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ABSTRACT

Theories and practical skills for use in optical shops are presented in this rate training manual, prepared for regular navy and naval reserve personnel. Light theories are analyzed in connection with mirrors, prisms, lenses, and basic optical systems. Following fundamentals of mechanical design and construction, maintenance procedures are studied to give a general knowledge of optical repair. Special descriptions are made of such instruments as spyglasses, telescopes, magnetic compasses, azimuth and bearing circles, sextants, stadimeters, telescopic alidades, binoculars, submarine periscopes, and night vision sights. To give enough background for readers, operations of lathes, grinders, milling machines, and drill presses are also discussed. Besides illustrations for explanation purposes, information on the opticalman rating structure is also provided. (CC)

OPTICALMAN 3 & 2

BUREAU OF NAVAL PERSONNEL

RATE TRAINING MANUAL NAVPERS 10205 A

PREFACE

This training manual was prepared for the Bureau of Naval Personnel by the Training Publications Division, Naval Personnel Program Support Activity, Washington, D.C. It is intended to serve as an aid for men of the U.S. Navy and Naval Reserve who are studying to acquire the theoretical knowledge and practical skill required for recommendation for advancement to Opticalman 3 and Opticalman 2.

Chapter 1 presents information on the enlisted rating structure, the Opticalman rating, requirements and procedures for advancement, and references which will be helpful in studying for advancement. A description of how this text may be used to the best advantage is also included.

Chapters 2 through 10 contain information on the theory of light, as well as the principles of optics and the skills used in optical repair.

The theory of light and optical elements is presented in a manner that will give the reader a complete understanding of how light is controlled and used to produce a magnified image of an object.

Chapters 11 through 14 contain descriptive matter and illustrations sufficient to provide a general knowledge of the instruments that Opticalman 3rd and 2nd class are required to maintain.

Technical assistance in preparing this manual was provided by the Service School Command, Naval Training Center, Great Lakes, Illinois; the Naval Examining Center, Great Lakes, Illinois; and the Naval Ship Systems Command, Washington, D.C.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

ADVANCEMENT

This training manual is designed to help you meet the occupational qualifications for advancement to Opticalman Third Class and Opticalman Second Class. Information presented is based on the June 1970 edition of the Manual of Qualifications for Advancement NavPers 18068-B.

ENLISTED RATING STRUCTURE

The two main types of ratings in the present enlisted rating structure are general ratings and service ratings.

GENERAL RATINGS identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

SERVICE RATINGS identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

THE OPTICALMAN RATING

Opticalmen maintain, repair, and overhaul telescopic alidades, azimuth and bearing circles, binoculars, compasses, gunsights, sextants, and other optical instruments. This includes inspection, casualty analysis, disassembly, repair, replacement or manufacture of parts, cleaning, reassembly, collimation, sealing, drying, gassing, and refinishing of surfaces.

The Opticalman rating is a general rating ONLY—there are no service ratings. The work of an Opticalman requires a high degree of intelligence and mechanical aptitude. Optical instruments are technical in nature, expensive, and delicate. For these reasons, just ANYONE cannot perform satisfactorily the work of an Opticalman. Intelligence is required to understand the principles of operation; and mechanical aptitude is necessary in order to repair and collimate it.

OPTICALMAN BILLETS

Opticalmen generally are assigned duty in optical shops aboard repair ships or tenders, and stateside or overseas ship repair facilities.

Occasionally, however, they are assigned duty ashore as instructors in Opticalman schools. Some Opticalmen are assigned to recruiting duty; others are assigned to Naval Reserve training units.

Other duty assignments include the U.S. Naval Examining Center, Great Lakes, where the servicewide advancement examinations are prepared and scored; the U.S. Navy Training Publications Division, Naval Personnel Program Support Activity, Washington, D.C. (This training manual that you are now studying was revised by a Master Chief Precision Instrumentman while he was assigned to an instructor billet at Training Publications Division.) Regardless of location, all Opticalmen are assigned by the Bureau of Naval Personnel, Washington, D.C.

Keep in mind that the men of your rating, like all other ratings, perform unique and important roles toward the fulfillment of the overall mission of the Navy. You must, therefore, avail yourself to every source and opportunity to improve your skills as an Opticalman.

Administrative Responsibilities

At the third or second class level, Opticalmen generally do not have the responsibility for administering an optical shop; but an Opticalman 2 is responsible for preparing casualty analysis inspection sheets for instruments and also for the maintenance of records and logs in the shop. Opticalmen on duty at the 3 or 2 level should therefore observe the work of Opticalmen at the first class and chief levels, and learn as much from them as possible about the work of a shop supervisor. This is the only way to develop to the maximum your usefulness to the Navy as an Opticalman. Be prepared for greater responsibility when it is assigned to you.

Shop safety is something you should always emphasize. When using tools and operating machines, it is easy for one to injure himself. This not only causes personal discomfort but results in a pecuniary loss to the Navy during absence from work. Opticalmen should keep the shop in excellent working shape and hazard-free, and work individually and collectively in a manner which minimizes personal injury.

REWARDS

Some of the rewards of advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancing are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement, you increase your value to the Navy in two ways. First, you become more valuable as a technical specialist in your own rating. And second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.
2. Complete the required military and occupational training courses, based on training manuals.
3. Demonstrate your ability to perform all the PRACTICAL requirements for advancement by completing the Record of Practical Factors, NavPers 1414/1.
4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.
5. Demonstrate your KNOWLEDGE by passing a written examination on (a) military requirements and (b) OCCUPATIONAL qualifications.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-2 gives this information for inactive duty personnel.

Remember that the qualifications for advancement can change. Check with your division officer or training officer to be sure that you know the most recent qualifications.

Advancement is not automatic. Even though you have met all the requirements, including passing the written examinations, you may not be able to "sew on the crow" or "add a stripe." The number of men in each rate and rating is controlled on a Navywide basis. Therefore, the number of men who may be advanced is limited by the number of vacancies that exist. When the number of men passing the examination exceeds the number of vacancies, some system must be used to determine which men may be advanced and which may not. The system used is the "final multiple" and is a combination of three types of advancement systems.

Merit rating system
Personnel testing system
Longevity, or seniority, system

The Navy's system provides credit for performance, knowledge, and seniority, and, while it cannot guarantee that any one person will be advanced, it does guarantee that all men within a particular rating will have equal advancement opportunity.

The following factors are considered in computing the final multiple:

Factor	Maximum Credit
Examination score	80
Performance factor (Performance evaluation)	50
Length of service (years x 1)	20
Service in pay grade (years x 2)	20
Medals and awards	15
	185

All of the above information (except the examination score) is submitted to the Naval Examining Center with your examination answer sheet. After grading, the examination scores, for those passing, are added to the other factors to arrive at the final multiple. A precedence list, which is based on final multiples, is then prepared for each pay grade within each rating.

REQUIREMENTS*	E1 to E2	E2 to E3	#† E3 to E4	#E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of	6 mos. as E-2.	6 mos. as E-3	12 mos. as E-4	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3, PN 3, FTB 3, MT 3.			Class B for AGC MUC, MNC. ††		
PRACTICAL FACTORS	Locally prepared check-offs.	Record of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer #		Naval Examining Center					

* All advancements require commanding officer's recommendation.
† 1 year obligated service required for E-5 and E-6; 2 years for E-7, E-8 and E-9.
# Military leadership exam required for E-4 and E-5.
** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.
†† Waived for qualified EOD personnel.

Figure 1-1.—Active-duty advancement requirements.

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 8 yrs service	36 mos. with total 11 yrs service	24 mos. with total 13 yrs service
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO Advancements. Also pass Military Leadership Exam for E-4 and E-5.				Standard Exam, Selection Board.	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for training duty.

Figure 1-2.—Inactive duty advancement requirements.

Advancement authorizations are then issued, beginning at the top of the list, for the number of men needed to fill the existing vacancies.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? You must study the qualifications for advancement, work on the practical factors, study the required Navy Training Manuals, and study other material that is required for advancement in your rating. To prepare for advancement, you will need to be familiar with (1) the Quals Manual, (2) the Record of Practical Factors, NavPers 760, (3) a NavPers publication called Training Publications for Advancement, NavPers 10052, and (4) applicable Navy Training Manuals.

The following sections describe them and give you some practical suggestions on how to use them in preparing for advancement.

The Quals Manual

The Manual of Qualifications for Advancement, NavPers 18068B (with changes), gives the minimum requirements for advancement to each rate within each rating. This manual is usually called the "Quals Manual," and the qualifications themselves are often called "quals." The qualifications are of two general types: (1) military requirements, and (2) occupational or technical qualifications.

MILITARY REQUIREMENTS apply to all ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all ratings.

OCCUPATIONAL QUALIFICATIONS are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups; then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rating.

The written examination you will take for advancement will contain questions relating to the practical factors and the knowledge factors of both the military requirements and the professional qualifications. If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

The Quals Manual is kept current by means of changes. The professional qualifications for your rating which are covered in this training manual were based on change 5 to the quals. By the time you are studying this course, however, the quals for your rating may have been changed. Never trust any set of quals until you have checked it against an UP-TO-DATE copy in the Quals Manual.

Record of Practical Factors

Before you can take the servicewide examination for advancement in rating, there must be an entry in your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the RECORD OF PRACTICAL FACTORS, NavPers 1414/1, is used to keep a record of your practical factor qualifications. This form is available for each rating. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically in the Manual of Qualifications for Advancement in Rating, and revised forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in the changes to the Quals Manual. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement.

If you are transferred before you can qualify in all practical factors, the NavPers 1414/1 form should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you may be required to start all over again and requalify in the practical factors which have already been checked off.

NavPers 10052

Training Publications for Advancement NavPers 10052 (revised), is a very important publication for anyone preparing for advancement. This bibliography lists required and recommended Rate Training Manuals, and other reference material to be used by personnel working for advancement. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be SURE that you have the most recent edition.

If extensive changes in qualifications occur in any rating between the annual revisions of NavPers 10052, a supplementary list of study material may be issued in the form of a BuPers Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications for your rating. If changes have been made, see if a BuPers Notice has been issued to supplement NavPers 10052 for your rating.

The required and recommended references are listed by rate level in NavPers 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class; but remember that you are also responsible for the references listed at the third class level.

In using NavPers 10052, you will notice that some Navy Training Courses are marked with an asterisk (*). Any course marked in this way is MANDATORY—that is, it must be completed at the indicated rate level before you can be eligible to take the servicewide examination for advancement in rating. Each mandatory course may be completed by (1) passing the appropriate enlisted correspondence course that is based on the training manual; (2) passing locally prepared tests based on the information given in the training manual; or (3) in some cases, successfully completing an appropriate Class A school.

Do not overlook the sections of NavPers 10052 which lists the required and recommended references relating to the military requirements for advancement. Personnel of ALL ratings must complete the mandatory military requirements training course for the appropriate rate level before they can be eligible to advance.

The references in NavPers 10052 which are recommended but not mandatory should also be studied carefully. ALL references listed in NavPers 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Rate Training Manuals

There are two general types of rate training manuals. The first type includes RATING manuals (such as this one) which are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational qualifications of ONE rating. The second type includes SUBJECT MATTER manuals or BASIC manuals which give information that applies to more than one rating.

Rate training manuals are revised from time to time to keep them up to date technically. The revision of a rate training manual is identified by a letter following the NavPers number. You can tell whether any particular copy of a training manual is the latest edition by checking the NavPers number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061. (NavPers 10061 is actually a catalog that list all current training manuals and correspondence courses; you will find this catalog useful in planning your study program.)

Rate training manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this course and other Navy training publications when you are preparing for advancement.

1. Study the military qualifications and the occupational qualifications for your rating before you study the training manual, and refer to the quals frequently as you study. Remember, you are studying the manual primarily in order to meet these quals.

2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can plan to study at the same time each day. If possible, schedule your studying for the time of day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the book without any particular plan, looking at the illustrations

and reading bits here and there as you see the things that interest you.

4. Look at the training manual in more detail to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book. As you look through the book in this way, ask yourself some questions:

- What do I need to learn about this?
- What do I already know about this?
- How is this information related to information given in other chapters?
- How is this information related to the qualifications for advancement?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying any one unit—chapter, section, or subsection—write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying the unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the training manual, write down the main ideas that you have gotten from studying this unit. Don't just quote the book. If you can't give these ideas in your own words, chances are that you have not really mastered the information.

9. Use enlisted correspondence courses whenever you can. The correspondence courses are based on rate training manuals or on other appropriate texts.

Taking a correspondence course helps you to master the information given in the training manual and also helps you to see how much you have learned.

10. Think of your future as you study rate training manuals. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn now will help you both now and later.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the occupational qualifications of your rating.

Some of the publications described here are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work or to advance, it is likely to be a waste of time, and may even be seriously misleading.

CHAPTER 2
THE NATURE OF LIGHT

Since the dawn of civilization, the real nature of light and the way it travels has been a constant source of intrigue to man. The answer to the question "What Is Light" has changed several times in the past 300 years and to this very day man is still experimenting, looking for the scientific facts that will give a true answer.

THEORY AND SOURCE OF LIGHT

Since there is no true answer that explains all of the characteristics of light, we can only study some of the theories of light and the known facts of light behavior.

Space in this manual does not permit a discussion on all theories of light, but some of them are considered briefly in order to give you an idea concerning their impact on the development of current theories.

LIGHT THEORIES

Scientists have always been interested in the properties of light, and because of their inquisitive minds and experiments, they developed various theories concerning light. The ancient Greeks, for example, believed that light was generated by streams of particles ejected from the eyes, and then reflected back into the eyes by objects they struck. This theory did not last long because it did not explain why a person could not see as well by night as by day.

Particles and Waves

In addition to the Greek theory of generated particles, Issac Newton believed light to be a flight of material particles originating from a source of light. It was during Newton's time that Christain Huygens and other physicists developed the theory that light energy was a product of wave motion. The argument between supporters of the particle theory and supporters of the wave theory has continued into our modern times.

Corpuscular Theory

In 1704, Newton published his book called "OPTICKS" in which he described light as a stream of particles he called corpuscles. From this, Newton's theory became known as the corpuscular theory. One of the primary arguments that supported the particle theory of light was the fact that light traveled in a straight line. Since waves created on water cause a disturbance around an obstacle and sound can be heard around the corner of a building, particle supporters would not believe that light was a wave phenomenon.

Huygens is generally considered to be the founder of the wave theory of light, and his basic concept is still very useful in predicting the behavior of light. Although Huygens' theory of wave motion appeared to be the logical explanation for some phases of light behavior, it was not accepted for many years. Huygens could explain the passage of waves through water, but he did not know how light waves passed through space when coming from the sun. In order to explain this mystery, he proposed that light passed through a medium that occupied all space which he called ETHER. He assumed that ETHER even occupied space that was already occupied by matter.

About 50 years after Huygens announced his theory of wave motion of light, Thomas, Young, Fresnel, and others, supported the wave theory, and Newton's corpuscular theory was virtually abandoned. These three scientists accepted the ETHER theory and assumed that light was waves of energy transmitted by an elastic medium designated by Huygens as ether.

Electromagnetic Theory

Three other scientists (Boltzmann, Hertz, and Maxwell) conducted experiments which proved that light and electricity are similar in radiation and speed. As a result of their experiments, they developed the ELECTROMAGNETIC theory. They produced alternating electric currents with short wavelengths which were undoubtedly of electromagnetic origin and had all the properties of light waves. This theory (sometimes called the Maxwell theory) held that energy was given off continuously by the radiating body.

For some years after promulgation of the Maxwell theory of light, scientists thought the puzzle of light was definitely solved. In 1900, however, Max Planck rejected the electromagnetic theory. He did not hold the view that energy from a radiating body was given off continuously. His contention was that the radiating body contained a large number of tiny oscillators, possibly resulting from electrical action of atoms in the body. His idea was that the energy given off by the body could be of high frequency and have high energy value, with all possible frequencies represented. Planck argued that the higher the temperature of the radiating body the shorter the wavelength of most energetic radiation would be.

Quantum Theory

In order to account for the manner in which radiation from a warm, blackbody is distributed among the different wavelengths, Planck found an equation to fit the experimental curves, which were based on lightwaves of different length. He then came to the conclusion that the small particles of radiated energy were GRAINS of energy like grains of sand. He therefore called these units quanta and named his theory the QUANTUM THEORY. He assumed that when quanta were set free they moved from their source in waves.

Five years later, Albert Einstein backed up Planck with some complex mathematical equations. He showed that quanta somehow manage to have a frequency, like waves. But the quanta are particles, just the same.

Experiments by R. A. Millikan showed that Einstein's equations were correct. In 1921, A. H. Compton studied the motion of the electron and the light quantum, both before and after their collision. He found that particles of light have momentum and kinetic energy, just like particles of matter. And that brings us right back to the corpuscular theory again.

Knowledge gained later by scientists from the study of diffraction, interference, polarization, and velocity (explained later) proved the corpuscular theory of light untenable. More recently, however, phenomena of light have been discovered which are not accounted for by the wave theory, so many scientists now accept Maxwell's electromagnetic theory.

Spectroscopy and the birth of the laser have given scientists valuable tools to experiment with, and the results of these experiments are causing scientist to review all previous theories of light. Although not conclusive there is strong evidence to support the belief that light is a combination of the QUANTUM THEORY and the ELECTROMAGNETIC THEORY.

In order for a theory concerning light propagation to be acceptable, it must prove all the phenomena of light propagation. Since we lack a proven theory, we have no choice but to accept the theory that best explains the passage of light through an optical instrument. This is the wave theory and it will be used for all discussions of light in this manual.

SOURCE OF LIGHT

Whether we have previously realized it or not, all of our lives we have been aware of the greatest source of light known to man. This is the Sun. The sun and all other sources of light, regardless of the amount that they give off, are considered to be luminous bodies because they emit energy in the form of visible light. All luminous bodies are placed in one of two categories, natural or artificial.

Natural

The only sources of natural light are the Sun, which is 93,000,000 miles away, and the stars. Although we receive light from the moon, it is merely reflected light that comes originally from the Sun.

Artificial

From the previous statement, it is easily understood that all light not coming from the sun and stars is artificial light. This covers all light from the first fire on earth to the modern laser. Man has made many artificial light sources since Thomas Edison invented the first incandescent bulb and with today's neon and fluorescent lights we have a wide variety of colors and intensities to choose from.

