clock will gain nearly 4^m ($3^m 56^s$/day, 24^h/year) over the ordinary clock. The following example will illustrate a method for finding the approximate Z.T. (watch time) corresponding to the L.S.T. for a given time and place.

Location: Lancaster, Pennsylvania (Longitude $5^h\ 05^m$ W.)
Date: November 22
L.S.T.: $23^h\ 30^m$ (estimated)

At the rate of $3^m\ 56^s$ gain per day, the sidereal clock will have gained roughly 4 hours over the ordinary clock in the period of time between September 22 and November 22. Therefore, the L.M.T. will be approximately $19^h\ 30^m$, corresponding to the estimated L.S.T. of $23^h\ 30^m$. In Lancaster we are about 5^h west of the standard meridian, hence the Z.T. will be approximately $19^h\ 35^m$ (7:35 p.m.).

ROLE OF THE PLANETARIUM

While there is no substitute for observing the sky at night to learn the constellations and stars, a planetarium lesson, or series of lessons, provides a most valuable means of interesting students in doing further observation. Should a school district have a planetarium, many of the complicated concepts and motions of astronomy can be graphically illustrated to the students. Observations which would take weeks, or perhaps months, can be recreated in a matter of minutes and some motions which can be observed only by plotting data are continuously observable through the manipulation of the planetarium projector.

USING THE CLASSROOM AS A SUBSTITUTE PLANETARIUM

In the teaching of earth and space science today, there are astronomy concepts concerning motions of celestial objects that are difficult to present without some means of three-dimensional orientation. The geocentrically (earth-centered) oriented planetarium available in some schools, colleges, and museums, provides an excellent opportunity to illustrate these concepts. Unfortunately, there are few installations available for such use by many earth science classes in Pennsylvania.

The importance of these concepts should not be overlooked or treated in an insignificant manner. Therefore, it is necessary to improvise by creating a planetarium atmosphere in the classroom. Ideally, the students should have had one planetarium experience for them to fully appreciate this improvisation. The teacher should have had several hours of planetarium experience in order to see how to present these concepts in the classroom. One of the great benefits from a planetarium-oriented classroom is the involvement of the students in creating problems in motion and solving them by becoming part of the motions themselves. In short, the students actually walk out motions or change the position of planet, moon, sun, and star cutouts.

Prior to setting up the classroom as a planetarium, the students should be introduced to the geocentric view of the universe through the use of a celestial sphere model with the earth at the center. From this model, the projection of earth-bound coordinates (longitude and latitude) and points of reference (zenith, nadir, North Star) can be clearly explained. This experience should be followed by a trip outside in order to discuss the actual projection of the local meridian onto the sky overhead (the celestial sphere), the altitude of the North Celestial Pole, the projection of the Equator onto the celestial sphere, and the apparent motions of the sun, moon, planets, and stars around the earth. Once students have a mental image of the celestial sphere and the geocentric earth, the classroom can be used to illustrate the seasons, moon motions, constellation relationships, and planet motions in a detailed fashion.

To set up the classroom, it is essential that the compass direction of SOUTH be located on the blackboard side of the room. Hopefully, the classroom is oriented so that true SOUTH is in the direction of the blackboard. If not, it may be necessary to close out any view of the outdoors so that the students will not become confused with the position of the real sun outside and the imaginary sun in the classroom.

The following points and lines may be indicated on the walls and ceiling by colored tape (reflective type if possible) or cut paper mounted with a silicone, putty-like material that does not harm paint or paper: zenith point, North Celestial Pole, celestial meridian, ecliptic, and celestial equator. In order to discuss the movement of any celestial object, it is necessary to use the background of stars as a reference system. The use of dark-blue poster paper and white dots for stars is quite effective. These constellation sheets can be moved as the seasons change.

Depending upon the grade level, the students might move paper images of the sun, moon, and planets around the moon from day to day or they might actually use their bodies, with signs, to demonstrate celestial motions.

Below are listed some of the concepts adaptable to the planetarium-oriented classroom:

1. The daily apparent motion of the sun, moon, planet, and stars around the earth.
2. The true motion of the moon, planets.
3. The seasonal change in the noon altitude of the sun and the background of stars.
4. The revolution of the moon around the earth.
5. The movement of the planets across the background of stars.

6. The precession of the Vernal Equinox point eastward across the background of stars.
7. Definition of the YEAR (Tropical and Sidereal).
8. Phases of the moon and the inner planets.
9. Moon cycles (synodic and sidereal).
10. Eclipses (solar and lunar).
11. Retrograde motion of the planets.

The planetarium-oriented classroom has one advantage over the planetarium chamber containing a fixed projector in the center of the room. It is possible to retain the celestial sphere concept but, in addition it is possible to switch from the earth-centered view to the sun-centered view by placing an orrery in the center of the room. The orrery is a simple device that demonstrates the revolution and rotation of the earth about the sun and the revolution of the moon around the earth utilizing gears and an arm connecting the sun and earth. With this device, the students can look at the solar system as though they were passive observers in space, just outside the solar system. This permits the teacher to move from the geocentric view to the heliocentric view in order to explain the actual relationship of celestial objects in motion. While viewing the earth on this orrery, the student can mentally project himself onto the surface of the earth as it moves before his eyes. A small toy figure stuck on the earth will aid in making this mental transfer of frames of reference.

An example of one demonstration that is easily transferred from the geocentric to the heliocentric view is the apparent eastward motion of the sun across the background of stars as the earth revolves around the sun. A yellow disc representing the sun can be moved counterclockwise around the classroom across the background of stars attached to the wall. The signs of the zodiac can be explained as those constellations that the sun is in front of from one month to the next. At the end of the sidereal year (20 minutes longer than the calendar year), the sun will have moved completely around the walls (the celestial sphere) and will have aligned itself with the same star again.

With the orrery, a meter stick can be held above the earth-sun line to point to the background of stars. This alignment is maintained as the earth is revolved around the sun; the stick pointing toward the constellations that the sun is in front of from one month to the next.

Information on the positions of the planets and the sun can be obtained from several different sources listed in the astronomy bibliography.

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The Milky Way

Major Topics Explored

Appearance of the Milky Way
Composition
Star Clusters
Nebulae

What does the Milky Way look like?

The Milky Way appears as a faint, luminous band of light that completely encircles the sky. It shows up best on a moonless night at a location which is away from the glare of city lights.

Why does the Milky Way appear as a luminous band of light across the sky?

To answer this question we must be aware that we are a part of a galaxy of stars known as the milky way galaxy and that we view this stellar system from the inside. Figure 3.27 shows the location of our sun within the galaxy as viewed edge on from the outside.

Figure 3.27 Drawing of an edge view of the Milky Way showing approximate position of our Solar System.

With the sun located at position X, if we look toward either position A or B we will see all those stars which lie between us and the edge of the galaxy. In these directions we see a scattering of stars. If we look toward either C or D; we see so many more stars along these lines of sight that we get the illusion of a continuous band of light.

Since the greatest dimension of the galaxy extends in all directions along its flat plane, the apparent band of light extends completely around the sky. This band of light is commonly referred to as the milky way and is the light from hundreds of billions of stars that appear along our line of sight when we look edge on through our lens shaped stellar system.

What does the Milky Way look like from above?

As seen in Figure 3.28 the center of the galaxy is a huge hub or nucleus consisting of stars which are closer together than those in our stellar neighborhood; however, they are still from light-months to light-years apart. Extending out from the nucleus and curved through the disc of the galaxy, are the spiral arms which also contain vast amounts of gas and cosmic dust. Associated with this interstellar medium are many young stars which are very hot and extremely luminous. It is in these clouds of gas and dust of the spiral arms that it is believed new stars are forming. Our sun is thought to be in or near a spiral arm.

Composition of the Milky Way

What is the Milky Way?

The problem of what the milky way actually is was solved by Galileo when he first turned his telescope on it and found the composition to be myriads of faint stars. When the term milky way galaxy is used, it includes all the stars in our star system.

Star Clusters

Does the Milky Way galaxy contain any other groupings of stars?

Yes. It contains star clusters of two types. Open or galactic clusters number in the thousands and are the most common. Generally, these clusters are composed of a few hundred stars which are loosely held together by mutual gravitation as they move through space. These clusters are located in the main disk of the galaxy, usually in or near the spiral arms. One example would be the Pleiades.

There are also globular clusters which number over a hundred and contain hundreds of thousands of stars. They are spherically symmetrical and are scattered in a roughly spherical distribution about the nucleus of the galaxy. They form sort of a halo surrounding the main body of the galaxy. M 13 is a fine example of a globular cluster.

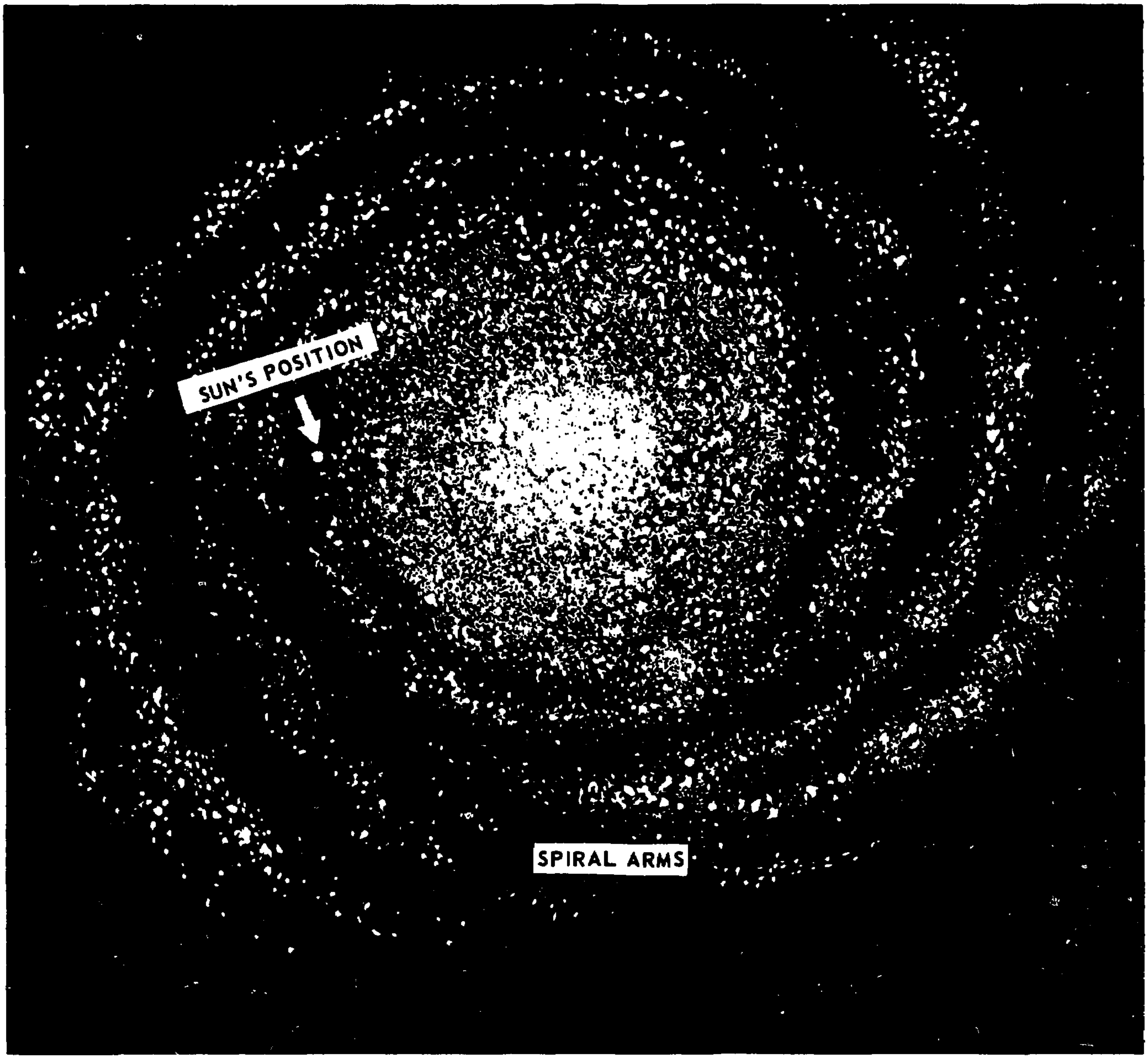

Figure 3.28 Top view of the Milky Way showing the approximate position of our Solar System.

Nebulae

Are the dark patches in the Milky Way areas where no stars exist?

No. These dark areas exist where nebulae obscure the stars behind. The dark nebulae are opaque clouds of dust whose grains are thought to be smaller than a ten thousandth of an inch in diameter. An example of a dark nebulae would be the Horsehead Nebulae in Orion.

Are all nebulae dark clouds of dust?

All nebulae are not dark clouds of dust. There are also bright nebulae which consist of clouds of gas which are close enough to hot stars to become ionized by ultraviolet radiation causing the gas to fluoresce. An excellent example of this type of bright nebulae would be the Orion nebulae. In some cases dust clouds which are near hot stars appear as bright nebulae due to reflected light from their particles.

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THE STARS

An understanding of the general composition and characteristics of stars is vital to an understanding of the determination of stellar distances, evolution of stars, and cosmology.

Major Topics Explored

General Characteristics of Stars
Apparent Magnitudes
Absolute Magnitude
Spectral Classes
Mass-luminosity Relation
Period-luminosity Relation
Other Types of Variable Stars
Stellar Motions
Radial Velocity
The Constellations: Yesterday, Today, and Tomorrow

General Characteristics of Stars

What are some of the chief differences among stars?

While it is difficult to generalize about the stars, the following characteristics will help to point out their vast diversity.

1. *Size*—Some very small stars (neutron stars) may exist which have diameters of ten miles or less. Super giants such as Epsilon Aurigae have a diameter of 2,500 times the sun's diameter.
2. *Composition*—While the composition of stars varies, they consist mainly of hydrogen and helium and a few metals.
3. *Temperatures*—Surface temperature ranges are from a few thousand degrees to fifty thousand degrees or more.
4. *Densities*—Stellar density varies from 10 billion tons per cubic inch (neutron stars) to a rarity better than the best laboratory vacuum.
5. *Mass*—The mass of stars ranges from 10% of the sun's mass to 100 times the sun's mass.
6. *Groupings*—Stars are always found within galaxies and most are grouped into various kinds of clusters inside the galaxy.

Apparent Magnitudes

This topic is vital to an understanding of determination of stellar distances, stellar evolution, and cosmology. The apparent brightness of a star refers to the way a star appears to us and is independent of the distance to the star. The absolute brightness (intrinsic brightness) of a star refers to the way a star would appear if it were at some standard distance from us, say 10 parsecs.

Stellar magnitudes can, with the aid of photoelectric photometers, be measured to the hundredth of a magnitude; the eye detects differences of magnitudes to about one-tenth, assuming the stars are of the same color. We determine the apparent brightness of a star by introducing a scale in which the given star is compared with a standard star or stars. Hipparchus, about 120 B.C., catalogued approximately 1000 stars into classes using the term magnitude to designate how bright a star appeared. The British astronomer Pogson in 1854, observing that the average 1st magnitude star under the old system was about 100 times brighter than the average 6th magnitude star, proposed that the scale be made precise by defining a 1st magnitude star as being exactly 100 times brighter than a 6th magnitude star. Pogson suggested that the ratio of light flux corresponding to a step of one magnitude be the fifth root of 100, i.e., approximately 2.512.

Magnitude Data

Object	*Magnitude (apparent)*
Sun	-26.5
Moon (full)	-12.5
Venus (brightest)	- 4
Jupiter (brightest)	- 2
Mars (brightest)	- 2
Sirius	- 1.4
Naked-eye limit	6
Binocular limit	10
100″ (visual) limit	20
200″ (photographic) limit	23.5

Let L_1, L_2, L_3, L_4 represent the brightness of stars of the 1st, 2nd, 3rd, and 4th magnitudes respectively. Then

$$\frac{L_1}{L_2} = 2.512; \frac{L_2}{L_3} = 2.512; \frac{L_3}{L_4} = 2.512$$

and $$\frac{L_1}{L_2} \cdot \frac{L_2}{L_3} \cdot \frac{L_3}{L_4} = \frac{L_1}{L_4} = (2.512)^{4-1} = (2.512)^3.$$

This suggests the general relation $\frac{L_m}{L_n} = (2.512)^{n-m}$ where L_m and L_n represent the brightness of stars of magnitudes m and n respectively.

Since $(2.512)^5 = 100$, it follows that

$$\log 2.512 = .4 \text{ and } \log \frac{L_m}{L_n} = .4(n-m).$$

Sample Problems

(a) The eclipsing variable Algol (β Persei) declines from a magnitude of 2.2 at maximum to a magnitude of 3.4 at minimum. What is the ratio of brightness at maximum to that at minimum?

Solution: $$\log \frac{L_{2.2}}{L_{3.4}} = .4(3.4 - 2.2) = .48$$

$$\frac{L_{2.2}}{L_{3.4}} = 3.02$$

(b) The bright star Castor can be resolved by a small telescope into two stars of magnitudes 1.99 and 2.85. What is the combined magnitude?

$$\log \frac{L_{1.99}}{L_{2.85}} = .4(2.85 - 1.99) = .344$$

$$\frac{L_{1.99}}{L_{2.85}} = 2.21$$

$$\frac{L_{1.99}}{L_{2.85}} + 1 = 2.21 + 1$$

$$\log \frac{L_{1.99} + L_{2.85}}{L_{2.85}} = \log \frac{L_x}{L_{2.85}} = .507 = .4(2.85 - x)$$

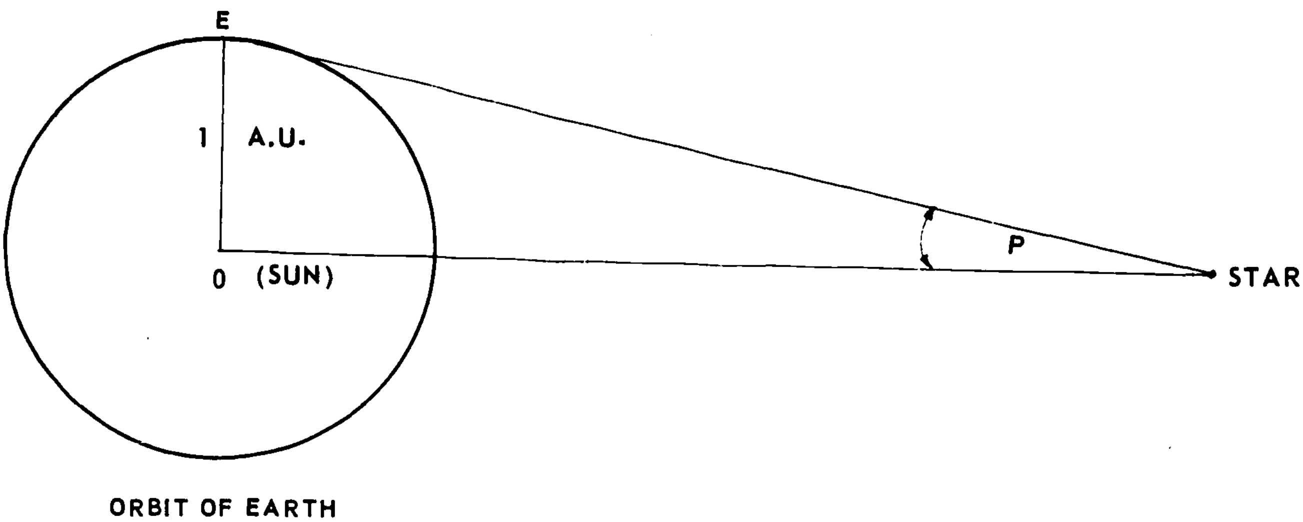
$x = 1.58$, the combined magnitude

Absolute Magnitude

Definition

Stellar parallax is the angle subtended by 1 astronomical unit at the distance of a particular star. (See figure 3.29.)

Figure 3.29
Diagram showing stellar parallax determination.



Definition

The parsec is the distance to a point whose parallax is 1″ of arc.

Definition

The absolute magnitude of a star is the apparent magnitude that star would have if it were at a standard distance of 10 parsecs.

If OE = 1 A.U. and p = 1″, then d = 1 parsec (by definition). Since d is very much greater than OE = 1 A.U., we may consider OE for practical purposes to be arc of a circle of very large radius. Using radian measure and the relation $\frac{\text{arc}}{\text{radius}}$ = central angle in radians, we have $\frac{1(\text{A.U.})}{d(\text{A.U.})} = \frac{1}{3600} \cdot \frac{\pi}{180}$ (radians). Note $1'' = \frac{1^\circ}{3600}$ and $1^\circ = \frac{\pi}{180}$ radians.

Solving for d, we get d = 206265 A.U. = 1 parsec. (1 parsec = 3.26 light years.) The nearest star has a parallax p = .76″. The known stellar population within 4 parsecs of the sun averages about one star to 520 cubic light years.

Distance Modulus (for possible teacher use)

The apparent brightness of an object varies inversely as the square of the distance while parallax varies inversely with distance. Letting m and M represent the apparent and absolute magnitudes respectively, we have

$$L_m = \frac{k_1}{d^2} \text{ and } L_M = \frac{k_1}{10^2} \rightarrow \frac{L_M}{L_M} = \frac{10^2}{d^2}$$

$$p = \frac{k_2}{d} \text{ and } p = .1 = \frac{k_2}{10} \rightarrow \frac{p^2}{.01} = \frac{10^2}{d^2}$$

$$\frac{p^2}{.01} = \frac{L_m}{L_M} = (2.512)^{M-m}$$

$$M = m + 5 + 5 \log p$$

or $M = m + 5 - 5 \log d$

since $d = \frac{1}{p}$.

The difference m–M depends only on the distance of the star and is called its distance modulus. The formula $M = m + 5 + 5 \log p$ is one of the most important relationships in astronomy. It has important uses, as we shall see.

The absolute magnitude of the sun is determined as follows:

The distance of the sun is $\frac{1}{206265}$ parsecs, hence

$$M = -26.7 + 5 - 5 \log \frac{1}{206265} \text{ and } M = 4.9$$

Sample Problems

(a) If the parallax of Altair is .205″, what is its distance in parsecs?

Solution $\frac{1}{.205} = 4.88$ parsecs.

(b) A star has parallax .04″ and its apparent magnitude is 4.99.

What is its absolute magnitude?

$\frac{1}{.04} = 25$ parsecs

$M = 4.99 + 5 - 5 \log 25$

$M = 3$

Star Counts (visual)

m	Number brighter	m	Number brighter
−2	0	5	1,700
−1	1	6	4,900
0	4	7	15,000
1	14	10	350,000
2	40	15	37,000,000
3	150	20	1,200,000,000
4	540		

Spectral Classes

(1) Harvard System: O, B, A, F, G, K, M, R, N, S and subclasses. Early classes are hot, blue stars; later classes cooler, reddish stars.

(2) Morgan-Keenan system: adds a Roman numeral to the Harvard letter indicating the type (Ia, Ib, II, III, IV, V).

Hertzsprung-Russell Diagram (H-R diagram)

The above diagram (figure 3.30) is for stars for which the trigonometric parallax has been found, i.e., for stars of known distance since the reciprocal of the parallax in seconds gives the distance in parsecs. Trigonometric parallaxes are reasonably good down to .01″; smaller values are unreliable. For stars at a distance greater than 100 parsecs, we obtain what is known as spectroscopic parallaxes by use of the H-R diagram. We assume that stars too far away for a direct measurement of parallax (and therefore not to be found on the diagram) are similar in characteristics to stars which appear on the diagram. We obtain a spectrogram of the star and classify it by spectral class and whether or not it is on the main sequence.

For example, Altair is an A5 main sequence star (between spectral classes A and F). Reading up from A5 to the main sequence, then reading across to the absolute magnitude scale, we find that the absolute photographic magnitude is approximately 2.5. Occasionally the horizontal scale in the H-R diagram is given in color index units. The eye and the photographic plate react differently to different colors. The eye is more sensitive to reds and yellows than to blue.

Thus a blue and a red star of the same instrinsic luminosity and at the same distance from us do not have the same apparent visual magnitudes. The red star has the smaller visual magnitude. We define the color index of a star to be $I = m_p - m_v$. The redder a star, the larger the value of I. The eye and the photographic plate respond equally to a white star (class AO), hence in this case $I = 0$. The approximate surface temperature (Kelvin) of a star may be found from the formula $\frac{7200}{I + .64}$. The range for color index is usually between −0.6 and 2.0 although there are some extreme values.

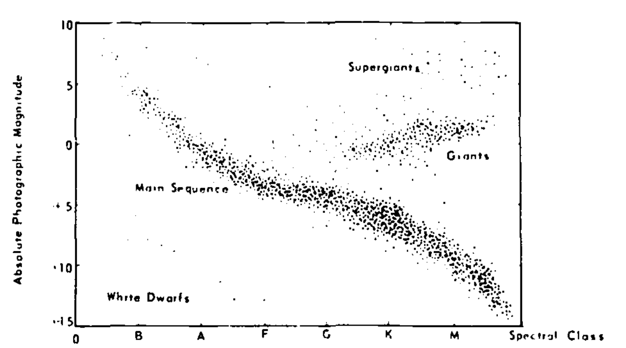


Figure 3.30 The Hertzsprung—Russell diagram.

The apparent magnitude of a star is easily obtainable and if we get its absolute magnitude from the H-R diagram, we can use the formula

$$M = m + 5 + 5 \log p$$

to solve for parallax p, and then obtain the distance

$$d = \frac{1}{p} \text{ parsecs.}$$

Figure 3.31 gives the distance to objects if we know the quantity m − M. Since a pattern is evident in the tabular values, the table can be extended if desired.

Mass-Luminosity Relations

Luminosity is approximately proportional to the mass raised to the 3.5 power. Most stars have masses somewhere between .1 and 50 times that of the sun.

The mass luminosity diagram is made from plots of binary stars; it is not possible to get the mass of a single star directly. Assuming that most single stars obey the same relation, we can obtain their masses if we know their absolute magnitudes. These we may obtain from the H-R diagram (figure 3.30).

DISTANCE MODULUS

Distance Modulus *m − M*	*Distance* *Parsecs*	*Distance (light years)* *Parsecs x 3.26*
−4	1.6	5.2
−3	2.5	8.0
−2	4.0	13
−1	6.3	21
0	10.0	33
1	16	52
2	25	80
3	40	130
4	63	210
5	100	330
6	160	520
7	250	800
8	400	1,300
9	630	2,100
10	1,000	3,300
11	1,600	5,200
12	2,500	8,000
13	4,000	13,000
14	6,300	21,000
15	10,000	33,000
16	16,000	52,000
17	25,000	80,000
18	40,000	130,000
19	63,000	210,000
20	100,000	330,000
21	160,000	520,000
22	250,000	800,000
23	400,000	1,300,000
24	630,000	2,100,000
25	1,000,000	3,300,000

Figure 3.31

Period-Luminosity Relation

(1) Cepheid variables and nature of cepheid variation.
(2) Magellanic Clouds and Cepheid variables.
(3) Determination of absolute magnitudes from periods. Graph.
(4) Determination of distance by use of the formula $M = m + 5 + 5 \log p$.

In 1952 the revision of about 1.5 magnitudes in the absolute magnitudes of certain class of cepheids brought about a revision of the extragalactic distance scale. About 1952 the extragalactic distance scale was doubled, i.e., these extragalactic objects are twice as far away as previously thought.

Other types of variable stars

(1) Eclipsing binary systems
(2) Irregular variables (Intrinsic)
  (a) Completely irregular variables
  (b) Semiregular variabies
  (c) Explosive variables (Novae)
(3) Regular or periodic variables
  (a) Long-period variables (60+ days)
  (b) Short-period variables (a few hours up to 60 days).

Stellar motions

If one has the parallax of a star, its proper motion and its radial velocity (calculated from the Doppler formula below), the space velocity of the star can be calculated.

Radial Velocity

Velocity of approach or recession along the line of sight may be calculated from the formula

$$\frac{\Delta\lambda}{\lambda} = \frac{v}{c} \text{ (Doppler formula)}$$

where λ = laboratory wavelength of a spectrum line
$\Delta\lambda$ = shift of spectral line
c = velocity of light
v = velocity of approach or recession along the line of sight.

The above formula holds when v is very much less than c; otherwise a relativistic formula must be used. Differential rotation of the sun is indicated by Doppler shifts. A proof of revolution of the earth about the sun is based on this relation. Discuss the velocity-distance relation and Hubble's constant. The reciprocal of Hubble's constant should give the age of the universe.

The Constellations: Yesterday, Today, and Tomorrow

Because the stars are in motion, their present arrangement is temporary. They seem to change position slowly only because they are at great distances. The constellations we know have existed only some thousands of years. See Figure 3.32 of Big Dipper showing the change in position of the stars in this constellation.

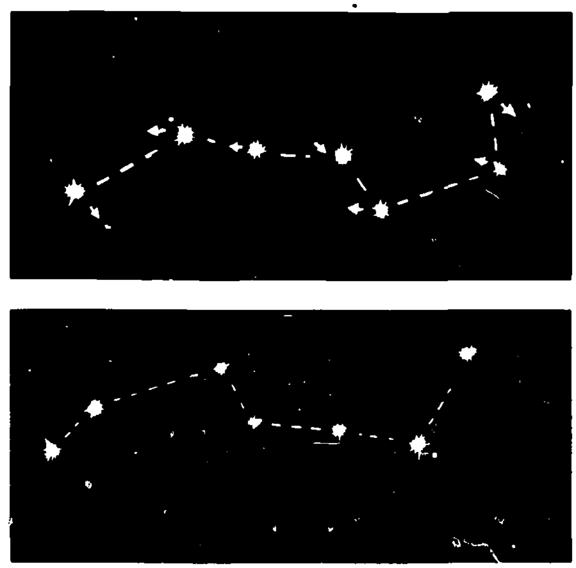


Figure 3.32 Diagrams showing the change in Stellar positions with the passage of time.

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THE UNIVERSE

INTRODUCTION

Man's conception of the universe began with the anthropocentric view in which he was the central figure. Surrounding him was a flat earth over which was a sky of stars that rose and set daily and moved westward with the change of seasons.

A stationary earth was the dominant feature of the geocentric view of the earth which the early Greek scholars held. The sun, planets, and moon revolved around the earth within the rotating sphere of "fixed stars".

From the time of Copernicus the heliocentric viewpoint provided a more realistic picture. The stars were brought to rest and the planetary system was established on a more nearly correct basis. The idea that the stars are other suns emerged and the thought developed that perhaps many of them had planetary systems of their own.

The invention of the telescope resulted in the first attempts to determine the structure of the universe. This ultimately led to the picture of our galaxy as a spiral structure, with our sun not at the center, through which we must view the celestial scene. The mysterious spirals and other "extragalactic nebulae" have been established as galaxies outside our own.

Major Topics Explored

- The Extent of the Universe
- Appearance of Galaxies
- Grouping of Galaxies
- The Local Group
- Cosmology and Cosmogony Differences
- Origin of the Universe
- Pulsars
- The Neutron Star

What is the extent of the universe?

As far as man has been able to see with his largest telescopes he finds additional galaxies. On properly exposed photographic plates the images of distant galaxies are more numerous than the images of the foreground stars which are part of our galaxy when telescopes are pointed away from the Milky Way. It has been estimated that there may be a billion galaxies within the range of the 200 inch Palomar telescope. At the farthest depths of space that we can observe we see only the giants among galaxies. The best guess at the distances involved would be between 5 and 10 billion light years away. Some of the unidentified sources of radio signals may be galaxies at even greater distances which are beyond the range of the largest optical telescopes.

Appearance of galaxies—How do they differ?

They are either elliptical, spiral, barred spiral, or irregular.

The ellipticals range in appearance from nearly circular to greatly flattened and have no spiral arms. The spirals have a central nucleus or hub around which stars seem to spiral out in long arms. The barred spirals are of the same general appearance but they have only two spiral arms. There are some galaxies which have no central hub and no definite shape and are called irregular.

Are there any groupings of galaxies?

Galaxies are grouped into two categories: regular clusters and irregular clusters. The regular clusters resemble globular star clusters and are almost entirely of elliptical type galaxies. The irregular clusters have little or no spherical symmetry or central concentration. They contain all kinds of galaxies and are more numerous than regular clusters. The number of galaxies involved ranges from over a thousand to small groups of a few dozen or less.

Does our galaxy belong to a cluster?

The Milky Way Galaxy is part of an irregular cluster which consists of 16 other galaxies. The two largest members are our own and the Andromeda Galaxy (M31). Altogether there are 3 spirals, 4 irregulars, and 10 ellipticals in what is called the Local Group all of which have a mutual attraction and a common space motion.

What is the difference between cosmology and cosmogony?

Cosmology deals with the organization and evolution of the universe while cosmogony is concerned with the origin of the universe. Modern usage tends to combine the two terms into one; that of cosmology. The researchers in the field of modern cosmology try to piece together the observable properties of the universe into a hypothesis which will also account for its structure and evolution.

What are the main theories of the origin of the universe?

The theory receiving the most attention today is the big-bang theory, the basis of which was put forth by Abbe Lemaitre in the 1920's. Lemaitre's theory of the "primeval atom" gave the universe a start from an original single chunk of matter. George Gamow used this idea to postulate the origin of all chemical elements as the result of a gigantic explosion. As the electrons, protons, and neutrons combined to form hydrogen, helium, and all the heavier elements, these atoms were being propelled through space by the force of the initial explosion. As the material expanded outward and the hot gases cooled, condensations formed which became the galaxies. Within these galaxy condensations smaller secondary condensations formed the stars. Should this theory prove to be valid, and if all matter was in the form of separate subatomic particles prior to the initial explosion, then we would have no way to discover by observation what took place prior to the explosion. Should this be the case the universe was truly "created" at the time of this explosion.

A second theory, the oscillating universe theory, accepts the same beginning as the big-bang theory; however, it claims that there is a periodic repetition of this event. According to this theory, the gravitational attraction between all of the galaxies will eventually cause them to stop moving outward. At this point they will reverse their motion and fall back together again toward the point from which they originally started. As they all collide at this point, there will be another great explosion and the cycle will begin again in endless repetition.

A third theory needs neither explosions nor oscillations and is the simplest of all cosmological hypotheses. The steady-state theory, as proposed by Hoyle, Bondi, Gold, and others, rests upon a single assumption. This assumption is that the universe is not only the same everywhere, except for minor local variations, *but the same for all time. Since nothing changes* with time, it is called the steady-state hypothesis. The creation of the universe at a particular time is ruled out and matter is being created continuously in space at a rate sufficient to replace what is leaving due to the recession of galaxies. The theory is sometimes called the "continuous theory". This picture of the universe is one in which it is infinitely large and infinitely old, with no beginning and no end.

Is there any real evidence which favors one theory over the other?

There is nothing in either the big-bang theory or the oscillating universe theory which would obviously rule them out at this present state of our knowledge; however, the discovery of quasars (quasi-stellar radio sources) throws serious doubt upon the steady-state theory. If the universe is in a steady-state, all portions of it should appear the same when viewed as a whole. This would hold true regardless of the time of viewing, a billion years ago or a billion years from now. We can, in effect, look back billions of years ago by observing galaxies which are billions of light years away. If there should be any differences between these distant galaxies and nearby ones serious doubt will be cast upon the steady-state theory. Should these quasars be as far from us as their red shifts indicate, more than a billion light-years away, they are the kind of evidence which shows a difference between what was happening a long time ago and what is happening now.

The implication is that the steady-state theory is wrong. One unresolved problem is that if the quasars are as far away as their red shifts indicate, their brightness would have to be caused by some physical process unknown to science. At the distances indicated by their red shifts, these sources would have to be many times brighter than the brightest galaxies. It is difficult to imagine how an object which appears as a pinpoint of light could outshine a galaxy of over 100 billion stars. The quasars occupy volumes on the order of 3 light-years in diameter as opposed to galaxies who have diameters of tens of thousands of light years. The process of producing such vast amounts of energy from such a small volume is unknown.

What have astronomers learned about the mysterious pulsars?

Pulsars are unusual star-like objects that radiate energy at radio frequencies in pulses at very precise regular intervals, some slightly over a second and some slightly less than a second. The pulse itself lasts from 1/50 to 1/20 second, followed by roughly one second of silence. The short duration of the pulse is of great importance in determining the size of the source. A general rule in physics is that no source of radiation can turn on or off in less time than it takes light to cross the source. The reasoning is that no physical process, in the case of the pulsar the order to change emission, can move faster than the speed of light. A pulse of 1/20 of a second would mean that the source of the pulse would have to be smaller than 10,000 miles in diameter.

Normal stars are far too large to meet the size criteria for pulsars. Since planets could not possess an energy source equal to that of our sun, they could be ruled out. The power of the transmission from pulsars equals about 10 billion times the total power production of all the electric generators on the earth. This makes it difficult to believe that it could come from another planet as a signal from intelligent life forms.

This would appear to leave two possible sources: white dwarf stars and neutron stars. Calculations indicated that it would be possible to obtain pulses from white dwarf stars as fast as once a second, but no faster. From what scientists predict as to the characteristics of a neutron star, it could pulsate from 10 to 10,000 times a second. In the Spring of 1968 only four pulsars had been discovered and they could have been either white dwarf stars or neutron stars from the information gathered up to that time.

At about the time the fifth pulsar was found in May, 1968, a discovery was made that showed what was thought to be single pulses of 1/20 second duration were a random scattering of many shorter bursts. Some of these shorter bursts had a duration of 1/10,000 second. Since an object cannot change its emission in less time than light can cross it, the radiating region would have to be no more than 20 miles across. This is much smaller than a white dwarf star but it could still be possible that the source might be a small radio flare on the surface of a spinning white dwarf. In checking this idea, it was calculated that to achieve the necessary brightness the flare area would have to have a temperature of 10 million billion billion degrees. An unlikely possibility.

The brightness of pulsars must be due to a process that is not a function of temperature. Only one known astronomical object remains to be examined, the neutron star. First, it must be known whether the pulses are due to actual pulsation or rotation. Fortunately, this is rather easy to determine. If a star is pulsating, it must give up energy and become cooler and more dense. Its pulse will then become faster. If the star is rotating, it will spin more slowly as it loses energy. When a pulsar was examined closely to determine whether it was speeding up or slowing down, it was found that the interval grew longer at the rate of 36.48 billionths of a second per day. Other pulsars were found to be slowing down, some at a rate of less than a billionth of a second per day. Since a lengthening period was the case with pulsars, their pulses are associated with rotation. Only one known astronomical object could rotate so rapidly—the neutron star. Thus, the identity of the pulsar was revealed.

How does the neutron star produce its energy pulses?

The mystery is not solved but theory would indicate that neutron stars have a magnetic field as much as a million million times as strong as the earth's. This magnetic field rotates with the star and acts as a particle accelerator. The particles move faster as they are swept outward along the magnetic lines of force until a point is reached where the magnetic field is moving at nearly the speed of light. Since no particle can attain the speed of light, they begin to dissipate some of their energy as radio waves, in the direction they are traveling. The production of radio waves creates an opposing force on the particle and prevents it from reaching the speed of light. This could account for the energy source without the requirement of unreasonable amounts of thermal energy.

What is a neutron star?

During the explosion of a supernova, temperatures at the center of the star rise so high that energy escapes in the form of neutrons. The core of the star collapses to a ball of nuclear matter. This core is called a neutron star because most of the electrons have been crushed into the positively charged nuclei to become neutrons. The star may have a diameter of only ten miles and a density of 10 billion tons per cubic inch. It could rotate as fast as 10,000 times per second before it would be torn apart. Even though it may have a surface temperature of millions of degrees, it could not be seen through the most powerful telescopes on earth, even if it were relatively close, because the small surface area would not produce enough light.

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TEACHER NOTES

The Atmosphere

INTRODUCTION

The study of the atmosphere presents a unique opportunity for students to learn some interesting scientific techniques and to apply physical principles encountered in other science courses. While many students have a natural curiosity about the weather, carefully made meteorological observations can stimulate them to even greater awareness of their environment. Every class should initiate a systematic program of weather observations early in the school year; the resultant data will then be available for discussion and interpretation when meteorology is taken up.

A few simple instruments will suffice. Instrument catalogs for all levels of sophistication are available from many companies. However, many instruments can be constructed very simply and inexpensively with readily available materials; some of these instruments are described. Under no circumstances should teachers or students attempt to make a mercurial barometer, because mercury vapor is extremely toxic and, moreover, the construction of a satisfactory barometer is only possible in specialized factories.

The following instruments are particuarly useful:

1. A maximum-minimum thermometer set to be read once a day, preferably in the early morning. (About $12.00.)
2. Sling psychrometers for dry- and wet-bulb temperatures can be purchased for $13.50 or constructed for next to nothing. A meteorologic slide rule, from which relative humidity and dew point temperatures can be determined from wet and dry bulb readings, costs about $2.00.
3. Rain gauges; one will do, but several inexpensive ones for loan to interested students to take to their homes provides an interesting basis for discussion of the natural variation of rainfall. Students can easily make them.
4. Snow measurements may be obtained with a yardstick.
5. Aneroid barometer should be read at regular times daily and readings recorded.
6. Wind observations can be made visually or with simple devices.
7. If funds are available, a recording barograph and a hygrothermograph provide wonderful opportunities to study the variation of pressure, temperature and humidity with time.
8. Observation forms can be made up and duplicated in schools.

It is probably not useful to involve every class in the study of weather maps and especially of weather-map codes. However, the Daily Weather Map can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. for three cents per day. It is well worth subscribing to this service for the minimum three month period ($2.40), for there is much that can be learned from comparing it to the students' observations and from its day to day changes.

There are numerous demonstration experiments described for illustrating physical principles applied to the atmosphere. The magazine *Weatherwise* published by the American Meteorological Society, 45 Beacon Street, Boston, Massachusetts 02108, is a useful addition to any school library. Suggested reference books and films are given at the end of each section.

Fields of Student Investigation

1. Weather elements and their observation
   - A. Pressure
   - B. Temperature
   - C. Humidity
   - D. Precipitation
   - E. Wind
   - F. Clouds
   - G. Visibility
   - H. Upper atmosphere observations
2. Basic principles and concepts
   - A. The earth's energy supply
   - B. Water in the atmosphere
   - C. Hydrologic cycle
   - D. Heat transfer processes
   - E. Air masses and fronts: Air motion
   - F. Atmospheric stability and instability, and pollution effects
   - G. Severe weather

Students should already have considerable background about the atmosphere. A brief review of its physical and chemical characteristics should suffice.

We live at the bottom of a sea of air which surrounds the earth, and our lives are profoundly affected by changes in the air. The atmosphere protects us from most of the meteors and meteorites (except the largest ones), cosmic rays and lethal portions of sun's radiation (X-rays, short-wave ultraviolet).

WEATHER ELEMENTS AND THEIR OBSERVATION

What is air?

The air is a mixture of gases—invisible, colorless, tasteless and odorless. Oxygen and nitrogen are its principal constituents. Ozone, in minute amounts, is an important constituent at 15-30 miles height, as it absorbs deadly ultraviolet radiation.

Although amounting to less than 4% by volume, water vapor is responsible for most of the phenomena we commonly call weather. It varies greatly from place to place and from time to time, but 95% of it occurs below 7 miles height, half of it below 6,000 feet.

Air pollution consists of dust, smoke, fumes, and other domestic and industrial wastes. However, certain types of dust provide nuclei around which water vapor condenses, forming clouds.

The atmosphere consists of several layers—troposphere, stratosphere, and ionosphere (subdivided into mesophere, thermosphere and exosphere)—each of which has distinct characteristics. In studying the weather, we are most concerned with the troposphere.

Why do meteorologists measure air pressure?

Pressure

The *pressure* of the air is a measure of its weight per unit area, measured by balancing its weight against the weight of a column of mercury. Pressure is expressed in units of millibar (abbr. mb), the average sea-level pressure being 1013 mb (corresponding to the weight of a mercury column of 29.92 inches length under standard conditions). Horizontal pressure differences cause winds.

Film

Solar Radiation I—American Meteorological Society, distributed by United Films, Inc., 221 Park Avenue South, New York, N. Y. 10003.

When people speak of "the temperature", they are referring to the temperature of what?

Temperature

Most *temperature* measurements are based on the fact that substances expand when the temperature rises.

Density difference between hot and cold air

Circulations of air are related to differences in density occasioned by temperature differences. Most atmospheric circulations are complicated by the rotation of the earth; however, smaller-scale flows (such as sea breezes) illustrate the effects of density differences.

Density of air is a function of temperature and pressure. To show the effect of temperature, we keep the pressure of a volume of air constant and the same as that of the ambient air.

a) By means of scotch tape (see Figure 4.1) we hang two paper bags of the same size upside down on a balance (see Balance Construction). To keep the bags open, we fold the rims of the open ends outward. After we established equilibrium by means of a rider, we hold a small candle for half a minute under the middle of one of the bags, 3 to 4" away from it, **being very careful not to set the bag on fire.** We note almost immediately that this bag apparently becomes lighter than the other one. By watching the flame, we see a strong updraft rising from it. 1) Could the observed effect be due to the bag being lifted by the updraft? (Yes) Inflate a toy balloon, hold the nozzle under the bag, and let a jet of air into it. 2) What is the difference between the effect of the candle and that of the air jet? (With hot air the bag stays up longer.)

   The combustion products of the candle are chiefly carbon dioxide and water vapor. 3) Which of these gases is lighter (less dense) than air? (Water vapor) 4) Could it be that the lighter gas makes the bag buoyant? (Yes) 5) How can we modify the experiment to eliminate this possibility? (Hint: Hold a sheet of aluminum foil under bag to prevent gases from getting into it.) 6) Does the result of the modified experiment warrant the conclusion that hot air is less dense than cold air? (Yes)

b) Turn on a 150 watt bulb and hold it about 2" from the bag for two minutes. 7) Does the bag with the warm air become lighter? (Yes) Does it make much difference how the air is warmed? (No)

Material: One balance, two medium sized paper bags, one toy balloon, one candle, one sheet of aluminum foil, about 12" x 12", 150 watt bulb, scotch tape.

Balance Construction

Household scales or analytical balances are not usable for the foregoing experiment. Good balances can be made as follows:

a) Drill or burn a small hole through the middle of any light stick of wood of 2 to 3 feet in length.

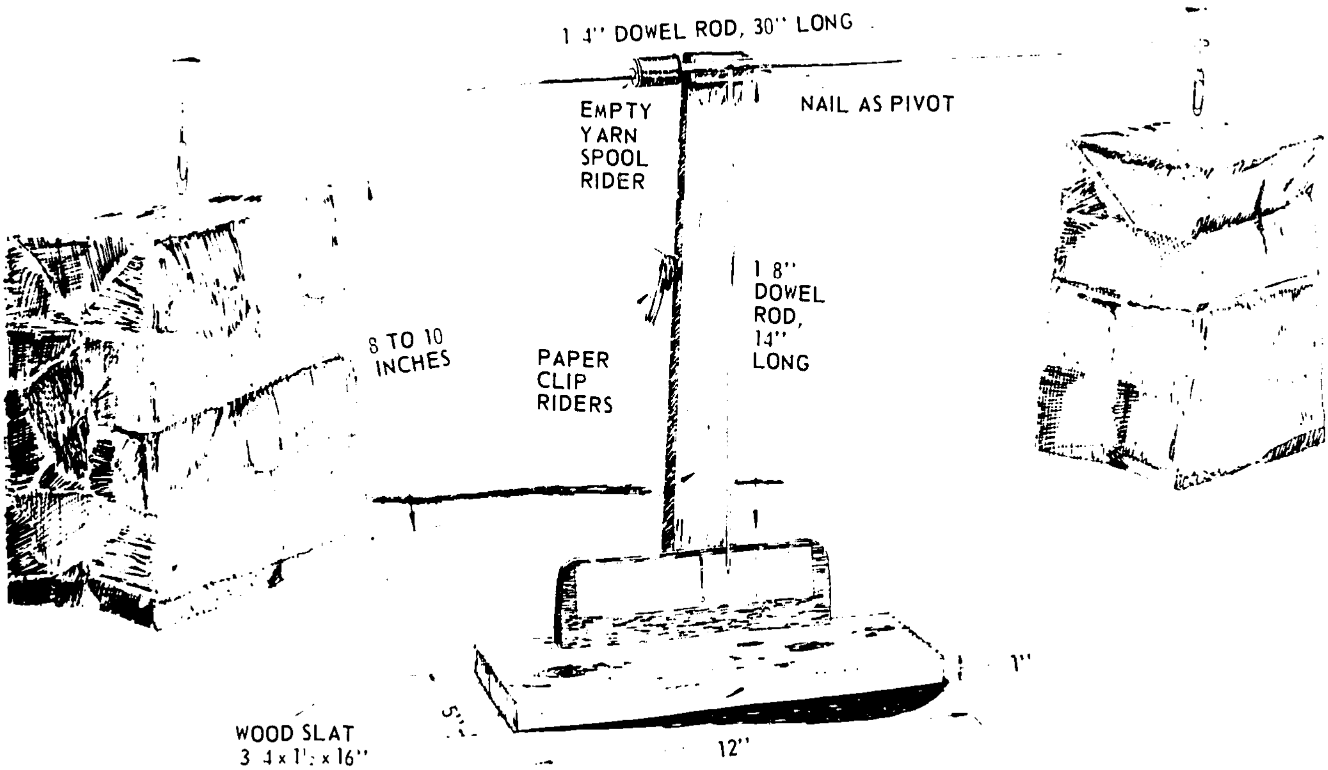


Figure 4.1

Put a straightened paper clip, bent into an "L"-hook, through the hole as a pivot (Fig. 1); the wire which should sit loosely in the hole is taped over the edge of a table.

b) From Plate 1 it is evident how the balance can be refined to include a wooden stand and a balance indicator; however, these features are not necessary.

For fine adjustment of the balance, a rider is made from a 3" piece of drinking straw (see Figure 4.2). Riders can also be made from wire or an empty spool of thread (see Figure 4.1).

Material. One ¼" dowel rod, 30" long, one ⅛" dowel rod, 14" long, wood board 1" x 5" x 12", wood slat ¾" x 1½" x 16", paper clips, glue, and nails.

c) A very good balance can be made entirely of cardboard and paper as shown in Figure 4.2. The construction of the base and the support post is evident. The beam is made of two sheets of 8½" x 11" writing paper, each rolled diagonally over a pencil; the ends are taped and the pencil is removed. The paper tubes are then rolled tightly into another sheet of paper and the end taped. For reinforcement the ends of the beam are scotchtaped; paper-clip hooks are then put through the tape. An indicator can be made of two drinking straws, but this is not necessary. The beam is attached to the support post by a wire paper clip.

Material: One heavy cardboard 8½" x 11", one mailing tube 15" long, 2" diameter, three sheets of good paper 8½" x 11", two drinking straws, paper clips, glue, scotch tape.

Air temperature measurements can provide many projects for interested students. As long as the thermometer is in thermal equilibrium with the air, even an inexpensive one will give sufficiently accurate readings. This can usually be accomplished by avoiding sunlight and body heat. Early morning readings at different locations can show the effect of air drainage in producing lower temperatures in low places. Readings over, or near, water bodies contrasted with those a short distance away can illustrate the thermal effect of water.

For many kinds of problems, temperatures exceeding, or falling below, a certain level are decisive in the solution. For example, buildings need to be heated when the daily average temperature is below 65°F; peas grow when the temperature exceeds 42°F, corn at 50°F or more. Air conditioning is used when the average temperature exceeds 72°F; snow melt for

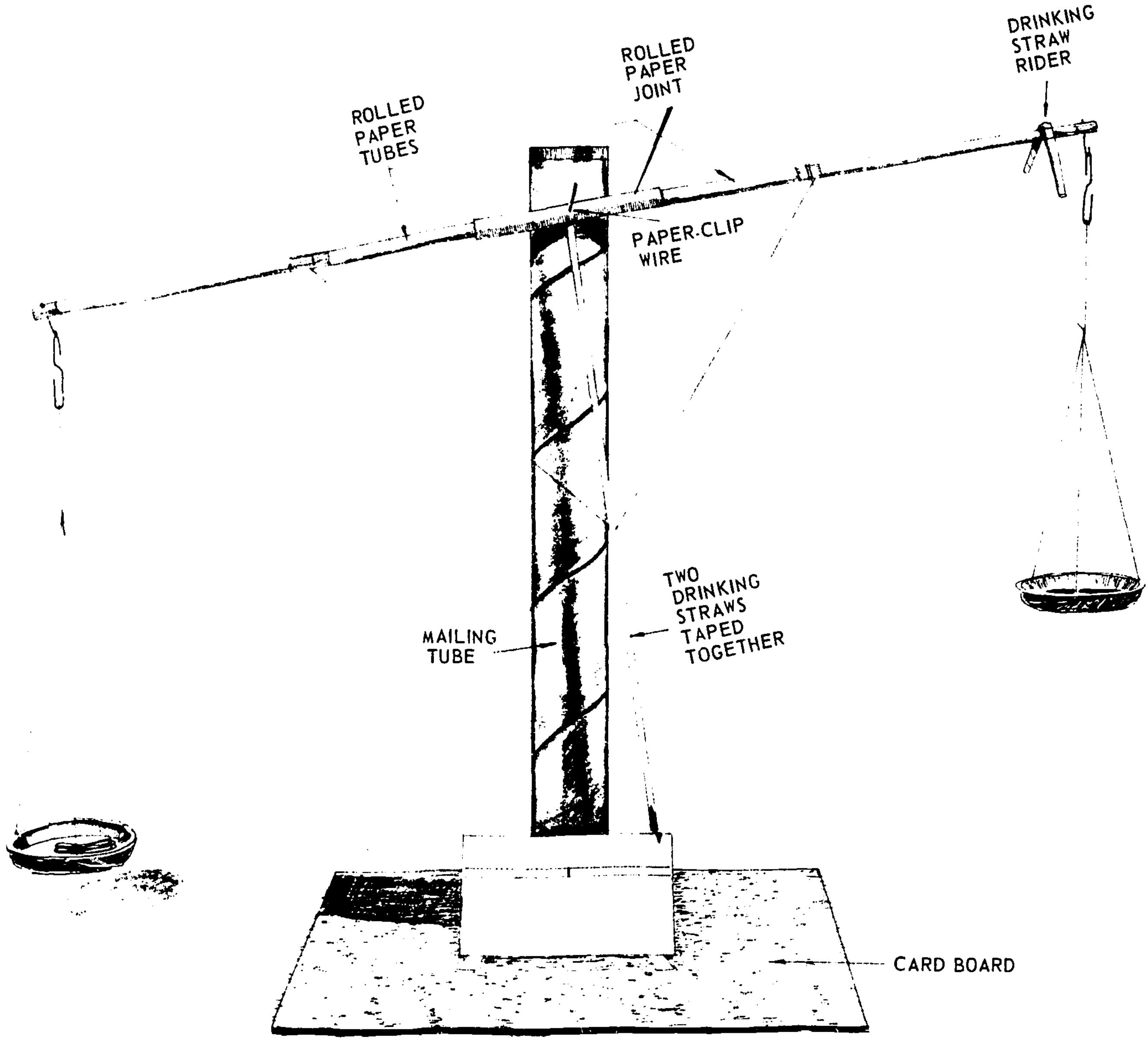

ROLLED PAPER TUBES
ROLLED PAPER JOINT
DRINKING STRAW RIDER
PAPER-CLIP WIRE
TWO DRINKING STRAWS TAPED TOGETHER
MAILING TUBE
CARD BOARD

Figure 4.2

flood calculations is based on temperature above 32°F. Usually, the number of degrees above or below a certain base temperature are accumulated each day, so that a degree-day sum results. The following is a degree-day calculation for home heating using a 65° base:

Day of the Week	*Maximum Temp. °F*	*Minimum Temp. °F*	*Mean Temp. °F*	*Degree Days*
Monday	70	46	58	7
Tuesday	62	49	51	14
Wednesday	60	39	50	15
Thursday	75	45	60	5
Friday	78	61	70	0
Saturday	72	45	58	7
Sunday	64	40	52	13
			Weekly Sum	*61*

The total heating degree-days for this week would be 61. The class could keep running totals of degree-days and compare them with those reported by the U. S. Weather Bureau. Departures from normal could be compared to the consumption of fuel at the school or elsewhere.

The air temperature in sunshine is practically the same as that in the shade because very little radiation is directly absorbed by the carbon dioxide gases. The thermometers with which we measure the air temperature must be carefully protected from direct radiation, because thermometers absorb a considerable amount of radiation. How temperature readings taken under the influence of direct radiation vary with the thermometers themselves can be demonstrated as follows.

We take two or more thermometers of different types, such as a dial thermometer (bimetal), an ordinary thermometer mounted on metal or plastic, etc., and a window thermometer in a glass or plastic tube. We first expose the thermometers in the shade and record the temperatures of each. Because of inaccuracies in calibration, there may be slight differences in the readings. Then we expose all thermometers to sunshine for a few minutes and read again. A 150 to 200 watt light bulb can be used as a radiation source as in Figure 4.3. We take readings before turning on the light and again 5 minutes after turning it on.

1. Are the temperature changes of the shaded and illuminated thermometers the same? (No)
2. Would ventilation reduce these differences? (Yes) Try it by repeating the experiment while equally fanning the thermometers with a piece of cardboard or an electric fan.

Material: Two or more thermometers of different types, one 150 to 200 watt light bulb, piece of cardboard or electric fan.

Humidity

Humidity refers to the water vapor content of the air; its measurements are based on the cooling associated with evaporation, on the expansion of materials, such as human hair, as they absorb water vapor, and on condensation taking place when air becomes saturated with water vapor.

Relative Humidity (in %) is the ratio of the amount of water vapor present to the maximum amount that would be present at saturation, multiplied by 100. The *Wet-Bulb Temperature* is the lowest temperature to which a thermometer can be cooled by evaporating water from a wet wick around its bulb. The *Dew-Point* is the temperature to which the air would have to be lowered in order for condensation (dew) to occur; the higher the dew-point, the more water vapor is in the air.

Dry- and Wet-Bulb Temperature Measurements

An instrument that consists of a dry-bulb and a wet-bulb thermometer mounted together is called a psychrometer. The rate of evaporation of water from the wet-bulb and, therefore, its cooling, depends on the relative humidity. The construction of a psychrometer should be clear from Figure 4.4. It is important

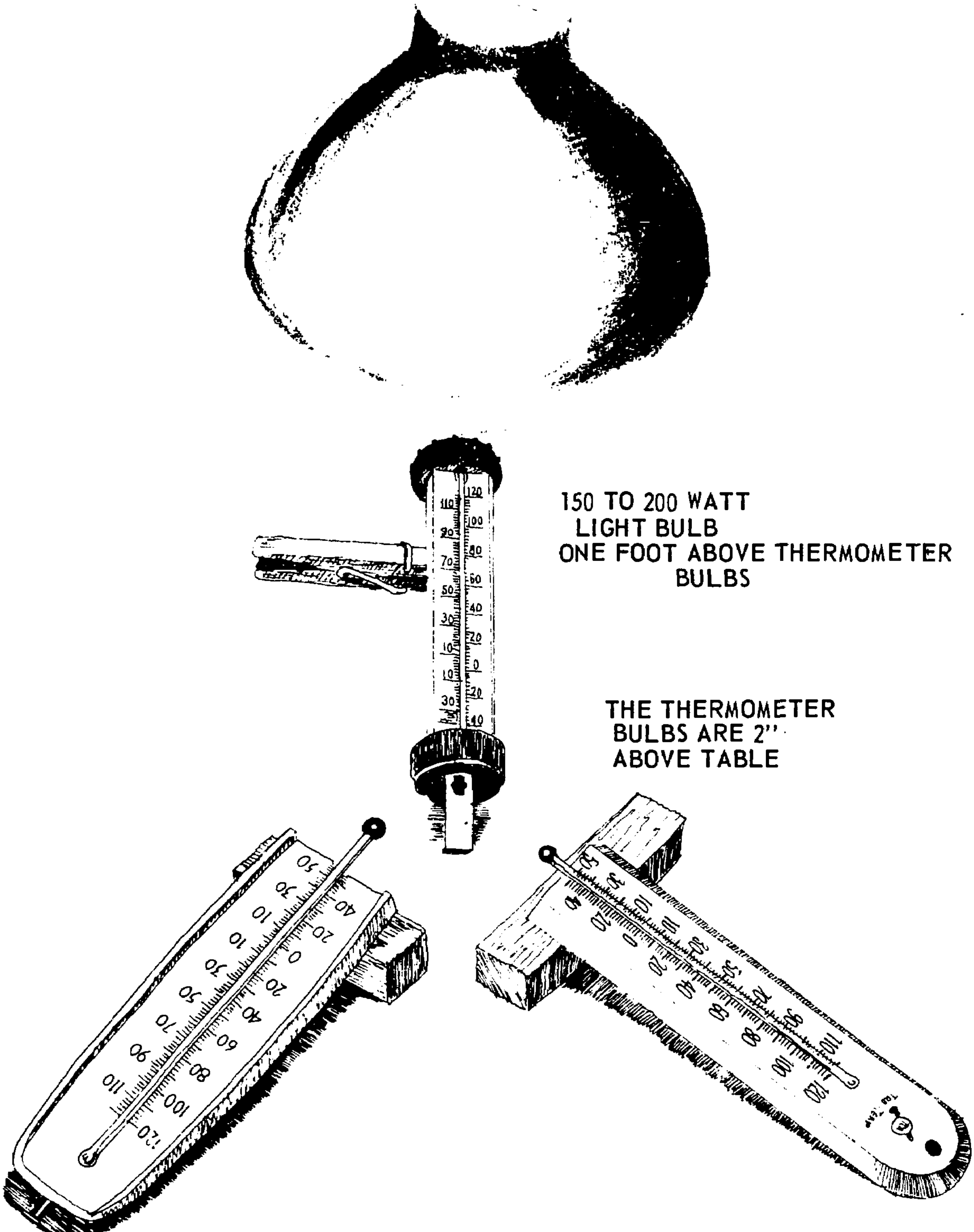

150 TO 200 WATT
LIGHT BULB
ONE FOOT ABOVE THERMOMETER
BULBS
THE THERMOMETER
BULBS ARE 2"
ABOVE TABLE

Figure 4.3

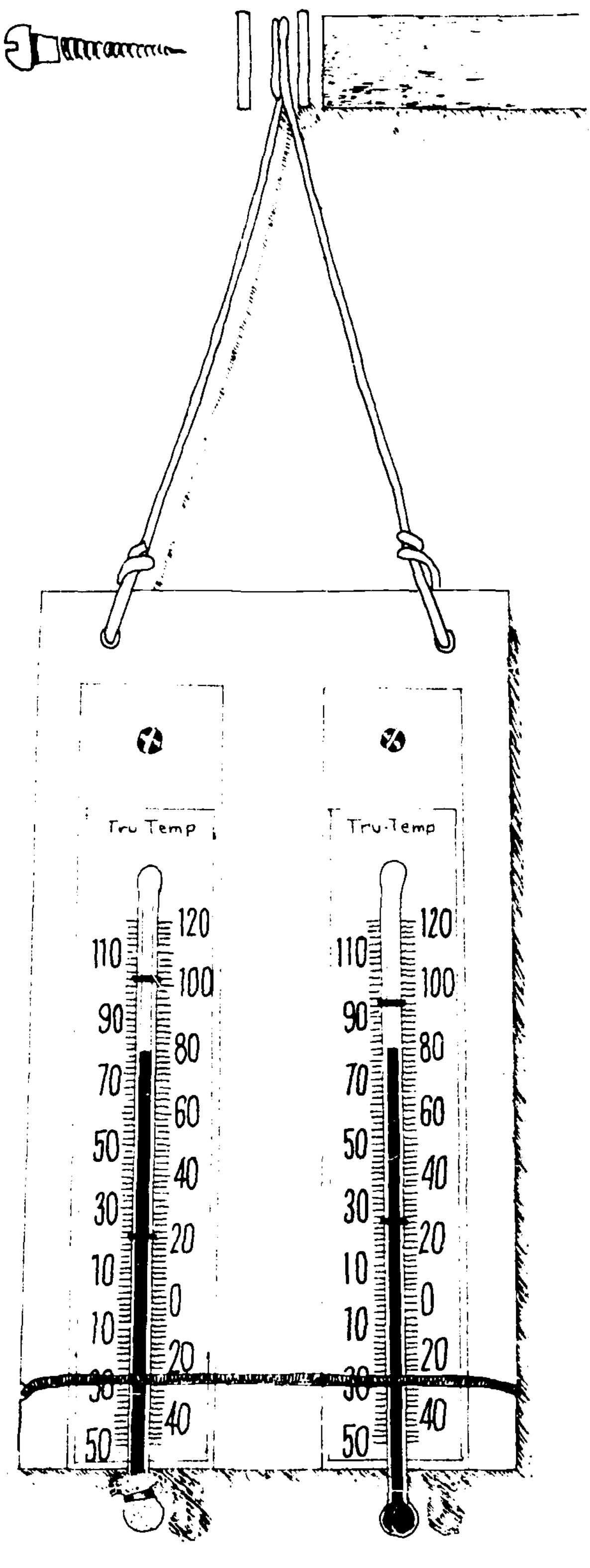


Figure 4.4

to cut away the lower end of the backings of two identical thermometers (a fine saw blade can be used), so that the bulbs and about ½" of the capillaries above the bulbs are free. Be sure not to disturb the mountings of the capillaries on the scales.