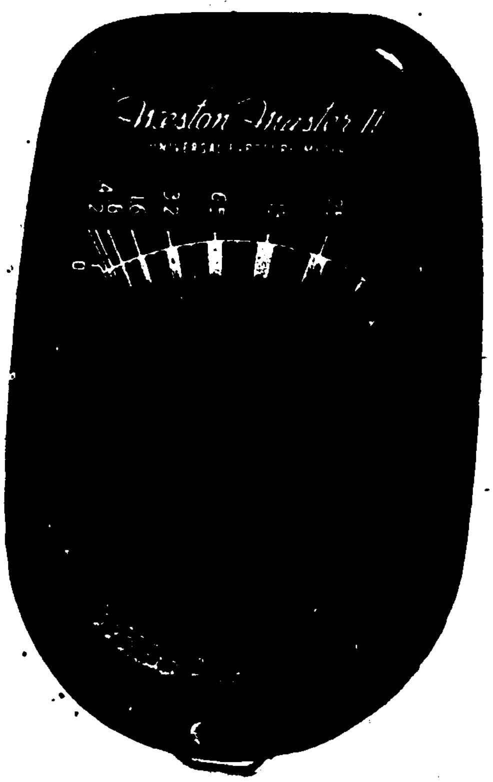
Illuminated Bodies

Any object that we are able to see, because of the light energy reflected from its surface, is called an illuminated body. The moon, because it reflects light from the sun, is an illuminated body. The book that you are now reading is an illuminated body because it reflects light energy, whether it is from the sun, a natural source, or an artificial source, such as fluorescent light fixtures.

Intensity of Illumination

Illumination can simply be stated as the act of casting light energy and the intensity of the amount of light energy that is given off is a major factor in determining how well we are able to see an object. We know very well that at night when there is little light available it is difficult to distinguish objects.

In determining the intensity of illumination, we measure the light energy coming from the luminous or illuminated body. One way to do this is with the exposure meter used by photographers (fig. 2-1). All you need to do is turn the meter toward a light source or an illuminated body and observe the movement of the hand. Although the meter has no internal source of power, and despite the fact that the hand has a spring acting against it, the hand will move when light strikes the sensing element. This is a good indication of the energy of light.



137.3
Figure 2-1.—Electric exposure meter.

The unit used for measuring the luminous intensity of light is called CANDLEPOWER. If a luminous source, for example, gives ten times as much illumination as a standard candle, it has the luminous intensity of 10 candlepower.

Because of the difficulty of getting exact measurements with a standard such as a candle, the National Bureau of Standards maintains a group of incandescent electric lights which fulfill certain conditions as standards of measurement. Secondary standards can be calibrated from these standard lamps by any laboratory.

The intensity of light which falls on a nonluminous source is generally measured in FOOT-CANDLES.

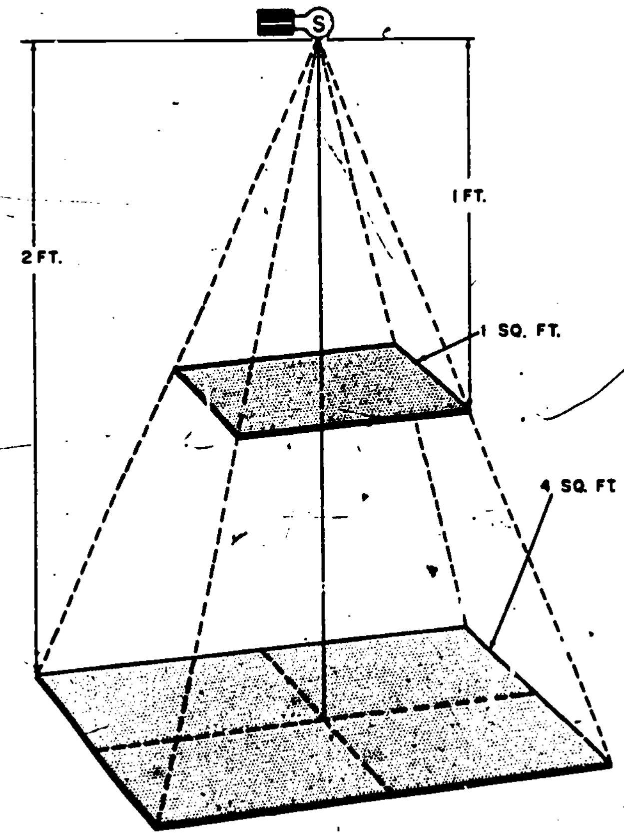
The surface of an object is illuminated by one foot-candle when its light source is one candlepower at a distance of one foot. The formula for this is:

$$\text{Foot Candles} = \frac{\text{Candle-power}}{(\text{Distance})^2}$$

Look now at figure 2-2. If the object is two feet from the light source, the light from the candle covers four times the area it covered after traveling one foot. The illumination at this point is ONLY one-fourth of a foot-candle. Illumination provided by a candle is therefore inversely proportional to the SQUARE OF THE DISTANCE between the candle and the object.

TRANSMISSION OF LIGHT

We know now that all forms of light obey the same general laws. When light travels in a medium or substance of constant optical density, it travels in waves in straight lines and at a constant speed. When light strikes a different medium from the one in which it is traveling, it is either reflected from or enters the medium. Upon entering a transparent medium, the speed of light is slowed down if the medium is MORE dense, or increased if the medium is LESS dense. Some substances of medium density have abnormal optical properties and, for this reason, they may be designated as optically dense. If the light strikes the medium on an angle, its course is bent (refracted) as it enters



137.12
Figure 2-2.—The inverse square law of light.

the medium. NOTE: Reflection and refraction are discussed fully later in this chapter.

When discussing the characteristics of light, however, we must use and explain these and other terms to the extent necessary for you to understand the discussion.

After you learn the characteristics of light and the types and function of various optical elements, you will then experience less difficulty in understanding image formation—the prime purpose of optical instruments.

Wave Energy

The pictures in illustration 2-3 were taken a fraction of a second apart. Note in part A that the pebble made a dent in the solution (milk) and that the surface is recovering its natural position and is rising. Part B shows that the surface of the milk has begun to rise and that the original wave is beginning to spread. Energy is spreading out in the form of little waves from the source of the disturbance of the surface of the milk by the pebble; and the waves are circles which get bigger and bigger as the amount of energy (wave motion) created by the pebble causes them to expand—the bigger the pebble, the greater the size of the waves and circles. When all the energy produced on the milk by the pebble is absorbed by the waves, they stop forming, as illustrated.

Thermal radiation and light waves are of the same nature and exhibit similar properties. Like light waves, thermal radiation normally travels in straight lines and can be reflected from a mirror or polished metal. Thermal radiation is not heat; it is energy in the form of wave motion.

During the latter part of the 18th century, scientists recognized that radiations from hot bodies consisted of electromagnetic waves (not mechanical) of the same fundamental nature as light waves. Luminous light sources such as the sun or the glowing filament of an electric light bulb act as oscillators in radiating energy in the form of light waves, and these waves spread out in all directions from their sources. The sun pours forth radiant energy from its surface at the rate of 70,000 horsepower for every square yard of its surface.

Because light travels outward in all directions from its source, the waves take the form of growing spheres (fig. 2-4), the luminous point of which is the center.

To understand the physical nature of electromagnetic waves, refer to figure 2-5, in which the transverse nature of electromagnetic waves is illustrated.

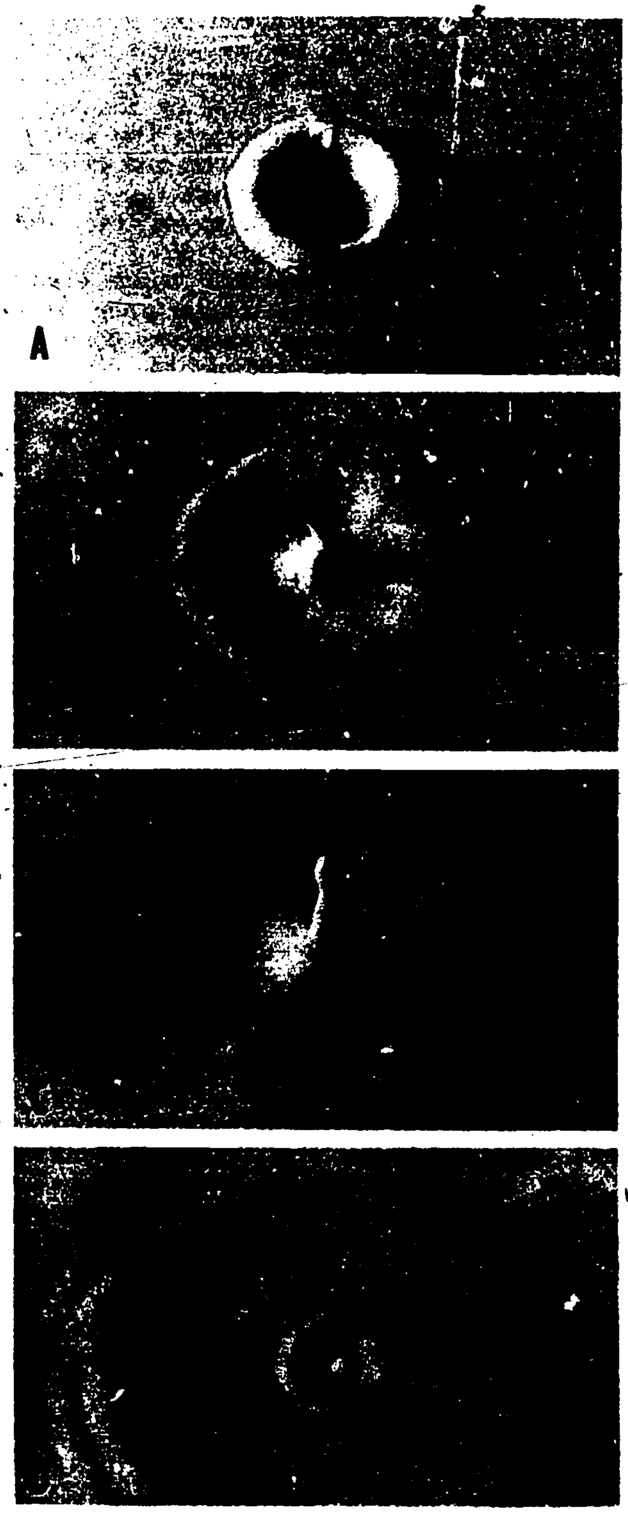
E and H denote the electric and magnetic vectors, respectively. The electric and magnetic vectors are ordinarily perpendicular to each other and to the direction of propagation.

The magnetic vector (H) oscillates along the Y axis while the electric vector oscillates along the X axis and the direction of propagation is along the Z axis.

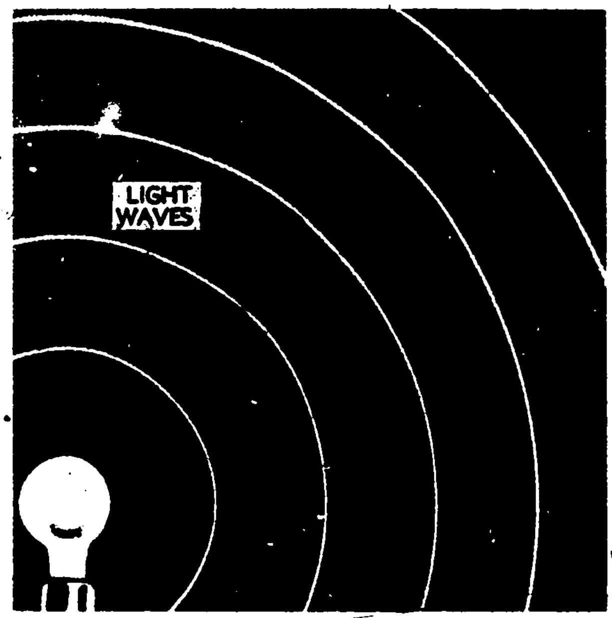
The reader thus must visualize light waves as traveling outward as illustrated in figure 2-4, and at the same time moving as illustrated in figure 2-5.

Light Rays

A basic problem in the design of optical systems is the calculation of wave surfaces as they progress through the various optical media. In optics, this calculation is approximated by



137.4
Figure 2-3.—Creation of waves in a liquid by a dropped pebble.



137.7
Figure 2-4.—Light waves created by a light.

considering a relatively small number of rays, and then tracing these rays through the system.

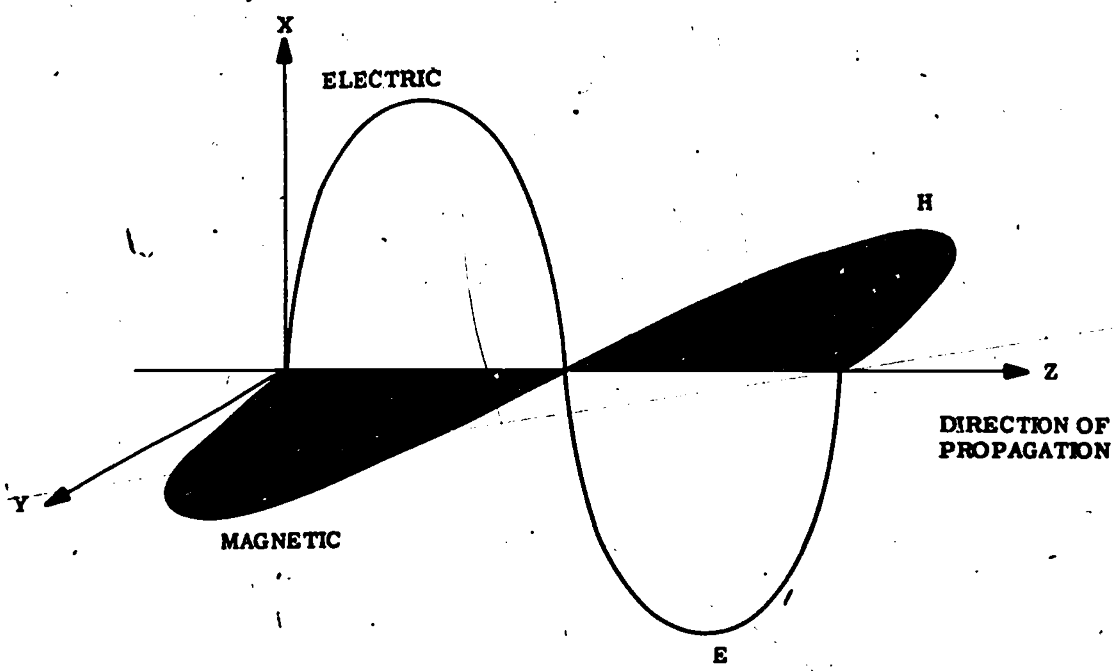
Single rays of light do not exist; but the term light ray is used throughout this manual for the sake of clarity and convenience in showing the direction of travel of the wave front. Light is indicated by one, two, or more, representative light rays in white lines, with arrow heads to indicate the direction of travel.

Refer now to illustration 2-4 again and observe that light is moving in all directions from the light bulb. Then study figure 2-6, which shows lines with arrow heads to indicate that the direction of travel of the light is along the radii of the sphere of light and at right angles to the fronts of the waves. The light which travels along these radii is designated as light rays.

A wave front which radiates from a light source is curved when it is near the source and the radii of the waves diverge or spread.

As these waves move outward, however, the wave front becomes less curved and eventually almost straight, as indicated in figure 2-7. After traveling a distance of 2,000 yards from their light sources, wave fronts are considered to be parallel to each other.

A pinhole camera (fig. 2-8) is a good example of the manner in which light travels outward from its source. Such a camera is merely a

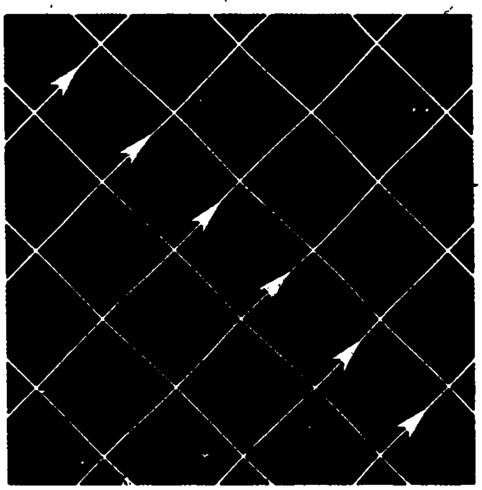


137.493

Figure 2-5.—The electromagnetic nature of a light wave.

137.8

Figure 2-6.—Direction of travel of light waves.

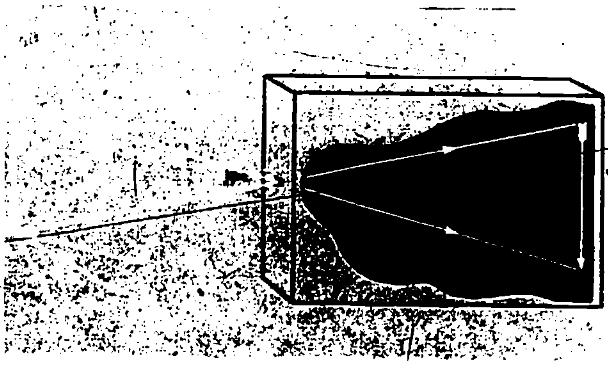


137.10

Figure 2-7.—Waves and radii from a distant light.

box with a sheet of film at one end and a tiny pinhole instead of a lens at the other end. Note that the camera is taking a picture of an arrow by light reflected from some luminous source and that each point on the arrow is sending out light rays in a dispersed manner.

One ray of light from each point on the arrow enters the pinhole in the front of the camera and lands upon the film. Since light travels in



137.11
Figure 2-8.—Light rays creating an image on the film of a pinhole camera.

straight lines, no light reaches a given point on the film except the ray which comes from the corresponding point on the arrow. The rays of light which pass through the pinhole of the camera form an inverted arrow on the film.

WAVELENGTH AND FREQUENCY

The action of waves on the surface of a liquid (fig. 2-3) helps to understand the wave motion of light but in order to understand fully the speed at which light travels you must comprehend the length of a wave and its frequency.