For outdoor measurements *select* an open place in the shade; wet the wick of the wet-bulb with clean water. Hold the sling psychrometer at arm's length and sling the thermometers around the handle three times per second; after a minute or so quickly read (without touching the thermometers) first the wet-bulb, then the dry-bulb thermometer. Repeat the procedure until two successive readings show no more temperature changes.

The relative humidity and the dew point can be determined from dry- and wet-bulb temperatures with the aid of *Psychrometric Tables;* these are found in many elementary texts on meteorology or can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 25¢. The relative humidity can also be determined by the formula:

$$R.H. = 100 - 300\ (T - W)/T$$

where T is the dry-bulb reading, W the wet-bulb reading; thus, if $T = 70°F$ and $W = 63°F$, $R.H. = 100 - 300\,(70-63)/70 = 100 - 300 \times 7/70 = 100 - 30 = 70\%$. The wick should always be thoroughly wet; in dry weather use very cold water so that the wick does not dry out during ventilation.

Materials: Two identical thermometers; wooden board approximately 8" x 4" x ¾", wire 15" long, dowel rod 6" long, ¾" diameter, three screws, two washers, thin white cotton material one inch square for wick and thread for fastening it to bulb, two rubber bands.

Dew-Point Measurement

In nature, the formation of dew, or frost if the temperature is low enough, occurs when the air is cooled by radiational heat loss at night. We can obtain a rough measure of the dew-point temperature by taping a thermometer bulb to the *outside* of a small tin can of shiny metal (see Figure 4.5); then we fill the can with a slush made of crushed ice, water, and a teaspoon of salt. We read the temperature the moment dew begins to form. Then we empty the can, being careful not to wipe the dew off, and read the temperature again as soon as the dew disappears. The average between the two temperatures is the approximate dew-point temperature.

Material: One thermometer, one small shiny tin can, tape, crushed ice, water, salt.

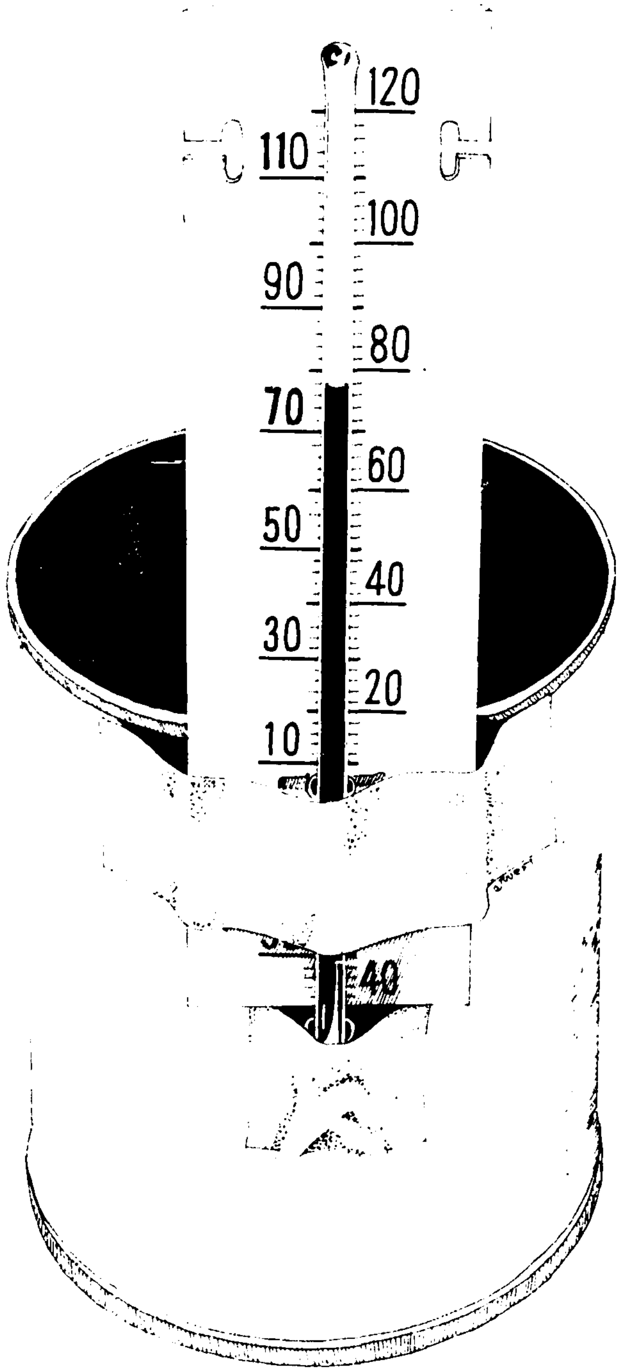


Figure 4.5

Relationship between Temperature, Dew-Point, and Relative Humidity

Temperature, dew-point, and relative humidity are not independent elements. The relationship between these elements can be demonstrated by the model shown in Figure 4.6. To make this model, cut four pieces of heavy white cardboard, each 3½″ x 11″; three of them are cut out and colored as shown by panels 2, 3, and 4 in Figure 4.7, which also gives the proper dimensions. After assembling the four panels as in Figure 4.8, we mark off a temperature scale on the left side of panel 4 as shown in Figure 4.6. The divisions are ¾″ apart, starting ½″ from the top edge. (Note that the scale is not linear as on a thermometer.) On the right side we mark divisions at the same level as on the left, but label them with the even numerals from 2 to 14; this is the scale of water vapor amounts in arbitrary units.

The black margin of panel 3, together with the black line on panel 4, appears as a beaker which represents the "capacity" of the air to hold water in vapor form. The water vapor is represented by the blue panel 2. The upper edge of the beaker is set at a given air temperature (on the left) and then indicates on the right side the maximum number of water vapor units that the air could hold at that temperature.

As an example, let us pull the water-vapor panel 2 by its tongue downward until no more blue shows in the "beaker". Then we set the top edge of the beaker by manipulating its tongue, to 70 °F and hold it there. The beaker is empty, i.e., the air is dry. We now evaporate some water into this air by sliding the water panel up until the water edge is even with the "2" on the right scale; this be the existing water vapor amount. 1) What is the relative humidity? 2) If we evaporate more water into the air so that the existing amount of water vapor is 4 units, what is the relative humidity? 3) Keeping the water vapor constant at 4 units, we raise the temperature to 75°F (by pushing the beaker panel up); what is now the relative humidity? 4) If we lower the temperature to 60° without changing the water vapor content, what is the relative humidity? 5) How does the relative humidity change, when the temperature changes without any change in water vapor? 6) If the air temperature is 75 °F and the relative humidity is 80%, to what temperature would we have to cool the air to reach the dew point?

It is evident that the water level in the beaker indicates the dew point on the temperature scale. If we lower the temperature below the dew point, the water above the beaker condenses out in form of fog or cloud, until the beaker is just full (we lower the water level to the top of the beaker). 7) What is the relative humidity? If we lower the temperature to dew point?

Answers to above questions: 1) (2/8) x 100% = 25%; 2) (4/8) x 100% = 50%; 3) (4/10) x 100% = 40%; 4) (4/6) x 100% = 67%; 5) when temperature rises, the R. H. falls; when temperature falls, R. H. rises; 6) 10 x 80% = 8 units = 70 F on left side which is dew point. 7) Then the beaker is full, the R. H. = 100%; Note, that all these values are very rough approximations, because the scales are greatly simplified.

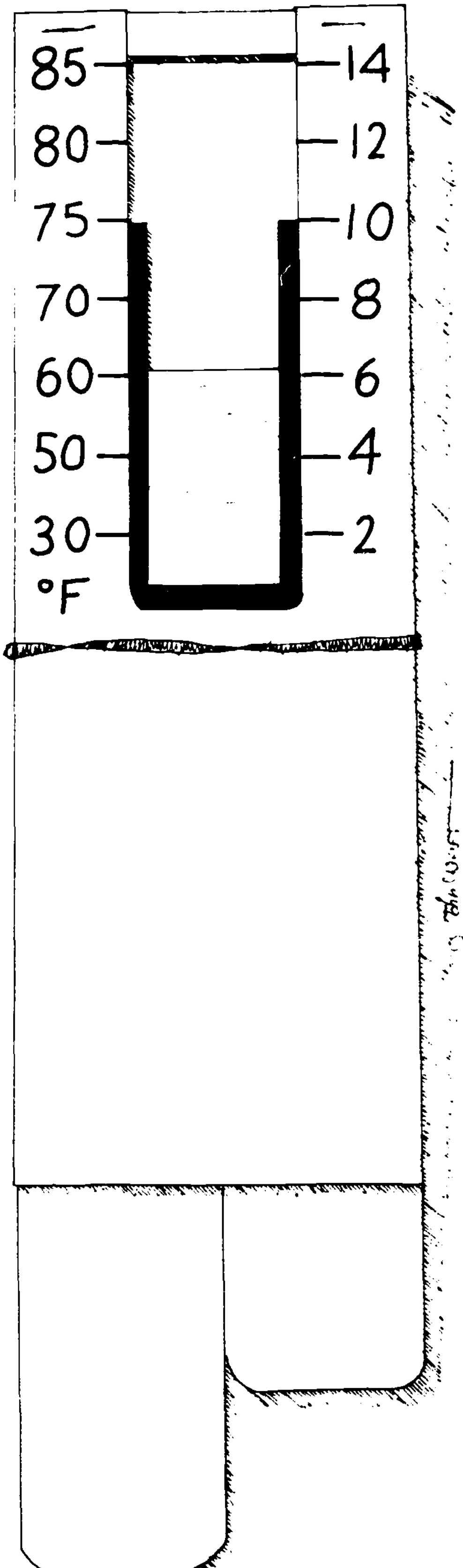


Figure 4.6

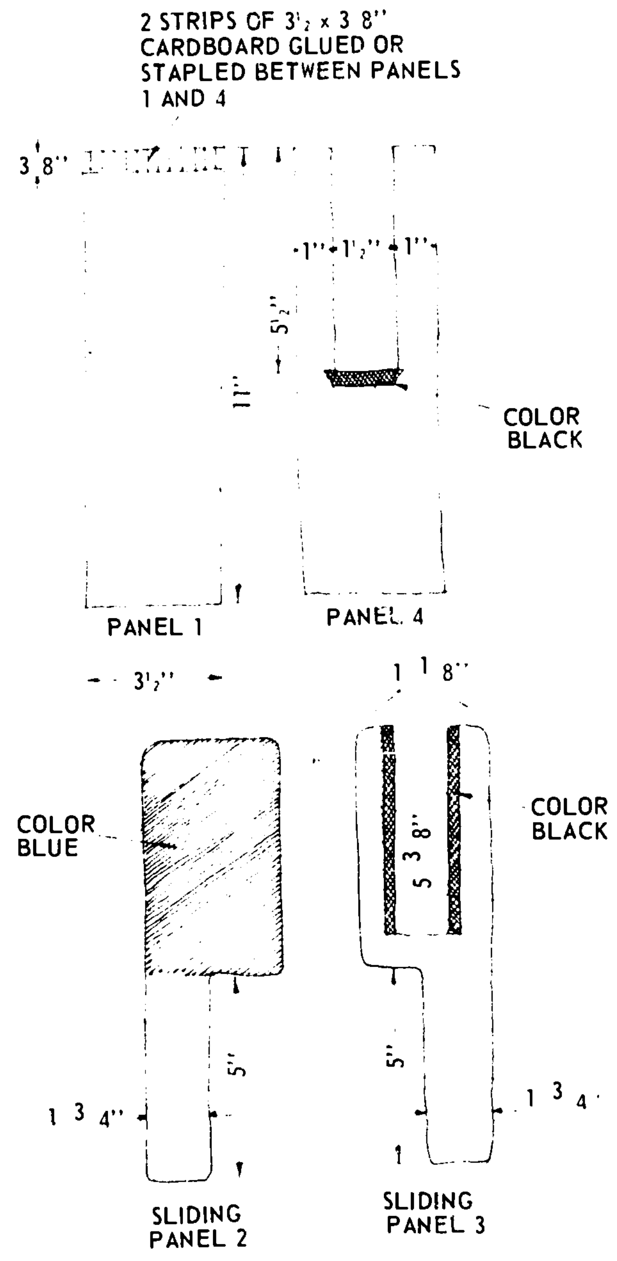


Figure 4.7

Materials: Four pieces of white cardboard, 3½" x 11" each, black ink, blue ink, glue or stapler, rubber band.

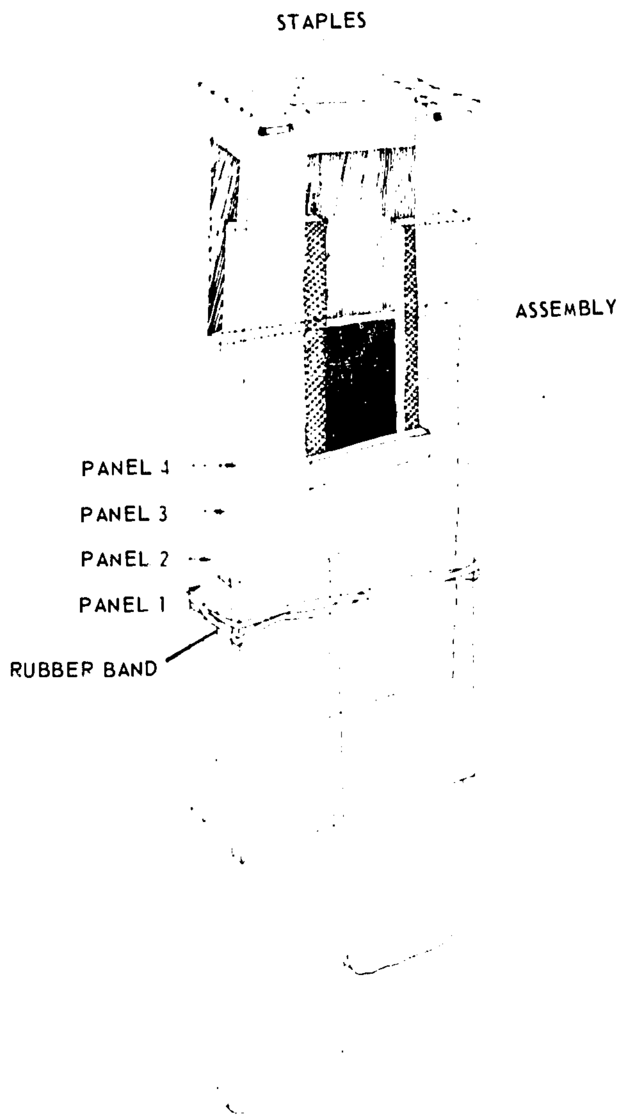


Figure 4.8

What is the difference between "shower" and "rain"? What is a "snow flurry"? Precipitation?

A knowledge of past and prediction of future rainfall in a region is not only important in agriculture and forestry, but also in industries, such as mining and paper manufacture, as well as in soil and water-resources management, in municipal maintenance, in sports, shipping, transportation, and many other human endeavors.

The main forms of precipitation are: rain; drizzle is rain consisting of very small droplets; snow consists of single ice crystals or of crystal aggregates (snow flakes); sleet is rain that has frozen while falling through a very cold air layer; hail forms in thunderclouds by the collision and freezing together of water and ice particles. When rain freezes on contact with the ground, the resulting ice coating is called glaze.

Rain Measurements

The amount of rainfall is measured as the depth of water on level, impermeable ground. Any cylindrical can can be used to catch precipitation, but it is desirable to determine the depth of water with an accuracy of 1/100 inch, so that it is necessary to magnify the depth of the raincatch. In addition, evaporation of water prior to measurement must be minimized; this is achieved by placing a funnel over the can.

The raingauge is constructed as illustrated in Figure 4.9. Two large tin cans from which the tops have been removed as well as the bottom of one of them, are soldered together (with hot or cold solder). A disk that fits loosely inside the can is made of wood or stiff foam plastic, in the center of which a hole is made

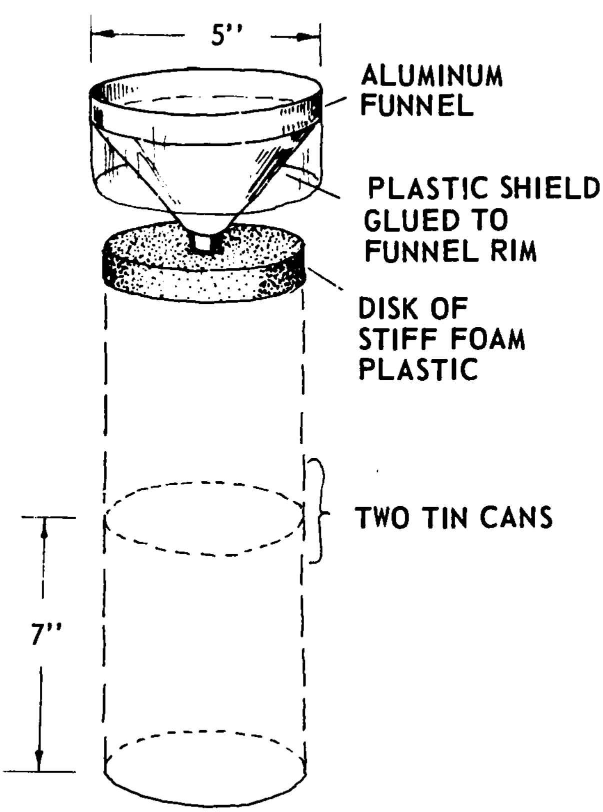


Figure 4.9

into which the funnel neck is glued. A sheet of tin-can metal or plastic 2" x 15" is cemented around the funnel rim to prevent driving rain from getting into the can without going through the funnel. The finished gauge is mounted on a post as suggested in Figure 4.10, and should be positioned so that it is as far away from any objects as these objects are high.

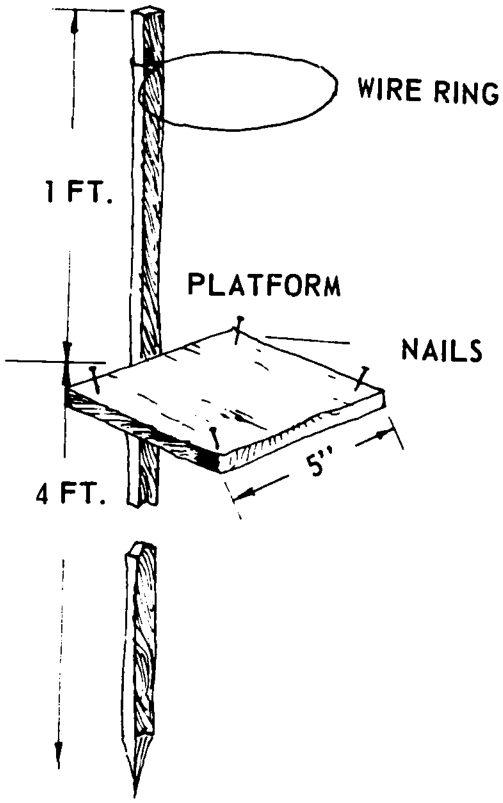


Figure 4.10

For measurement the contents of the can are poured into another cylindrical can of much smaller diameter, preferably not more than 2". Several such small tin cans can be soldered together in the same manner as the raingauge itself. Wi'h a very slender redwood stick, which shows water marks well, we measure the height of the water column in the measuring tube. The depth of precipitation, P, is computed from the relationship $P = H (d/D)^2$, where D the inner diameter of the funnel top. For example, let D be $5\frac{3}{8}$", $d = 1\frac{1}{8}$"; thus the factor $(d/D)^2 = \frac{(9/8)^2}{43/8} = (0.21)^2 = 0.044$. So if the length of the watermark was $H = 1\frac{3}{16}$, the precipitation amount was $P = 1.19 \times 0.044 = 0.05$".

When precipitation falls in form of snow, the funnel is removed. The snow caught in the can is melted prior to transfer into the measuring tube. This is best done by adding a known depth of warm water and subtracting that amount from the measured value.

Materials: Two large tin cans, at least 7" high and 4" diameter, one metal funnel about 5" diameter, wooden post 1 x 1½" cross section, 3 to 4 ft. long, 5' x 5' x ¾" wooden board, 1" x 4" x 4" wood or stiff foam plastic, strip of sheet metal or plastic 2" x 15", 18" stiff wire, redwood stick ⅛" x $\frac{3}{16}$" x 12", two or three tin cans of very small diameter, nails, glue, liquid or hot solder.

If six inches of snow falls in your neighborhood, does the same amount fall all over town? All over Pennsylvania?
Snow Measurements

In case of snowfall, two measurements are of interest: the depth of the snowcover and the water content of the snow; . . . . the water content can vary from ½" to $\frac{1}{30}$", but is usually assumed to be $\frac{1}{10}$". The depth of the accumulated snow cover is measured by simply pushing a yardstick vertically through the snow to the ground and reading. For this we must select a spot where the snow has not drifted and make several measurements, taking as the final result the average of the various readings. For measuring the water content of the snow, we use the raingauge, without the funnel, because otherwise the snow quickly clogs the funnel and is blown out by the wind. At the time of observation, we pour a measured amount of hot water into the snow and after melting, pour out the same amount before measuring the snow water in the same manner as we measure rain water. However, we need another conversion factor, because the inner diameter of the can rim is different from that of the funnel rim.

Snow crystal imprints can be obtained by exposing for a short time during a snowfall a small sheet of white cardboard or glass which has been lightly smoked over a candle flame. Care should be taken that the cardboard or glass surface does not become hot during the smoking process, because then the smoke clings to the surface and is not easily disturbed by the snow crystals falling on it. The imprints can be fixed by dipping the sheet into a thin solution of shellac.

Material: One yardstick, one tin can, the top of which has been removed, a sheet of white cardboard or glass, shellac, candle.

What is wind?

Wind is the most important weather element in industrial and metropolitan areas, because it helps to dilute air pollution and to remove it from the area. In the absence of wind, serious air-pollution episodes may develop. Wind is also vital for the pollination of certain plants, such as corn, and is a factor in the spread of air-borne plant and animal diseases.

Wind observations are best made in the middle of an open field; the wind direction, i.e., the direction FROM which wind blows according to eight points of the compass, N, NE, E, SE, etc., can be ascertained by "feeling the wind with one's face, by noting smoke drifts, flags, etc." The wind speed can be estimated according to the Beaufort Scale.

Wind Measurements

A wind vane can be constructed with the material listed under a) below according to the dimensions in Figure 4.11. Before drilling the hole in the vane shaft, the assembled vane is balanced on a knife edge to find the center of gravity. A nail that fits loosely through the shaft is then hammered into the handle. If a piece of soldering wire is wound around and fastened to the front end of the vane, the center of gravity shifts closer to the middle of the shaft.

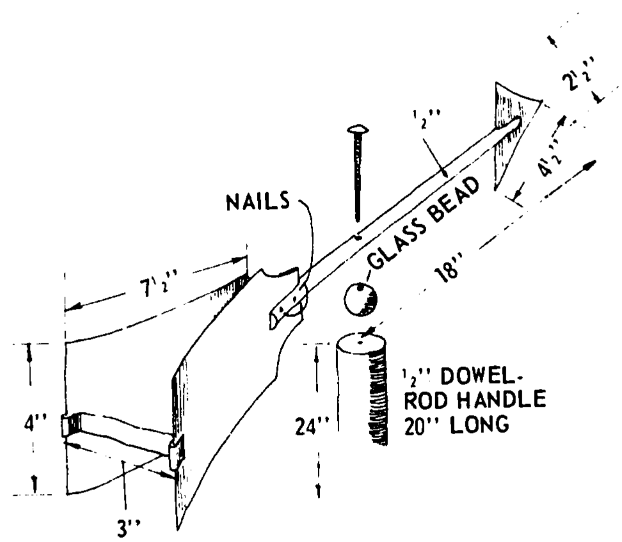


Figure 4.11

Beaufort Wind Scale

No.	*Description of Wind Effect*	*Equivalent in Knots* (1 knot = 1.15 mph.)
0	Smoke rises vertically	less than 1
1	Wind direction shown by smoke drift but not by wind vane	1-3
2	Wind felt on face; leaves rustle; vane moved by wind	4-6
3	Leaves and small twigs in constant motion; wind extends light flag	7-10
4	Raises dust and loose paper; small branches are moved	11-16
5	Small trees in leaf begin to sway; crested wavelets form on inland water	17-21
6	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	22-27
7	Whole trees in motion; inconvenience felt in walking against wind	28-33
8	Breaks twigs off trees; generally impedes progress in walking against wind	34-40
9	Slight structural damage occurs; chimney pots and slate removed	41-47
10	Seldom experienced inland; trees uprooted; considerable damage occurs	48-55
11	Very rarely experienced; widespread damage	56-65
12	Hurricane force	above 65

For wind-speed measurements, a cup anemometer can be built from three small aluminum funnels and the other materials listed under b) below. The funnel spouts are cut away as shown in Figure 4.12 and the funnel opening folded over and closed off with liquid solder. The remaining construction and assembly can be seen in Figure 4.13. Finally, one cup is painted flat-black for easier revolution counting.

In order to calibrate the anemometer, it is mounted on a broomstick so that it can be held out of a car window well above the car top. While the driver drives at a constant speed along a straight stretch of road on a calm day, the observer holds the instrument out of the window and counts the revolutions per minute; this is done for speeds of 5, 10, 15, 25, and 40 mph. A calibration graph is then constructed by plotting revolutions per minute versus speed in mph. The wind speed can also be converted into knots (1 knot = 1.15 mph) which are the commonly used units in meteorology.

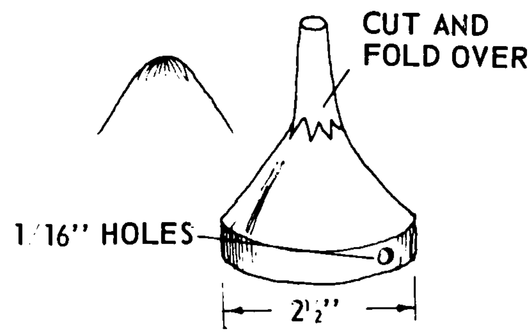


Figure 4.12

Materials: a) Sheet of tin-can metal, 4" x 15", sheet of tin-can metal 4½" x 5", strip of tin-can metal ½" x 4", one ½" dowel rod 20" long, one stick of wood 24" long, glue, nails, one glass bead.

b) Three aluminum funnels 2½" wide, three 3/16" dowel rods, 7" long, one metal (or plastic) pencil cap, one metal lid 1¾" to 2" diameter (such as from ink bottle), one 3" nail, one small metal washer, ⅜" diameter, one stick of wood 24" long (¾" dowel rod), glue, flat-black paint.

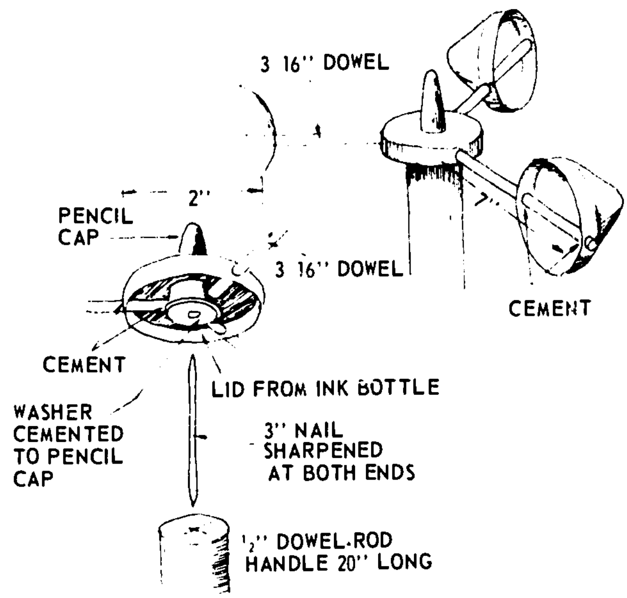


Figure 4.13

How do you measure the cold in cold?

If some days seem colder than others, even though the reading on the thermometer may be the same, or even higher, it is not just your imagination. Arctic studies done by the U. S. Army have found the answer—the Chill Index.

This "chill factor" takes into account both temperature and wind velocity. In combination they effect the rate of heat loss from your body. Should the temperature be zero degrees F, and the wind calm, the chill factor and the thermometer reading are the same. However, if the temperature is zero degrees F and the wind velocity 10 mph the chill factor now becomes minus 21 degrees. This is the same as saying that with a temperature of zero degrees and a wind velocity of 10 mph the combined effect is equivalent to the heat loss you would expect from a temperature of minus 21 degrees.

During the winter months many weather reports give the chill index for that particular day. This should be taken into consideration when deciding upon the proper dress for winter activities such as skating, sledding, or snowmobiling.

The following chart (Figure 4.14) gives the chill index for various temperatures from 50 degrees to minus 60 degrees and wind velocities up to 40 mph. Wind speeds greater than 40 mph produce little additional effect upon the lowering of the chill index. Particular attention should be paid to wind and temperature combinations indicated as those which will produce danger from the freezing of exposed skin.

ESTIMATED WIND SPEED IN MPH	ACTUAL THERMOMETER READING (°F.)											
	50	40	30	20	10	0	–10	–20	–30	–40	–50	–60
	EQUIVALENT TEMPERATURE (°F)											
	50	40	30	20	10	0	–10	–20	–30	–40	–50	–60
5	48	37	27	16	6	–5	–15	–26	–36	–47	–57	–68
10	40	28	16	4	–9	–21	–33	–46	–58	–70	–83	–95
15	36	22	9	–5	–18	–36	–45	–58	–72	–85	–99	–112
20	32	18	4	–10	–25	–39	–53	–67	–82	–96	–110	–124
25	30	16	0	–15	–29	–44	–59	–74	–88	–104	–118	–133
30	28	13	–2	–18	–33	–48	–63	–79	–94	–109	–125	–140
35	27	11	–4	–20	–35	–49	–67	–82	–98	–113	–129	–145
40	26	10	–6	–21	–37	–53	–69	–85	–100	–116	–132	–148
(wind speeds greater than 40 mph have little additional effect)	LITTLE DANGER (for properly clothed person)			INCREASING DANGER			GREAT DANGER					
				Danger from freezing of exposed flesh								

Figure 4.14 The Wind—Chill Index.