A wavelength is the DISTANCE BETWEEN the crest of one wave and the crest of the next (adjacent) wave, as illustrated in figure 2-9. The best way to measure a wavelength is by the FREQUENCY—the number of waves which pass a point in one (1) second. You can determine this by putting a stake in water and counting the number of waves which pass the stake per second. See figure 2-10.

If waves are moving at a speed of 3 feet per second and have a frequency of 6 waves per second, you can determine the wavelength by using the formula that shows the relationship which exists between the speed, frequency, and wavelength of light.

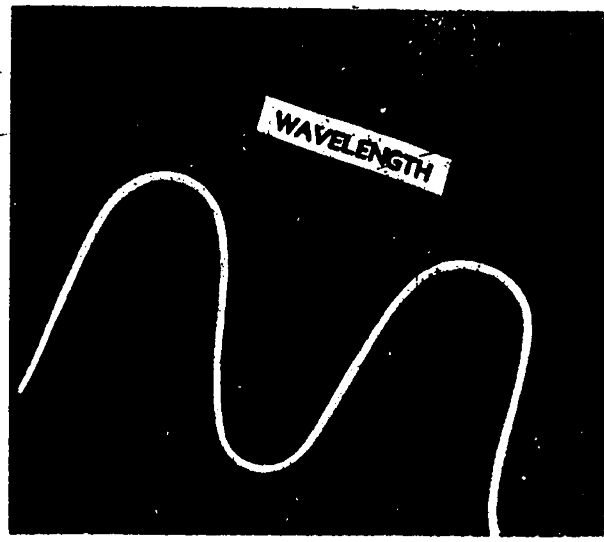
The formula is:

$$c = f\lambda$$

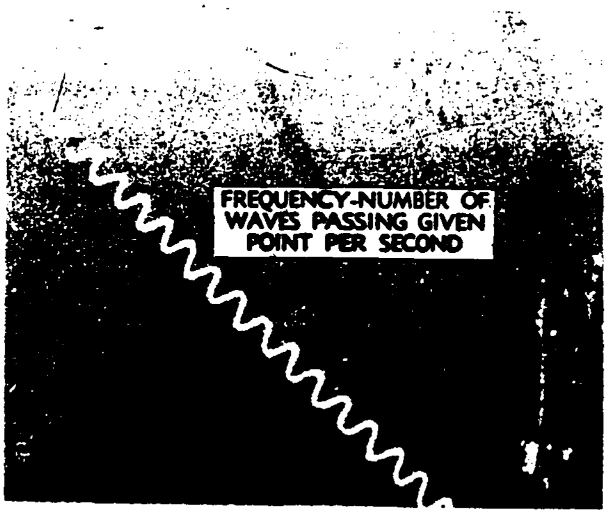
c = speed of light in a vacuum

f = frequency of waves

λ = (Greek letter "Lambda") wavelength



137.14
Figure 2-9.—Measurement of a wavelength.



137.15
Figure 2-10.—Determination of wave frequency.

By applying the formula to the above problem, we get

$$3 = 6\lambda$$

$$3/6 = \lambda$$

$$\lambda = .5$$

Light waves, in contrast with waves on water, are much too short to be measured in inches or millimeters. (A millimeter is about 1/25th of an inch. A light wavelength is sometimes measured in microns, represented in formulas by μ. A micron is one-thousandth of a millimeter.) For measuring a minute wavelength of light, a shorter unit than a micron must be used. This unit is the MILLIMICRON, which represents one one thousandth of a micron and is abbreviated $m\mu$.

Another important unit used for measuring wavelengths is the ANGSTROM UNIT (AU), which is 1/10th of a millimicron, or one ten-millionth of a millimeter. Because these units are still inconveniently long for measuring the shortest electromagnetic waves, the X-ray unit (XU) is used for this purpose. It is one one-thousandth of an Angstrom unit.

ELECTROMAGNETIC SPECTRUM

The ELECTROMAGNETIC SPECTRUM may be divided into nine major regions of radiation, depending on the general character of the waves: (1) long electric waves, (2) radio waves, (3) radar, (4) infrared, (5) visible light, (6) ultraviolet, (7) X-rays, (8) Gamma, and (9) Cosmic rays. Together, all of these form the electromagnetic spectrum, illustrated in figure 2-11. The visible portion of the electromagnetic spectrum consists of wavelengths from .00038 to .00066 millimeters. The different wavelengths represent different colors of light. Note the arrows which point to the wavelengths of the colors of the rainbow in the spectrum. Observe also that the wavelengths in this part of the spectrum (vision and photography) are in millimicrons of wavelengths. Wavelengths in the electromagnetic spectrum (extreme left) are in microns.

Note in illustration 2-11 that the wavelengths we call light are between 400 and 700 millimicrons, each spectral color has its own small range of wavelengths. If light around 660 millimicrons of wavelengths, for example, reaches your eyes, you see RED (sensation of red on the retina). Around 460 millimicrons the wavelengths of light which reach your eyes are BLUE; so the red waves are therefore much longer than the blue waves.

When light with a wavelength of 300 millimicrons reaches your eyes, you receive no sensation of color. Radiation of this wavelength is generally called ULTRAVIOLET LIGHT. Ultraviolet rays (radiation) from the sun cause sunburn and sometimes blisters. CAUTION: All short-wave radiations can do some damage if you get too much of them. A prolonged dose of strong X-rays, for example, causes irreparable damage to the body. Gamma rays are deadly short wave radiation given off by atomic particles.

Note that the infrared light rays are between 1 micron and 100 microns in the electromagnetic spectrum. These rays are called HEAT rays. We cannot see infrared rays; but if we could see them, everything would look different. Study illustrations 2-12 and 2-13. Figure 2-12 shows a photograph taken by visible light; figure 2-13 shows a picture of the scene in figure 2-12 taken with infrared film with a red filter over the lens.

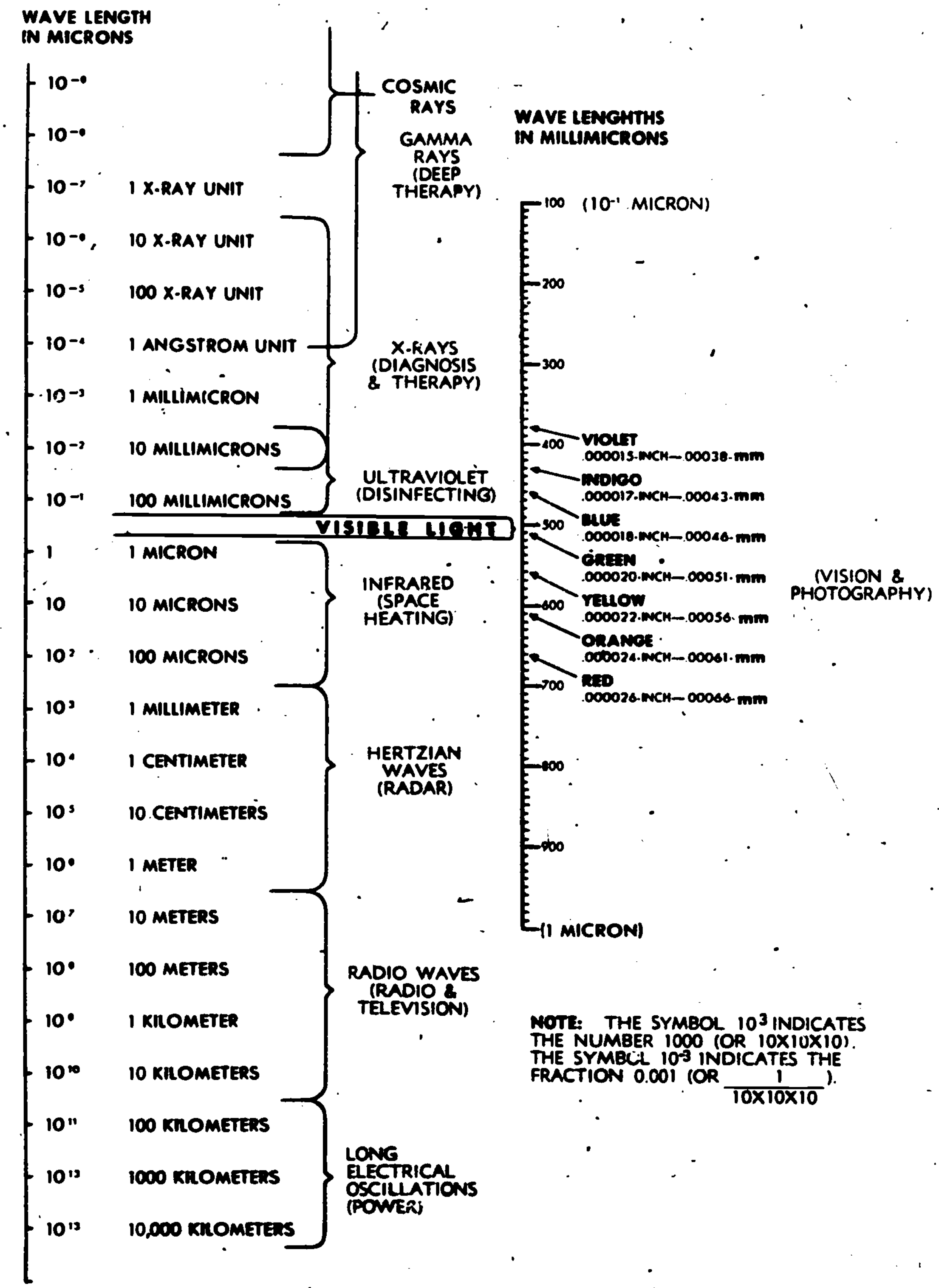
Infrared light is used also for signaling between ships at night. In aerial reconnaissance, too, we use infrared photography to get more and better details of the area photographed. A camouflaged object, for example, may blend with its surroundings and be invisible from the air; but if it does not reflect the same amount of infrared as its surroundings, an infrared photograph makes the camouflage stand out clearly.

During World War II SNOOPERSCOPES with powerful spotlights which sent forth beams of invisible infrared light were used to watch the enemy at night. When the infrared beams sent out by the spotlight struck an object and reflected it back to the snooperscope, the scope changed the infrared to visible wavelengths. SNIPERSCOPES used on rifles in the Pacific during the war work on the same principle as the snooperscope.

Observe in figure 2-11 that RADAR waves are adjacent to the infrared rays in the electromagnetic spectrum and have wavelengths a little longer than infrared. We know that these wavelengths travel at the same speed as light because they have been sent to the moon and reflected back in about 2.6 seconds. Because the distance of the moon from the earth is approximately 240,000 miles (in round numbers), $2 \times 240,000 \div 2.6$ seconds = 184,615, the speed of radar in miles per seconds.

SPEED OF LIGHT

The difference in the speed of light through air, glass, and other substances accounts for the bending of light rays. Without this characteristic of light, a glass lens could not bend light rays to a focus, as you will learn later in



137.16

Figure 2-11.—Electromagnetic spectrum.

137.18

Figure 2-12.—Photograph of scene in illustration 2-13 taken by visible light.

137.17

Figure 2-13.—Photograph taken by infrared light.

this text. The length of all waves in the electromagnetic spectrum is also connected to corresponding frequencies and the speed of light.

Because light travels with such high velocity, it was years before any one could measure its speed. Galileo tried to measure it by having two men in towers on hills some distance apart flash lights at each other. Each person flashed his light as soon as he saw the light signal of the other. Galileo reasoned that he could determine the speed of light by dividing the total distance the light traveled by the time required for the transmission of signals. His experiment was not successful; and he concluded that the speed of light was too great to be measured by this method. His final thought relative to the speed of light was that its transmission through space was perhaps instantaneous.

Roemer's Measurement

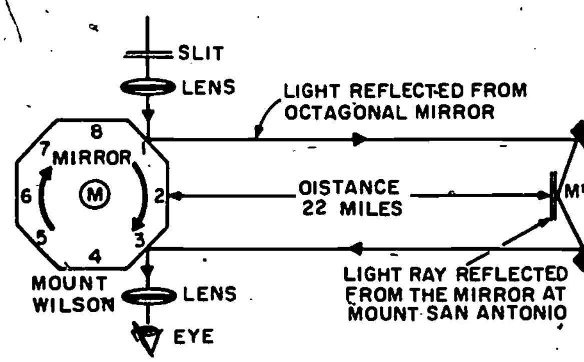
Olaus Roemer, a Danish astronomer, in 1675 calculated the speed of light by observing the irregularities in the times between successive eclipses of the innermost moon of Jupiter by that planet.

Roemer observed the position of Jupiter's moons revolving around the planet. The moons appeared on one side and then moved across in front of the planet and disappeared behind it. He could calculate accurately when one of the moons would be eclipsed by the planet. When he tried to calculate ahead six months, however, he learned that the moon eclipse occurred about 20 minutes later than he had calculated. He therefore concluded that the light had taken this amount of time to cross the diameter of the earth's orbit, which is approximately 186,000,000 miles. The difficulty was that Roemer did not correctly evaluate the speed of light; later measurements showed that the time was about 1,000 seconds, which gave 186,000 miles per second as the velocity of light.

Michelson's Measurements

The most accurate measurements of the speed of light were made after 1926 by A. A. Michelson, a distinguished American physicist, and his colleagues. Professor Michelson used an octagonal mirror in an apparatus illustrated in figure 2-14. He measured the speed of light in air over the exact distance between Mt. Wilson and Mt. San Antonio, California. The light source (mirror) and the telescope were located on Mt. Wilson and the concave and plane mirrors were located on Mt. San Antonio, about 22 miles distant.

Study the illustration. Mirror M is stationary, and Professor Michelson passed a pencil of light through a slit and a lens to the octagonal mirror. NOTE: A pencil of light is a narrow group of light rays which come from a point source, or converging toward a point. A pinhold opening produces a pencil of light rays. Mirror M then reflected the light from position 1 to Mirror M', which (in turn) reflected the pencil of light back to point 3 on the octagonal mirror.



137.13

Figure 2-14.—Michelson's mirror method for measuring the speed of light.

The octagonal mirror was next put into motion and increased in speed enough to move position 2 on the octagonal mirror into the position formerly occupied by position 3 during the time required for the light to travel from position 1 on the octagonal mirror to Mt. San Antonio and return. After several years of observation with his apparatus, Professor Michelson concluded that the speed of light in air was 299,700 kilometers (a kilometer is .6214 mile) per second.

Sometime later, Professor Michelson used an evacuated tube one mile long to measure the speed of light in a VACUUM. The vacuum tube removed variations in air density and haze from the test, and the experiment showed that the speed of light in a vacuum was slightly higher than in air. The velocity of light in a vacuum is generally accepted as 300,000 kilometers per second, or 186,000 miles per second.

Modern physicists compute the speed of light with great accuracy. Some of their measurements are based on light interference. For all practical purposes, however, the speed of light in air or in a vacuum is considered as 186,000 miles per second. In media more dense than air, the speed of light is slower, as indicated by the speed of yellow light in the following substances:

Quartz	110,000 miles per second
Ordinary crown glass.	122,691 miles per second
Rock salt . . .	110,000 miles per second
Boro-silicate crown glass.	122,047 miles per second
Carbon disulfide . . .	114,000 miles per second
Medium flint glass	114,320 miles per second
Ethyl alcohol .	137,000 miles per second
Water	140,000 miles per second
Diamond . . .	77,000 miles per second

NOTE: All colors of light travel at the same speed in air or empty space. In denser media, the velocity of light varies for different colors.

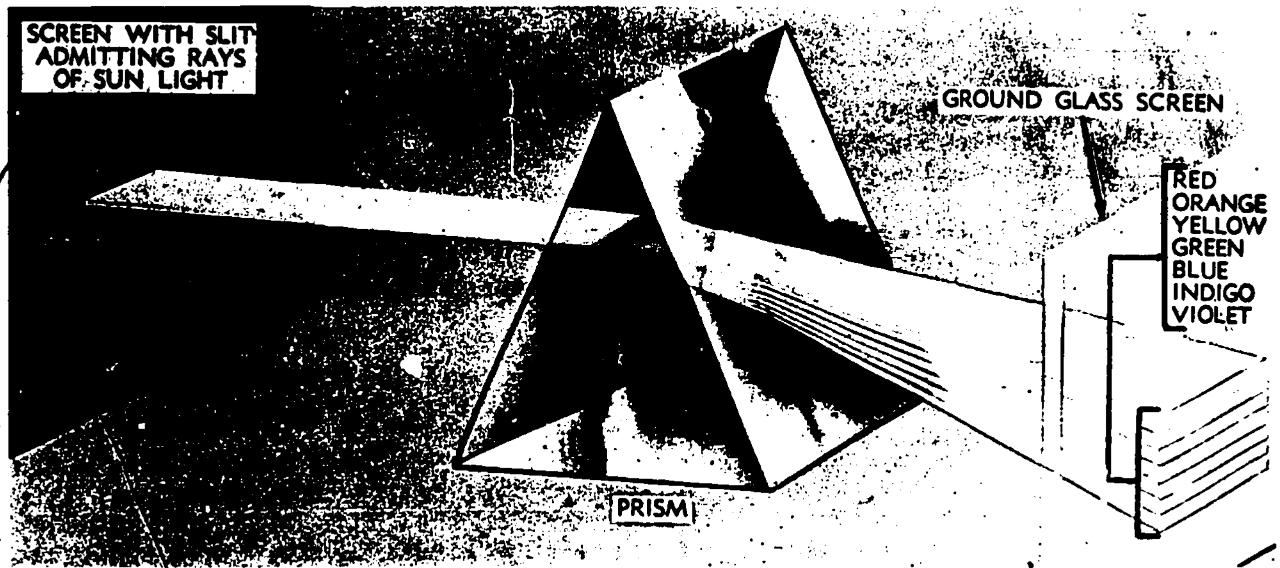
COLOR OF LIGHT

Because sunlight includes the whole range of wavelengths between 400 mμ and 700 mμ it is a mixture of all visible colors between red and violet. Illustration 2-15 shows how you can prove this. When the sun is shining, put a prism on a table in a room with one window and cover the window with dark paper or cloth. Then cut a horizontal slit about an inch long and 1/16th of an inch wide in the paper to admit a small quantity of light. Hold the prism close to the slit to ensure passage of sunlight onto one of the long faces of the prism. (Lenses and prisms are discussed in detail in chapter 3 and 4. At the same time, hold a ground glass screen or a sheet of white paper on the other side of the prism, 6 to 8 inches away. When the sunlight passes through the prism, wavelengths of various colors refract at different angles toward the base of the prism and produce the colors of sunlight (the rainbow) on the glass screen or sheet of white paper. This breaking up of white light into its component colors is called DISPERSION.