Reference

Edinger, James G. (1967), *Watching For The Wind,* Anchor Book, Doubleday & Co., Inc., Garden City, New York ($1.25).

Clouds

Clouds, apart from their aesthetic aspects utilized by photographers, determine to a large extent the brightness of a day. Therefore, prediction of cloudiness is important for power plants who can then anticipate peak loads of electricity used in various sectors of their networks. Such predictions also enable resort areas and transportation systems leading to such areas to anticipate customer "load"; State police also use them for anticipating traffic volume on highways. Clouds also give the meteorologist much information on the states of the atmosphere and furnish clues to impending weather changes.

We can distinguish ten major cloud types; their names and their abbreviations in ( ) will be given here; for photographs and descriptions of clouds, consult elementary texts on meteorology or write to the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., for the "Manual of Cloud Forms and Codes for States of the Sky," CIRCULAR S, U. S. Department of Commerce, Weather Bureau (30¢), or for the U. S. Weather Bureau "Cloud Code Chart" (10¢).

Family A: HIGH CLOUDS,
at heights above 20,000 feet.
1. Cirrus (Ci)
2. Cirrostratus (Cs)
3. Cirrocumulus (Cc)

Family B: MIDDLE CLOUDS,
at heights between 6,500 and 20,000 feet.
4. Altostratus (As)
5. Altocumulus (Ac)

Family C: LOW CLOUDS,
at heights close to the ground up to 6,500 feet.
6. Stratus (St)
7. Stratocumulus (Sc)
8. Nimbostratus (Ns)

Family D: CLOUDS WITH VERTICAL DEVELOPMENT, ranging from 1,500 feet to level of high clouds.
9. Cumulus (Cu)
10. Cumulonimbus (Cb)

Cloudiness, i.e., the relative amount of sky covered by clouds, is most easily estimated according to the aviation weather code:

CLEAR,
represented by the symbol O, denotes that no clouds are present.

SCATTERED, ◐,
means clouds cover only half of the sky or less.

BROKEN, ◕,
means clouds cover more than half of the sky, but some blue area is still visible.
OVERCAST, ●,
is the sky shows no blue area.
OBSCURED, ⊗,
is the case of the sky not being visible on account of dense fog, smoke, etc.

Large-scale collections of clouds are monitored by weather satellites which have revealed considerable organization in cloud patterns (bands, streaks, eddies, etc.).

Visibility

Visibility in meteorology as a measure of the transparency of the air is an important element for aircraft landings, for land and sea traffic, for rescue operations and aircraft reconnaissance, for aerial spraying operations in agriculture, alpine sports, etc. It is defined as the largest horizontal distance (in miles) at which prominent dark objects such as hills, large buildings, tree groves, etc. can be seen against the horizon sky. For this observation, a place with an unobstructed horizon is necessary; however, a rough qualitative estimate of the transparency of the air is often sufficient, especially, when the degree of air pollution is judged by the transparency of the air. An example of a four-step scale is as follows:

1. "poor visibility" for hazy or foggy conditions.
2. "fair visibility" for average conditions.
3. "good visibility" for clear-air conditions.
4. "excellent visibility" for extremely clear air.

The last step can be omitted at places where such a condition is too rare to be included.

References

Battan, Louis J. (1962), *Cloud Physics and Cloud Seeding*, Anchor Books, Doubleday & Co., Inc., Garden City, New York ($0.95).

Clausse, Roger, and Facy, Leopold (1961), *The Clouds* (Evergreen Profile Book 30), Grove Press, Inc., New York ($1.35).

Upper-Air Observations

Temperatures, pressures, humidities, and winds aloft are measured by balloon-borne instrument packages called radiosondes that send out radio signals of the various weather elements at different heights up to roughly 100,000 feet. Radar is used for tracking tropical storms, thunderstorms, tornadoes, and precipitation regions, as well as for the study of clouds. The most recently developed tools for observations are the weather satellites that give information on the worldwide distribution of clouds, occurrences and positions of storms, particularly hurricanes, and surface temperatures.

Reference

Reiter, Elmar R. (1967), *Jet Streams*, Anchor Book, Doubleday & Co., Inc., Garden City, New York ($1.25).

BASIC PRINCIPLES AND CONCEPTS

The explanations of most weather processes and phenomena can be derived from relatively few basic principles. These, together with diligent observations of the actual weather and its changes, should provide sufficient background for the understanding of the fundamental concepts of meteorology.

Major Topics Discussed In This Section

1. Earth Rotation—daily changes
2. Earth Revolution and Axis Tilt—seasonal changes
3. Changing Solar Angles
4. Earth Radiation
5. Clouds and Water Vapor as Radiation Controls.

Can anyone explain what causes our seasons?

The Atmosphere's Energy Supply

1. The distribution of various *climates*, the *daily* and *seasonal variations* of *weather elements* are caused by the motions of the earth in its orbit around the sun which is the energy source for all atmospheric and life processes. The earth's rotation about its axis causes day and night and diurnal variations in temperature, cloudiness, etc. The tilt of the earth's axis, making an angle to the orbital plane of 66½°, together with the earth's revolution around the sun, causes the seasons from the lower middle latitudes to the poles in both hemispheres. Near the equator, seasonal variations are slight. The output of radiational energy from the sun is constant for all practical purposes, and the slight variation of distance between earth and sun is also negligible as compared to other variables.

The greatest variable is the amount of energy received in different regions of the earth. The higher the sun is above the horizon, the greater the concentration of radiative energy on a unit surface area (Figure 4.15). The length of daytime, which varies with latitude and season, is also important. Clouds reflect a large portion of radiation and, therefore, control energy in this way. The cloud-free atmosphere lets most of the sun's radiation pass through, but the infrared radiation emitted by the earth's surface (all bodies radiate energy, the nature of which depends on the temperature of the radiating body) is blocked

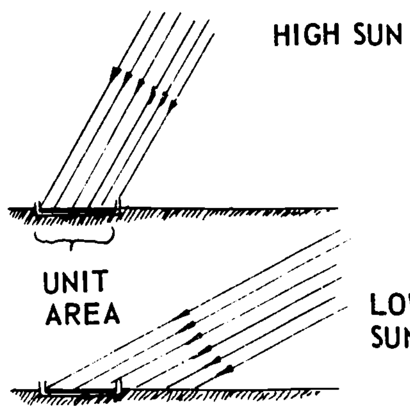


Figure 4.15

to a large extent by the water vapor and carbon dioxide in the air, especially in the lowermost layers. This is sometimes called "greenhouse effect"; however, the parallel is not perfect, because in a real greenhouse there is a roof that keeps the warm air inside. Without the roof, the air inside would be the same as outside.

Clouds are even more powerful barriers to outgoing earth's radiation. Thus, the state of the atmosphere determines the heat balance between incoming solar radiation and outgoing terrestrial radiation. For these reasons, the maximum daily temperature is high when the sky is clear; at night, under the same conditions, the minimum temperature drops to a low level, especially when the air contains a little water vapor. On the other hand, cloudy skies keep the diurnal temperature variation small by diminishing the maximum and raising the minimum temperature.

The Sun and the Seasons

The effects of the varying position of the earth relative to the sun's rays can be demonstrated by the model shown in Figure 4.16. On a 10" x 12" sheet of white cardboard, a circle of 4¾" radius representing the atmosphere is drawn as well as the sun's rays at ½" intervals as shown. Out of another sheet of cardboard a disk of 4" radius is cut out and marked, as in Figure 15, to represent the earth's cross section, which is fastened with a paper fastener concentric with the atmosphere circle and so that it can be rotated. The angles on the earth disk represent latitude at ten degree intervals.

a) If we line up the equator with the heavy center ray as in Figure 4.16, the earth is in the position of either spring or autumn equinoxes, and the right-hand side of the earth disk shows the noon position of the sun. We see that the sun is straight overhead (at the zenith) at the equator. 1. How high (in degrees of angle) above the horizon is the sun at the North and South Poles? At 30°, 60° latitudes? 2. How does the path length of the sun's rays through the atmosphere change with latitude? 3. How many latitude degrees does a bundle of sun's rays of ½" width cover at the equator? At 45° latitude? Near the pole? 4. What can you state about the solar radiation intensity at low, middle, and high latitudes, considering the answers to questions 2 and 3?

b) Now we turn the earth disk to the position it has during the summer solstices, i.e., we line up 23½° N latitude with the center ray. 5. How high is the sun above the horizon at the equator? Is the sun there in the northern or southern sky? 6. How high is the sun at the N-pole? 7. What can you say about the length of daylight north of the Arctic Circle? South of the Antarctic Circle? 8. Where is the sun at the zenith? 9. What can you say about the radiation intensity at 45° N and S latitudes as compared to that during the equinoxes?

c) Finally, we turn the earth disk to the position it has during the winter solstices and answer again the questions 5 through 9, for this condition.

Material: One piece of white cardboard 10" x 12", one piece of grey (or other color) cardboard 8" x 8", one paper fastener.

Answers: 1) Zero degrees at both poles; 60° at 30 degree latitude, 30° at 60 degree latitude. 2) The path length increases with increase in latitude. 3) At the equator about 8° latitude, at 45° latitude about 10 degrees, near the pole about 28 degrees. 4) Solar radiation intensities decrease from low to high latitudes. 5) At the equator the sun is 66½° above northern horizon. 6) 23½° above the horizon at north pole; 23½° below the horizon at south pole. 7) North Arctic Circle day length is 24 hours; south of the Antarctic Circle the day length is zero hours. 8) Sun is at the zenith a noon along 23½° north latitude. 9) At 45° north latitude solar radiation intensity is greater, at 45° south latitude it is less than during equinoxes. Answers for c) are same as for b) except that "north" and "south" are exchanged.

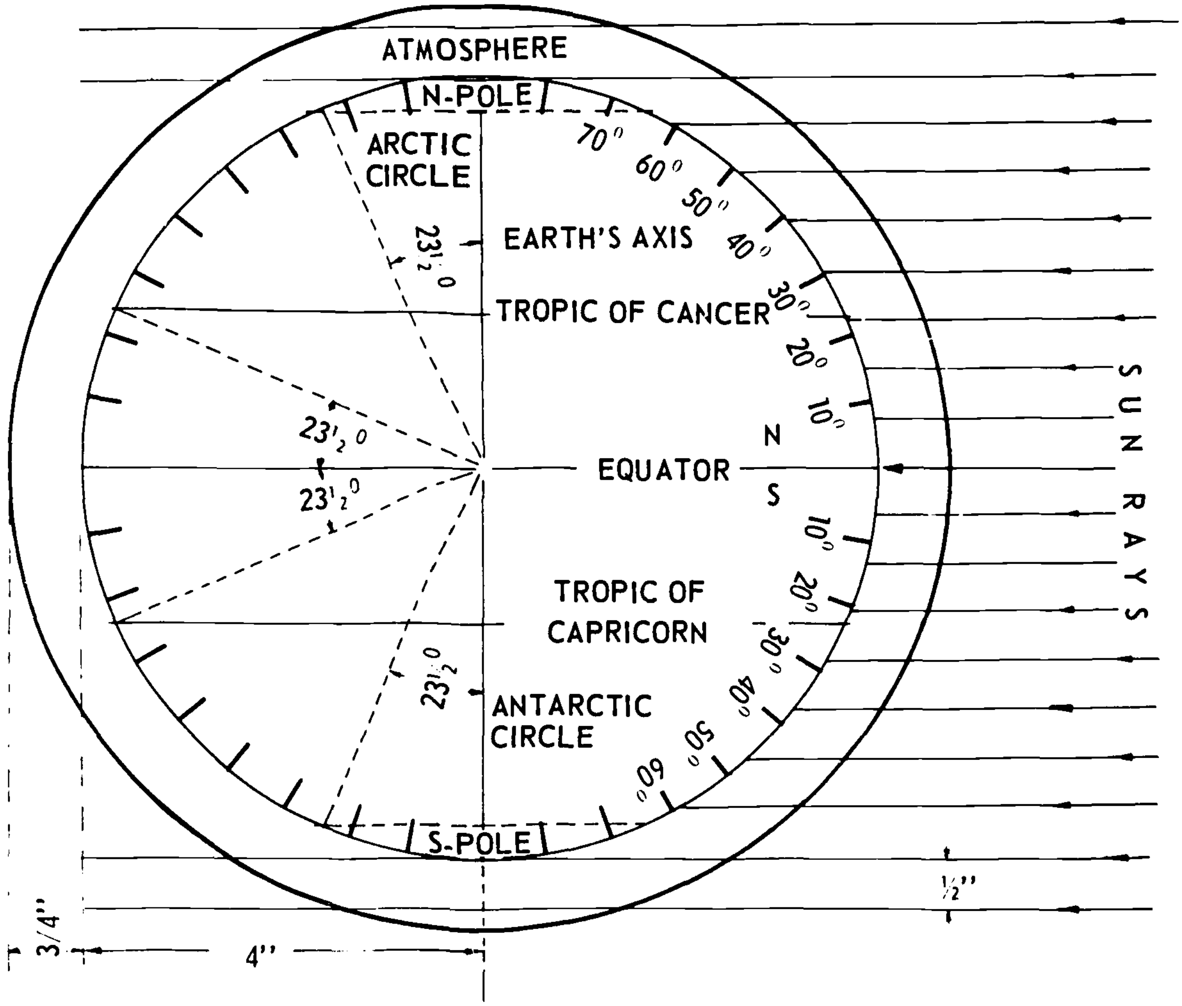


Figure 4.16

Water in the Atmosphere

Major Topics Discussed in the Section

1. The Three Phases of Water; precipitation processes
2. Phase Changes: Heat Transfer
   a. Evaporation: liquid to vapor–600 calories per gram required.
   b. Melting: ice to liquid–80 calories per gram required.
   c. Evaporation: ice to vapor–680 calories per gram required.
   d. Condensation: vapor to liquid–600 calories per gram released.
   e. Freezing: liquid to ice–80 calories per gram released.
   f. Sublimation: vapor to ice–680 calories per gram released.
3. Condensation Nuclei
4. Hydrologic Cycle

What are the three phases of water?

Water, the basic ingredient of life, occurs in all three states of matter. The oceans are the major sources of atmospheric water.

a) *Water vapor* is invisible; the maximum amount that can be present is greater, the higher the temperature. A lowering of temperature leads eventually to the saturation of the air which, in turn, leads to condensation.

b) *Liquid water* in tiny droplets makes up fogs and clouds. The very low fall velocity of the droplets is usually compensated for by the slight upward motion of the air so that clouds do not sink toward the earth. When droplets grow by collision, they may fall out of the clouds and reach the surface as rain. Condensation alone does not lead to precipitation; certain other conditions must be fulfilled also, e.g., the collision of ice crystals and supercooled water droplets produces large enough ice particles to fall out of the clouds, usually melting to rain drops in the warmer air below the clouds. Rain may also be caused by collision of different sizes of water droplets. It takes a million to a billion cloud elements to make one medium-sized raindrop.

Most current attempts at rain-making involve the conversion of some supercooled cloud droplets into ice particles; this not only improves the possibility for the aggregation of cloud elements, but also increases the buoyant lifting of the cloud air by the release of the heat of fusion.

c) Ice in the form of tiny crystals is found in clouds whose temperatures are far below the melting point of ice (32°F). Usually, clouds, even at temperatures of 15°F, consist of liquid water droplets, which are called "supercooled"; their natural freezing point is well below 32°F, depending on their size. Ice always melts at 32°F, but water requires much lower temperatures to freeze.

Phase Changes of Water

Can you name some phase changes in the atmosphere?

The phase changes are not only all-important for weather processes, but also for life processes (transpiration by plants, perspiration and water loss by the breathing of animals and man). All phase changes are connected with heat transactions.

a) Liquid water to water vapor, *Evaporation*, requires heat (roughly 600 calories for evaporating one gram of water), because water molecules are held together by electrical bonds that must be separated. Thus, evaporation is a cooling process. Other conditions being the same, the drier the air, the greater the evaporation rate, and the colder the water and its environment become.

The wet-bulb effect is a manifestation of evaporational cooling and can be demonstrated as follows: First, feel the sensible temperature of a piece of cotton cloth; then dip it into water, wave it through the air a few times and feel it again. 1. What is the difference between the sensible temperatures of the cotton in the dry and the wet state? (Colder in the wet state.)

2. Why is it possible for laundry to freeze outdoors, although the air temperature is above 32°F? (The rate of evaporation may be fast enough to lower the temperature of the laundry below freezing; this happens when the wet-bulb temperature is well below 32°F.)

b) Ice to water vapor, *Evaporation*, can take place without the ice melting first; a snow cover can disappear even when the temperatures are far below 32°F. Again, heat is required for this phase change and more than for the previous one, because ice has a hexagonal crystal structure in which the electrical bonding is stronger.

c) Ice to liquid water, *Melting*, requires heat to loosen the bonds between ice molecules; melting is a cooling process; when ice is heated, its temperature rises to 32°F and remains there until all ice is melted. Only then will continued heating raise the temperature of the water.

d) Liquid water to ice, *Freezing* (or Fusion), can only take place if heat is removed from the water. The same amount of heat (80 calories per gram) required for melting is released when water freezes. Thus freezing is a warming process!

e) Water vapor to ice, *Sublimation*, releases the same amount of heat as was required for the reverse process; it, too, warms the air in which it takes place. Note that the use of the term sublimation is different in meteorology from that in chemistry.

f) Water vapor to liquid water, *Condensation*, releases the same amount of heat (called *latent heat*) as was required to evaporate the water. Thus, condensation warms the air; it constitutes an important source of heat for the atmosphere. Cooling of air is the primary cause for condensation by which clouds and fogs are formed, but, paradoxically, the heat released by condensation partially offsets the cooling of the air.

In addition to the heat release attending the formation of clouds and fog (which is a cloud on the ground), these have further consequences on the temperature, because they reflect sunlight away during daytime and trap the earth's heat at night. Where air pollution is a problem, fog formation can worsen the pollution by reducing sunlight that would heat and thereby stir the air. Fogs also have other economic significance in that they have been found to result in the loss of about 7 million dollars annually by airline companies alone, not counting the disruption of other transportation systems and the loss of lives on highways.

The condensation of water vapor cannot take place without the presence of certain types of submicroscopic particles, called condensation nuclei. These are produced by all combustion processes, whether or not smoke is visible; the spray from the ocean also produces condensation nuclei when the droplets evaporate leaving minute salt particles suspended in the air.

Take a gallon glass jug, paint the back-half black or tape a piece of black paper to it. Close the jug airtight with a stopper through which a hole has been punched; put a short piece of copper or glass tubing (e.g. eye-dropper or plastic tube) through the stopper and fasten a 6″ to 10″ piece of rubber tubing to it. If the jug has a screw cap (see Figure 4.17), punch a hole from the inside through the middle of the cap including the cardboard disk inside. Widen the hole until the elongated rubber bulb from an eye dropper can just be *squeezed* through the hole, with the open end on the inside. Make a small hole in the closed tip of the rubber bulb and push the glass (or plastic) tubing from the inside through the rubber bulb (see Figure 4.18). If the assembly is not airtight, close the leaks with candle wax.

For a demonstration model of this hydrologic cycle (see Figure 4.19), we make a wooden stand as in Figure 4.20. Between the nails we put a can top or large jar lid as a trivet on which we fasten a short piece of candle or set a sterno-heat can.

Into another coffee can lid, we punch holes on opposite sides near the rim. Through one hole we stick a metal funnel that has a rim diameter of about 3″ to 4″. The other hole we widen to a diameter of ½″. Then we roll a sheet of tin-can metal, 3″ x 6″, into a tube of 6″ length and about ¾″ diameter and tie it near the top and bottom with wire. The tube is fastened with liquid (or hot) solder on top of the hole, and the funnel, too, is soldered into the can lid (Figure 4.21). From a tin can, 7″ to 8″ long, with a diameter of 3½″, we remove the top and punch a small hole through the rim of the bottom. With a 10″ piece of stiff wire we hang this can from the dowel so that it is tilted at an angle of about 20° from the horizontal with the bottom over the middle of the funnel, as shown in Figure 4.22.

Fill the coffee can about half full of boiling water and put several pieces of ice in the hanging can and light the candle or sterno. After a few minutes the hydrologic cycle will start. 1. What do you observe? 2. What does the water in the can represent? 3. What does the suspended can represent? What the ice in it? 4. What does the funnel represent? 5. What does the candle or sterno represent?

Figure 4.17

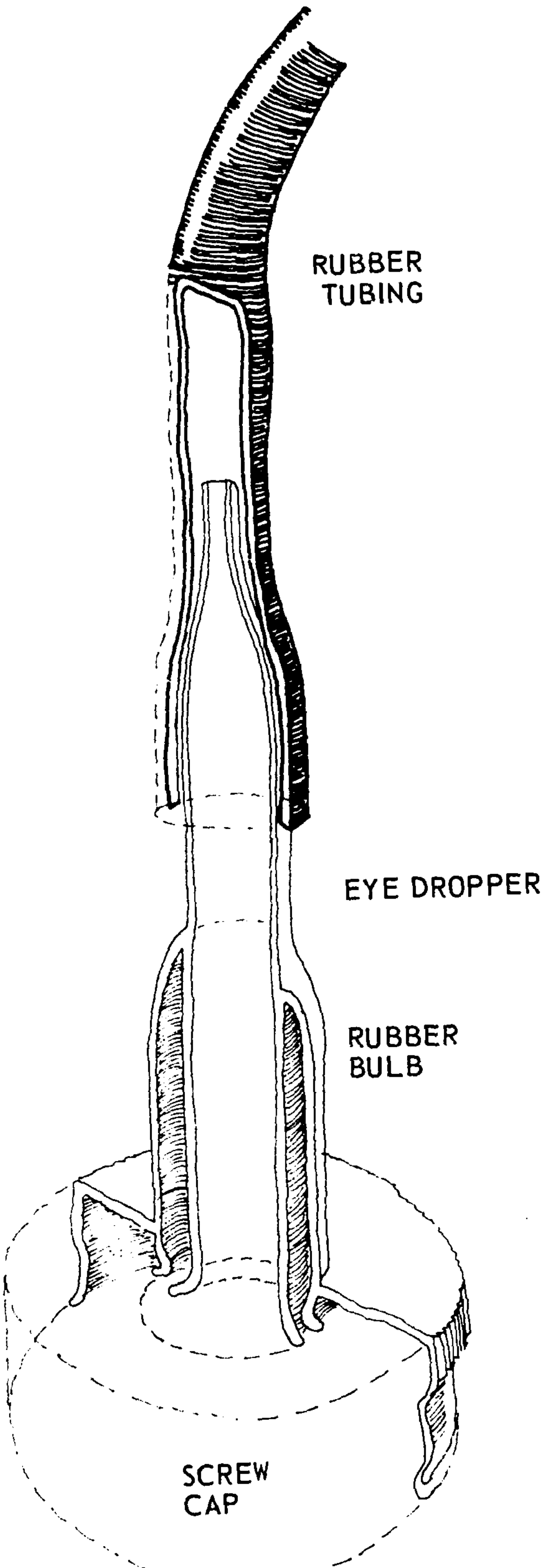


Figure 4.18

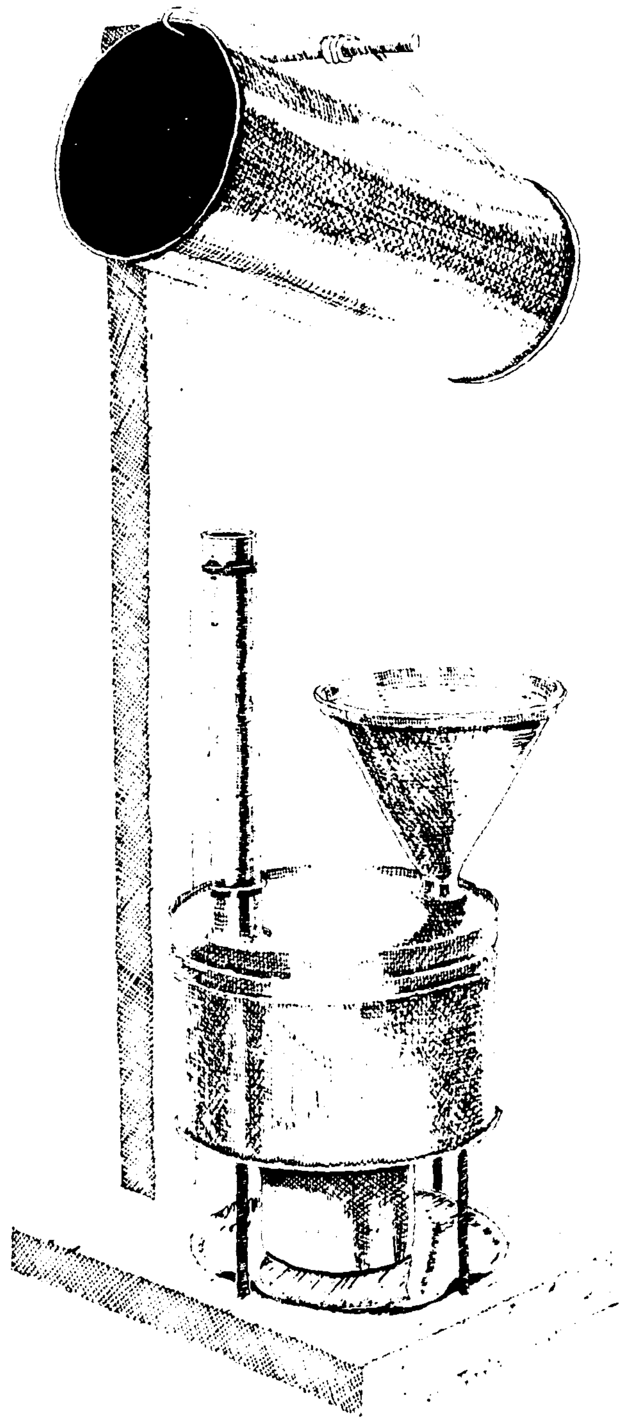


Figure 4.19

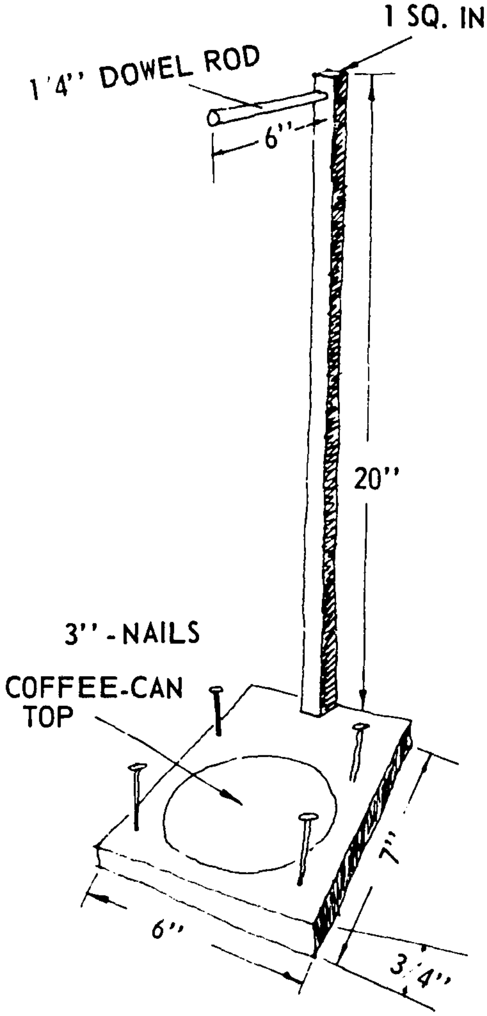


Figure 4.20

Material: One piece of wood, ¾″ x 6″ x 7″, one stick of wood, 1″ x 1″ x 20″, a 6″ piece of ¼″ dowel rod, four 3″ nails, a tin-can lid or large jar lid, a short candle or sterno canned heat, a piece of tin-can metal 3″ x 6″, one coffee tin can, 3½″ high, 5″ diameter, one tin can 7″ to 8″ high, 3½″ diameter, one metal funnel 3″ to 4″ diameter, two 4″ pieces of thin wire, one 10″ piece of heavy wire, liquid (or other) solder, glue, boiling water and a few ice cubes.

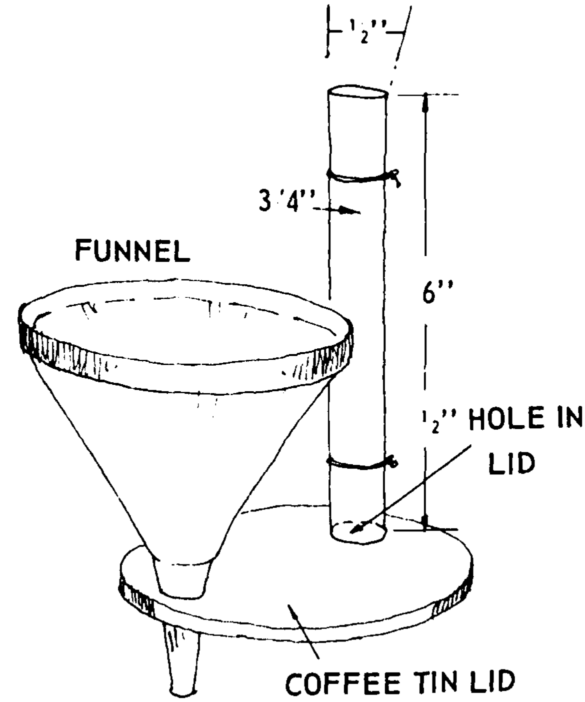
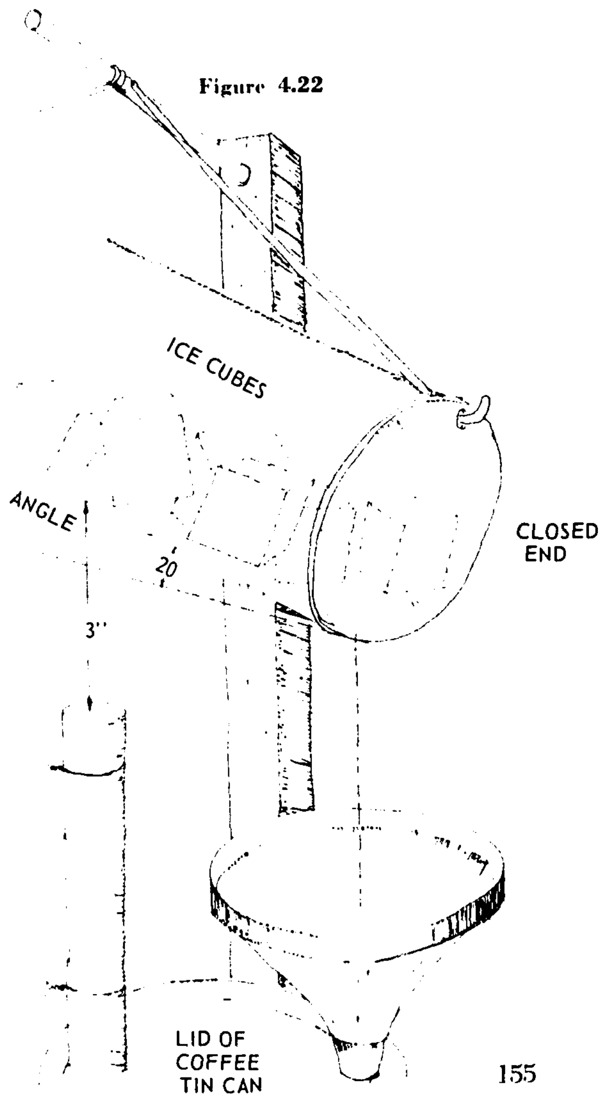


Figure 4.22



Answers: 1) Steam condenses on suspended can with ice, runs along the bottom and drips off into the funnel. 2) The water represents the oceans, lakes, rivers, etc. 3) Essentially a cloud; the ice in it represents the expansional cooling that the rising moist air experiences. 4) The funnel is the earth's surface along which the precipitation runs off. 5) The candle or sterno represents the sun's energy used for the evaporation of the water.