SELECTIVE REFLECTION AND ABSORPTION

If you look at a piece of red paper in the sunlight, you see red; but this does not mean that the paper is making red light. What it does mean is that the paper is reflecting a high percentage of the red light which falls on it and is absorbing a high percentage of all other colors.

When you look through yellow glass, you see yellow; because the glass is transmitting yellow light and is absorbing most of the other colors. Usually, yellow glass absorbs violet, blue, and some green; but it transmits yellow, orange, and red. When yellow, orange, red, and a little green all enter your eye at the same time, however, the color you see is yellow.



137.19

Figure 2-15.—Dispersion of light into a spectrum by a prism.

Selective absorption of light is what takes place when a color filter is used on an optical instrument. An image may be blurred by haze or fog, but when a yellow filter is put into the line of sight the image becomes sharper. The reason for this is that a thin haze permits most of the light to pass through; but it scatters some of the blue and violet light in all directions. Haze is therefore visible because of the scattered blue and violet colors. The yellow filter absorbs blue and violet and the haze becomes almost invisible.

COLOR VISION

A pure spectral color is composed of light of one wavelength, or a very narrow band of wavelengths. When this light enters your eyes, it gives a sensation of color; but you cannot judge the wavelength of light from color sensation. Most of the colors you see are not pure spectral colors but mixtures of these colors. The sensation you get from these mixtures are therefore not always what you may expect.

VISIBILITY OF OBJECTS

In order to fully understand our ability to see an object, we must understand what light is and how it reacts with matter. Just to be sure you understand let's recap what we have studied:

- Light is a form of energy.
- Experiments show that light has the nature of particles and is propagated in waves.
- Visible objects give off light that enters our eyes.
- Luminous objects are a source of light.
- Nonluminous objects reflect light from another source.
- Light travels in straight lines as rays of light.
- Only the energy of a wave travels.
- The intensity of light is measured in candle power.
- Wavelengths is the distant between two successive waves.
- Frequency is the number of waves passing a fixed point in one second.
- Visible light is a relatively small range of the electromagnetic spectrum.

- The speed of all electromagnetic waves is the same in a vacuum.
- The speed in more dense media is less, and varies with the wavelength.
- White light is made up of a mixture of wavelengths between about 400 and 700 millimicrons (mu).
- When an object reflects some of the wavelengths of light, but absorbs others, it gives a sensation of color.

We see things because of reflected light. Objects look different because they reflect light in a different manner. The difference in the intensity of light makes a difference in the visibility of an object. Color, likewise, makes a difference in the visibility of objects. If one object absorbs twice as much color as another object, you have no difficulty in differentiating between them. You can therefore judge the size and shape of an object because of the difference in color or intensity of reflected light.

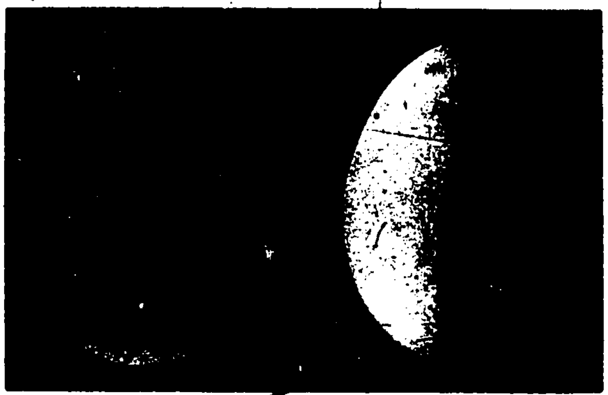
Refer now to illustration 2-16, one part of which is an egg and the other part is a piece of white cardboard cut to the approximate dimensions of the egg. You can easily distinguish each by the way light is reflected from them. All parts of the cardboard reflect light equally, because all rays of light fall on it at the same angle. Rays of light on the egg, however, strike the shell at different angles; and the amount of light reflected from any surface depends upon the angle of incidence (explained later) with which the rays of light strike the shell.

Another way to tell the difference between the egg and the piece of cardboard is by the shadows cast by the egg. Observe the right side of the egg. Because of the difference in the angles with which the light strikes the egg, you can detect roughness in the shell. This roughness indicates texture, which causes an object to show minute differences in color or shape all over the surface.

For the sake of convenience, we can divide objects into three different classes, according to the reaction of light when it falls upon them: OPAQUE, TRANSLUCENT, AND TRANSPARENT.

OPAQUE OBJECTS

All the light which falls upon an opaque object is either reflected or absorbed—none of the light passes through. This is important, because most objects are opaque. No object,



137.24

Figure 2-16.—Visual determination of difference between objects.

however, is completely opaque. If it is thin enough, you can see through anything. Even heavy metals such as silver and gold allow some light to pass through them when they are painted in a thin film on glass. When this film is made a little thicker, it permits light to pass through, but you cannot see through the film. It is translucent, not opaque.

Tubes which hold lenses and prisms in optical systems are opaque, to prevent entrance of light into the system except through the front lens. These tubes are painted a dull or flat-black color inside, so that they will absorb and not reflect light which falls on them.

TRANSLUCENT

When light falls upon a translucent object, some of it is absorbed and reflected; but MOST OF THE LIGHT is transmitted through the object and diffused or scattered in all directions. This is what happens, for example, when light passes through ground glass plate, stained glass windows, or a thin sheet of paraffin. If you hold these items in front of a strong light, you can see that much of the light passes through, even though you are unable to see a clear image of the source of light.

Transparent

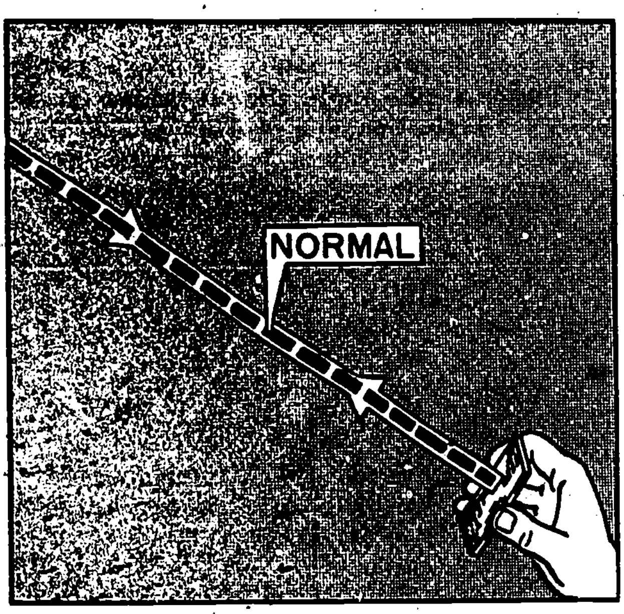
A transparent object reflects and absorbs a small amount of the light which strikes it; but it permits most of the rays to pass through.

Reflection and absorption are prime factors in determining the quality of optical glass used in the manufacture of instruments. This will be discussed in greater detail later in the manual.

A window pane is a good example of a transparent object. Clear glass is considered to be transparent, but the thicker the glass is the greater the loss of transparency.

REFLECTION

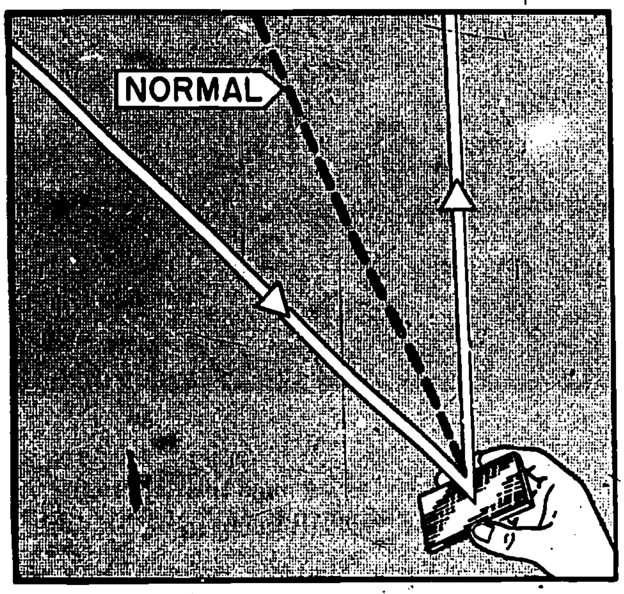
You know from experience that a mirror reflects light. If you experiment with a plane mirror in a dark room with a window through which you can admit light, you will find that you can reflect a beam of light to almost any spot in the room. When you hold a mirror perpendicular to a beam of light, you can reflect the beam back along the same path by which it entered the room. Figure 2-17 shows how to do this.



137.25

Figure 2-17.—Reflection of a beam of light back on its normal or perpendicular.

If you shift the mirror to an angle from its perpendicular position, the reflected beam is shifted at an angle from the incoming beam twice as great as the angle by which you shifted the mirror. Study figure 2-18. If you hold the mirror at a 45° angle with the incoming beam, the reflected beam is projected at an angle of 90° to the incoming beam. Remember this characteristic of light.



137.26

Figure 2-18.—Reflection of beams of light at different angles.

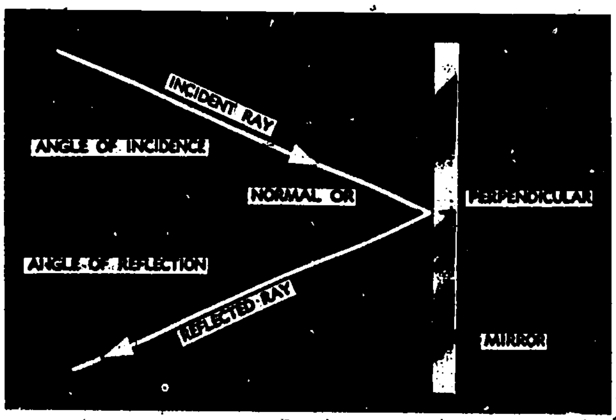
The simple experiments just discussed illustrate one of the dependable actions of light. You can reflect light precisely to the point where you want it, because any kind of light reflected from a smooth, polished surface acts in the same manner. This property of light is put to use in many types of fire control instruments.

Refer now to figure 2-19, the ray of light which strikes the mirror is called the INCIDENT ray, and the ray which bounces off the mirror is known as the REFLECTED ray. The imaginary line perpendicular to the mirror at the point where the ray strikes is called the NORMAL or PERPENDICULAR. The angle between the incident ray and the normal is the ANGLE OF INCIDENCE; the angle between the reflected ray and the normal is the ANGLE OF REFLECTION.

Law of Reflection

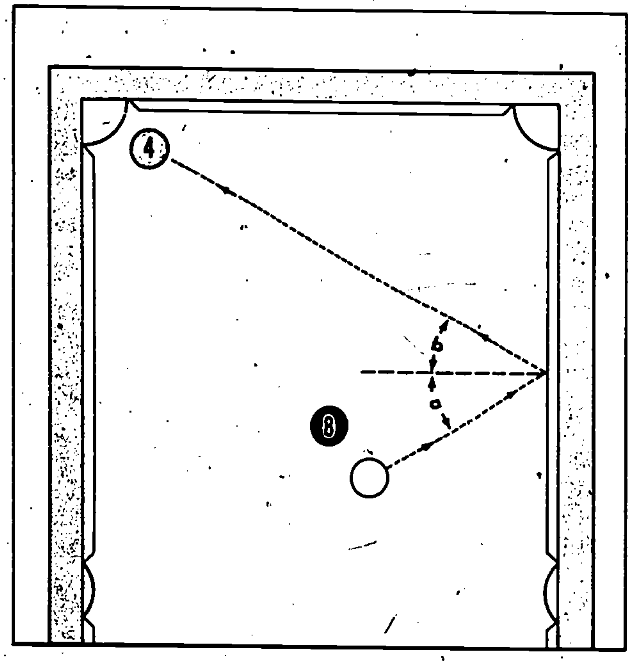
The law of reflection is covered by three basic statements:

- The angle of reflection equals the angle of incidence.
- The incident ray and the reflected ray lie on opposite sides of the normal.
- The incident ray, the reflected ray, and the normal, all lie in the same plane.



110.30
Figure 2-19.—Terms used for explaining reflected light.

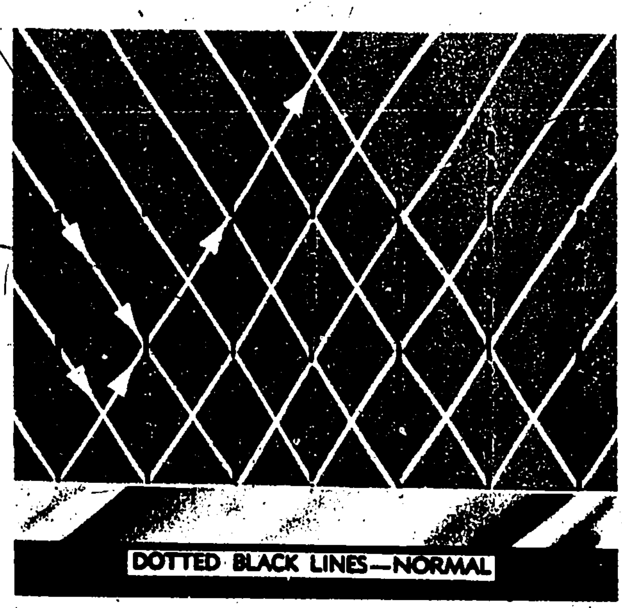
By applying the law of reflection, you can see that in all cases of reflection the angle of reflection can be plotted as long as the angle of incidence is known, or vice versa. To illustrate, study figure 2-20. In this instance you desire to put the No. 4 ball in the nearest pocket, but your cue ball is behind the 8 ball. If you are an expert pool player, you know where to strike the right side of the pool table with the cue ball in order to have it reflect on a line which will enable it to hit the No. 4 ball and put it in the pocket. Angle b must equal angle a.



137.29
Figure 2-20.—Application of the law of reflection on a pool table.

Regular Reflection

Whenever there is mirrorlike reflection in which the angle of reflection is equal to the angle of incidence, you have speculor or commonly called, "regular reflection." Speculor reflection can only come from a plano polished surface, and, if the incident light is parallel, the reflected light will be parallel as shown in figure 2-21. It also stands to reason that if the incident light is diverging or converging then the reflected light will be traveling in a like manner.

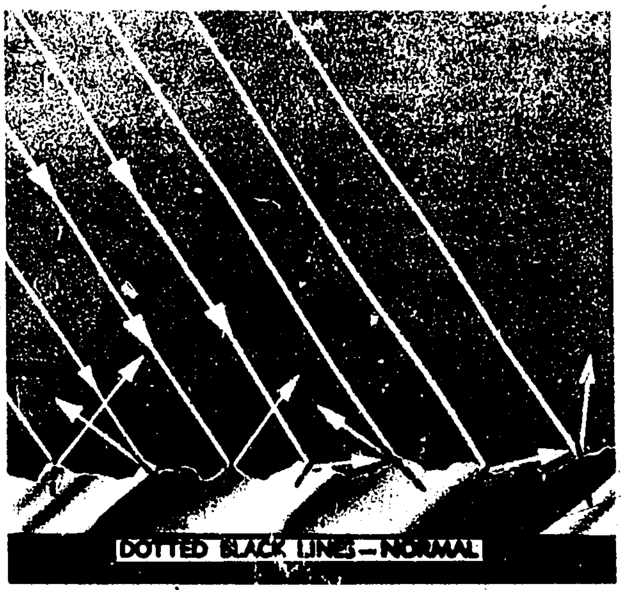


137.30
Figure 2-21.—Regular reflection.

Diffuse Reflection

The antithesis of speculor reflection is diffuse reflection and it will occur when light is reflected from a rough surface, or an object that has an irregular surface. Diffuse reflection is defined as a random distribution of included angles for a series of rays traveling from the same source. As shown in figure 2-22, diffuse reflection is a scattering of the incident light and it accounts for our ability to see all

27



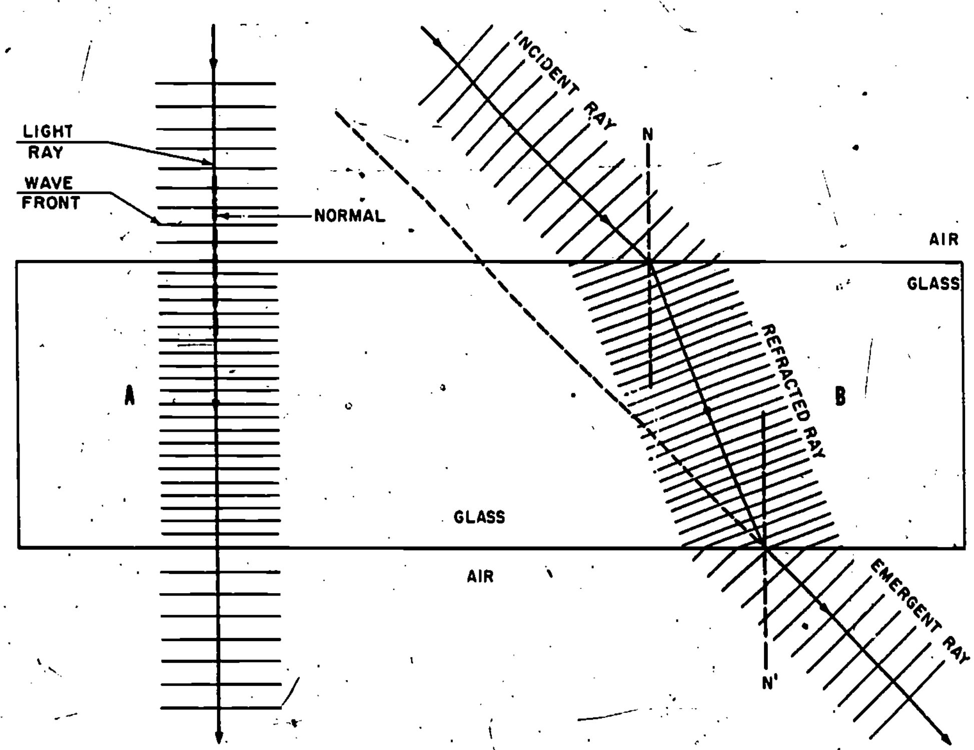
137.31
Figure 2-22.—Diffuse reflection.

nonluminous objects as well as distinguish shape and texture. The surface of the paper in this manual is essentially rough and the light that is reflected from it is diffused.