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Film

The Rainmaker--Available from Australian Embassy, 1735 Eye St. N. W., Washington, D. C.

HEAT TRANSFER

Major Topics Discussed In This Section

1. Heat Transfer Processes
   a. Solar Radiation
   b. Conduction
   c. Convection (by air and ocean currents)
   d. Latent Heat
2. Effect of Surface Reflectivity on Air Temperature

Can anyone name one or more heat transfer processes?

1. Various *heat transfer* processes are involved in changing the temperature of the atmosphere. Because air is essentially transparent to *solar radiation*, it is not directly heated by sunshine. Most of the air-temperature changes observed near the ground are due to heat transfer between the ground and the air above it. Because air is a poor heat conductor, *Conduction* involves only an air layer a few inches thick and in direct contact with the surface. When the air temperature has been sufficiently raised, *Convection* will set in: the warmed air rises and is replaced by cooler air from above. Turbulent wind increases the efficiency of this process. When the ground is colder than the air, the heat transfer is to the surface, and the air gets colder, so that there is no tendency for vertical currents and heat exchange with air aloft. But turbulent wind will produce mixing with the relatively warmer air above and slow down the cooling process. On a windy day the temperature does not rise as high during daytime nor drop as low at night.

The circulation established by convection can be demonstrated in the following manner: Take a cardboard box (shoe box) of dimensions similar to those in Figure 4.23, cut a window into the box top and cover the opening with transparent plastic. Cut out two holes in one side and tape or glue two cardboard tubes over them and otherwise make the box airtight. A box can also be made from two sheets of 8½" x 11" cardboard; one bent to form the bottom (3" x 11") and the back (5½" x 11") of the box. Out of the other sheet, cut two pieces 3" x 5½" and one 3" x 11" and then tape them into a box as shown in Figure 4.23, the front being covered by a sheet of plastic. Cut two holes in the top into which two cardboard tubes are fastened to complete the model. Wind the end of a stiff piece of 12" wire around a candle, make a hook of the other end, and hang it over the rim of one of the chimneys. Light the candle and be careful to hang it so that the box does not catch fire (have a beaker with water handy). Hold a piece of smoldering string over the other chimney, watch the smoke travel, and draw a picture of the circulation.

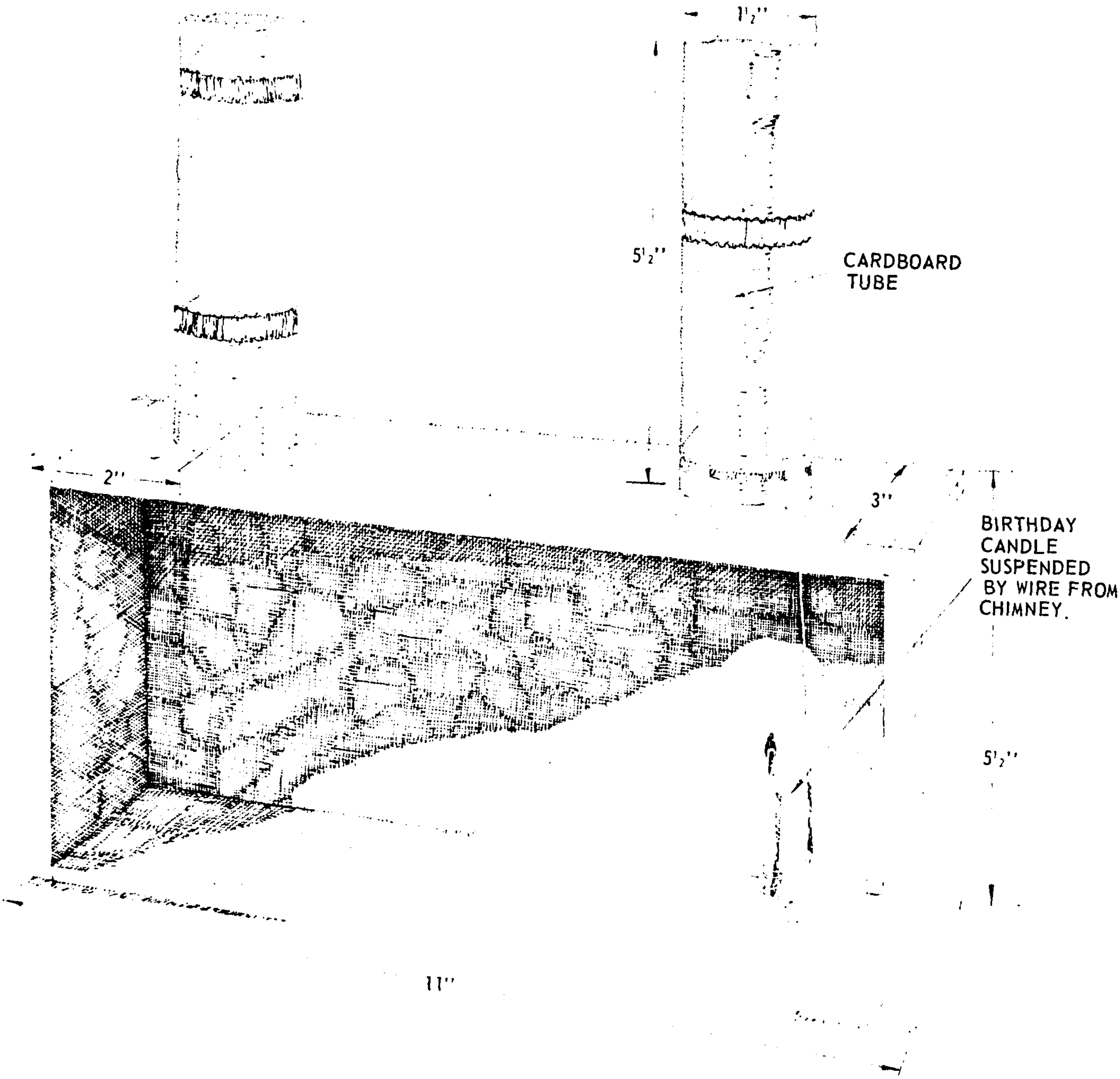
Material: Two sheets of 8½" x 11" cardboard, two cardboard tubes 5½" long, 1½" diameter, a sheet of transparent plastic 5½" x 11", 12" of stiff wire, a small birthday candle, and tape.

Latent heat is contributed to the air by the evaporation of water into it; this heat is released and converted to sensible heat when the water vapor condenses. By this process large amounts of heat can be transported by the air over large distances; much of the difference between the energy received in equatorial regions and that received in polar regions is equalized by the transport of water vapor, originating from tropical oceans.

Ocean currents also help to equalize the uneven heat distribution on the earth. An example is the Gulf Stream that flows from the Gulf of Mexico northeastward across the Atlantic and makes the climate of northern Europe considerably warmer than that at similar latitudes in North America. For example, Trondheim in Norway, 63°N and 10°E, has an average annual temperature 23°F higher than Frobisher, Canada, 63°N and 68°W.

Does the reflectivity of surfaces affect air temperature? How?

The radiational *heating* of *different* kinds of *surfaces* is important for its influence on the air temperature. This heating depends on the reflectivity of the various surfaces, because the energy reflected cannot contribute to raising the temperature of the surface.



1½''
5½''
CARDBOARD
TUBE
2''
3''
BIRTHDAY
CANDLE
SUSPENDED
BY WIRE FROM
CHIMNEY.
5½''
11''

Figure 4.23

Land and water reflect roughly the same amount of radiation (less than 30%), but ice and snow surfaces reflect considerably more radiation (50% and more). Yet, water surfaces show quite a different response to radiation than does land, as is easily verified on a sunny summer day by stepping from the hot beach sand into the cool water. Water requires more heat to warm up to the same temperature as land, because water is mobile so that the warmed water at the surface is readily mixed with the cooler water below the surface. Of secondary importance is the fact that some of the heat is used up in evaporating water, that radiation penetrates the water to some depth, and that the heat capacity (specific heat) of water is somewhat greater than that of land.

Water stays relatively cool under the same radiation conditions that land gets very hot. In turn, water retains its heat longer, so that it cools much more slowly than does land.

The differences in temperature of water and land under the same radiation conditions can be demonstrated as follows: Fill one of two shallow containers (cut-down tin cans) with water, the other with sifted soil and insert the bulb of a thermometer just under the surface of each (see Figure 4.24). The thermometers are propped up so that the bulbs remain fixed. After the temperatures have stabilized, take the readings and record them. Then place a 150 to 200 watt bulb about 10″ above the middle between the two containers, turn the light on and take readings of each thermometer every minute for about 5 minutes. 1. What is the rate of temperature change in water as compared to that in soil? (It is slower.) Repeat the experiment but this time wet the soil. 2. Is the temperature change of wet soil slower or faster than that of dry soil? (Slower.) Why? (Because some of the radiational heat is used to evaporate the water from the soil.)

Material: Two tin cans, two thermometers, one 150 to 200 watt bulb, soil and water.

The difference in thermal properties between water and land is responsible for the large differences between continental and maritime climates. Maritime climates have smaller annual temperature ranges (difference between the mean monthly temperatures of the warmest and coldest month of the year), smaller diurnal temperature ranges (difference between daily maximum and minimum temperatures), and smaller day-to-day changes of temperature. For example Eureka, California has an average annual temperature of 52°F, the same as Omaha, Nebraska; the annual range at Eureka is only 10°F, while it is 56°F at Omaha.

The temperature differences between land and sea produce the monsoons and land-and-sea breezes, respectively. In summer and during daytime, the land is warmer than the adjacent sea so that the warmer air rises over the land and is replaced by cooler air from the sea. The subsequent heating and lifting of the moist air from the ocean tends to produce rainfall. In winter, and at night, the circulation is reversed.

Reference

Battan, Louis J. (1966), *The Unclean Sky*, Anchor Books, Doubleday and Company, Inc., Garden City, New York ($1.25).

AIR MASSES AND FRONTS; AIR MOTION

Major Topics Discussed In This Section

1. Air Masses and Fronts
2. Pressure Gradient as Cause of Wind
3. Angular Momentum and Coriolis Effect
4. Convergence and Divergence
5. Winds around Pressure Systems
6. Vertical Motion and Clouds—Adiabatic Temperature Changes

How are air masses formed?

The relative deficiency of sunlight at high latitudes produces cold ground therefore cold air. This effect is especially marked over continents in winter where there is very little water vapor to act as a blanket. Therefore, large volumes of air at high latitudes and over the continents take on the cold, dry characteristics of the underlying surfaces. At the same time, large volumes of air at low latitudes are still very warm and relatively moist. These *air masses* move out of their source regions on occasion and produce marked changes in the weather. The boundary zones between different air masses are called *fronts* and are often regions of bad weather. The motion of the air masses constitutes an important mechanism for equalizing the temperature differences that will otherwise be found between the equator and the poles. The contrast of air masses is less pronounced in summer, when the polar regions also receive a considerable amount of radiation.

Can anyone explain what causes wind?

Horizontal air flow—the *winds*—are caused by horizontal differences in pressure so that the air tends to move from higher to lower pressure. The greater the pressure differences per unit of horizontal distance, called *pressure gradient*, the stronger is the wind. When the nozzle of an inflated balloon is opened, the air flows out; the greater the pressure difference be-

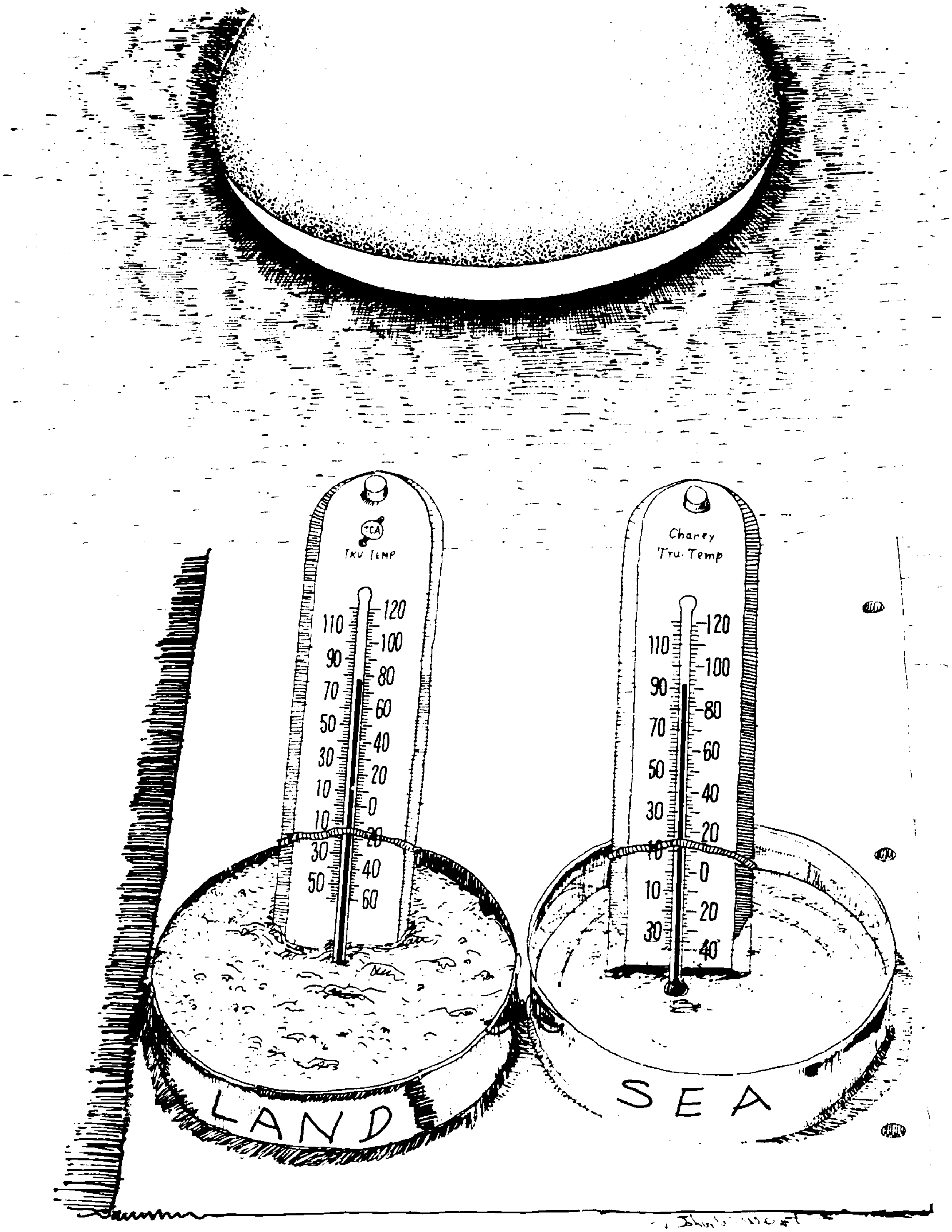


Figure 4.2

tween the inside and the outside, the faster the air flows from the balloon.

On a large scale, the air does not flow straight from regions of high to low pressure, called Highs and Lows or anticyclones and cyclones, respectively, because the rotation of the earth imparts an angular momentum to all air masses. The *angular momentum* of a unit of mass is the product of the spin radius (distance from the earth's axis) and the angular velocity (angle swept through in unit time, or spin rate). In the absence of other forces, the angular momentum will be conserved so that if the spin radius is increased, the angular velocity must decrease in order to keep the product constant.

The principle of conservation of angular momentum can be demonstrated in two ways:

a) To a stout string, tie a rubber stopper or any small object weighing about one-half ounce; this is the mass. The string is pulled through a hollow handle. The rim of the handle should be smooth so that the string will not be frayed or cut. A stick of wood, pencil or the like, is knotted to the other end of the string so that the mass cannot fly off (see Figure 4.25).

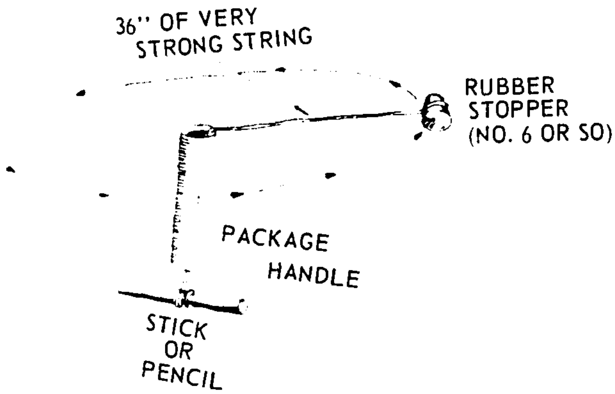


Figure 4.25

Swing the mass above your head in a horizontal circle around the handle until the mass has a substantial momentum. Then, while the mass is coasting around, pull the string by the stick to make the spin radius shorter. What do you observe? (Spin becomes faster.) Repeat the experiment, but let the mass spin somewhat faster with only half the spin radius by holding the stick at an appropriate distance below the handle. Then let the string out to make the spin radius larger. What happens now? (Spin becomes slower.)

b) Fill a large round bowl (see Figure 4.26) to within an inch or so from the top with water. Sprinkle some dust into the water to make its motion visible. Stir the water in a circular motion until the entire water assumes a fairly steady rotation. Insert a glass tube vertically (prepared as in Figure 4.26) into the water to a depth of about two inches and slowly suck a 6'' to 10'' column of water up into the tube. What do you observe? (Water column in tube rotates faster.) Does it matter whether you insert the tube at the center of the rotating fluid or near the periphery? (No.)

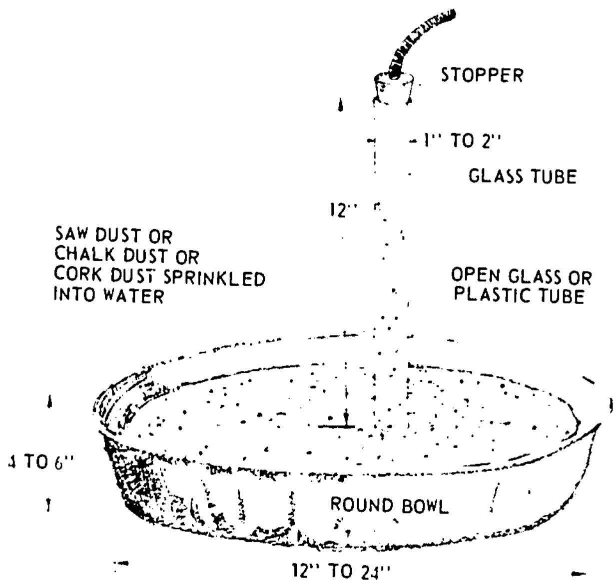


Figure 4.26

The solid earth and still air have the same angular velocity everywhere because they rotate as a unit, once in 24 hours. Because the distances of the earth's surface from the axis vary with latitude, the angular momentum is a maximum at the equator (largest spin radius) and diminishes to zero at the poles (zero spin radius). When a mass of air moves poleward from a given latitude, its spin radius decreases and therefore its spin rate must increase to conserve its angular momentum. Therefore, it will spin faster than the earth's surface underneath; i.e., it will acquire an eastward motion. In the northern hemisphere, this means that air moving from south to north (a south wind) will turn toward the east to become a westerly wind. On the other hand, a wind from the north will increase its spin radius and therefore diminish its angular velocity about the axis so that the air will move westward relative to the earth's surface. In other words, all moving masses on the northern hemisphere will be deflected to the *right* of their motion regardless of their direction; in the southern hemisphere, they will be deflected to the *left* of their motion. This effect is called the *Coriolis* deflection.

Because of the Coriolis deflection, winds do not flow directly into a Low or out of a High, but circle around these pressure systems, clockwise around Highs, counterclockwise around Lows in the northern hemisphere; in the southern hemisphere the rotations are reversed. Near the earth's surface, however, friction with the ground makes the air turn slightly into a Low and out of a High in both hemispheres. This causes *convergence* of the air in the case of a Low, *divergence* in the case of a High. This can be shown by the model in Figure 4.27. It consists of a sheet of 8½" x 11" cardboard with a 7" diameter circle drawn

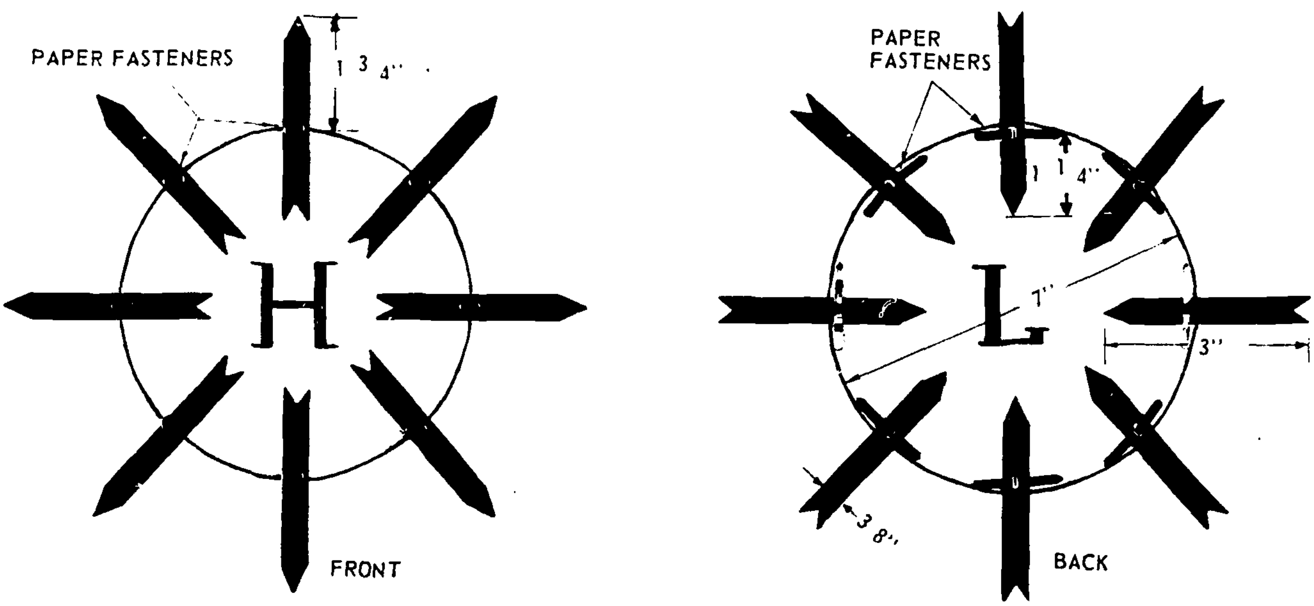


Figure 4.27

with the same center on each side of the cardboard. Sixteen ⅜" x 3" arrows of black cardboard are fastened with paper fasteners, eight on each side as shown, the arrows showing the winds straight out of the HIGH and straight into the LOW.

In the northern hemisphere, the Coriolis deflection is to the right; so we turn each arrow about 30° to the right, i.e., clockwise. (In the absence of friction, the Coriolis force would turn the flow 90° from the direction of the pressure gradient force.) 1. Is the resulting circulation a clockwise or counterclockwise spiral for the HIGH? (Clockwise.) For the Low? (Counterclockwise.)

To show the circulation patterns for the southern hemisphere, we return the arrows to their initial position and then turn each about 30° to the left (counterclockwise). 2. What are the resulting circulations for the HIGH and the LOW? (Counterclockwise for HIGH, clockwise for LOW.)

The Buys Ballot rule (pronounced: boys-ballot) states that, in the northern hemisphere, if a person stands with his back to the wind, low pressure lies to the left; high pressure lies to the right. 3. What is the Buys Ballot rule for the southern hemisphere? (Same, but "right" and "left" are exchanged.) 4. In which direction is the LOW relative to an observer who notes a south wind a) in the northern hemisphere, b) in the southern hemisphere? (a) W to the NW; (b) E to the NE.

Material: One sheet of cardboard, 8½" x 11" or larger, sixteen strips of black cardboard, ⅜" x 3" each, eight small paper fasteners.

Convergence and divergence near the surface produce *vertical air motion* in the central regions of pressure systems. In Lows, the convergence forces the air upwards; in Highs, divergence causes sinking of air (see Figure 4.28). Ascending air experiences expansion because the pressure decreases with increasing height, while descending air experiences compression. Expansion of the air lowers the temperature, even though no heat is lost. Conversely, compression raises the temperature. Such *temperature changes* are said to be *adiabatic* and occur with vertical motion only, because the pressure decrease upward is 10,000 times as great as in the horizontal direction.

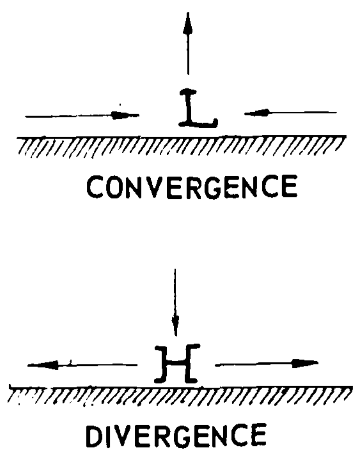


Figure 4.28

Adiabatic heating can be demonstrated with a bicycle or car tire pump. Holding a finger airtight over the pump nozzle, we rapidly pump 5 to 10 times and note how the pump cylinder gets warm. The cooling of expanding air can be shown by feeling the air let out from an inflated football, bicycle tire, etc.; this cooling is usually sufficient to indicate a temperature drop on a thermometer held into the escaping air stream.

When the temperature drop of ascending air is large enough to cause saturation, clouds will form. Thus clouds and precipitation are always connected with upward motion of air. By contrast, the temperature of subsiding air increases, and therefore its relative humidity decreases, so that any clouds present will evaporate. This explains the generally "bad" weather connected with Lows and the "good" weather connected with Highs.

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Film

The Inconstant Air—McGraw-Hill Films, 330 West 42nd St., New York, N. Y. 20036.

ATMOSPHERIC STABILITY

Major Topics Discussed In This Section

Stable Air: potentially warm aloft—no vertical motion; fog, haze, stratus-type clouds, steady precipitation.

Unstable Air: potentially cold aloft—vertical motion; good visibility, cumulus-type clouds, showers, thunderstorms.

Pollution: temperature stratification effects upon air pollution.

Stable and Unstable Air

The vertical decrease of pressure does not usually produce an upward wind because of the counterbalancing influence of gravity. However, occasionally there are relatively strong upward and downward motions which are governed by the temperature distribution in the vertical, rather than by the pressure distribution. Because vertically moving air changes temperature adiabatically, we must compare air at the same level in order to determine whether the air aloft is warmer and therefore lighter, or colder and therefore heavier than the air below. In other words, we must bring two air samples to the same height; this is done by increasing the temperature of the higher air by 5½ F for every 1,000 ft. altitude difference. For example, if the air temperature at the ground is 50 F and the air at 2,000 ft. height is 43°F, the air at 2,000 ft. height is potentially warmer than the air at the ground, because if we bring that air down to the ground its temperature would be $43 + (2 \times 5\frac{1}{2}) = 54$ F.

If the potentially warmer (lighter) air lies above potentially colder (heavier) air, the air is said to be *stable*. If, however, the air aloft is potentially colder than the air beneath it, the air is said to be ***unstable***. The difference between these two conditions is the fact that vertical motion of air is suppressed under stable, but facilitated under unstable, temperature distributions. When the temperature aloft is actually (not only potentially) warmer than the air beneath it, as, e.g., when the temperature at the ground is 50°F and 200 ft. it is 55°F, a very stable condition, called *inversion*, exists.

Stability or instability of the air is an important characteristic that determines what kind of weather phenomena may occur. For example, cumuliform clouds, thunderstorms and shower-type precipitation occur in unstable air, whereas stratiform clouds, steady precipitation and fog occur in stable air. Upward motion in stable air, caused by convergence or upslope flow, is very slow and operates over large areas. In unstable air, upward motion is rapid and localized.

Effect of Temperature Stratification on Air Pollution

In industrial or metropolitan areas, air pollution may become quite serious under stable conditions, especially inversions, because vertical currents are absent. Under unstable conditions, these currents mix the polluted air near the ground with cleaner air from aloft. The conditions of stable and unstable temperature stratifications can be demonstrated with the following model (see Figure 4.29).

We cut the top out of a 4" diameter tin can, then cut a ring about 2" wide from the can wall. The rest of the can should be trimmed to a height of 2½" to 3". Into this we fit a transparent sheet of plastic rolled into a cylinder, 24" long. The cylinder is tightly taped to the tin can, and the ring is taped to the top of the cylinder for reinforcement. The seam of the cylinder is also taped together. About 10" from the bottom of the cylinder we punch a hole through the seam and insert an 18" piece of rubber tubing, the end of which should reach to within an inch from the inside bottom of the tin can. The tubing is taped to the cylinder at the entrance hole.

Now we fasten two thermometers to a ⅜" dowel rod about 30" long, so that when the rod rests on the bottom of the can, the lower thermometer bulb is about 2" from the bottom, the upper thermometer bulb 2" from the top rim of the cylinder. The rod with the thermometers is held in the middle of the cylinder by a 7" piece of wire wound around the rod and hooked and taped over the cylinder edge. The entire assembly is then placed in a larger tin can and held in place by string, rubber bands, paper clip and nail, as shown in Figure 4.29.

We now pour a slush of crushed ice and water between the outer and the inner can and read the thermometers after about 5 minutes. 1. What is this stratification called? (Inversion.) 2. Is it stable or unstable? (Stable.)

We gently blow some smoke through the rubber hose into the bottom of the cylinder until it fills

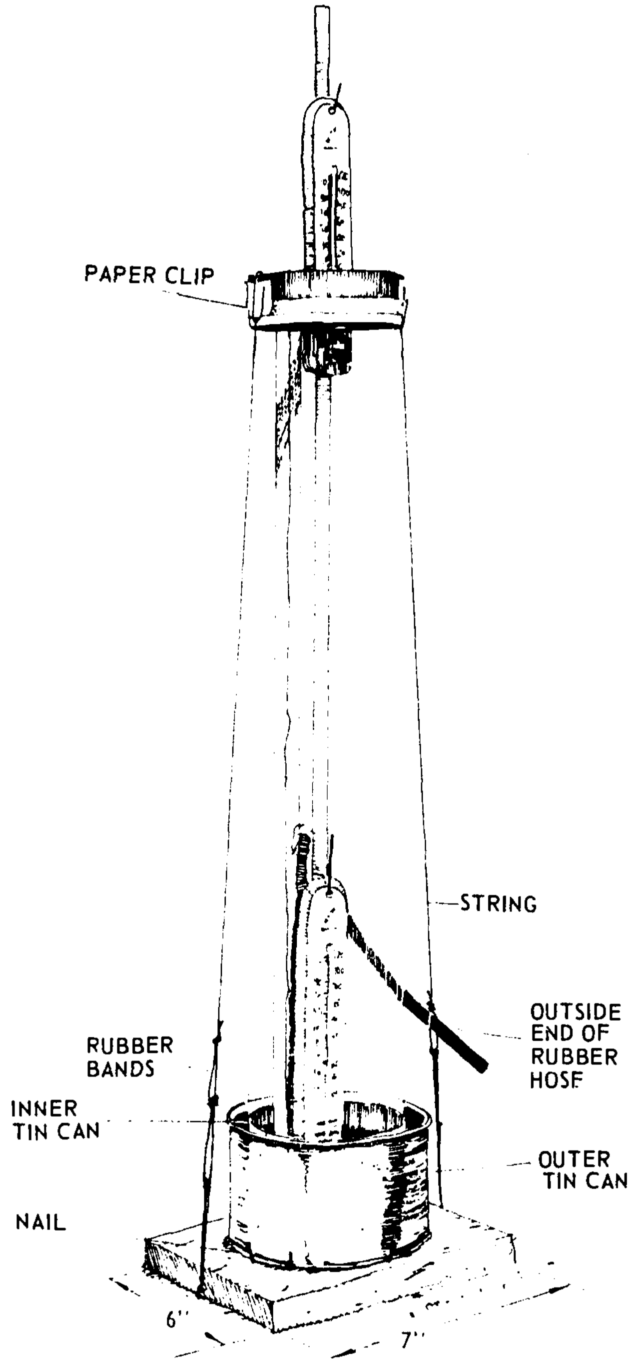

Figure 4.29

about ⅓ of the cylinder. This smoke will stay there. 3. Why? (Because the air is very stable.) Now we empty the outer can without disturbing the cylinder and pour very hot water into the outer can. Read the temperatures every minute and observe carefully the development of instability and the attendant behavior of the smoke. Note how columns of heated air intermittently push upward, until the smoke emerges from the top of the cylinder.

Material: Two equal thermometers, a sheet of transparent plastic 13" x 24", ⅜" dowel rod, 30" long, one tin can 4" diameter, 6" high, one tin can 5" diameter or more, 2" to 3" high, stiff wire, 7" long, two paper clips, 4 ft. of string, two rubber bands, piece of wood ¾" x 6" x 7", six nails, tape, 18" of thin rubber hose, ice water and hot water.

Any process that warms the air near the ground promotes instability; thus radiational heating of the ground during daytime tends to make the air unstable and to produce vertical currents. On the other hand, at night when the ground cools by radiational heat loss the air becomes cold near the ground, while the air aloft remains relatively warm, producing stable conditions. For this reason, air pollution is more noticeable at night and early morning than in daytime.

SEVERE WEATHER

Major Topics Discussed In This Section

Thunderstorms and Thunderstorm Electricity
Tornadoes
Hurricanes

Can you describe a thunderstorm? Tornado? Hurricanes?

Most severe weather phenomena are a manifestation of atmospheric instability of great magnitude, especially when the air in the low levels is very warm and moist.

Tornadoes (Twisters) are the most violent and destructive storms. These whirlwinds have a diameter that rarely exceeds ¼ mile, but the wind speeds are on the order of several hundred miles per hour. More tornadoes occur in the U. S. A. than in all other countries combined. Great instability of the lower atmospheric layers is one of the prerequisites of the formation of tornadoes. By imitating natural conditions, we can make a working model of a miniature tornado (see Figure 4.30). For this we must provide the following: 1. A system of very unstable air, i.e., one in which the air is very warm at the bottom and relatively cold at the top. This is achieved by heating the air from below; the resulting convection is increased by having the heated air rise through a chimney. 2. A means of imposing a rotating motion on the rising air; this is done by guiding the cold air entering the system to force the hot air up the chimney. 3. A source of steam to make the whirl visible as the cloud-funnel does in nature.

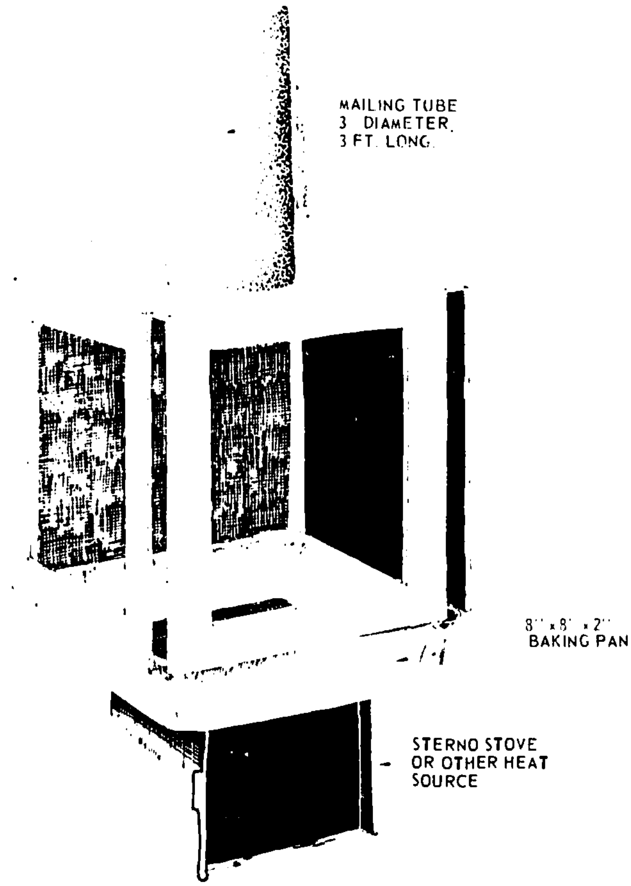

Figure 4.30

The model consists of a square pan (in which water is heated) and a cubic box (without a bottom) on top of it. Two adjacent sides of the box have windows, one through which light shines, the other for observing. On the right-hand side of each of the four box sides are slots; the width of the slots is about $\frac{1}{16}$ of the side length of the box. The top of the box is as large as the top of the pan and has in the center a hole, the diameter of which is ⅓ of the side length. Over this hole a chimney 2½ to 3 feet long is placed, having a diameter slightly larger than that of the hole.

The model described here is built around a square baking pan 8" x 8" and 2" deep. The box is made of masonite, sheet metal or thin plywood. Needed are the five sheets shown with their dimensions in Figure 24. To attach the sides to the top, glue, nail, or screw four strips of wood about ¾" x ¾" x 6" to the underside of the top sheet (bottom of Figure 4.31). Paint the inside surfaces of the box with flat-black paint. The sides are fastened to the top so that the two windows are next to each other and that there

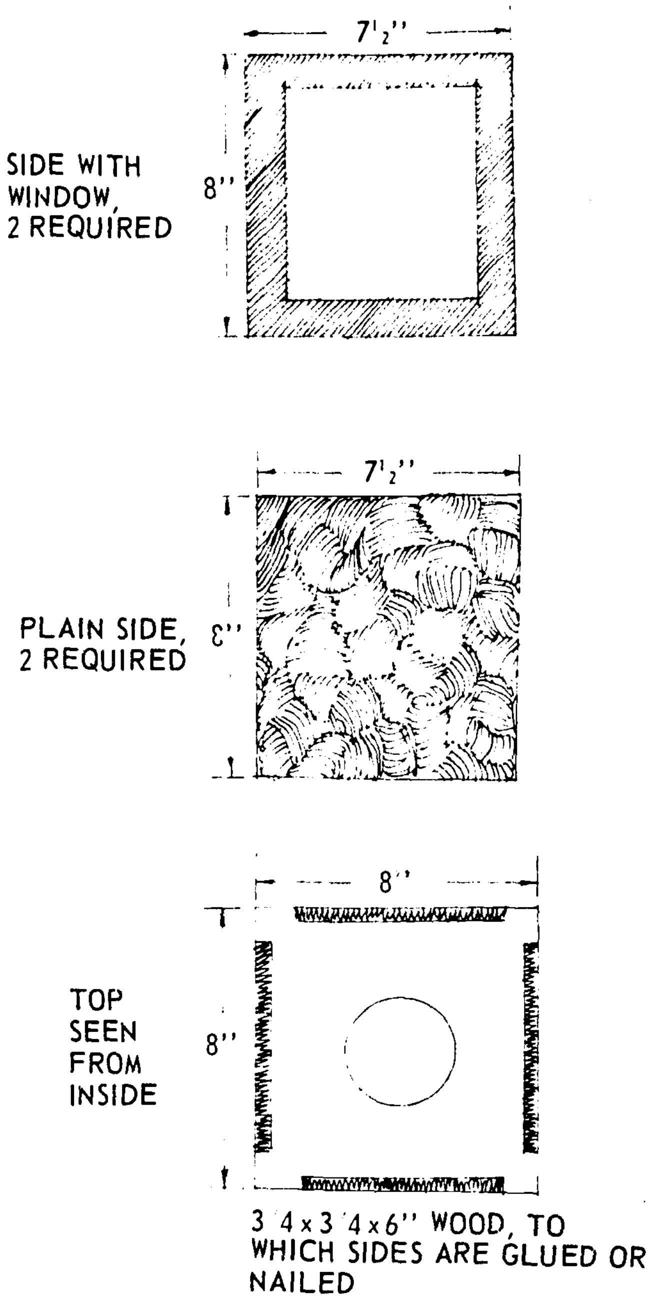

Figure 4.31

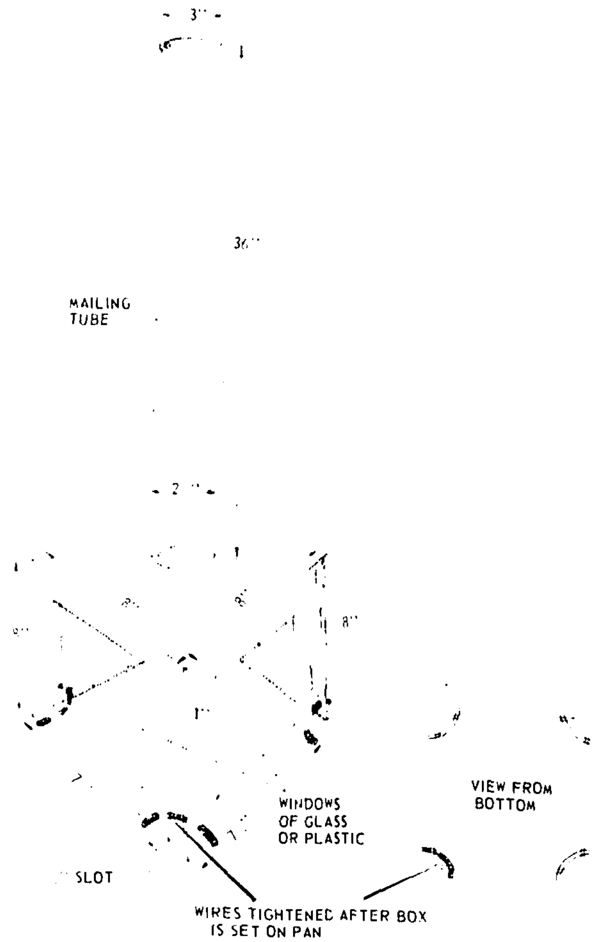

Figure 4.32

is a ½" slot on the right-hand side of each of the four sides as shown in Figure 4.32. About ⅜" above the bottom edge of each side, punch or drill a small hole about 1" from the left end and another hole about ⅜" from the right end. Four pieces of stiff wire, each 2½" long, are pulled through the holes across each corner as shown in Figure 4.32. Set the box on the pan so that the rim of the pan is inside the box and the wires rest on the pan corners. Press the wire ends tightly against the box sides and pull them while bending, so that the box sits fast on the pan. Then glue or tape sheets of transparent plastic or thin glass over the cut-out area of the window frames.

The chimney is fastened to the box top with glue or tape. There should be no air leaks between chimney and box, between sides and top of the box, and between the box and the pan, so that the air can enter the box only through the slots.

Fill the pan through a slot with hot water to within ½" from the rim and place the model on a hot plate, sterno burner, or other heat source. A small electric immersion heater can also be used. The water should be heated until ample steam develops, but it should not boil. Have a bright light shine through one of the windows and observe through the other. We can make the steam better visible by blowing smoke into the box.

1. What do you observe? 2. What are the directions of the motions? 3. Why does smoke make the steam more easily visible? 4. What motion do you ob-

serve on the water surface? Why? (The motion of the water can be made better visible by blowing a small amount of fine ashes or chalk dust onto the water.)

Answers: 1) A miniature tornado forms. 2) The whirl is counterclockwise. 3) Smoke furnishes condensation nuclei on which more steam can condense. 4) The water surface slowly develops a counterclockwise motion also, because the whirling air drags it along.

Material: Four sheets of masonite 7½" x 8" one sheet of masonite 8" x 8", one baking pan 8" x 8" x 2", two sheets of clear plastic 6" x 6½", one 3" x 36" mailing tube, four pieces of stiff wire, each 2½" long (paper clips), four strips of wood (molding) about ¾" x ¾" x 6", flat-black paint, glue (waterproof), short nails or screws, tape, a light source and a heat source.

Explain what causes a hurricane. A thunderstorm.

Hurricanes are tropical storms that can be thought of as large collections of showers and thundershowers, usually arranged in bands spiraling about a central eye. The heating from below is accomplished by warm seas and a substantial amount of latent heat of condensation released in the atmosphere. Hence, hurricanes form over the tropical oceans in late summer and fall when the seas are warmest. The eye is usually a few miles in diameter, and winds from 50 to 200 miles per hour may extend over a radius of 100 miles or so.

Electric discharges connected with *thunderstorms* are the result of production of electric charges by collision of cloud elements and subsequent separation in the strong vertical currents within the thundercloud. When the electrical potential is sufficiently great, a giant spark, having a current of thousands of amperes, occurs within the cloud or between the cloud and the ground. This current heats the air to some 30,000 degrees; the explosive expansion of the air column through which the lightning passes causes a shockwave that we call thunder.

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Film

Tornado—Available from local Weather Bureau Office, Environmental Science Services Administration.

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For additional reference reading, write for *An Annotated Meteorological Bibliography for Secondary Schools*, U. S. Department of Commerce, Weather Bureau, Washington, D. C., to the Superintendent of Documents, U. S. Government Printing Office, Washington D. C. 20402.

Selected publications on weather by the Superintendent of Documents, U. S. Government Printing Office; includes pamphlets on clouds, floods, hurricanes, lightning, winter storms, thunderstorms, and tornadoes.

General Films

Above the Horizon—American Meteorological Society, distributed by United Films, Inc., 221 Park Avenue South, New York, N. Y. 10003.

The Unchained Goddess—American Telephone and Telegraph Co. at local telephone office.

In addition, many other good films can be obtained through: The American Meteorological Society, 45 Beacon St., Boston, Massachusetts. Environmental Science Services Administration, Weather Bureau (contact local office), National Film Board of Canada, 680 Fifth Avenue, New York, N. Y. 20019.

The Exploration of Space

INTRODUCTION—THE IMPORTANCE OF SPACE SCIENCE INFORMATION IN SCHOOL CURRICULA

The exploration of space affects your life today. It will continue to affect your life more and more as time goes on. Man's activities in space affect your thinking, your reading, your conversation and many facets of everyday life.

Space exploration is a consideration in national and world politics and has also affected the trends of science. It is rewriting today's textbooks.

It is probable that you come into almost daily contact with some product or byproduct which is the result of space research. Drawing broadly from all fields of science and engineering, space technology offers promise of uncovering a flood of new benefits for mankind.

"If there has been a *single* factor responsible for our success over the past two hundred years, it has been the characteristic American confidence in the future. America's commitment to the exploration of space for peaceful purposes is a firm commitment. We will not retreat from our national purpose. We will not be turned aside in our national effort by those who would attempt to divert us. Our national purpose in space is peace—not just prestige."—President Lyndon B. Johnson.

The U.S. Space Program, undertaken in 1958, was accelerated because three Presidents and the Congress considered it basic to our national strength and essential to our continued leadership of the free world. Some of the major reasons why we entered the space program are the necessity that we retain unquestioned preeminence in all areas of science and technology, including space, the demands of national security, the potential economic benefits of space technology, the anticipated new scientific knowledge which exploration of space would yield, and finally, the stimulating effects of this challenging national enterprise on all segments of American society.

For the first time in the history of man the opportunity to leave the earth and explore the solar system is at hand. However, viewed in man's terms of time and distance, the challenge of space exploration might seem insurmountable. Yet one has only to review the technological accomplishments of mankind in the 20th century and the "impossible" becomes merely "difficult".

Space does not submit readily to conquest. The exploration of space is following the pattern by which man mastered flight within the atmosphere, each new development providing a platform from which to take the next step and each step an increment of scientific knowledge and technological skill.

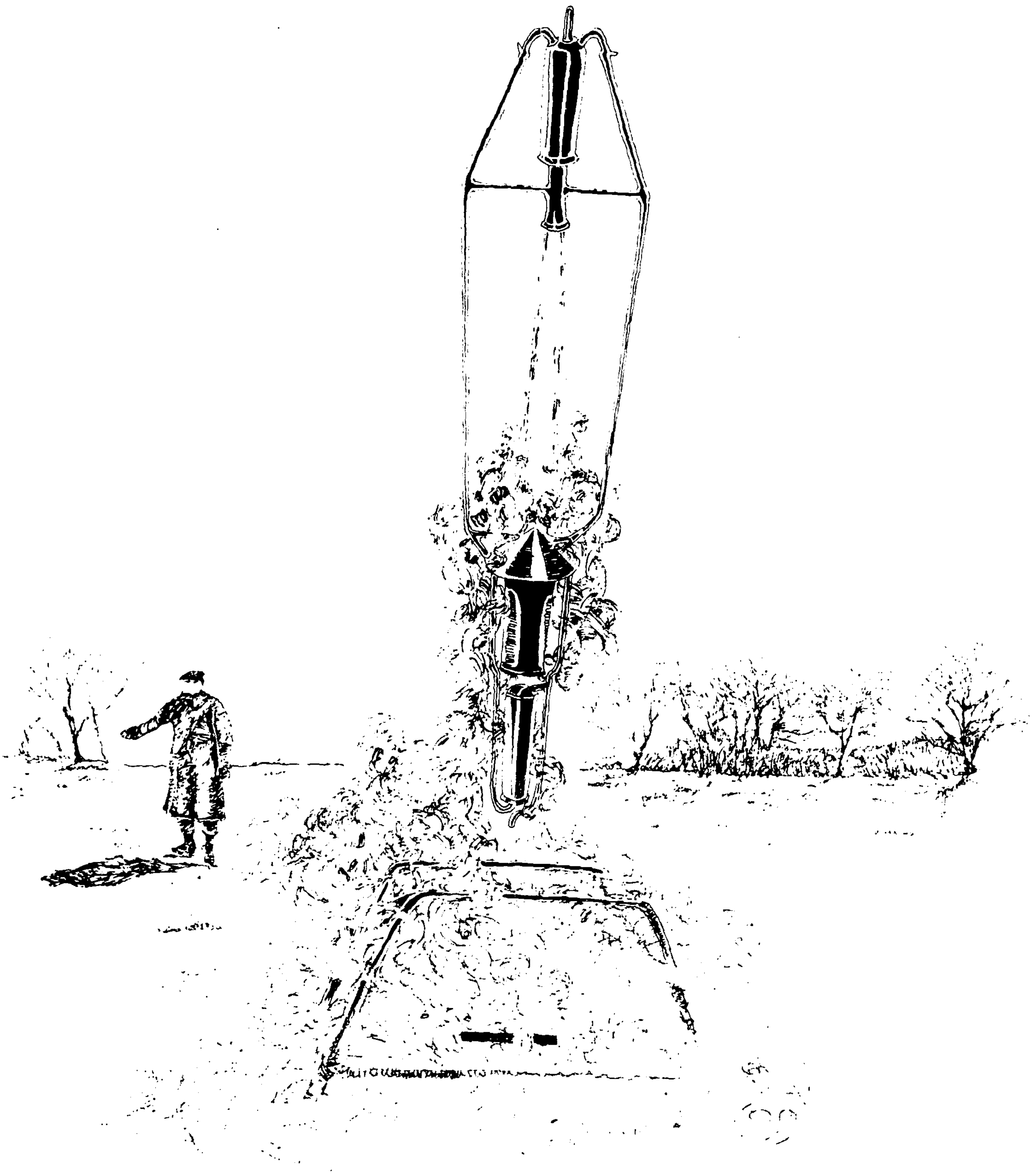
The first goal is the exploration of our own solar system. This in itself is an assignment of awesome dimensions. There are no plans at present for exploration beyond our solar system. Perhaps only dreams exist. Tomorrow, who is to say these dreams of today will not be realized.

The youth of America are enthusiastically interested and vitally concerned in aeronautics and the exploration of space. It is the responsibility of our schools to transmit the new knowledge flowing from the space program to our students. Their excitement and interest in this *unique* national research effort should be used to motivate teaching. We hope teachers will also be stimulated to explore the many avenues available to them.

Our space programs are far reaching in their effect upon our world. The educational "fallout" from the programs has significant implications for our schools and for all of our students.

FIELDS OF STUDENT INVESTIGATION

- The Early History of Space Flight
- Satellites and Space Probes
- Manned Space Exploration
  - Problems of Man in Space
  - Project Mercury
  - Project Gemini
  - Project Apollo
- The Next Decade in Space



THE EARLY HISTORY OF SPACE FLIGHT

The idea of traveling to a distant world developed as an understanding of the universe and the solar system evolved. In 160 B.C., a part of "Cicero's Republic", entitled "Scipio's Dream", presented a conception of the whole universe. Lucian of Greece wrote his Vera History in 160 A.D. This was the story of a flight to the moon. With the renaissance of science and the work of Copernicus, Kepler, Newton, and Galileo, men's minds turned once again toward the thought that traveling to other worlds might be possible. Such writers as Voltaire, Dumas, Jules Verne, Edgar Allen Poe, and H. G. Wells filled books with tales of space travel. Today one has only to pick up any magazine or newspaper to find similar stories.

The history of rocket development is also interwoven with evolving ideas of the universe and space travel. It is only with the evolution of the rocket that space travel was possible. The following chronological events lead to our present state-of-the-art:

1) We know the rocket is an ancient device and when the first rocket was fashioned remains a secret of the past.

2) The earliest known direct ancestor of our present day rockets was a Chinese invention. In 1232 A.D., at Kai-fung-fu, China, the Chinese repelled attacking Mongols with the aid of "arrows of flying fire". This was the first recorded use of rockets.

3) By 1258 rockets had traveled to Europe. They are mentioned in several 13th and 14th century European chronicles.

4) In 1379, a crude powder rocket destroyed a defending tower in the battle for the Isle of Chiozza. This was during the third and last Venetian-Genovese war of the 14th century.

5) The early 19th century brought a period of intense interest in the military rocket. Great Britain's Sir William Congreve developed a solid-propellant rocket which was used extensively in the Napoleonic Wars and the War of 1812. The "rocket's red glare" in the "Star Spangled Banner" was created by Congreve's rockets fired by the British during their siege in 1814 of Fort McHenry near Baltimore.

6) The most useful outgrowth of the Congreve rocket during the 19th century was a lifesaving rocket first patented in Britain in 1838. This device carried a line from shore to a stranded vessel, enabling the distressed crewmen to be pulled back to shore on a breeches buoy.

7) Almost a century passed before rocketry advanced further. In 1903, a Russian schoolteacher, Constantin Tsiolkovsky, published the first treatise on space travel advocating the use of liquid fuel rockets. This paper remained unknown outside Russia, and for many years was ignored by the Russians.

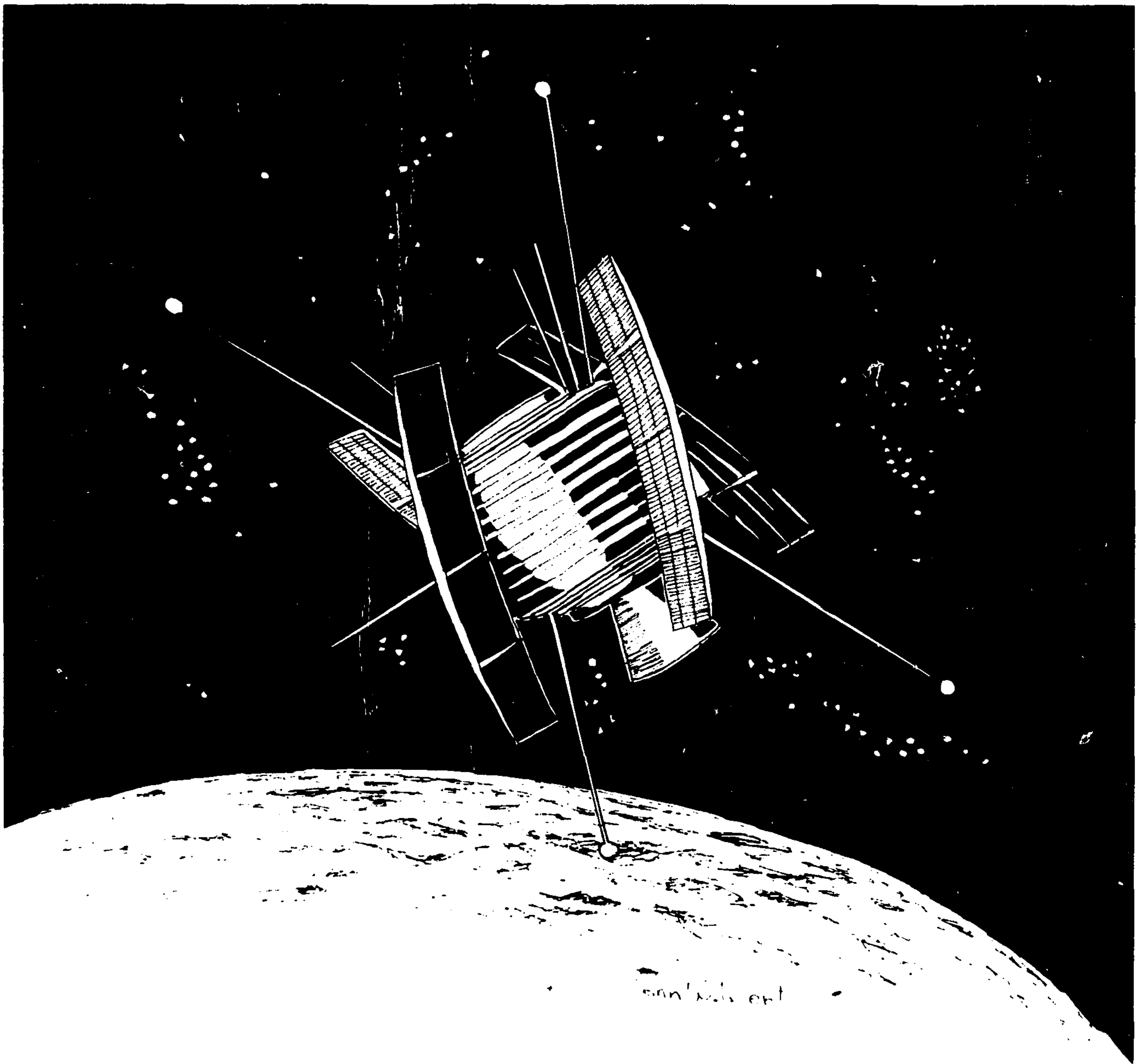
8) Robert H. Goddard, an American, and Hermann Oberth, a Rumanian-German, working separately laid the foundation for modern rocketry. Professor Oberth provided the chief impetus for experimental rocket work in Germany when, in 1923, he published his book, "The Rocket Into Interplanetary Space." Professor Oberth discussed many problems still faced by rocket scientists and explained the theories and mathematics involved in lifting an object from earth and sending it to another world. The inspiration for the formation of the German Society for Space Travel (Verein fur Raumschiffahrt) came from Hermann Oberth's book. Both Oberth and Goddard favored the liquid-fuel rocket. Dr. Goddard, a professor at Clark University in Massachusetts, sent a finished copy of a 69-page manuscript to the Smithsonian Institution in 1919 as a report on the investigations and calculations that had occupied him for several years. This paper entitled, "A Method of Reaching Extreme Altitudes," caught the attention of the press because of a small paragraph on the possibility of shooting a rocket to the moon and exploding a load of powder on its surface.

Almost simultaneously with the publication of this paper, Dr. Goddard concluded that a liquid-fuel rocket would overcome some of the difficulties he had encountered with pellets of powder.

For the next 6 years, Dr. Goddard worked to perfect his ideas. By 1926 he was ready for an actual test flight, and on March 16 launched the world's first liquid-fuel rocket. The flight to an altitude of 184 feet proved that this type of rocket would perform as predicted.

Dr. Goddard launched the first instrumented rocket on July 17, 1929, with a barometer, a thermometer, and a small camera focused to record the instrument readings at maximum altitude. Through continual improvement, his rockets by 1935 reached 7,500 feet and speeds of over 700 mph. By the late 1930's Dr. Goddard was recognized as probably the world's most foremost rocket scientist.

9) After World War II, the United States experimented with captured German V-2 rockets to



advance its knowledge of liquid rocket technology. On February 29, 1949, United States experimenters at White Sands, New Mexico, launched a V-2 with an American-developed WAC-Corporal second stage to a record 244-mile altitude. The Aerobee and Viking sounding rockets were also developed for high altitude scientific experiments. The post-war development of missiles produced several types that could be adapted to space missions. Among these were Jupiter, Thor, Atlas, and Redstone.

10) By 1955, the United States and the Soviet Union had initiated programs to launch satellites for the International Geophysical Year (IGY) to take place from July 1957 through December 1958. In the IGY, the world's scientists cooperated to learn more about the earth, sun, and solar-terrestrial relationships.

11) On October 4, 1957, the Soviet Union launched the world's first artificial satellite, Sputnik I, into orbit. On January 31, 1958, the United States launched its first satellite, Explorer I. And the space age had started.

SATELLITES AND SPACE PROBES

There are three main types of satellites: scientific, application, and unmanned lunar and interplanetary. Space probes, such as sounding rockets, are not satellites because they do not attain earth orbit, however, they are included here since they usually carry on-board experiments which parallel those found on satellites.

Scientific Satellites

These satellites are designed to gather scientific data about such things as cosmic rays, air density, meteoroids, radiation fields, temperatures, and other information about the earth's upper atmosphere and outer space.

EXPLORERS—Explorer I, launched February 1 1958, was this nation's first satellite. This series comprises the largest group of satellites in the United States program. Explorer I made one of the most significant contributions to the Space Age when its data confirmed the existence of the previously theorized Van Allen Radiation Region.

VANGUARD—Project Vanguard was inaugurated as part of the American program for the IGY. Vanguard had more than its share of problems. The launch vehicle—also known as Vanguard—had not been perfected prior to the start of the program and often blew up on the pad or shortly after liftoff. The first successful Vanguard (I) weighed three pounds and went into orbit on March 17, 1958. Data from Vanguard I showed that the earth was slightly pear shaped and provided information on the composition of the upper atmosphere. It transmitted radio signals from a 2,000 mile orbit for more than six years. Though silent today, Vanguard I will continue to orbit the earth every 134 minutes for an estimated 200 years, making it the oldest satellite in orbit.

Vanguard II, a 20-pound device designed to examine weather conditions, was launched on February 17, 1959. The last of the series, Vanguard III, was orbited September 18, 1959 and mapped the earth's magnetic field. Although plagued by failure this pioneering effort set the stage for future satellite research and development.

OAO—The Orbiting Astronomical Observatory carries a telescope to view the universe unhampered by the earth's atmosphere. The 3600-pound satellite measures 9 feet high by 16 feet wide.

OSO-AOSO—The Orbiting Solar Observatory weighs 540 pounds and permits study of the sun and its activity from a vantage point above our hazy atmosphere. Two OSO satellites launched March 7, 1962 and February 3, 1965 provided data about solar X-ray and gamma rays as well as solar flare activity. The Advanced Orbiting Solar Observatory is a more refined version of the OSO and will continue the program of gathering information about the sun.

OGO—The first Orbiting Geophysical Observatory was launched September 4, 1964 and discovered that the solar wind makes up a large percentage of the Van Allen radiation belts. All on-board experiments are related to the gathering of data about the environmental conditions of the upper atmosphere and outer space.