REFRACTION

As you study the meaning of refraction, refer to figure 2-23, which shows what happens to rays of light as they pass through a sheet of glass. Both plane surfaces of this glass plate are parallel and air contacts both surfaces. Glass and air are transparent, but the glass is optically more dense than air; so light travels approximately one-third slower in glass than in air.

Observe the dotted lines (N & N') in the illustration. These are the normals erected for the incident and refracted rays. When a light ray (wave front) strikes the surface of the glass at right angles (parallel to the normal), it is not bent as it passes through the glass. This is true because each wave front strikes



137.32
Figure 2-23.—Refraction of light beams by a sheet of glass.

28

the surface squarely. The wave front is slowed down when it strikes the surface of the glass, but it continues in the same direction it was going before striking the glass. When it squarely strikes the other surface of the glass, it passes straight through without deviation from its course.

If a wave front strikes the first surface of the glass at an angle, as illustrated in part B of figure 2-23, one edge of the first wave front arrives at the surface an instant before the other edge; and the edge which arrives first is slowed down as it enters the denser medium before the second edge enters. Observe that the second edge continues to travel at the same speed, also, until it strikes the surface of the glass. This slowing down of one edge of the wave front before the other edge slows down causes the front to PIVOT TOWARD THE NORMAL.

The information just given relative to a wave front which strikes glass plate is applicable FOR ANY FREELY MOVING OBJECT. When one side of the object is slowed down as it hits something, the other side continues to move at the same speed and direction until it also hits something. This action causes the object to pivot in the direction of the side which hits first and slow down. Pivoting or bending of light rays (wave fronts) as just explained, is called REFRACTION; and the bent (pivoted) rays are labeled REFRACTED RAYS.

If the optical density of a medium (glass in this case) remains constant, the refracted light rays continue to travel in a straight line, as shown in part B of figure 2-23, until the surface from which they emerge (glass-to-air surface) causes interference. At this point, an opposite effect occurs to a wave front. As one edge of the front reaches the surface (glass-to-air), it leaves the surface and resumes original speed (186,000 miles per second, at which it entered the glass).

Speeding up of one edge of a wave front before the other edge speeds up, causes the front to pivot again; but this time it pivots toward the edge of the front which has not yet reached the surface of the glass. Again, THIS BENDING OR PIVOTING OF THE WAVE FRONT IS CALLED REFRACTION.

If the glass plate has parallel surfaces, the emergent light ray (ray refracted out of the glass) emerges from the second surface at an angle equal to the angle formed by the incident ray as it entered the glass. If you draw a dotted line along the emergent light ray (fig. 2-23), straight back to the apparent source of the ray, you will find that the emergent ray is parallel to the incident ray.

If the optical density of a medium entered by a light ray (wave front) is constant, the light follows its course in a direct line, as illustrated in part B of illustration 2-23.

Laws of Refraction

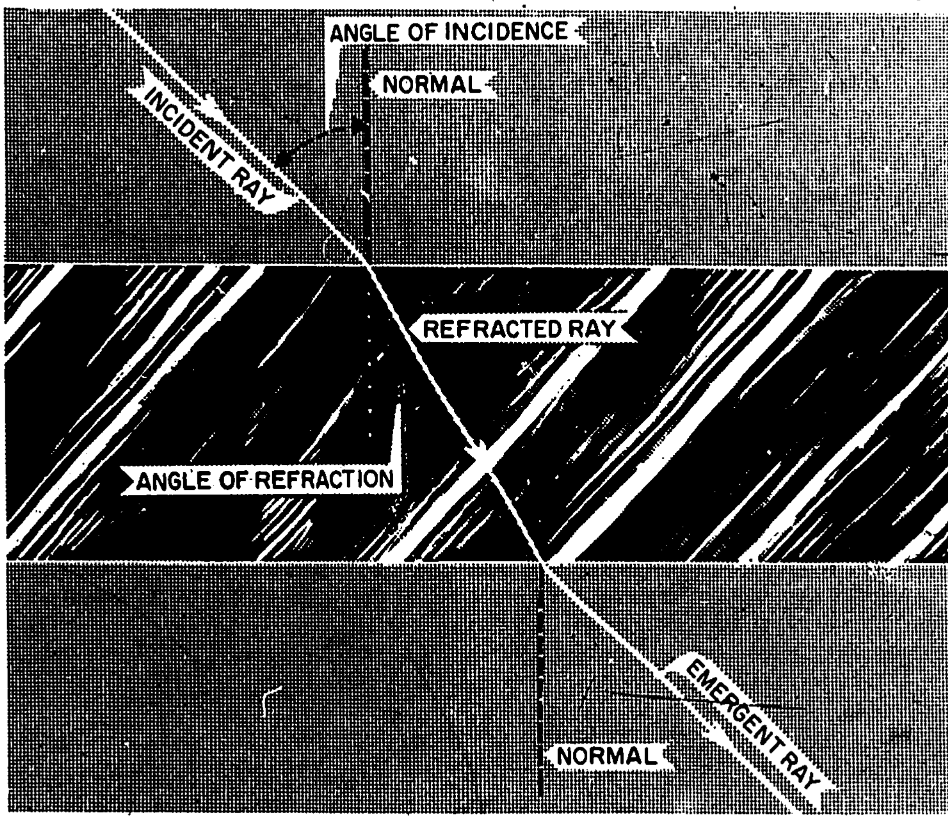
You should understand thoroughly all laws of refraction. Briefly stated, they are as follows:

1. WHEN LIGHT TRAVELS FROM A MEDIUM OF LESSER DENSITY TO A MEDIUM OF GREATER DENSITY, THE PATH OF THE LIGHT IS BENT TOWARD THE NORMAL.
2. WHEN LIGHT TRAVELS FROM A MEDIUM OF GREATER DENSITY TO A MEDIUM OF LESSER DENSITY, THE PATH OF THE LIGHT IS BENT AWAY FROM THE NORMAL.
3. THE INCIDENT RAY, THE NORMAL, AND THE REFRACTED RAY ALL LIE IN THE SAME PLANE.
4. THE INCIDENT RAY LIES ON THE OPPOSITE SIDE OF THE NORMAL FROM THE REFRACTED RAY.

Study illustration 2-24 and then review carefully all laws of refraction. Note the NORMAL, the ANGLE OF INCIDENCE, and the ANGLE OF REFRACTION.

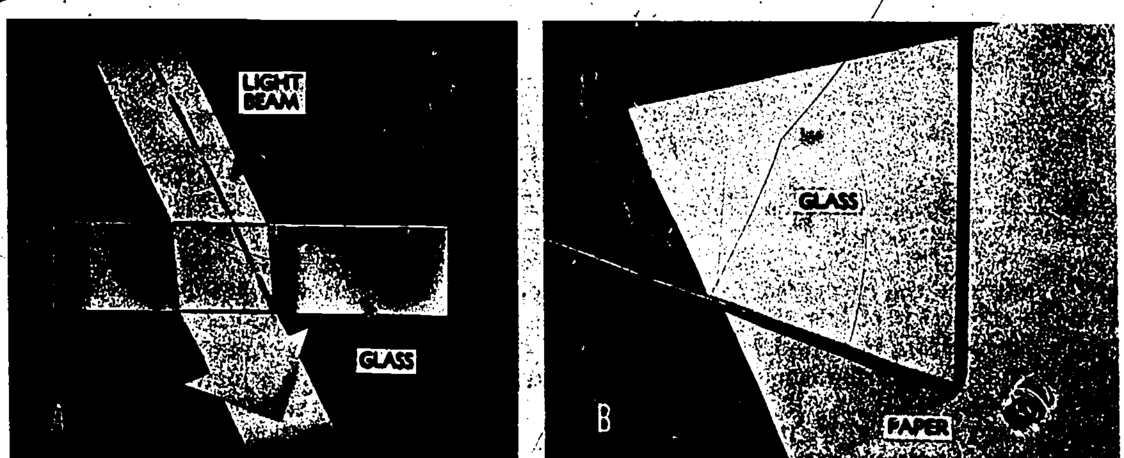
The amount of refraction is dependent upon the angle at which light strikes a medium and the density of the new medium—the greater the angle of incidence and the more dense the new medium, the greater the angle of refraction. If the faces of the medium are parallel, the bending of light at the two faces is always the same. As illustrated in part A of figure 2-25, the beam which leaves the optically more dense medium is parallel to the incident beam. An important thing to keep in mind in this respect, however, is that the emergent beam must emerge from the more dense medium into a medium OF THE SAME INDEX OF REFRACTION AS THE ONE IN WHICH IT WAS ORIGINALLY TRAVELING; that is, air to glass to air, NOT air to glass to water (as an example).

You can demonstrate refraction visually by placing the straight edge of a sheet of paper at an angle under the edge of a glass plate held vertically (part B, fig. 2-25). Observe that the straight edge of the sheet of paper appears to have a jog in it directly under the edge of the glass plate. The portion of the paper on the



12.233

Figure 2-24.—Terms used for describing refraction.



137.34

Figure 2-25.—Effects of refraction.

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other side of the glass appears displaced as a result of refraction. If you move the sheet of paper in order to change the angle of its straight edge, the amount of refraction is increased or decreased.

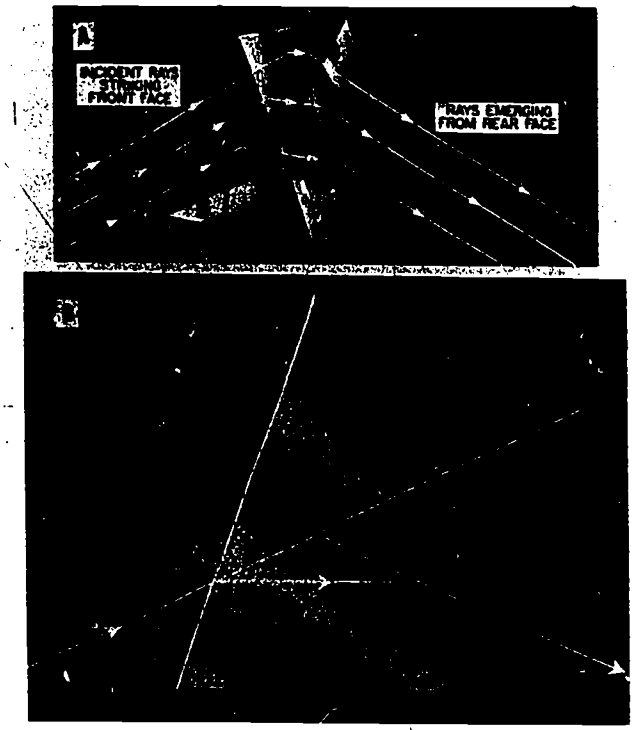
Study figure 2-26, which shows a straight stick in a glass of water. Note that the stick appears bent at the surface of the water. What you see here is an optical illusion created by refraction. When a ray of light passes from air into water, it bends; and when it passes from the water into the air, it also bends. This illustration shows why a fish in water is NOT WHERE HE SEEMS TO BE—he is much deeper.

137.33

Figure 2-26.—Optical illusion caused by refraction.

The angle between the refracted ray of light and a straight extension of the incident ray of light through the medium is called THE ANGLE OF DEVIATION. This is the angle THROUGH WHICH THE REFRACTED RAY IS BENT FROM ITS ORIGINAL PATH BY THE OPTICAL DENSITY OF THE REFRACTING MEDIUM.

Now observe figure 2-27. This illustration shows how light is effected by a medium whose entrance and emergence faces are not parallel to each other. In this illustration all laws of refraction still apply.



110.32

Figure 2-27.—Passage of light rays through a prism.

Index of Refraction

As you read earlier in this chapter, the speed of light in a vacuum is about 186,000 miles per second. Its speed through ordinary glass, however, is about 120,000 miles per second. This ratio between the speed of light in a vacuum and the speed of light in a transparent medium is known as the INDEX OF REFRACTION for that medium. On optical drawings and in optical text books, the index of refraction is designated by the letter n. It is written as a number and applies to the relation between the angle of incidence and the angle of refraction when light passes from one medium to another, or from a vacuum to a medium.

The index between two media is called the "RELATIVE INDEX" while the index between a medium and a vacuum is called the "ABSOLUTE INDEX." The index of refraction expressed in tables is the absolute index while in practice the relative index is figured. When working with optical drawings of instruments, the relative index must be figured because you will have light passing from one medium to another. (AIR TO GLASS, GLASS TO GLASS, and GAS TO GLASS).

When determining the absolute index the formula is:

$$\text{INDEX OF REFRACTION} = \frac{\text{Velocity in Vacuum}}{\text{Velocity in Medium}}$$

Now apply the formula when figuring the absolute index of a diamond in which light travels at 77,000 miles per second.

$$n = \frac{186{,}000}{77{,}000} = 2.415$$

If you need to determine the relative index of a diamond in water, you need only substitute the velocity in water for the velocity in a vacuum.

$$n = \frac{140{,}000}{77{,}000} = 1.818$$

Following is a list of absolute indices of refraction for some materials:

Vacuum	1.000
Air	1.0003
Water	1.33
Fused Quartz	1.46
Crown Glass	1.52
Canada Balsan	1.53
Light Flint	1.57

NOTE: For most computations the index of air is considered to be the same as vacuum (1.000).

Since the index of refraction of transparent materials of high purity shows a constant relationship to the physical properties of the materials, you can therefore determine the identify of transparent materials by measuring their indices of refraction.

Angle of Refraction

The amount that a ray of light is refracted (angle of refraction) in a transparent medium depends on two factors:

- The angle at which light strikes the surface (ANGLE OF INCIDENCE).
- The density of the medium. (INDEX OF REFRACTION.)

When light from the same source strikes two different media at the same angle, the light striking the medium with the highest index of refraction is refracted the most.

In 1621, Willebrord Snell, a Dutch astronomer and mathematician at the University of Heyden, found the correct relation between the angle of incidence and the angle of refraction. SNELL developed a formula for determining the angle of refraction known as SNELL'S LAW.

$$n \text{ sine}\,\theta = n' \text{ sine}\,\theta'$$

In this formula n is the index of refraction in the first medium, n' is the index for the second medium, sine is a trigonometric function, and θ (the Greek letter, theta) refers to the first angle, while θ' refers to the second angle. Simply stated, SNELL'S law says:

- THE INDEX OF REFRACTION OF THE FIRST MEDIUM, TIMES THE SINE OF THE ANGLE OF INCIDENCE, IS EQUAL TO THE INDEX OF REFRACTION OF THE SECOND MEDIUM, TIMES THE SINE OF THE ANGLE OF REFRACTION.

NOTE: In order to find the sine of an angle, you must refer to a table of natural trigonometric functions.

A very important thing for the reader to remember is, ALWAYS MEASURE THE ANGLE OF INCIDENCE BETWEEN THE INCIDENT RAY AND THE NORMAL, LIKEWISE THE ANGLE OF REFRACTION IS MEASURED BETWEEN THE NORMAL AND THE REFRACTED RAY.

In order to apply the formula to a practical problem let's assume that the ray light in figure 2-24 is contacting at an angle of 45°, a plate of glass, whose index of refraction is 1.500. According to Snell's law, the index of refraction (n) of the first medium (AIR = 1.000) times the sine of the angle of incidence (45° = .7071) equals the index of refraction (n') of the second medium (GLASS = 1.500) times the SINE of the angle of REFRACTION.

$$1.000 \times .7071 = 1.500 \times \text{sine}\,\theta'$$

$$.7071 = 1.500 \times \text{sine}\,\theta'$$

$$\frac{.7071}{1.500} = \text{sine}\,\theta'$$

$$.4714 = \text{sine}\,\theta'$$

By referring once again to the natural trigonometric tables, we find that .4714 is the value of the angle 28° 7' 30", the angle of refraction in the second medium.

If you now reverse the direction of the light ray to where the first medium is glass, and the second medium is air, and the angle of incidence at the surface of the glass is 28° 7' 30", you will find the angle of refraction is 45°. This may seem strange, but by application of Snell's law the formula will be:

$$1.500 \times .4714 = 1.000 \times \text{sine of } \theta'$$

$$.7071 = 1.000 \times \text{sine of } \theta'$$

$$\frac{.7071}{1.000} = \text{sine } \theta'$$

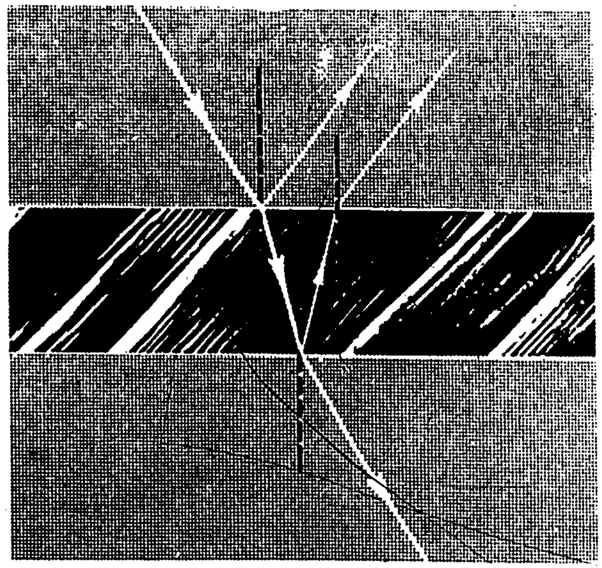
$$.7071 = 45°$$

What you just proved by solving the last equation is known as the LAW OF REVERSIBILITY, something you should remember. The law means that if the direction of a ray of light AT ANY POINT IN AN OPTICAL SYSTEM IS REVERSED, THE RAY RETRACES ITS PATH BACK THROUGH THE SYSTEM, regardless of the number of prisms, mirrors, or lenses in the system.