IMP—The Interplanetary Monitoring Platforms, sometimes called the Interplanetary Explorer Satellites, provide data on radiation and magnetic fields between the earth and moon. The first of a series of seven, named Explorer XVIII and launched November 26, 1963, discovered a high-energy radiation area beyond the Van Allen belt.

PEGASUS—The Pegasus series of satellites gathered information on the number and size of meteoroids in near-earth orbit, data vital for the design of manned spacecraft.

DISCOVERER Even though a military satellite program, Discoverer is mentioned here because they have provided valuable data about radiation, meteoroids, air density and aerospace medicine. A major contribution of the program was the development of the technology for midair recovery or sea recovery of packages sent from an orbiting satellite to earth.

Discoverer I, launched February 28, 1959, was the first U. S. satellite sent into a polar orbit. Discoverer 14 demonstrated for the first time that a returning satellite could be recovered in midair. This feat was accomplished on August 18, 1960 when a 300-pound capsule ejected from the satellite descended by parachute to an altitude of 8,000 feet where it was picked up by a C-119 "Flying Boxcar" aircraft. The Discoverer program was also a major factor in testing and perfecting the Agena rocket which was to become the reliable upper stage for a number of space science launch vehicles.

SOUNDING ROCKETS Generally speaking the sounding rockets are designed to attain altitudes of about 4,000 miles and return data by telemetry or capsule recovery. Those designed for lower altitudes may investigate geophysical properties of the earth's upper atmosphere. All these sounding rockets are designed to probe a vast region of the atmosphere too low for satellites and too high for balloons to reach. Another significant but less known purpose of sounding rockets is to flight test instruments intended for future use in satellites.

Applications Satellites

Space technology is being put to immediate use in two ways. One is to identify and make widely known the new processes and techniques which have developed from the space program that can stimulate creation of new industrial processes, methods, and products which add new dimensions to everyday living. Another involves the development of satellite systems to aid such areas as weather forecasting, communications, and navigation.

COMMUNICATIONS SATELLITES There are passive and active communications satellites, the former reflect signals, the latter transmit radio and/or television signals.

ECHO The first passive communications satellite was Echo I which was a large silver balloon. It was launched on August 12, 1960. Voice and crude television signals were bounced from the 100 foot balloon from one point on the earth to another. Echo II, launched into a polar orbit on January 25, 1964, concluded the series. Both were visible to the naked eye as they orbited the earth.

SCORE Although not an actual communications satellite, Project Score relayed the first voice from outer space two years before Echo I was launched. A tape recorder mechanism atop an Atlas ICBM in earth orbit transmitted President Eisenhower's Christmas greetings to the world in December 1958.

TELSTAR-COURIER Telstar I relayed the first telecast from the United States to Europe after being launched on July 10, 1962. It was also the first instantaneous-relay communications satellite. The experiment proved highly successful for seven months when it was silenced by radiation from the Van Allen belt. On May 7, 1963, Echo II was launched into a higher orbit to assure minimum contact with the radiation region. The technique used by Telstar was perfected two years previous by the Army's Courier communications satellite.

RELAY An active-repeater satellite like Telstar, Relay I was launched on December 13, 1962, and carried the telecast of President Kennedy's signing a bill making Sir Winston Churchill the first honorary U. S. Citizen. The second and final Relay satellite was launched on January 21, 1964, and provided the first communications satellite link between the U. S. and Japan. It also carried coverage of President Kennedy's trip to Europe in 1963 the funeral of Pope John XXIII, and the election of Pope Paul VI. Both were low altitude satellites orbiting at about 4,000 miles above the earth.

SYNCOM—After being injected into a synchronous earth orbit on February 14, 1963, Syncom I failed to operate due to electrical complications. Synchronous satellites orbit at an altitude of 22,000 miles in time with the earth's rotation, enabling the instrument package to remain relatively stationary. With this system as few as three satellites could provide complete global coverage. The second launch, July 26, 1963, was successful and Syncom II carried the first live telephone call via satellite between President Kennedy, in Washington; UN Secretary U Thant, in New York; and Nigerian Prime Minister Balewa, speaking from his African nation across the Atlantic. Four months later the same satellite carried the proceedings of President Kennedy's funeral to Europe. Syncom III was launched on August 19, 1964, and relayed the Olympic games from Japan to the U. S.

EARLY BIRD Operated by COMSAT (Communications Satellite Corporation), which is owned equally by the public and the common carriers, Early

Bird can accommodate 240 trans-Atlantic telephone conversations or a single television transmission. This is the first commercially-owned communications satellite and it was orbited April 6, 1965. Its first public television demonstration was held on May 2, 1965, and commercial service began on June 28, 1965.

LES–The Lincoln Experimental Satellite tests equipment and techniques which may be adapted for Department of Defense communications satellites. Built by the Massachusetts Institute of Technology's Lincoln Laboratory LES is carried as a "bonus" payload aboard the Titan III-C booster whose third stage has start, stop, and restart capabilities which permit changes in orbital altitude. (These satellites orbit from 1,700 to 9,000 miles above the earth.) Two of these satellites were launched on February 11, 1965, and May 6, 1965, respectively.

The MIT satellite transmits voice communications while a separate LCS (Lincoln Calibration Sphere), orbited with LES II, is being used to calibrate radio astronomy measurements.

TIROS–The Television Infrared Observation Satellite program has saved countless lives and millions of dollars' property damage through advanced warnings of hurricanes and other weather disturbances. Tiros Satellites now provide almost global coverage of weather conditions as compared to the coverage of about 25 per cent of the earth's surface at the start of the program. The first Tiros satellite was launched April 1, 1960. Since then, Tiros I and the subsequent satellites have proven to be the most effective storm detection system known.

In addition to contributing significantly to the discovery and tracking of hurricanes and other weather phenomena, Tiros satellites are providing valuable data for meteorological research which may eventually lead to long-range weather forecasts and perhaps greater understanding of how hurricanes and other destructive storms breed and how their development may be curbed. Tiros photographs are also proving useful in geology and geography, in showing the magnitude of river and sea ice, and in furnishing information on snowcover for use in predicting the extent of spring floods.

NIMBUS–Advanced equipment intended for use in future operational weather satellites is tested in Nimbus which is a research and development project. Nimbus I was launched August 28, 1964, and was the first satellite to provide both day and night pictures of the earth. Cameras provided the day pictures while a high resolution infrared observation system enabled the night photographs to be taken. Nimbus II, launched May 15, 1966, contained equipment not only for providing day and night pictures of the earth and its clouds but also for measuring the earth's heat balance. Heat balance refers to how much of the sun's radiation the earth absorbs and how much it reflects back into the atmosphere. This was the first time such information was obtained on a global basis. Study of heat balance may provide data to increase *our understanding of how storms are born,* develop, and die.

TOS and ESSA–The work of NASA's research and development program with meteorological satellites has led to the world's first operational weather satellite system, called TOS (for TIROS Operational Satellite). Financed by the Weather Bureau, a part of the Environmental Science Services Administration of the United States Department of Commerce the system is furnishing weathermen with daily pictures of the weather over nearly the entire earth. A TOS satellite is named ESSA for Environmental Survey Satellite. ESSA I was launched on February 3, 1966; ESSA II, on February 28, 1966; and ESSA III, on October 2, 1966.

ATS–The Applications Technology Satellite is designed to test promising techniques and equipment for use in future meteorological, navigation, and communications satellite systems.

TRANSIT–The Department of Defense experimental navigation satellite program called TRANSIT is designed to lead to a worldwide operational navigation-satellite system for American military ships. The operational system will position four satellites which will provide accurate data for navigational fixes on the average of once every one and three-fourths hours. Ships will know their exact position on the earth regardless of weather or time of day. The first Transit satellite was launched April 13, 1960. Several additional Transits were launched prior to July 1964, when the system was declared operational.

NAVIGATION AND AIR TRAFFIC CONTROL SATELLITE–NASA is studying a satellite system which would aid aircraft and ships in determining their exact locations regardless of weather. In operation the ship or aircraft would radio a signal to the satellite which would relay it to the ground. Computers at the ground station utilizing the satellite as a reference point would calculate the position of the plane or ship and flash this information via the satellite to the ship or aircraft. The operation would take less than a second.

NUDETS—Nuclear Detection Satellites are designed to detect man-made nuclear explosions detonated in space and distinguish them from natural phenomena such as solar radiation. The Air Force develops, launches, and controls NUDETS in cooperation with the Department of Defense and the Atomic Energy Commission. Neutron and Gamma radiation detectors are sensitive enough to detect a nuclear test conducted more than ten million miles out in space.

Unmanned Lunar and Interplanetary Spacecraft

With the exception of manned landings, unmanned instrumented spacecraft are the best means of obtaining information about the moon and other planets. The increased knowledge obtained from these unmanned probes led the way for manned lunar landings.

LUNAR ORBITER—Lunar Orbiter I, launched August 10, 1966, was the first of a series of spacecraft designed to orbit the moon and return closeup pictures and other information about the earth's only natural satellite. Lunar Orbiter II, launched November 6, 1966, continued the study of the moon in preparation for the manned landing.

RANGER—Prior to the manned landings on the moon, Project Ranger made the greatest single advance in lunar knowledge since Galileo first studied the moon more than three centuries ago. Ranger spacecraft telecast to earth 17,255 close-ups of the moon. Features as small as ten inches across on the lunar surface were visible to man for the first time. As a means of comparison, man can discern lunar objects no smaller than a half mile in size through the best telescopes on earth. Rangers VIII through IX, the last of the series, began transmitting pictures when they were only 20 minutes away from the moon and continued to transmit until crashing into the lunar surface.

SURVEYOR—Designed to land on the moon, Surveyor decelerates from a lunar approach velocity of 6,000 miles per hour to a touchdown speed of 3 and one-half miles per hour. The first landings were designed to test soft landing techniques. Each carried a single scanning television camera. Their legs were instrumented to return information on the hardness of the moon's surface. Surveyor I soft-landed on the moon's surface June 2, 1966, and telecast thousands of close-ups of its surroundings.

MARINER—This series of spacecraft is designed to fly in the vicinities of Mars and Venus and return information to earth. Of the first four launched, two successfully completed their mission. On December 14, 1962, Mariner II flew to within 21,648 miles of Venus, giving man his first relatively close-up study of the cloud-covered planet. Contact with Mariner II, now in solar orbit, was lost on January 3, 1963, when the craft was 53.9 million miles from earth.

On July 14, 1965, Mariner IV sent back the first close-up pictures ever taken of another planet as it sped by Mars at distances ranging from 10,500 to 7,400 miles. It actually came as close at 6,118 miles to Mars but took no pictures as it was on the night side. Interplanetary data was received from Mariner IV until October 1, 1965, when the spacecraft was about 191 million miles from the earth. Attempts have been made to track the craft as it orbits the sun. Mariner IV far exceeded design expectations and established new records for space communications. The following information was provided by Mariners II and IV:

1) The solar wind consisting of very hot electrified gases, rushes constantly from the sun's turbulent surface.
2) The density, velocity, and temperature of the wind fluctuate with the solar cycle.
3) Solar flares increase the magnitude of the wind.
4) The wind influences the amount of cosmic radiation in interplanetary space.
5) Interplanetary magnetic fields vary directly with the magnitude of the solar wind. The wind modifies and distorts both the interplanetary and earth's magnetic fields. The wind creates interplanetary fields.
6) Micrometeoroids are far less numerous in interplanetary space than around the earth. However, no comparable concentrations around Venus and Mars are reported.
7) Reliable radio communication is possible between the earth and spacecraft over interplanetary distances.
8) Tracking data contributed to the refinement of the Astronomical Unit (AU) which is the distance from the earth to the sun.

PIONEER—Pioneer was the NASA designation of the first series of long-distance spacecraft. The most notable of the early craft was Pioneer V, launched on March 11, 1960. Radio communication was maintained until June 26, 1960, when the spacecraft was about 22.5 million miles from earth, a record for the time. Pioneer V is still in orbit around the sun.

A new series of experiments was begun with Pioneer VI on December 16, 1965. The series is designed to monitor, on a continuing basis, such phenomena as radiation, magnetic fields, and the solar wind.

VOYAGER—An advanced series of spacecraft called Voyager will study Mars from orbits around the Red Planet and from instrumented packages landed on its surface. This is the most recent of the unmanned spacecraft series.

THE GRAND TOUR—NASA plans call for the first "Grand Tour" to take place in 1977 with an unmanned spacecraft visiting Jupiter, Saturn and Pluto. The trip would take 8½ years instead of the 40 years it would take to go directly to Pluto. The saving in time would be accomplished by aiming first for Jupiter, whose enormous gravitational attraction will fling the craft toward the next planet at a greatly increased velocity. Once every 175 years the planets are lined up relatively close and along an arc which enables the space billiards game to be played. If launched in September of 1977, the spacecraft would reach Jupiter by February of 1979, Saturn by September of 1980, and Pluto in March of 1986.

A second Grand Tour would start in 1979, and would aim for Jupiter, Uranus and Neptune. Assuming a launch in November of 1979, Jupiter would be reached by April 1981, Uranus in July 1985, and Neptune in November 1988, completing the nine year trip.

These planetary roving robots will take pictures, analyze the atmosphere, determine temperatures, measure radiations and magnetic fields, and—in the case of Mars—look for evidence of life. Starting in 1971, Mariner spacecraft began to explore Mars and Venus in greater detail.

MANNED SPACE EXPLORATION

Problems of Man in Space

Since almost the beginning of civilization man has been fascinated by the thought of space travel. Not until this decade did the dream become a reality.

In order that man can live in space he must resolve certain major problems posed by the space environment. Outer space is an extremely hostile environment to say the least. Because there is practically no atmosphere there is no dispersion of light and the celestial bodies shine brightly against a black background. The heat of the sun bakes one side of the spacecraft while the dark side freezes in subzero cold.

Meteoroids are numerous in the near space around the earth. Small ones may pierce the hull of a spacecraft or the material of a space suit. Cosmic radiation streaming from the sun and other sources in the universe present a danger to man. It may modify materials so as to interfere with proper functioning of equipment and structures. Ultraviolet and X-rays, unabsorbed by an atmosphere, can rapidly deteriorate and degrade materials. All these sources of radiation can be lethal to man without suitable protection. The very high vacuum of space can produce unusual changes in ordinary materials; for example, turning rubber brittle and welding together certain separate items. It can kill a man with a damaged space suit in less than 30 seconds.

Zero g (weightlessness) causes liquids to crawl along the walls of their containers, causing problems in storage and the pumping of water, liquid oxygen, and nitrogen for cabin atmosphere, and liquid propellants. It must also be known whether prolonged conditions of weightlessness will upset delicate biological processes, impair the function of vital organs, and have any adverse effects upon man's capabilities for performing his mission in space. With relatively short flights that have been made to the moon and back these have not proven to be major problems.

Support of life in space poses certain problems which bear a resemblance to those of submarines designed for long submerged periods. Tests must be made to determine how man will react to the isolation of long space flights. Systems must be developed to purify water and air for reuse, provide food, and waste disposal. Studies are being conducted to develop food which is compact, lightweight, nutritious, palatable, and morale-supporting while requiring neither heating nor refrigeration.

Space suits and spacecraft had to be developed that would protect man from the high vacuum, temperature extremes, small meteoroids, radiation, and other space hazards.

The reason for man in space is relatively simple, no computer can be programmed to report on the unknown. They can only be programmed to report on what we know or expect to find. The judgment and observation of man is needed to augment, interpret, and enrich the data gathered by instruments. It has also been shown that man increases the reliability of spacecraft. When automatic instruments malfunctioned the men in control managed to save the spacecraft, themselves, and generally the mission.

Project Mercury

This pioneering effort was organized on October 5, 1958, to orbit a manned spacecraft, investigate man's abilities and reaction to space flight, and recover both man and spacecraft. This was Project Mercury.

One of the outcomes of Project Mercury was that it was shown that the high gravity forces of launch and reentry and weightlessness in orbit for as much as 34 hours did not impair man's ability to control a spacecraft. It proved that man not only augments the reliability of spacecraft controls but that he can also conduct scientific experiments and observations that expand and clarify information obtained from instruments.

Mercury has confirmed that man can consume food and beverages while weightless, if they are in suitable containers such as squeeze tubes. The project also laid a firm foundation for the technology of manned space flight.

The first American rocketed into space was Astronaut Alan B. Shepard, Jr., on May 5, 1961. Atop a Redstone rocket launched from Cape Canaveral (now the John F. Kennedy Space Center), Florida, his Mercury spacecraft reached an altitude of almost 115 miles and a top speed of approximately 5000 miles per hour during a suborbital flight of slightly more than 15 minutes. Recovery was made about 302 miles downrange from the Cape. The first American to orbit the Earth was Astronaut John H. Glenn, Jr. Launched by an Atlas booster his Mercury craft orbited the earth three times on February 20, 1962. During the flight his orbital altitude ranged from 86 to 141 miles at a speed of about 17,500 miles per hour.

Table 5.1 gives some features of these and other Mercury flights.

Project Gemini

The Gemini Project extended the technology and experience gained through Project Mercury and vastly increased our knowledge about space, earth, and man. The last of the series, Gemini XII, was completed on November 15, 1966. In achieving all of its major objectives the project has demonstrated that man can:

1) Maneuver the craft in space.
2) Leave the spacecraft, survive, and do useful work in space provided he is properly clothed and equipped.
3) Rendezvous and dock his craft with another vehicle in space.
4) Function effectively in space for a period of two weeks and return to earth in good physical condition.
5) Control the spacecraft during its descent from orbit and land it within a selected area.

Photographs of earth and its cloud cover taken from the orbiting Gemini craft have provided a wealth of information for oceanographers, meteorologists, geologists, and geographers. Medical data on the astronauts, taken before, during, and after the Gemini flights has advanced medical knowledge on how the human body functions.

Table 5.2 gives information on the Gemini Flights.

HIGHLIGHTS OF MANNED MERCURY FLIGHTS

Astronaut	Date	Flight Time*	Orbits	Spacecraft Name
Alan B. Shepard, Jr.	5/5/61	00:15:22	Suborbital	Freedom 7
Virgil I. Grissom	7/21/61	00:15:37	Suborbital	Liberty Bell 7
John H. Glenn, Jr.	2/20/62	04:55:23	3	Friendship 7
M. Scott Carpenter	5/24/62	04:56:05	3	Aurora 7
Walter M. Schirra, Jr.	10/3/62	09:13:11	6	Sigma 7
L. Gordon Cooper, Jr.	5/15, 16/63	34:19:49	22	Faith 7
Totals		53:55:27	34	

* Hours:Minutes:Seconds

MANNED GEMINI FLIGHTS

Spacecraft	Pilots	Date(s)	Flight Time*
Gemini III	Grissom-Young	Mar. 23, '65	04:53:00
Gemini IV	McDivitt-White	June 3-7, '65	97:56:11
Gemini V	Cooper-Conrad	Aug. 21-29, '65	190:56:01
Gemini VI	Schirra-Stafford	Dec. 15-16, '65	25:51:24
Gemini VII	Borman-Lovell	Dec. 4-18, '65	330:35:13
Gemini VIII	Armstrong-Scott	Mar. 16, '66	10:42:06
Gemini IX	Stafford-Cernan	June 3-6, '66	72:20:56
Gemini X	Young-Collins	July 18-21, '66	70:46:45
Gemini XI	Conrad-Gordon	Sept. 12-15, '66	71:17:08
Gemini XII	Lovell-Aldrin	Nov. 11-15, '66	94:34:30

* Hours:Minutes:Seconds

Project Apollo

The Apollo program is the largest and most complex of the manned space flight projects. Its goals are to land astronauts on the surface of the moon and bring them back safely and to establish the technology to meet other National interests in space.

The Apollo program consisted of unmanned flights, manned flights in earth orbit, a lunar orbital flight and finally, lunar landing missions.

The first manned launch of the Apollo program took place on September 26, 1968. Astronauts Walter Schirra, Don Eisele, and Walter Cunningham were placed in earth orbit by a Saturn IB rocket. Apollo 7 splashdown took place in the Atlantic, south of Bermuda, on October 22, 1968, the crew being picked up by the Carrier Essex.

Apollo 8 was the first manned flight for the Saturn V rocket and was launched December 21, 1968. Astronauts Frank Borman, James Lovell, and William Anders orbited the moon ten times and returned to earth on December 27, 1968.

March 3, 1969, the Apollo 9 mission began with the Saturn V lifting Astronauts James McDivitt, David R. Scott, and Russell L. Schweickart into earth orbit for a ten day mission. One of the principal objectives of the flight was to test the lunar landing module in space. At the successful completion of the mission the capsule splashed down on March 13, 1969.

Apollo 10 was an eight day mission to encompass all aspects of an actual manned lunar landing except the landing. Launch took place on May 18, 1969, and a nominal 115-mile Earth-parking orbit was achieved. One and one-half orbits later trans-lunar injection occurred. The trajectory was so satisfactory that only one of four scheduled midcourse corrections was needed. About 76 hours into the mission lunar-orbit insertion occurred at approximately 69 miles above the moon. On the 12th revolution Stafford and Cernan, in the lunar module, separated from the command module and achieved a new orbit around the moon of 9.7 by 70.5 miles simulating the Apollo 11 lunar landing mission.

When the descent stage was jettisoned, in preparation for the return to the command module, an uncontrolled gyration of the ascent stage occurred. This was later attributed to an error in the flight plan checklist, resulting in an incorrect switch position. The lunar module entered an intercept trajectory and achieved stationkeeping on the 16th lunar orbit. On the 31st lunar orbit the service propulsion system was restarted while on the back side of the moon and Apollo 10 was on its way home. The 192 hour, 3 minute, 23 second flight; one minute 24 seconds longer than planned, ended with splashdown on May 26, 1969.

The historic voyage of Apollo 11 began with liftoff from the Kennedy Space Center at 9:32 a.m. July 16, 1969, from Pad 39A. On schedule to within less than a second the trip to the moon began. The primary objective of Apollo 11 was simply stated: perform a manned lunar landing and return to earth. This would complete the national goal set by President John F. Kennedy on May 25, 1961, when he stated, ". . . this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to Earth."

Strapped to their couches in the command module atop the 363-foot, 7.6 million-pound thrust Saturn V rocket are three astronauts, each of them born in 1930, each weighing 165 pounds, all within an inch of the same height five feet, 11 inches. The Commander is Neil A. Armstrong, civilian and ex-test pilot; Command Module Pilot Michael Collins, and Lunar Module Pilot Edwin E. (Buzz) Aldrin, Jr., are both officers of the U. S. Air Force.

On July 20th Armstrong and Aldrin entered the Lunar Module, made a final check, and at 1:46 p.m. (100 hours and 12 minutes into the flight) the Eagle undocked and separated from Columbia. One hour and 22 minutes later, on the 13th orbit of the moon, the lunar module descent engine was fired and the journey to the surface of the moon began. The landing was not an easy one. Seeing that they are approaching a large crater, Armstrong takes over manual control and steers the craft to a smoother spot. His heartbeat rises from a normal 77 to 156. When three of the 68 inch probes beneath the four spacecraft's four footpads touch the lunar surface, flashing a light on the instrument panel, Armstrong shuts off the ship's engine and the craft settles down with a jolt as he radios Mission Control: "The Eagle has landed." Touchdown occurred at 4:18 p.m. about 102 hours and 45 minutes into the flight, July 20, 1969, at site 2, at 0° 41′ 15″ N. Lat. and 23° 26′ E. Long. on the southwestern edge of the Sea of Tranquility.

Aldrin looking out of the window, reports: "We'll get to the details around here, but it looks like a collection of just about every variety of shapes, angularities and granularities, every variety of rock you could find. The colors vary pretty much depending on how you're looking . . . There doesn't appear to be [illegible] of a general color at all; however, it looks as though some of the rocks and boulders of which there are quite a few in the near are[illegible] going to have some interesting colors to them."

In describing the surface, he said: "It's pretty much without color. It's gray and it's a very white, chalky gray, as you look into the zero phase line, and it's considerably darker gray, more like ashen gray as you look up 90 degrees to the sun. Some of the surface rocks close in here that have been fractured or disturbed by the rocket engine are coated with this light gray on the outside, but when they've been broken they display a dark, very dark gray interior, and it looks like it could be country basalt."

Their first task after landing was to prepare the ship for launching so that all would be in readiness for the ascent and rendezvous with Columbia orbiting above.

More than five hours ahead of the original schedule, at 10:30 p.m., Armstrong opens the hatch of the lunar module and squeezes through the opening. Strapped to his back is a portable life support and communications system weighing 84 pounds on Earth, 14 pounds on the Moon. He moves slowly down the 10-foot, nine-step ladder. On reaching the second step, he pulls a "D-ring," which deployed a television camera so arranged that it will transmit to Earth his progress from that point. He pauses on the last step to report: "I'm at the foot of the ladder. The LM footpads are only depressed in the surface about one or two inches . . . the surface appears to be very, very finegrained, as you get close to it, it's almost like a powder." At 10:56 p.m., about 109 hours and 42 minutes into the mission, Armstrong puts his left foot on the moon as he announces: "That's one small step for a man, one giant leap for mankind."

This event marked the first time in history that man has ever stepped on anything that has not existed on or originated from the earth. The first print made by a man on the moon is that of a lunar boot resembling a galosh. The soles are made of silicon rubber and the 14 layer sidewalls of aluminized plastic. Specially designed as a super insulator, it also protects from abrasion. On earth it weighs four pounds, nine ounces; on the moon, 12 ounces.

After lowering a Hasselblad camera to Armstrong, Aldrin emerges from the landing craft at 11:11 p.m. and backs down the ladder while his companion takes photographs. Armstrong then trains a TV camera on a small stainless steel plaque on one of the legs of the ship and reads: "Here men from the planet Earth fi[illegible] foot on the Moon, July 1969 A.D. We came in peace for all mankind." Below the inscription are the signatures of the Apollo crew and President Nixon.

Next the first of three experiments is set up. From an outside storage compartment Aldrin removes a foot-long tube containing a roll of aluminum foil inside of which is a telescoped pole that is to be driven into the lunar surface. The foil is suspended from it, with the side marked "Sun" facing the Sun. Its function is to collect particles of the "solar wind" which blows constantly through space so that they can be brought back and analyzed in the hope that they will provide information on how the Sun and planets were formed. A three by five foot nylon flag of the United States is removed from a leg of the spacecraft at 11:41 p.m. Its top edge is braced by a spring wire to keep it extended on the windless surface of the Moon. The astronauts erect the flag on a staff pressed into the lunar surface. Taken to the Moon are two other U. S. flags which will be brought back to fly over the houses of Congress and the flags of the 50 states, the District of Columbia and U. S. Territories, the United Nations and those of 136 foreign countries.

At 11:48 p.m. the astronauts received a message from President Nixon speaking from the Oval Room at the White House. At the conclusion of the conversation they saluted toward the television camera. Armstrong begins collecting lunar rocks and soil while Aldrin sets up the two remaining experiments. One a seismic device to record moonquakes, meteorite impact, or volcanic eruption and the other a laser-reflector to make precise Earth-Moon distance measurements. After checking with Mission Control to make sure all chores have been completed, Aldrin starts back up the ladder to reenter the Lunar Module at 12:45 p.m. At 1:09 a.m. Armstrong rejoins Aldrin in the landing craft. The hatch is closed at 1:11 and they begin removing the life support systems on which they have depended for two hours and 47 minutes.

After a sleep period of about seven hours, and after a total time on the surface of the moon of 21 hours and 36 minutes, the ascent engine is fired (1:54 p.m. July 21). The Lunar Module, using the descent stage as a launching pad, leaves the surface of the Moon to return and dock with Columbia at 5:35 p.m. while circling the back side of the moon. The docking took place on the 27th orbit of the Moon by the Command Module and 128 hours and three minutes into the mission. Four hours later the Lunar Module was jettisoned and at 12:56 a.m. the Service Propulsion System was fired while the Command Service Module was behind the Moon, in its 59th hour of lunar orbit. Apollo 11 is on its way home and the astronauts sleep for about 10 hours.

The Moon crew splashes down about 13 miles from the U.S.S. Hornet at 12:51, July 24, 1969.

So ends man's first mission to the Moon. It lasted 195 hours, 18 minutes and 35 seconds, or a little more than eight days. The entire mission lasted almost 36 minutes longer than planned and was considered the most trouble-free mission to date. A success in every respect.

Apollo 12

As the time approached for the lift-off of Apollo 12 a low overcast moved in and rain began to fall. When a search plane reported that there was no lightning within 20 miles of the pad the decision was made to launch on schedule. At 11:22 a.m., November 14 1969, the giant Saturn V rocket left for the second trip to land men on the Moon. Thirty-six seconds and again at 52 seconds after lift-off the vehicle was struck by lightning. For a few heartstopping seconds telemetry ceased and then details started to come back from the Command Module. The vital inertial platform, heart of the spacecraft guidance system, was lost as all circuit breakers and overload detectors were triggered into an automatic disconnect. This dropped the entire load on the backup battery system. Within three minutes the crew had closed all the circuit breakers and overload detectors. All circuits were back in operation and the fuel cells were again on-line. The all-Navy crew of Apollo 12 had escaped disaster. Mission commander Charles Conrad, command module pilot (Yankee Clipper) Richard F. Gordon, and lunar module pilot (Intrepid) Alan F. Bean were on their way to the Moon. The course of Apollo 12 was a departure from that followed by all previous manned lunar missions. The three prior missions had flown a free return trajectory so that if the spacecraft failed to achieve a lunar orbit it would loop around the Moon and return to Earth. The location of the landing site in the Ocean of Storms made a free return trajectory impossible.

Bean and Conrad land on the surface of the Moon in the Lunar Module Intrepid on November 19, at 1:54 p.m. During the landing, Conrad manipulated the onboard computer to correct for errors which would have landed the craft five miles north of its target. A precision landing was made just 600 feet from Surveyor 3 (an unmanned spacecraft which landed on the moon in April, 1967) in the Ocean of Storms at 3° 11′ 51″ S. Lat. and 23° 23′ 7.5″ W. Long., about 120 feet northeast of Head Crater. This site was about 950 miles west of where Apollo 11 had landed.

A major objective of Apollo 12 was to deploy the Apollo Lunar Service Experiments Package (ALSEP) which consisted of a magnetometer, seismometer, lunar atmosphere detector and a SNAP 27 nuclear power generator. Conrad was the third man to walk on the Moon with Bean following shortly after. In their first lunar exploration Conrad spent three hours 39 minutes outside Intrepid while Bean logged two hours 58 minutes. As interested TV viewers watched, Bean tried to mount the TV camera on a tripod and inadvertently pointed it at the Sun. It ceased to function and as one reporter put it "Never have so many watched so few to see so little."

After a five hour sleep and a conference with Houston they were ready to return to the lunar surface. A long traverse was planned for the second Moon walk. It was on this walk that they salvaged pieces of tubing, cable, trenching scoop and the camera from Surveyor 3. The second Moon walk lasted three hours and 49 minutes.

After a total of 31.6 hours on the Moon, the Lunar Module ascent stage was fired and the Intrepid docked with the Yankee Clipper three and one-half hours later. In prior lunar missions the Lunar Module was jettisoned and placed into an orbit which would prevent its interference with future missions. This time Intrepid would be sent from orbit to impact on the Moon. Traveling at about 5,000 mph, the 5,500 lb. (Earth weight) craft struck the Moon about 45 miles from the ALSEP seismometer. The force of *impact* was about 30,000,000 footpounds. On Earth such an event would register a minor tremor for perhaps two minutes. The shock waves registered on the lunar seismometer for 55 minutes, building up to a peak at the eight minute mark and then slowly declining. The result astounded the geophysicists as the phenomenon was completely outside any Earth experience.