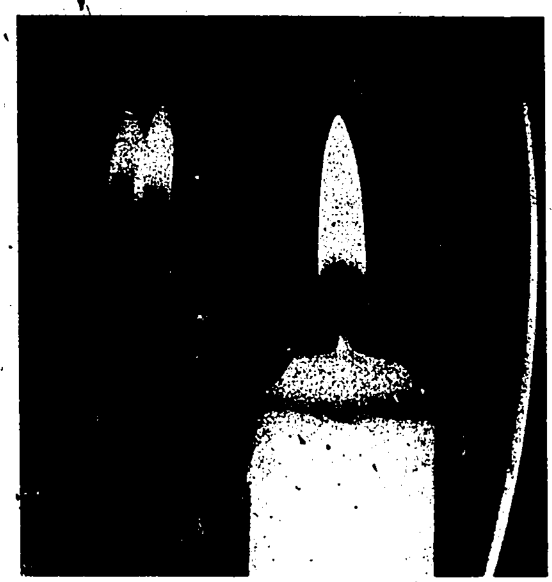
Reflection and Refraction Combined

Smooth glass reflects part of the light which falls upon it, about 4 percent (more if the angle of incidence is large): but most of the light which enters the glass is refracted. Figure 3-35 shows a ray of light passing through plate glass. The dotted lines are the normals. The white arrow to the right of the first normal line indicates reflected light. The line of light which extends upward from the second normal represents the amount of light reflected back into the glass when the light strikes the lower surface. This is called INTERNAL REFLECTION. An internally reflected ray of light is refracted at the upper surface of the glass and emerges parallel to the reflection from the incident ray.

Study next illustration 2-29, which shows reflections from both surfaces of a glass plate. Note the two images. If you have several plates of glass in a stack with thin layers of air between the plates on the inside, you can see twice as many reflections as the number of plates of glass. NOTE: You will occasionally find a condition such as this in optical instruments.



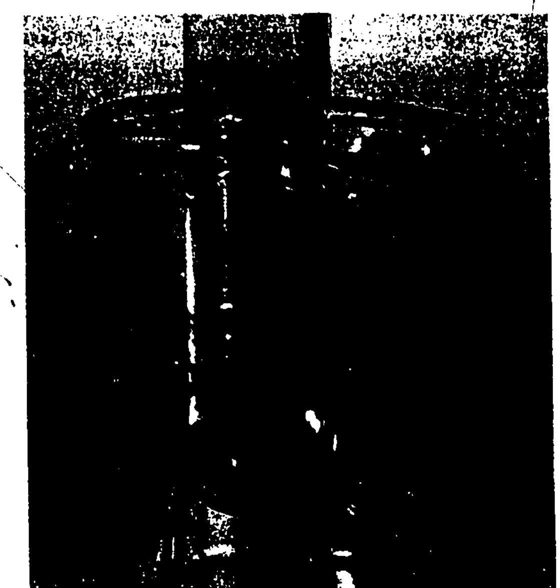
137.35
Figure 2-28.—Reflection and refraction combined.



137.36
Figure 2-29.—Reflection from the surfaces of a glass plate.

If you have five lenses in a system, you have ten faces; and each face reflects part of the light. The image you see when you look through the instrument is fromed ONLY by the light which passes through the lenses. A complex instrument such as a submarine periscope may have many surfaces which reflect part of the light, and the lenses and prisms must have a coating or film applied to them to eliminate reflection and prevent loss of light in the instrument.

You know that optical glass is highly transparent, but it is still visible because of reflected light from its surface. Other glass objects are visible partly because of refraction. You can see part of the background through the glass, but the glass bends the rays from the background before they reach your eyes. In accordance with the angle at which it strikes the surface of the glass, each ray bends at a different angle. The background, therefore, appears distorted when you see it through the glass. As in figure 2-30.

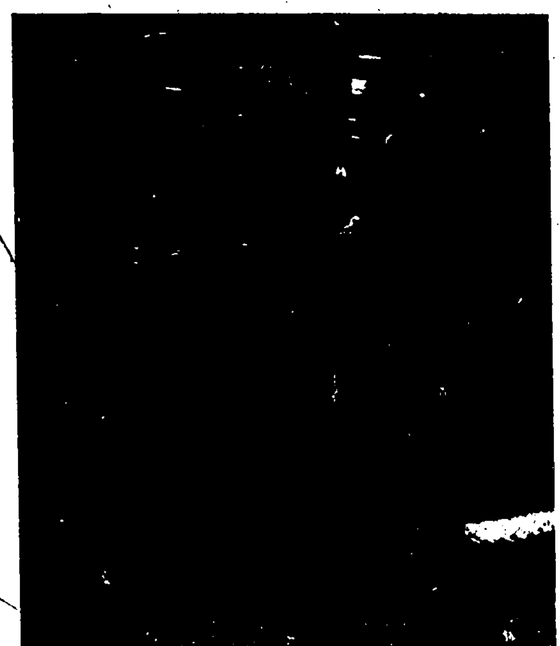


137.37

Figure 2-30.—Visibility resulting from combined reflection and refraction.

Reflection can take place ONLY at a surface between two media with different indices of refraction. Because the rod in figure 2-30 is in air, the difference between the two media is fairly large and the rod is visible. This same rule applies to refraction, as you can prove by Snell's law. If the indices of refraction of the two media are identical, the angle of incidence equals the angle of refraction and there is NO refraction.

Illustration 2-31 is the same as figure 2-30 except that water has been put into the glass beaker, and the appearance of the part of the glass rod IN THE WATER looks different from the part OUT OF THE WATER. The reason for this is that the index of refraction between the two media is now much smaller, so there is less reflection and less refraction.



137.38

Figure 2-31.—Effect of visibility by the reduction of reflection and refraction.

If the water in the glass beaker is replaced with a solution of the same index of refraction as glass, there is no reflection or refraction and the end of the glass rod in the solution is invisible. See figure 2-32.

Total Internal Reflection

You have learned that a small amount of reflection occurs when light passes from one transparent medium to another as in figure 2-28. When light passes from a more dense medium to a lesser dense medium there is one special angle of incidence which will not produce refraction nor reflection as we have thus far studied. This special angle of incidence is called the CRITICAL ANGLE and when an

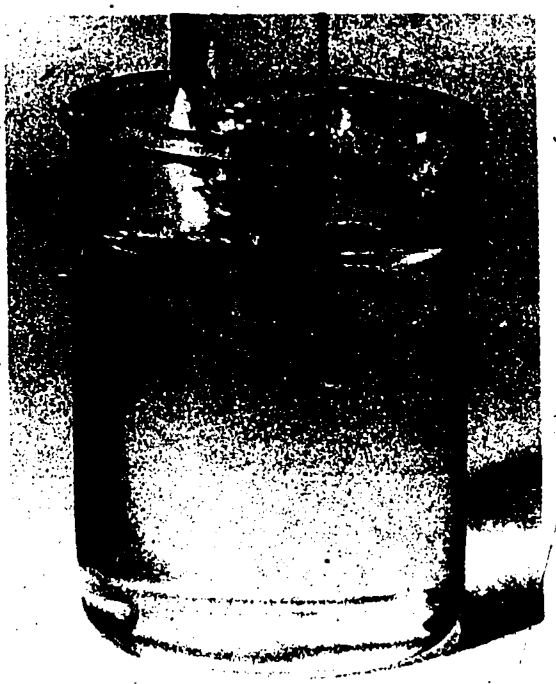


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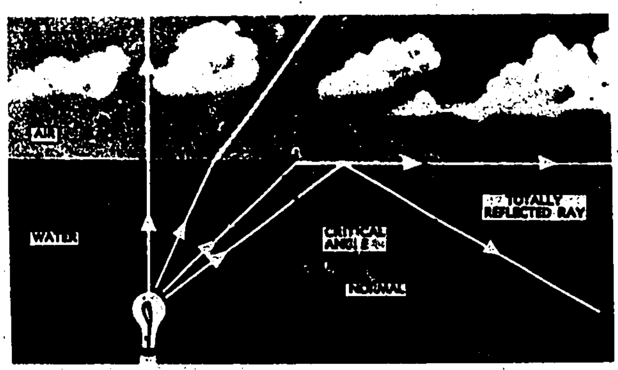
Figure 2-32.—Elimination of visibility by eliminating reflection and refraction.



137.40
Figure 2-33.—Angles of light rays from an underwater source.

incident ray strikes the surface between the two media at this angle, it will be transmitted along the media's surface as shown in figure 2-33.

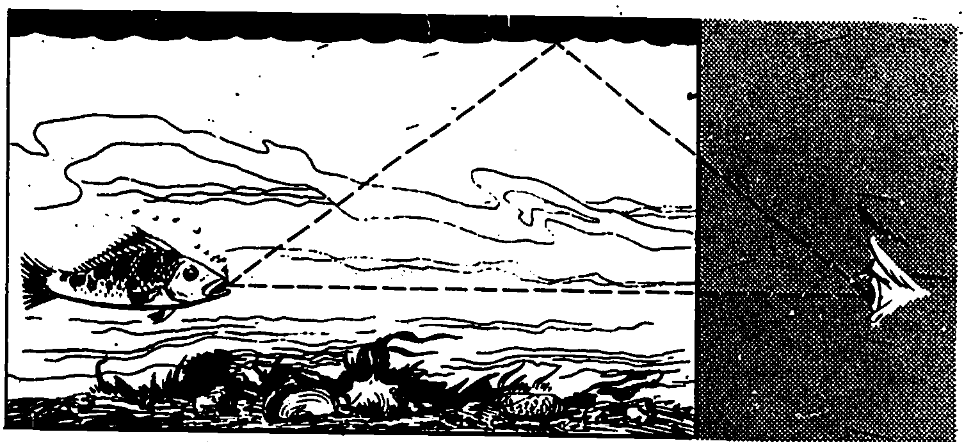
Should a ray of light strike the surface at an angle of incidence greater than the CRITICAL ANGLE, TOTAL INTERNAL REFLECTION will occur (fig. 2-33). This phenomena of total internal reflection is very useful and will be discussed further in chapter 3 when PRISMS are covered.

Study figure 2-33 carefully, this shows that rays of light from an underwater source are incident at various angles to the surface. You will notice that as the angle of incidence increases, the angle of refraction becomes proportionately greater, until you reach the critical angle. When you reach the critical angle, and the ray is refracted along the surface, the angle of refraction is 90° to the normal. Always bear in mind that the critical angle can only be shown when light is traveling from a more dense to a less dense medium. Remember that for all angles of incidence greater than the critical angle, total reflection will result.

The actual critical angle of an optical medium depends upon the index of refraction of that medium. The higher the index of refraction, the smaller the critical angle.

One example of total internal reflection at the surface of water is shown in figure 2-34. Rays of light from the sand and the fish strike the upper surface of the water at an angle greater than the critical angle and are reflected downward into the water. The reflected rays, however, strike the end of the aquarium at LESS THAN the critical angle, so they pass through and you can see an image of the fish reflected by the upper surface of the water. The path of a reflected ray is illustrated in figure 2-35.

137.41
Figure 2-34.—Total internal reflection at the surface of water.



137.42

Figure 2-35.—Effect of total internal reflection on light rays.

Suppose you desire to calculate the critical angle of a medium when the other medium is air. How can you do this? Use water as one medium, as an example, and air as another; then make proper substitutions in the formula (Snell's law) and solve the equation. The index of refraction of water is 1.333; when the angle of incidence is the critical angle, the angle of refraction is 90 degrees. The procedure for solving the problem follows:

Snell's law: $n \text{ sine } \theta = n' \text{ sine } \theta$

$$1.333 \text{ sine } \theta = 1.000 \text{ sine } 90^\circ$$

$$\text{sine } \theta = \frac{1.000 \times 1.000}{1.333} = \frac{1.000}{1.333}$$

$$\text{sine } \theta = .750817$$

$$\theta = 48^\circ\ 36'$$

Critical angles for various substances (when the external medium is air) are as follows:

Water	48° 36'
Crown glass	41° 18'
Quartz	40° 22'
Flint glass	37° 34'
Diamond	24° 26'

The small critical angle of a diamond accounts for its brilliance, provided it is a well-cut diamond. The brilliance is due to total internal reflection of light; the light is reflected back and forth many times before it emerges to produce bright, multiple reflections.

ATMOSPHERIC REFRACTION

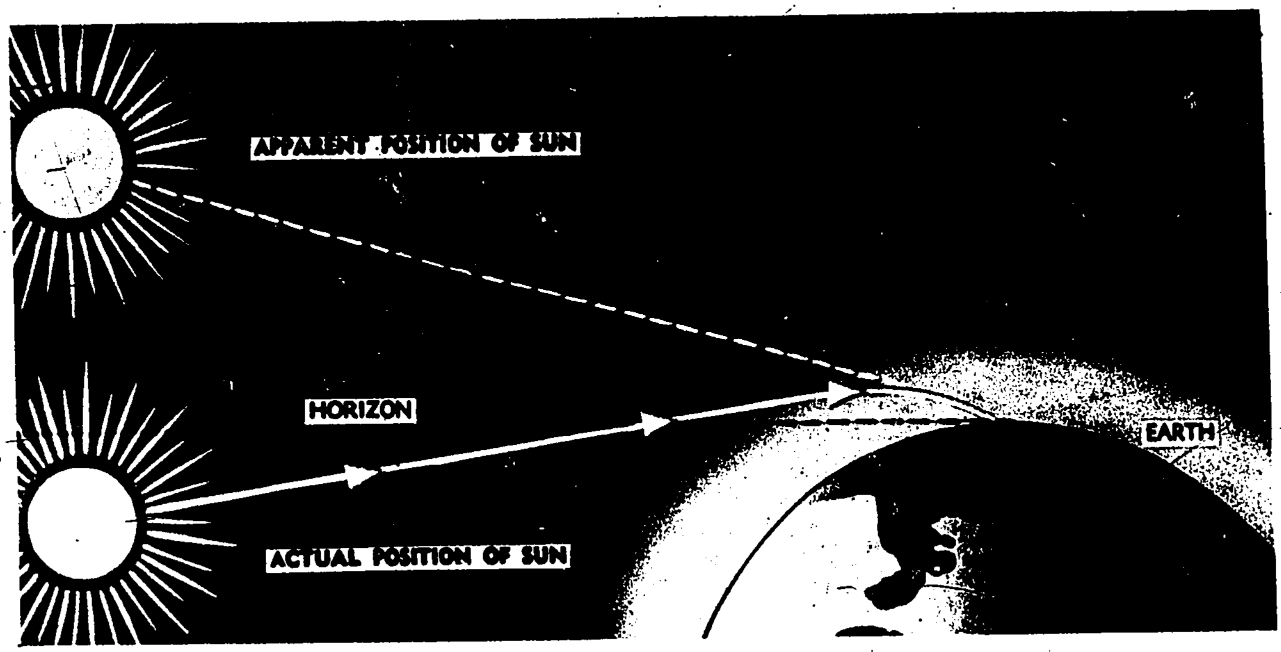
At a surface which separates two media of different indices of refraction, the direction of the path of light changes abruptly when it passes through the surface. If the index of refraction of a single medium changes gradually as the light proceeds from point to point, the path of light also changes gradually and is curved.

Although when air is most dense it has a refractive index of only 1.000292, the index is sufficient to bend light rays from the sun toward the earth when these rays strike the atmosphere at an angle.

The earth's atmosphere is a medium which becomes more dense toward the surface of the earth. As a result, a ray of light traveling through the atmosphere toward the earth at an angle does not travel in a straight line but is refracted and follows a curved path. From points near the horizon, in fact, the bending of light is so great that the setting sun is visible even after it is below the horizon (fig. 2-36).

Mirages

Over large areas of heated sand or water there are layers of air which differ greatly in temperature and refractive indices. Under such conditions, erect or inverted (sometimes much distorted) images are formed which are visible



137.44

Figure 2-36.—Visibility of the sun below the horizon as a result of refracted light.

from great distances. These images are MIRAGES.

Observe the apparent lake of water in a desert in illustration 2-37. This looks like a real lake but it is ONLY a mirage caused by the refraction of light over the hot sand. The sand heats the air directly above it, though the air at a higher level remains comparatively cool. Because cool air is more dense than hot air, the index of refracting is fairly low at the surface and gradually increases at higher and higher altitudes.

Study illustration 2-38 to learn what happens to light rays in a mirage. Light rays in cool air do not bend, as shown, but the ray which travels downward toward the hot air curves upward. When an observer looks at an object along the hot air ray, he thinks he sees it along the dotted line in the illustration.

You perhaps have observed mirages on asphalt highways on clear, hot days. When the highway rises in front of you and then flattens out, its surface forms a small angle with your line of sight and you see reflections of the sky. These reflections look like puddles of water in the road. Under proper conditions of the atmosphere and light, you can even see an approaching car reflected in the mirage.

Looming

Looming is the exact opposite of a mirage. Ships, lighthouses, objects, and islands sometimes loom—they appear to hang in the sky above their real locations. On some bodies of water (Gulf of California and Chesapeake Bay, for example) looming is common. Figure 2-39 shows the path of light rays in looming.

The reason for looming is that air is cooled at the water's surface and the index of refraction of the air decreases higher up causing the rays of light to bend downward, as shown in the illustration. This explains why a lighthouse appears to hang in the sky.

Heat Waves

On a hot day the columns of heated air which rise from the earth are optically different from the surrounding air and rays of light are irregularly refracted. The air is turbulent and conditions under which observations are made change constantly. An object viewed through such layers of air therefore appears to be in motion and the air is BOILING, or the image is DANCING BECAUSE OF HEAT WAVES. This condition is particularly bad for using a high-powered telescope, one of more than 20 power.

137.45

Figure 2-37.—Picture of a mirage in a desert.

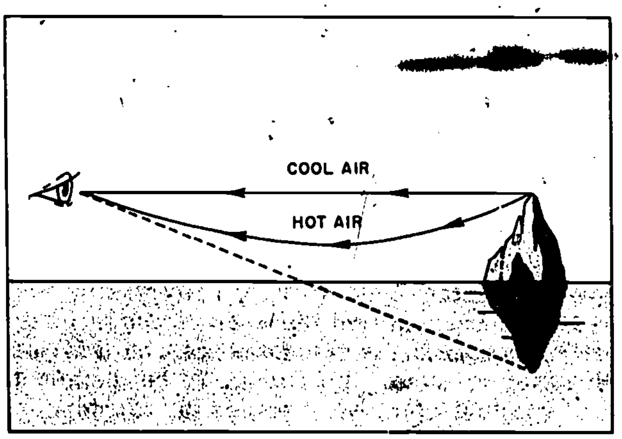


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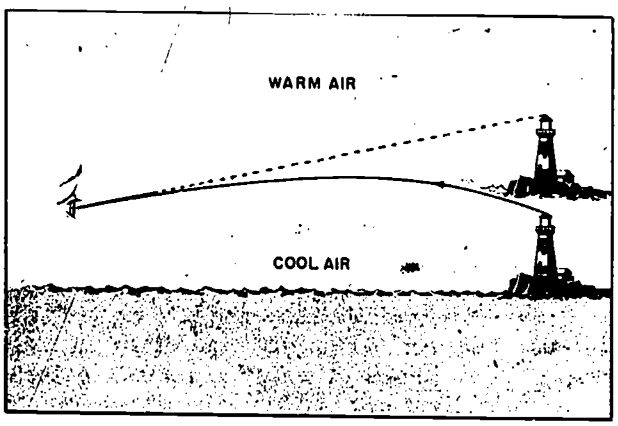
Figure 2-38.—Path of light rays in a mirage.



137.47

Figure 2-39.—Path of light rays from a looming object.

The heat waves are caused by the refraction of light waves at various changing angles, thereby creating a distortion.

Rainbows

The formation of a rainbow is a good example of refraction, reflection, and dispersion all combined. Before we can see a rainbow, however, several conditions must be ideal. First of all, you must be looking toward a point where the atmosphere holds millions of drops of water, either in the form of mist or falling rain. The sun must be shining from a point behind the viewer, and it must be fairly low in the sky.

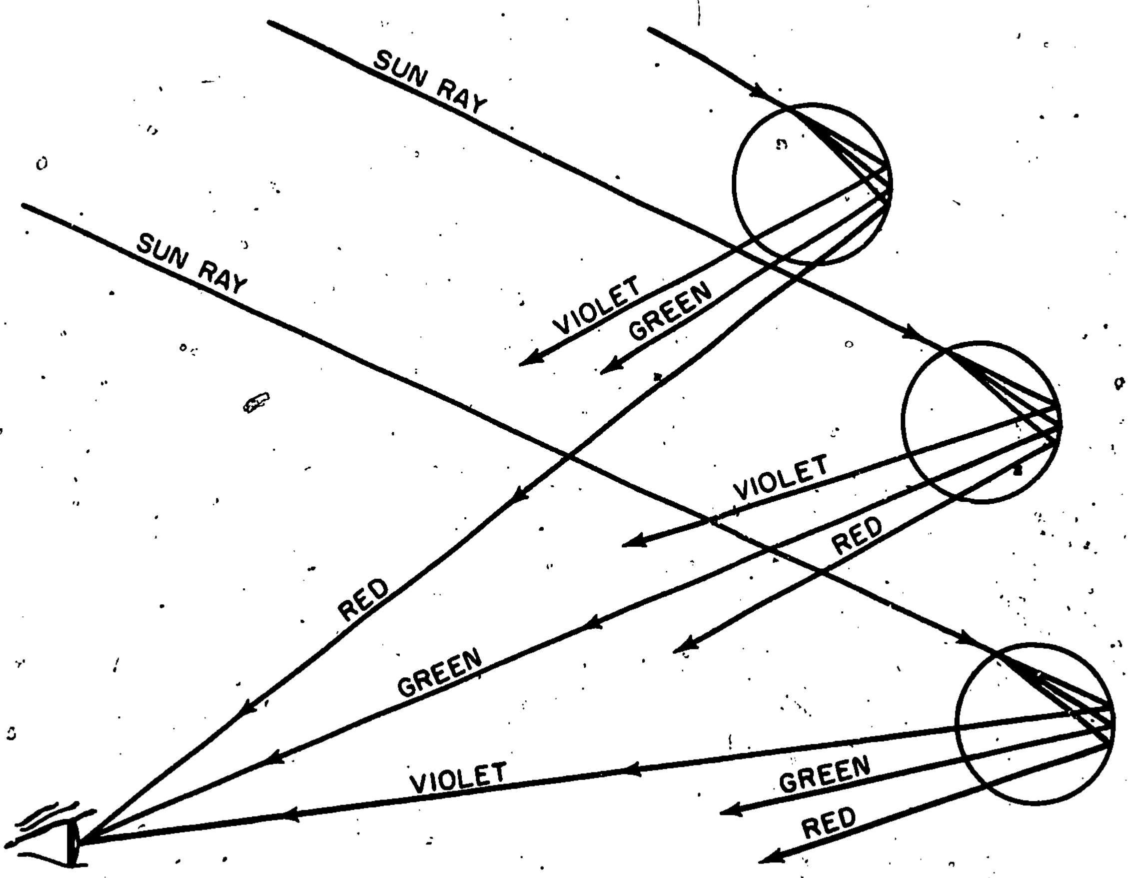


Figure 2-40.—Formation of a rainbow.

(When standing on the ground you can never see a natural rainbow at noon.)

Figure 2-40 illustrates what takes place in the formation of a rainbow. Of course, it takes millions of drops of water and you can see six colors, but, for simplicity, the diagram only shows three drops of water and three colors.

Rays of light are striking at many points on the surface of each drop, but the rays that strike at certain points, as shown in the diagram, are the only ones that can be seen. When the ray enters the drop of water, it is immediately refracted and dispersed. The light is then reflected back toward the surface due to internal reflection and is refracted again as it leaves the drop of water, continuing to be dispersed into spectral color as it enters the atmosphere again.

CHAPTER 3
MIRRORS AND PRISMS

The following chapter will be devoted primarily to describing plane mirrors and prisms, and the effect they have on light transmission. However, before we get into the discussion of mirrors and prisms, it is best to explain two other basic knowledge factors. These are measurement systems used in optics, and image descriptions.

MEASUREMENTS IN OPTICS

An Opticalman at various times works with at least four systems of measurement: the English system, metric system, degree system, and the mil system. You are already familiar with the English system where the basic unit of length is the foot. The basic unit, the foot, can be converted to smaller or larger units by multiplying or dividing by known conversion factors. The English system is not entirely satisfactory for optical measurements because it is complicated and cumbersome. The lack of simple relationships between units makes it very difficult to carry out computations. Hence, other systems of measurement are sometimes more desirable.

METRIC SYSTEM

Shortly after the French Revolution, near the end of the 18th century, the National Assembly of France decided to appoint a commission for the purpose of developing a more logical measuring system than those that were current at that time. The product of that commission was the "metric system," which has been adopted by most civilized countries except the United States.

In 1960, the International Conference on Weights and Measures adopted a modernized version of the metric system called the International System of Units. Officially abbreviated SI, it was established by international agreement to provide a logical interconnected framework for all measurements in science, industry and commerce. The six base units of measure under SI are:

Length = Meter - m
Mass = Kilogram - k
Temperature = Kelvin - k
Time = Second - s
Electric Current = Ampere - A
Luminous Intensity = Candela - cd

In your work as an opticalman, you will use the metric system of measuring as well as the English system. The diameter and focal length of lenses are usually stated on optical drawings, for example, in millimeters—not in inches. In addition, with some experience, you will find the metric system much easier to use than the English system.

Decimals are basic in the metric system of measurement. You can easily convert from one unit to another. Suppose you know that an object, for example, is 0.67 meter long and you desire the answer in decimeter. All you need do is multiply by 10 and you get an answer of 6.7 decimeters in length. If you wish the answer in centimeters, multiply by 100, and you get 67 cm. For an answer in millimeters, multiply by 1,000 and you get 670 mm.

Suppose you desire to use the English system of measurement to get in feet an object which is 0.67 yard long. You must multiply by 3 to get the answer in feet, and by 36 to get the answer in inches.

What, then, is the difference in using the English or metric system of measurement? The English system has several conversion factors, whereas, in the metric system, all you need do is move the decimal point.

The unit of length in the metric system is the METER, which is equal to 39.37 inches. A meter is divided into 100 equal parts called centimeters; and each centimeter is divided into ten parts called a millimeter, because each millimeter is 1/1,000 part of a meter. All units of linear measurement of the metric system are multiples or fractional parts of a meter in units of 10.

Following is a table of metric units, with their equivalents in inches, yards, and miles:

	1 millimeter =	.03937	inch
10 millimeters =	1 centimeter =	.3937	inch
10 centimeters =	1 decimeter =	3.937	inches
10 decimeters =	1 meter =	1.0936	yards
10 meters =	1 dekameter =	10.936	yards
10 dekameters =	1 hectometer =	109.36	yards
10 hectometers =	1 kilometer	.6214	

The names of multiples in the metric system are formed by adding the Greek prefixes: DEKA (ten), HECTO (hundred), KILO (thousand), and MEGA (million). Sub-multiples of the system are formed by adding LATIN PREFIXES: DECI (tenth), CENTI (hundredth), MILLI (thousandth), and MICRO (millionth).

For quick, approximate conversion from inches to the metric system units, or vice versa, refer to a metric unit inch conversion table, which your optical shop will have. For more exact conversion, and for conversion of large units, use the following table:

From	To	Multiply	
Millimeters	inches	Millimeters by	.03937
Inches	Millimeters	Inches by	25.4
Meters	Inches	Meters by	39.37
Meters	Yards	Meters by	1.0936
Inches	Meters	Inches by	.0254
Yards	Meters	Yards by	.9144
Kilometers	Miles	Kilometers by	.6214
Miles	Kilometers	Miles by	1.609

The unit of volume in the metric system is the LITER, which is the volume of a cube 1/10th of a meter on each side. A liter is equal to 1,000 cubic centimeters which is equivalent to 1.057 quarts.

The unit of mass in the metric system is the GRAM, the weight of one millimeter of distilled water at 4°C. For all practical purposes, a gram may be considered as the weight of one cubic centimeter (cc) of water.

The three standard units of the metric system (meter, liter, and gram) have decimal multiples and sub-multiples which make it easy to use for all purposes. Every unit of length, volume, or mass is exactly 1/10th the size of the next larger unit.

Standard abbreviations for principal metric units are:

Meter	m
Centimeter	cm
Millimeter	mm
Liter	l
Milliliter	ml
Cubic centimeter	cc
Gram	g
Kilogram	kg
Milligram	mg

DEGREE SYSTEM

The degree system is a means of measuring and designating angles or arcs. A degree is 1/360th of the circumference of a circle, or the value of the angle formed by dividing a right angle into 90 equal parts. Each degree is divided into 60 parts called minutes, and each minute is divided into 60 parts called seconds.

NAVY MIL

A Navy mil is a unit of measurement for angles, much smaller than a degree—1/6,400 of the circumference of a circle.

A mil is the value of the acute angle of a triangle whose height is 1,000 times its base. For example, when you look at an object 1,000 meters distant and 1 meter wide, the object intercepts a visual angle of 1 mil. Another way to say this is: A mil is an angle whose sine or tangent is 1/1,000. NOTE: For very small angles, the sine and tangent are practically the same.

IMAGE DESCRIPTION

An image is a representation or optical counterpart of an object produced by means of light rays. An image-forming optical element forms an image by collecting a bundle of light rays diverging from an object point and transforming them into a bundle of rays which converge or diverge from another point. If the beam actually converges to a point, a REAL IMAGE of the object is produced. If the beam diverges from a point, it produces a VIRTUAL IMAGE of the object.

REAL IMAGE

A real image is one that actually exists and is produced when the rays of light coming from an object converge at a common point. The image formed by the lens of a camera on the ground glass plate, as illustrated in figure 3-1,

137.49
Figure 3-1.—Real image of a sailor on photographic plate.

is a real image. A real image can be projected on a screen as with a movie projector.

Refer now to figure 3-2 and trace the incident light rays from the object to the ground glass of the camera where the real image is formed. The plane in which the image lies is called the image plane and is the plane where all of the converging light rays intersect.

VIRTUAL IMAGE

A virtual image is an image in effect only, and not in fact an image. A virtual image has no existence and cannot be projected on a screen. When a bundle of rays having a given divergence has no real or physical point of intersection of the rays, then the point from which the rays APPEAR to proceed is called the virtual image. The image of any real object produced by a plane or convex mirror or negative lens is always virtual.

A virtual image is so called because it does not have a real existence. It exists only in the mind and is apparent only to the eyes of the observer. A good example is the virtual image seen by the sailor in figure 3-3. The image of the sailor looking into the mirror appears to be on the other side of the mirror, a distance equal to the distance between the sailor and the mirror.

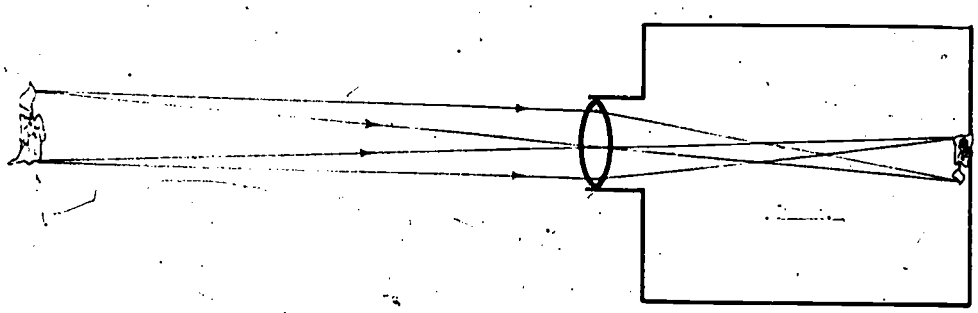
A virtual image exists only when it is viewed by the eye in contrast with the real image that actually exists and can be reproduced by film or projected on a screen.

IMAGE ATTITUDE

One of the most important features a designer must consider when designing an optical system is "IMAGE ATTITUDE." In fact, the position of the image in relation to the object is often the primary reason for employing an optical system. In describing image attitude, we use the terms invert and revert. Invert means to turn over or upside down. Thus, for object R, the inverted image is ᴚ. Revert means to turn the opposite way so that right becomes left and vice versa. Thus, for object R, the reverted image is Я.

When you desire to describe an image—any image with its actual object—you can say that it is:

1. Real or virtual.
2. Erect or inverted.



137.494
Figure 3-2.—Formation of a real image by a positive camera lens.

137.50

Figure 3-3.—Virtual image of a sailor formed by a mirror.

3. Normal or reverted.
4. Of the same size as the actual object, or larger or smaller than the actual object.

Normal and Erect

When we describe the attitude of an image, we are always making a comparison of the image with the object. If the image has the identical attitude as the object, it is said to be NORMAL AND ERECT. This is illustrated by the letter F shown in A figure 3-4.

Reverted and Erect

When you look in a mirror as the sailor in figure 3-3, you don't see yourself as others see you because your image is reverted. If you hold a cut out of the letter F up to a mirror, it would be reverted and erect as illustrated in B of figure 3-4.

Normal and Inverted

The image of an object that is upside down only is termed normal and inverted (C, fig. 3-3). An example of how an image can be normal yet inverted is shown in figure 3-5, where you view a barn reflected on the surface of water.

Reverted and Inverted

Refer again to illustration 3-1. The image of the sailor in this illustration is formed on a photographic plate (ground glass) by the lens of a camera. The image is inverted (upside-down) and reverted (left to right). You know this is true because the sailor is the object, which is erect; and his picture on the ground glass is the image (upside-down). NOTE: ALWAYS COMPARE THE IMAGE WITH THE ACTUAL OBJECT.

The rule of describing an image, in comparison with the object which formed it, is as follows: STAND BETWEEN THE OPTICAL ELEMENT AND THE OBJECT AND LOOK AT THE OBJECT. Then stand so that you may view the image which is formed and you may compare the attitude of the image with the way the object looks.

Take another look at illustration 3-1, in which you see the image as it appears when you look toward the lens which forms it; and you see the object (sailor) as he looks when you

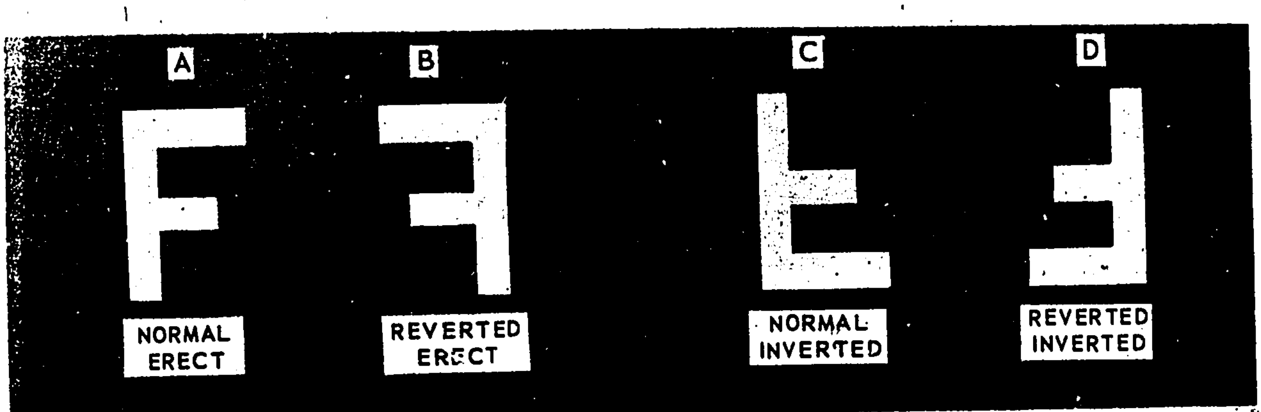


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Figure 3-4.—Positions of images of the letter F created by a small mirror.

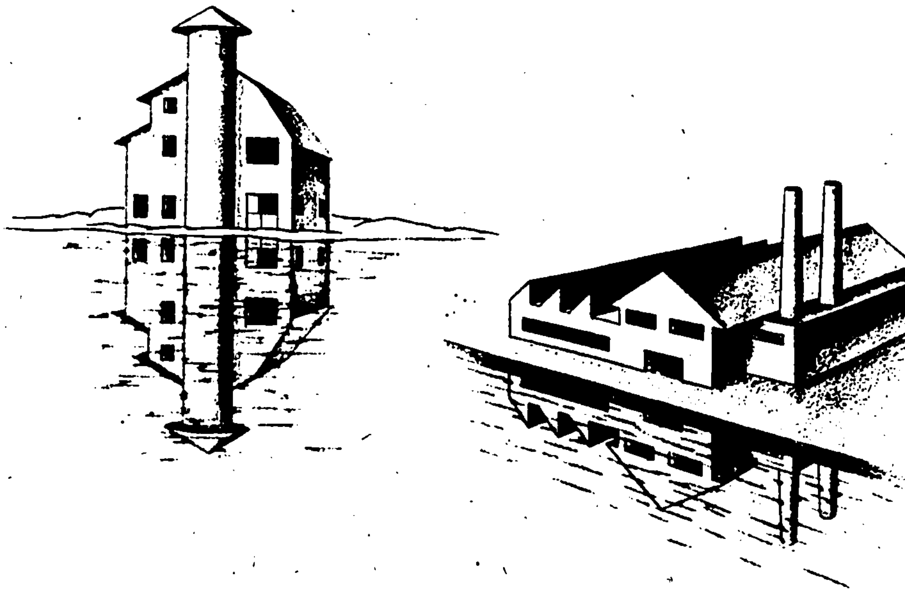


Figure 3-5.—Normal and inverted reflected image. 142.243

stand between him and the lens and observe him from that point.