During the 45th revolution, after 89 hours of lunar orbit by the Command Service Module, and while on the far side of the Moon, the Service Propulsion System ignited to place Apollo 12 into a trans-earth trajectory. The return flight was uneventful except for the view of the Earth's eclipse of the sun. The Command Module hit the water 3.5 miles from the prime recovery ship Hornet at 3:58 p.m., November 24, 1969. The total flight time was 244 hours 36 minutes 25 seconds - 62 seconds longer than planned.

Apollo 13

At 2:13 p.m., Saturday, April 11, 1970, Apollo 13 and its crew (James A. Lovell, Commander; Fred W. Haise, Jr., Command Module Pilot; and John L. Swigert, Command Module Pilot) were launched from Kennedy Space Center. The premature cut-off of one of the second stage engines had to be compensated for by longer burns of the remaining engines and the engine of the third stage. Earth orbit was achieved at 2:26 p.m. with no further difficulty.

The landing site of Apollo 13 was to be different than that of Apollo 11 and 12 in that it was to be in the rugged, high terrain of the Fra Mauro region of the Moon. Because of the location of the site the course of the spacecraft had to follow a no "free return" trajectory that was first flown on the Apollo mission.

The course of Apollo 13 was so exact that a scheduled course correction was cancelled. At 8:54 p.m., Sunday, a course change was accomplished which rerouted the craft to sweep within 70 miles of the Moon rather than the 155 mile altitude of the earlier course. The change would put the Lunar Module Aquarius in the proper position for the desired landing site and also meant that they lost the free return of their previous trajectory and could only return to Earth by making another course correction.

Monday evening at 9:15 p.m. Lovell and Haise left the Command Module Odyssey and entered Aquarius for the first time. Mission Control asked them to check a helium tank that had shown a slightly high pressure on the launch pad. Lovell found that the pressure in the tank was showing a normal rise.

The two spent about an hour inside the Lunar Module telecasting their activities to Earth. Haise was still in the LM, Lovell in the tunnel between Aquarius and Odyssey holding a camera and making his way between the TV wires, and Swigert was in Odyssey. Suddenly they were startled by a loud bang. At first, Lovell and Swigert thought that Haise had released a valve, as planned, in Aquarius. But Haise, now back in the Command Module, and scanning the instruments, saw that one of the main electrical systems of Apollo 13 was deteriorating. At about 10:07 p.m., Monday, Swigert radioed the words that were to unite all mankind in a common concern: "Hey, we've got a problem here."

At a point about 205,000 miles from Earth an explosion within the Service Module started to drain all electrical power from the Command Module. Oxygen from a fuel cell tank, which was also part of the life support system, was venting into space.

An hour-and-a-half after the explosion, and with only 15 minutes of electrical power left and the oxygen supply at a dangerous level, Haise and Lovell are ordered to activate the systems of the Aquarius which will serve as their space "lifeboat". The first major problem was to maintain the integrity of the inertial guidance platform and transfer this alignment from Odyssey to Aquarius. Had the guidance platform been lost their exact position in space would not be known and course corrections for the return trip home impossible. Swigert used battery power to maintain the alignment in Odyssey alive until the alignment transfer could be made to Aquarius. It had to be done fast and it was.

There was enough water, power, oxygen and rocket thrust available in the Lunar Module to bring the crew home safely, but the LM had to function perfectly. The LM was designed to take two astronauts to the surface of the moon and return them to a rendezvous with the Command Module. It now had to return three astronauts close enough, and accurately enough, to Earth so that they could again enter the crippled Command Module for the fiery reentry through the atmosphere. The LM's descent engine had to accomplish the course correction, as the craft swings around the Moon, or they would enter deep space and be beyond any hope of survival. Fortunately the use of the LM descent engine had been practiced in space by the crew of Apollo 9 and by the present crew in simulations at the Kennedy Space Center. At 3:42 a.m., Tuesday, April 14, the critical burn was accomplished and the crew of Apollo 13 was on their way home. The prayers of the whole world rode with them and offers of assistance and best wishes came from friendly and hostile nations alike. Tuesday, April 14, the U. S. Senate adopted a resolution which urged all businesses and communications media to pause at 9 p.m., their local time, to "permit persons to join in prayer for the safety of the astronauts."

The only successful lunar experiment of the flight took place at 8:09 p.m., April 14, as the 15-ton spent third stage of the Saturn V rocket struck the Moon with a force equal to 11½ tons of TNT. It hit 85 miles west northwest of the site where the Apollo 12 astronauts had set up their seismometer. Scientists on Earth said, "the Moon rang like a bell."

The Odyssey splashed down in a routine landing at 1:08 p.m., April 17, 1970, within four miles of the U.S.S. Iwo Jima, 142 hours 54 minutes 41 seconds after launch.

Thus, the ill-fated Apollo 13 came home and the words of the President of the United States summarized the feelings of many when he said, "The three astronauts did not reach the Moon, but they reached the hearts of millions of people in America and in the world."

Apollo 14

The crew of Apollo 14, Alan B. Shepard, Jr., John L. Swigert, Jr., and Fred W. Haise, Jr., had been chosen in August, 1969 just after the first successful manned Moon landing by Apollo 11 in July, 1969. The launch of Apollo 14 was tentatively scheduled for October 1970. Its destination was to be the Moon's Littrow region.

The outcome of the Apollo 13 mission had a profound effect on the plans for Apollo 14. A board of inquiry into Apollo 13's onboard explosion called for several alterations in the Apollo spacecraft which necessitated several postponements in the launch of Apollo 14.

To lessen the chance that an explosion such as Apollo 13's could happen again, the teflon insulation covering the wiring in the service module's oxygen tanks was replaced with less flammable stainless steel sheaths. Experience with the behavior of fluids under zero-G conditions during earlier Apollo flights showed that fans to stir the oxygen in the tanks were not needed so they were removed. To insure the craft's ability to return the astronauts safely to Earth should a similar mishap take place, an extra oxygen tank was installed, plus an extra 135 pound silver-zinc emergency battery. Also added were five one-gallon bags to hold an extra supply of drinking water. These extra facilities would be enough to see the astronauts through a three-day return trip to Earth if their prime supplies should again be destroyed near the Moon.

An estimated half million persons were in or near the John F. Kennedy Space Center to watch the launch of Apollo 14. As the countdown reached its final minutes, the sky which had been slightly clouded suddenly became overcast and rain began to fall. Launch officials, obeying rules laid down after Apollo 12 was struck by lightning, called a hold in the countdown until weather conditions were more favorable. It was the first launch delay in the Apollo program. The countdown clock stopped at eight minutes and two seconds and stayed at that point for 40 minutes before the countdown resumed. The sky was still overcast but weather experts circling the launch site in airplanes said the danger of lightning had passed.

Just seconds before liftoff at 4:30 p.m. Eastern Standard Time, January 31, 1971, a second gust of rain carrying wind swept the launch site. Thirty-six seconds after Apollo 14 left its launch pad, it disappeared into the clouds.

As is standard procedure, the moment the spacecraft and rocket cleared the launch tower, responsibility for monitoring the flight and contact with the crew passed from Kennedy Space Center to Mission Control at the Manned Spacecraft Center in Houston, Texas.

By coincidence, the launch of Apollo 14 fell on the 13th Anniversary of the launching of America's first Earth satellite. It was on January 31, 1958 that the 30.8 pound Explorer I satellite was put into orbit by a Jupiter-C rocket.

In contrast, Apollo 14 went into Earth orbit weighing about 300,000 pounds, thus becoming the heaviest man-made object in Earth orbit—nearly 10,000 times as much as Explorer I.

Apollo 14 Commander Shepard was also the first American to fly through space. That first flight of the Mercury project on May 5, 1961—nearly ten years before Apollo 14—lasted only 15 minutes and 22 seconds. The flight was suborbital because Shepard's craft, Freedom 7, was not boosted into Earth orbit. The flight was an arc-like path that reached an altitude of 116.5 miles before beginning its descent and reentry. Shepard's top speed was 5,180 miles an hour and he was weightless for only five minutes.

Commander Shepard, Lunar Module Pilot Mitchell and Command Module Pilot Roosa were on their way to the Moon to conduct the most scientifically oriented mission thus far. The command module had been named Kitty Hawk and the lunar module was named Antares after the star on which the landing craft oriented itself as it headed down to the Fra Mauro region of the Moon.

The first of several problems began when Roosa detached the command module, turned it 180 degrees and tried to dock with the lunar module. This maneuver had been performed nine times before in space with no problems. But the crew of Apollo 14 had their first problem. Roosa made five attempts to dock without success. On the sixth attempt the docking latches sprang into place solving the problem for the moment, but leaving the rest of the mission in doubt.

Docking would have to be done once more at the critical time when Shepard and Mitchell would return from the Moon and connect with Roosa in the command module. Should the docking mechanism fail at this time, Shepard and Mitchell would have to "space walk" to enter Kitty Hawk. Although astronauts have "walked" through space, such a transfer has never been made in Moon orbit.

The second problem arose when Shepard and Mitchell powered up Antares in a final check before the Moon landing. A battery in the ascent stage was reading three-tenths of a volt below normal. The battery was one of two and although one battery would be sufficient, Mission Control would not permit a Moon landing without the back-up battery also functioning properly. Ten hours later another check showed that the battery had deteriorated no further and would be able to provide the required power.

The third problem arose just after Shepard and Mitchell separated from the command module, in preparation for the Moon landing. Antares' guidance computer was receiving a warning signal from the craft's abort mechanism. The computer would react to this signal upon the firing of the descent engine and would boost the spacecraft back into Moon orbit to reunite with Kitty Hawk. The defect was traced to a faulty switch and corrected.

The fourth problem was encountered as Antares swooped closer and closer to the Moon. The on-board landing radar, which controls the descent rate by continuously measuring the decreasing altitude, failed to lock on the lunar surface. Mitchell kept flicking the circuit breaker on and off when finally, at 22,713 feet, the radar came to life.

Incidents such as these serve to illustrate the advantage of manned spacecraft. Men can monitor and supersede machine decisions.

Antares made its successful Moon landing on February 5, at 4:17 a.m. after 114 hours, 17 minutes into the mission.

The astronauts were further plagued with several minor problems. As Shepard and Mitchell were ready to leave Antares for the first time, Shepard noticed that the radio in his backpack was not operating properly. The problem was traced to a circuit breaker which had been left in the wrong position.

On the surface of the Moon, the S-band antenna failed to stand properly, Moon dust was an annoyance as it clung to clothing and equipment and apparently clogged a fastener of the Suprathermal Ion Detector, and the Cold Cathode Ionization Gauge kept falling over as Mitchell tried to steady it on the uneven lunar surface.

Undaunted by these events, the astronauts were able to complete all of their assigned tasks before they crawled back into Antares.

In two separate Moon walks, Shepard and Mitchell spent a total of nine hours, 25 minutes setting up scientific experiments and exploring the Moon. A pull-cart known as the modularized equipment transporter (MET) containing tools, cameras and scientific instruments proved to be of great benefit to the astronauts.

A complete accounting of the many scientific experiments performed by the crew of Apollo 14 may be found in Science at Fra Mauro, 1971.

At 1:49 p.m., on February 6, 1971, Antares' rockets departed from the Moon to join with Roosa in Kitty Hawk.

Apollo 15

Apollo 15 was launched from Cape Kennedy at 9:34 a.m. EDT, July 26, 1971. The all air force crew was made up of Col. David R. Scott, Commander; Major Alfred M. Worden, Command Module Pilot; and Lt. Col. James B. Irwin, Lunar Module Pilot.

This mission took Scott and Irwin to the Hadley Rille area of the Moon named for John Hadley (1682-1744) the British scientist-mathematician who improved reflector telescope design and invented the reflecting quadrant which was the forerunner of the mariner's sextant.

The command ship Endeavour was named after the scientific rocket ship commanded by Captain James Cook, English explorer. In the Endeavour Captain Cook explored the Pacific and also discovered Australia. The lunar landing craft was named Falcon for the U. S. Air Force mascot.

The lunar landing craft touched down at 6:15 p.m. EDT on July 30, 1971 and Commander Scott radioed

Mission Control "Falcon is on the plain at Hadley". Falcon was located on the lunar plain called Palus Putredinis (Marsh of Decay) at 26° 5′ North Latitude and 3° 39′ East Longitude, on the half of the Moon facing Earth.

The landing site was chosen so the Apollo 15 mission could study three different types of lunar topography—a more basin (plain), lunar rille (gorge), and a mountain front. Nearby the lunar Apennine Mountains towered 15,000 feet above the plain and the mile-wide Hadley Rille, 600 to 1200 feet in depth.

The purpose of the expedition was to gather information which would tell us not only more about the Moon but also more about the Earth, the Sun, and the solar system. Because the Moon cooled earlier than the Earth and has not been eroded by wind and water, it contains on and near its surface a record of the past that has been obliterated on Earth.

Scott and Irwin were able to cover the necessary distance by the use of the Lunar Roving Vehicle (LRV). During three separate motor trips they explored the rim of Hadley Rille, the edges of deep craters, and the slopes of the Apennine Mountains. At a number of scientific stops the astronauts turned on the LRV color television camera so viewers throughout the world could observe such spectacular scenes as the canyon depths of Hadley, the crater-scarred plain of the Marsh of Decay, and the rounded peaks of the towering Apennines.

On their second lunar trip the astronauts discovered a unique crystalline stone perched on a rock that was lying on an Apennine slope. They noticed a crystalline structure characteristic of plagioclase, a mineral that is a primary component of the rock anorthosite. Anorthosite is believed by many scientists to be the main component of the primordial lunar crust, thought to have been formed some 4½ billion years ago.

This possible discovery of anorthosite also is important in that it, or some other material of comparable density, is needed to explain apparent discrepancies between calculations of the total man of the Moon and the densities of rocks collected by previous Apollo missions. All of the latter samples collected were denser than the Moon's average density. (A more familiar example of a plagioclase rock is the gem with the name of Moonstone.)

Another important find is the lunar bedrock discovered in the rim of Hadley Rille. This is the rock that is believed to underlie the lunar seas which were formed by lava flows. Analysis of such rocks can give the time when the flows originated, some 3½ to 4 billion years ago at the Apollo 11 and 12 sites. The formation of the original crust and of the seas are two of the major events in selenological (lunar geological) history. Altogether, Scott and Irwin gathered about 170 pounds of lunar rock samples, many of which are unlike any brought back by previous missions.

Perhaps of equal importance are the abundant photographs taken on the Moon by Scott and Irwin and from orbit by Worden, pilot of the command module Endeavour.

Some observations which, with further data and study, may result in new conclusions about the Moon are:

1. The absence of the anticipated boulder fields below the Apennines.
2. The gently rolling, uniformly smooth (but crater-scarred) surface of the Marsh of Decay.
3. The well-defined layers, strata, and fracture lines marking the walls of the Rille and the Apennine mountainsides.
4. The rounded contours of the Apennines and surrounding areas.
5. The large number of completely clean, rather than dusty, or partially buried, rock fragments.
6. The different directions of rock layers in the walls of Hadley Rille and on the Apennine Mountain slopes. Hadley's were horizontal; the Apennine's, diagonal. This information suggests they were formed at different times.

The Apennines are believed to be composed of material which was thrust up from below the surface by tremendous internal pressures built up when an object the size of Rhode Island impacted on the Moon and created the Sea of Rains. Hadley Rille is believed to have originated as the result of lava flows or by fracturing. The layering observed by both the Rille and mountains confirms that the Moon's surface was built up in stages by many lava flows or ejector blankets (showers of rocks thrown up by impacts). Each layer covers a different time period in the history of the Moon and can give details on its formation and evolution.

The astronauts drove core tubes into the lunar plain as deep as 7 feet 9 inches. Preliminary analysis indicates 44 layers in the core tube, indicating at least 44 separate volcanic or impact events at this site. One of the things scientists are studying in the core samples are trapped solar particles. Such a study could provide details on the history of the Sun during the past billion or more years and increase our knowledge of how it influences Earth's climate.

Scott and Irwin also placed heat sensors down two of the holes they bored. The purpose is to determine the internal temperature of the Moon, a fundamental measurement needed to understand the history and evolution of a planetary body.

While Scott and Irwin were on the Moon's surface Worden was collecting a wealth of photographs and other scientific data from orbit.

An X-ray detector aboard Endeavour picked up secondary X-rays which result when solar X-rays strike materials on the Moon. The device indicated the distribution of minerals and found high concentration of aluminum and sparse amounts of magnesium in the highlands and the opposite in the plains. The study of how minerals are distributed on the Moon may give new clues to their distribution on Earth, helping mankind to inventory its limited mineral resources.

A magnetometer on the command ship also detected a very weak lunar magnetic field. A gamma ray spectrometer detected radioactive hotspots on the Moon which indicate concentration of elements such as potassium, thorium, and uranium. The heat from such deposits could have caused rocks to melt producing local volcanic eruptions in the past.

Worden described small dark conical mounds which he recognized as cinder cones (dead volcanic craters) on the Moon's Littrow area which is on the southeastern border of the Sea of Serenity. Carefully rechecking the area on subsequent orbits, Worden found no evidence of current activity of any kind. The cones indicate to some scientists that volcanic activity had lasted up to 1½ billion years ago. This could mean that the Moon was hot at least until then.

Other scientists regard the cinder cones as indicators that carbon dioxide and water may have been briefly present on the Moon. On Earth large amounts of these two compounds are needed to bring the volcanic cinders to the surface and spread them around.

Volcanic activity on the Moon could originate from two possible main sources: 1) a former molten core, although many scientists say the Moon's core was never molten; 2) gravitational compression of material on which more scientists agree). Rocks can also be melted and volcanic flows created by radioactive heating and by impact of another body. The pull of the Earth's gravity could also crack thin crustal areas, releasing gases. Current moonquakes are thought to be due to Earth's gravity pull on the Moon.

The mass spectrometer aboard Endeavour identified pockets of neon, argon, and carbon dioxide in the lunar environment. If these are lunar emissions, they would indicate the presence of a tenuous and transitory lunar atmosphere.

Scott and Irwin completed their work on the Moon's surface and at 1:11 p.m. E.D.T., August 2, they launched Falcon from the Moon. This was the first launch from the Moon that all mankind could see. The TV camera on the Lunar Roving Vehicle, which was left behind, telecast the lift-off of Falcon.

Left behind on the Moon was the Apollo Lunar Surface Experiment Package which contained instruments which will return to Earth data on moonquakes, meteorite impacts, the lunar magnetic field, the solar wind, the nearby nonexistent wisps of lunar atmosphere, and heat escaping from beneath the surface of the Moon.

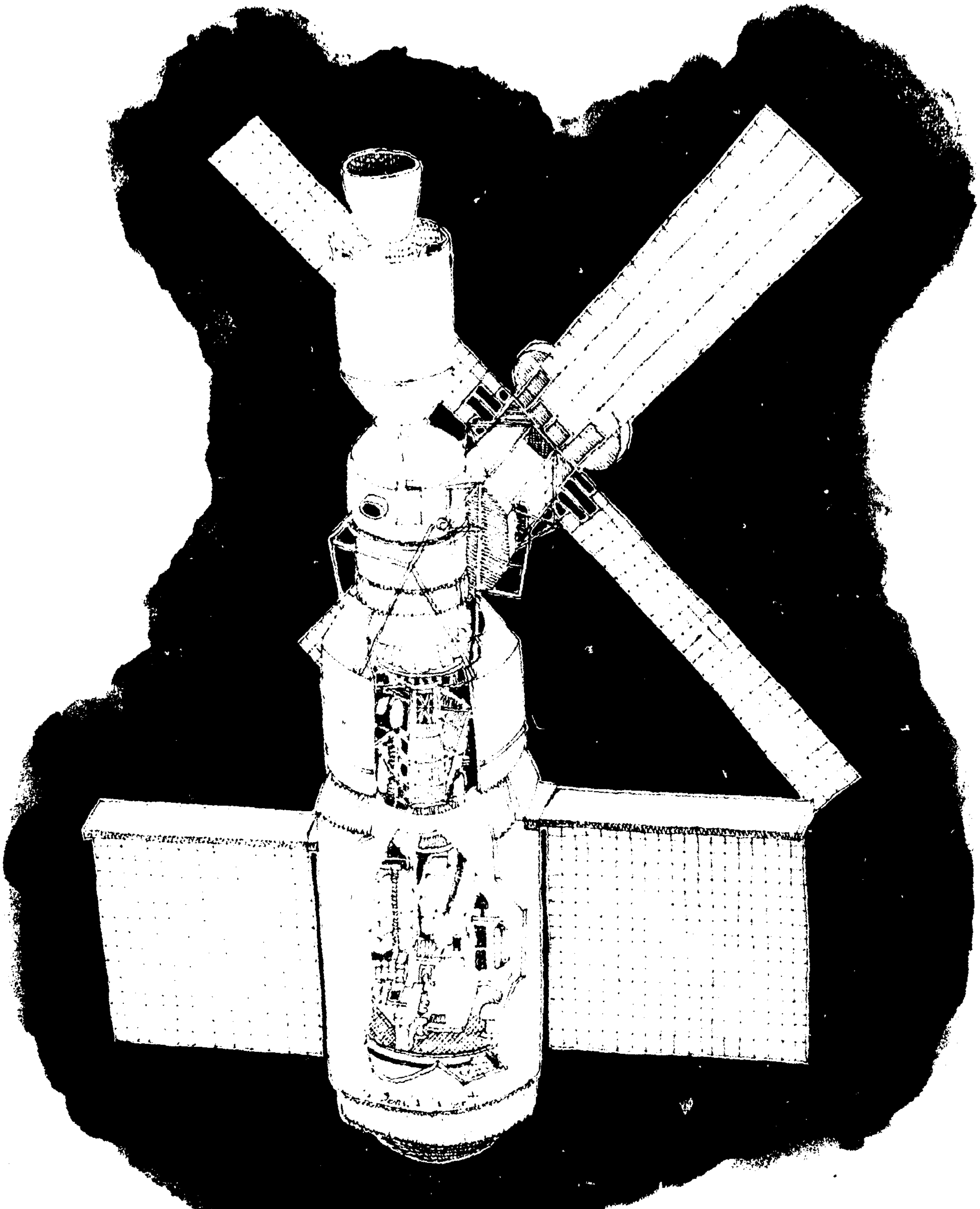
After Scott and Irwin docked and transferred to Endeavour, Falcon was cast adrift and impacted on the Moon. The vibrations were picked up by the seismometers at both Apollo 12 and 14 sites which are nearly 700 miles away. On Earth a comparable impact would be sensed no farther than 100 miles away. Analysis of the data from the earlier impact of the Saturn upper stage indicated a lunar crust of at least 20 miles thick. Earth's crust varies from 3 to 30 miles with the thinnest part being under the sea.

While still in lunar orbit the crew of Endeavour launched a 78½-pound scientific subsatellite. It is providing new details on lunar gravity, particularly the *high gravitational areas called mascons;* the Moon's space environment, including the effect of solar flares, and on the Earth's magnetic field through which the Moon regularly passes and also information on the weak localized lunar magnetic fields.

On August 5, about 197,000 miles from the Earth, Worden performed the first deep space walk. The walk was necessary to pick up film cassettes from the Scientific Instrument Module (SIM) bay and bring them into the cabin. Otherwise the film would have been lost as the service module, in which the SIM bay is located, was discarded as Endeavour neared Earth. Only the 11½-foot-long command module of the 363-foot-long Apollo/Saturn V space vehicle, that takes off from Cape Kennedy, returned to Earth.

The crew of Endeavour was in for a rougher than normal landing as only two of the three parachutes were open at splashdown at 4:46 p.m. EDT, August 7. Endeavour submerged briefly and then bobbed up in an upright position. Although the increase in landing speed from 19 m.p.h. to 22 m.p.h. did not significantly affect the crew, it pointed out again that no mission yet has been without its hazards regardless of the care and precautions that are taken in the assembly of the nearly nine million parts that make up the Apollo/Saturn V space vehicle.

The Apollo 16 mission began with lift-off at 9:34 a.m. EDT, July 26, and lasted for 295 hours and 12 minutes or it ended at splashdown at 4:46 p.m. EDT, August 7, 1971.



THE NEXT DECADE IN SPACE

The manned space flight programs have been primarily concerned with learning how to operate effectively and safely in the space environment while accomplishing missions of increased complexity and importance. The astronauts have been space test pilots undertaking experimental flights. The chief objective of the Mercury, Gemini and Apollo programs has been to build a manned space flight capability. The success of these programs attests to growth of that capability.

With manned space flight capability developed, more attention can be paid to scientific objectives that can be achieved through the employment of men at the scene of the activity. The capabilities developed in the Apollo Program can be used by scientifically trained astronauts in programs oriented more toward scientific experimentation.

Such a program is the Skylab Program in which the third stage (S-IVB stage) of the Saturn launch vehicle will be fitted out as an orbital workshop to be the forerunner of the Space Station. This Earth orbiting laboratory will be occupied by three astronauts for as long as two months. The equipment will be used to conduct scientific experiments, make solar observations and determine the effects of long space missions on the health of the crew. Skylab is the first step in manned utilization of space.

To realize the full potential of space stations operating costs must be reduced and workers with various skills and normal physical condition must be accommodated. In a near Earth orbit station a new, low cost, surface to orbit and return transportation vehicle is needed. These vehicles will be the building blocks in the system to be employed in future space activities of continuing the exploration of the Moon and the planets. The Space Station module design may be used as living quarters in various Earth orbits, in lunar orbit or on a planetary mission. The very long lifetime of the Space Station permits major reductions in utilization costs.

Areas of Exploration

The Space Station will be a scientific laboratory and a site for applying the new environment of space to the direct benefit of man. Of the number of promising areas of exploration three broad areas seem most promising: Earth Applications, Materials Processing and Science.

EARTH APPLICATIONS—Direct economic returns can be foreseen through the use of Earth orbiting space platforms. Only from such a space station can broad areas of the Earth be observed simultaneously to determine trends in large-scale phenomena such as changes in snow pack, crop condition, air and water pollution and relationships between the sea and the atmosphere. Instruments can detect changes as they occur and will observe areas where surface observations are infrequent, such as the broad ocean areas, the Arctic and Antarctic.

THE ROLE OF MAN—Man should be sent into space and maintained there only to perform tasks which require human judgment. Initially he would develop the systems and techniques best suited to the tasks involved and what useful phenomena can best be observed from space. When the techniques become established routine automated equipment can be introduced and humans freed to maintain, redirect and supervise the machines. The communications function can also be reduced by having man analyze and interpret the raw data to select that which will be sent to Earth. Here man's role would be to recognize the formation of patterns—a task very difficult to program into a computer.

The Earth Applications aspect would involve the following areas:

METEOROLOGY—This is one of the areas where space application has already been of benefit to the world. Equipment operated by men on the space station would supplement the observations of the automated satellites. Maintenance and repair of these complex satellites would be possible and would result in significantly extending their useful lifetimes.

MINERAL PROSPECTING—Another area of great potential return is prospecting for mineral resources. Simultaneous photography with films sensitive to radiations in different parts of the spectrum give promise of revealing much new information.

CROP CONDITIONS—Infrared sensitive color film would allow crop condition identification on a worldwide basis. Air photos can detect certain crop diseases before they are discernible on the ground.

HYDROLOGY—Microwave imagery can record the distribution of water both on the Earth's surface and in the ground near the surface of the Earth. This hydrological mapping can be accomplished even through a thick cloud cover. Areas of subterranean seepage can be detected which is not discernible in visible light either from high altitude or from the surface.

The Materials Processing aspect would involve the following processes:

METAL FOAM—The weightless environment in an orbiting space station would permit the production of a foamed steel with the weight of balsa wood but with many of the properties of solid steel. This process cannot be done on earth because the weight of the liquid metal causes the gas foam bubbles to float to the surface of the metal before cooling can take place. In space the gases would remain entrapped, producing a porous spongelike material. Under zero G it would also be possible to mix materials of vastly different properties and densities. For example, steel and glass. These composite and foamed materials should result in lighter and stronger materials for basic study, industrial applications and the construction of future spacecraft.

CRYSTAL GROWTH—The size of Earth grown crystals is limited by gravity and the introduction of contaminants. In a very clean zero gravity space environment there are no such limits to growth and crystals of a very large size can be grown. These space grown crystals could be used as very large power transistors or optical blanks for lenses of near perfect quality. It would also be possible to produce very large dislocation free crystals.

LEVITATION MELTING—The suspension of a material (levitation) is important because it offers the possibility of melting and shaping materials without contamination from any type of mechanical restraint or crucible. Metallic materials and structures may be shaped by the manipulation of surrounding electromagnetic fields. By such a method perfect spheres could be produced for use as ball bearings. Alloys could be formed with uniformity resulting from maximum intermixing of the constituents and refinement of metals to a high degree of purity should also be possible.

Another use of the space station is to conduct scientific investigations to extend man's knowledge of the universe. Probably the following areas would be investigated first:

ASTRONOMY Astronomical observations from the Earth have always been limited by the atmosphere. Astronomers have long wanted to get their instruments into space where atmospheric turbulence, light-ray scattering, sky brightness, cloud cover and pollution would no longer be problems which limit the resolving power of their telescopes.

PHYSICS The study of cosmic rays, which are charged particles such as protons and electrons that originate outside the solar system and travel at very high speeds, may well hold the answers to some basic questions about the nature of matter. Physicists would like to place machinery in orbit which would detect cosmic rays of much higher energies and possibly prove that "anti-matter" occurs naturally in the universe. Other experiments would test those aspects of Einstein's Special and General Laws of Relativity that cannot be tested on Earth.

LIFE SCIENCES The space station offers life scientists the opportunity to study life processes under conditions that cannot be duplicated on Earth. These conditions include a zero gravity environment of any desired length and the lack of periodicities associated with the rotation and revolution of the Earth. Perhaps other factors which are not yet recognized as affecting life will also be discovered as they are removed.

The Future

The history of our scientific and technological progress indicates that many uses will be made of space which are not yet envisioned. With this in mind it is important to try and build today what will be able to continue to serve in the future. Eventually we should have in space a national research facility called Space Base. The Space Station would serve as a part of this facility, to be retained and used as the Space Base grows. Space Stations will grow by the addition of Space Station modules, experiment modules, utility modules and storage units for liquid fuels, oxidizers and any other consumable supplies.

The Space Base will provide both artificial gravity areas, used in those operations which are enhanced by the presence of gravity, and zero gravity areas in which to conduct experiments where this condition is desirable. It would serve as a supply depot, launch site and mission control facility for deep space spacecraft.

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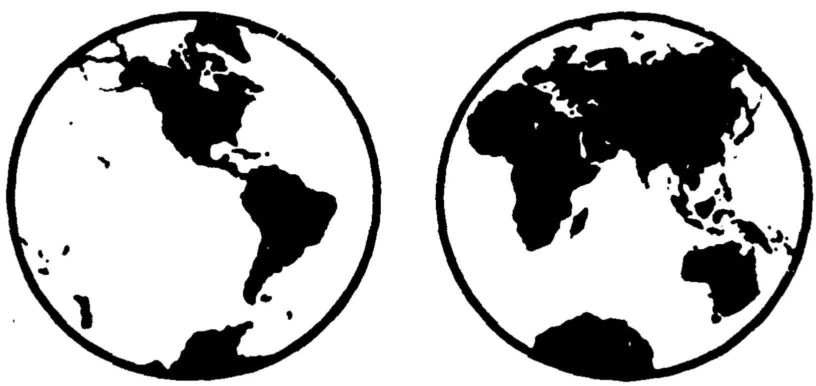

HERE MEN FROM THE PLANET EARTH
FIRST SET FOOT UPON THE MOON
JULY 1969, A.D.
WE CAME IN PEACE FOR ALL MANKIND

NEIL A ARMSTRONG
ASTRONAUT

MICHAEL COLLINS
ASTRONAUT

EDWIN E ALDRIN JR
ASTRONAUT

RICHARD NIXON
PRESIDENT UNITED STATES OF AMERICA

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GEOLOGIC MAP OF PENNSYLVANIA