Now study illustration 3-6, part A of which shows where to stand to view an object itself, and also where to stand to view the image created of that object by a mirror. Note the position of the OBJECT and also the position of the IMAGE, which is seemingly behind the mirror.

Part B of figure 3-6 shows the position to stand for viewing an object, and then the position to stand for viewing on plate glass ~~or a~~ screen the image of that object created by a positive lens. (The straight line through the center of the lens is the optical axis; positive lenses converge light rays to a point. Lenses are discussed in detail in chapter 4.)

IMAGE TRANSMISSION

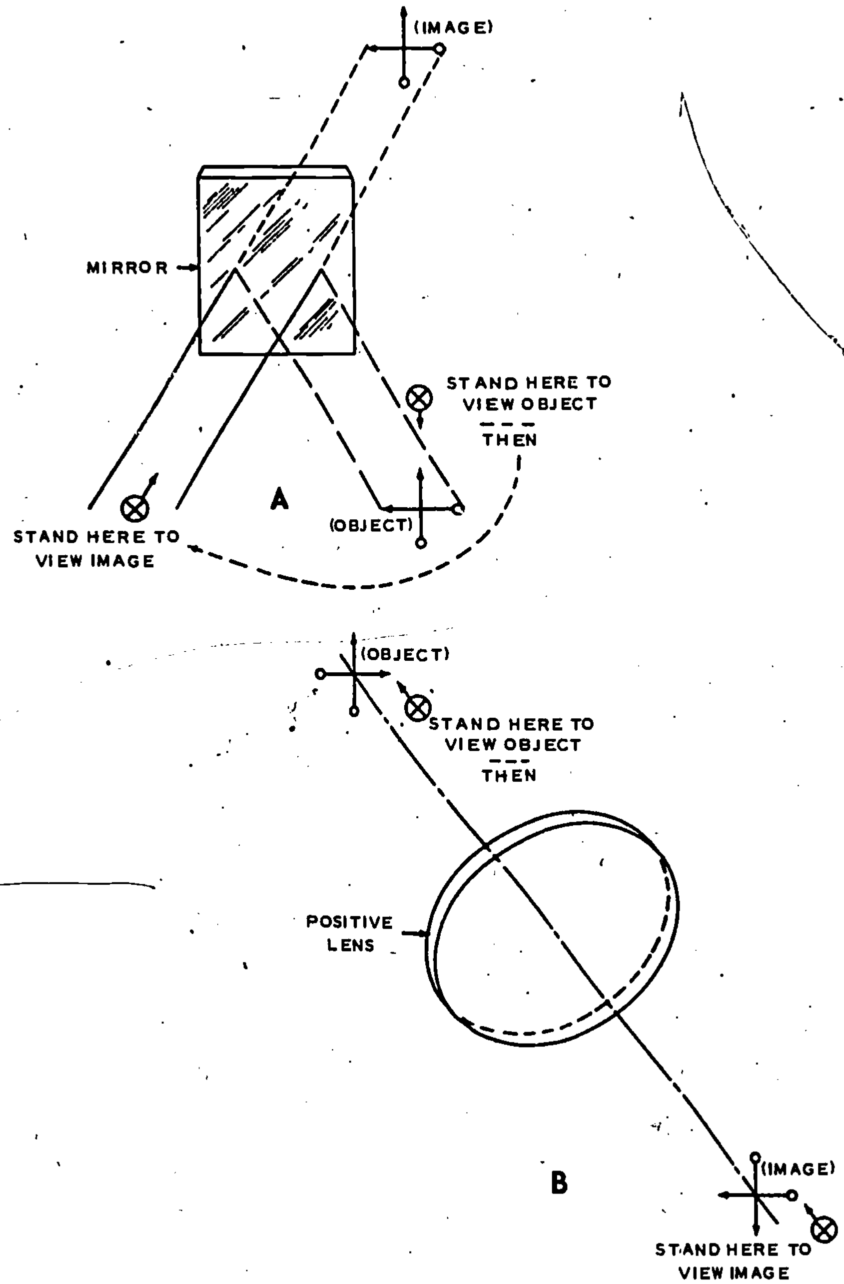
Image transmission by use of a mirror or prism is, in fact, light reflection put to practical use. The mirror or prism is mounted so that it will transmit light from an object to whatever point is desired.

PLANE MIRRORS

In a dark room, a tiny point of light viewed in a mirror appears to be located behind the mirror and on the other side of the room from where it actually is. The observer sees along the path of the reflected ray to the point where the incident ray is reflected by the mirror (eye A, fig. 3-7). His line of sight is extended in his mind in a direct line through and beyond the mirror. The apparent position of the point of light in the mirror is located directly across the room from the light source and at the same distance behind the mirror as the light source is in front of the mirror.

As long as the observer can see the reflection of the point of light in the mirror, regardless of his location in the room, its apparent position is unchanged. Observe the line of sight of eye B in illustration 3-7. The source of light (object) is reflected, and the apparent position of its reflection is changed only when the position of the object or the mirror is changed.

If the point of light (source) is replaced by a letter covered with luminous paint (F, fig. 3-8), light from every point on the letter sends out incident rays which are reflected by the mirror. Each incident ray and/or reflected ray obeys the laws of reflection and their paths can therefore be plotted accordingly. The entire image formed by a combination of an infinite number of images of individual points of light is consequently reflected to the eye of the observer. As the observer looks along the paths of the reflected rays, he sees the image formed by



A. POSITION TO STAND FOR VIEWING AN OBJECT ITSELF, AND THE POSITION TO STAND FOR VIEWING THE IMAGE CREATED OF THAT OBJECT BY A MIRROR.

B. POSITION TO STAND FOR VIEWING AN OBJECT, AND THE POSITION TO STAND FOR VIEWING THE IMAGE OF THAT OBJECT CREATED BY A POSITIVE LENS.

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Figure 3-6.—Viewing objects and images created of them by optical elements.

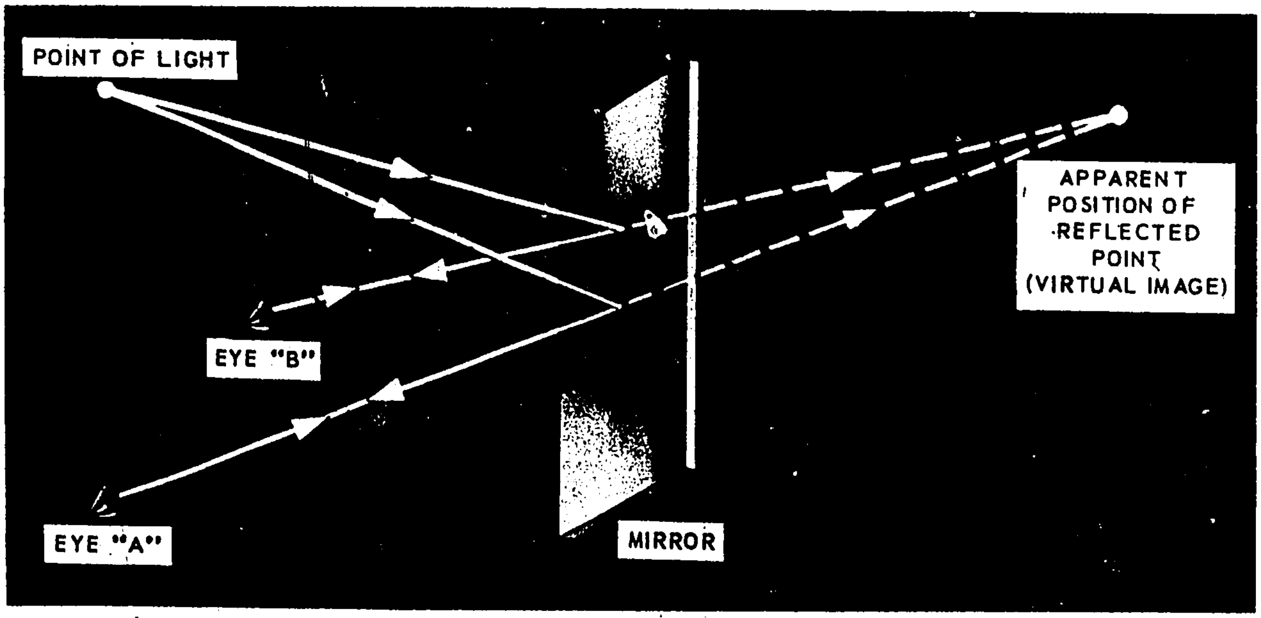

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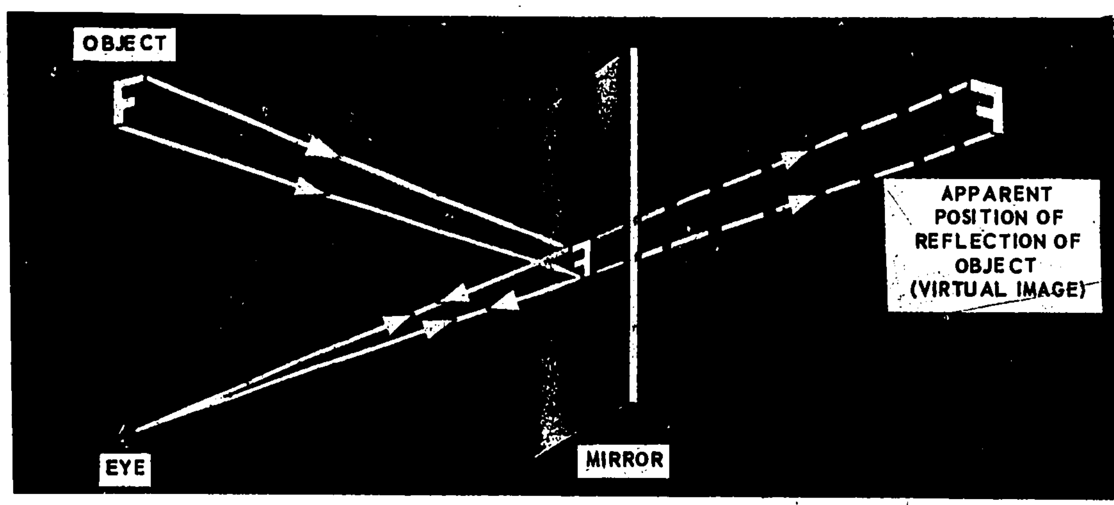
Figure 3-7.—Apparent position of a virtual image formed by a plane mirror.



137.54

Figure 3-8.—Apparent position of an object reflected by a plane mirror.

the points of light (seemingly back of the mirror and in an erect, reverted position).

A single mirror can be so mounted that it will reflect light (image) for a practical purpose. An adjustable mirror on a car fender is a good example of such reflection. If the image cannot be reflected satisfactorily with a single mirror, a second mirror can be so placed that it will reflect light from the first mirror and retransmit it. Illustration 3-9 shows how mirrors can be arranged so that they will change the line of sight.

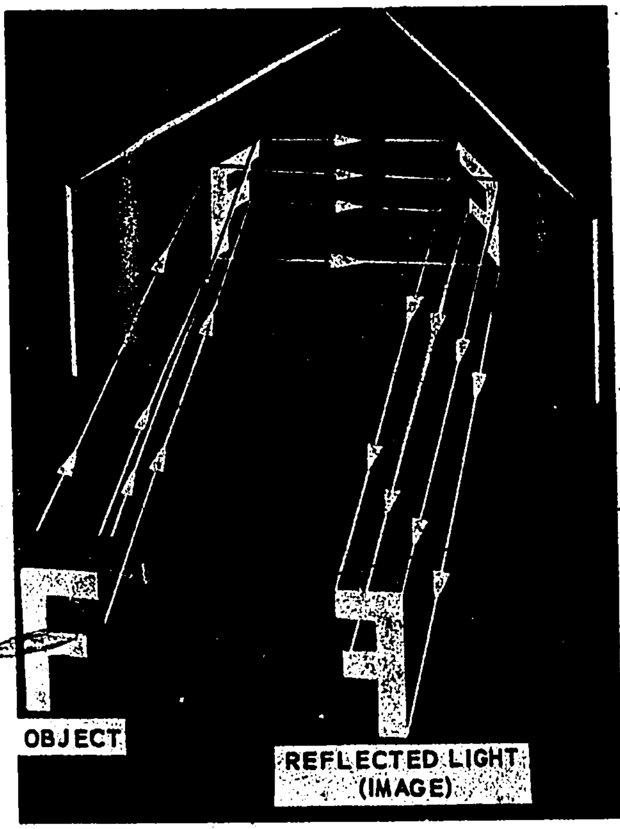


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Figure 3-9.—Apparent attitude of an object produced by two plane mirrors placed at right angles.

The two mirrors shown in the illustration are placed (mounted) together in such a manner that the angle they form is 90°, as illustrated. Light from an object (F) strikes the reflecting surface of one mirror after which light rays from every point on F are reflected by the first mirror to the second mirror, which reflects them again in rays parallel to the original rays (incident rays to the face of the first mirror). The light reflected by the two mirrors is, therefore, reflected a total of 180 degrees. Also, since the two mirrors are mounted so that the observer is looking at the back of the object (F), the image attitude is unchanged in relation to the object. If you were to stand between the mirrors and the object (F), the object would appear as (ꟻ), which is exactly what is seen as a result of the two reflections from the mirrors.

NOTE: Review the information given earlier in this chapter concerning the comparison of images with their objects.

REFRACTING PRISMS

A prism is a piece of glass whose surfaces ARE FLAT BUT AT LEAST TWO OF WHICH ARE NOT PARALLEL. Prisms are generally made from borosilicate crown glass, because it has high resistance to abrasion and damage by atmospheric elements. Some prisms are used for both refraction and reflection in military optical instruments. Much of your repair work in the optical shop concerns them and, therefore, you should understand fully how prisms ACT IN CONTROLLING THE DIRECTION OF LIGHT.

Unlike a lens, a prism is a block of glass bound by plane surfaces, and it can be designed to refract and reflect light in numerous ways. The use of prisms in optical instruments, therefore, permits variations in design which otherwise would be impossible. Plane mirrors, for example, are sometimes used to change the angles of light rays, but the silvered surfaces tarnish and cause loss of light—which becomes more serious as the instrument becomes older. A prism, on the other hand, can be mounted in a simpler and more permanent mount and used for the same purpose.

The surfaces of a prism are not easily disturbed, and it can produce more numerous reflection paths than a mirror. Prisms are used singly or in pairs for changing the direction of light from a few seconds of arc (measuring wedges) to as much as 360 degrees.

Review illustration 2-27 which shows how light is refracted by a prism. Note that the incident ray of light is bent toward the NORMAL of the front face and away from the normal of the rear face (surface). Observe, also, the angle of deviation which is a measure of the amount of change in direction of a light ray caused by a prism.

Wedge

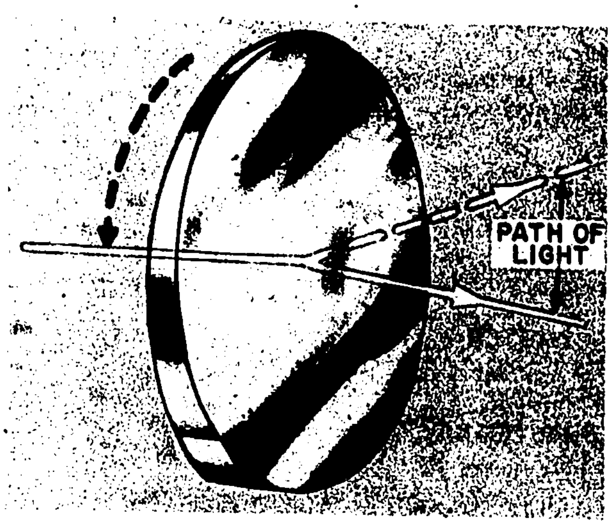
Prisms with two plane surfaces at slight angles which divert the paths of light through angles by refraction instead of reflection are called optical wedges. Optical wedges are used in fire control instruments; they may be used where the angle of deviation required is a matter of fractions of seconds.

The angle at which a wedge diverts a path of light depends upon the angle between the entrance and emergence faces and the index of refraction of the glass.

Some wedges employed in fire control instruments appear to be disks or plates of glass with parallel surfaces, because the angle between the surfaces is so slight it cannot be detected except by actual measurement. All wedges cause a certain amount of deviation in the path of light which passes through them. Some instruments which use wedges are therefore designed to create a definite amount of initial deviation of a ray of light when it enters the wedge. This deviation is called CONSTANT DEVIATION, WHICH MAKES IT POSSIBLE FOR THE WEDGE TO NEUTRALIZE the deviation in the path of light, or divert the light at a negative angle.

It is possible to change the path of light passing through a wedge by rotating the wedge. See illustration 3-10. The extent to which a wedge diverts the path of light may also be varied by changing the position of the wedge in relation to the other elements of the optical system, as shown in part X of illustration 3-11.

Another method for changing the path of light by prisms is through the use of pairs of wedges geared to rotate in opposite directions. Two or four elements are used and they are referred to as ROTATING WEDGES OR ROTATING COMPENSATING WEDGES. Part Y of figure 3-11 shows how light is refracted by wedges in three different positions.



137.112
Figure 3-10.—Direction of light changed by a rotating wedge.

Prism Diopter

The dioptric strength of a prism is a MEASUREMENT OF THE DISTANCE THE REFRACTED RAY OF LIGHT DEVIATES FROM THE PATH OF THE INCIDENT RAY AT ONE METER FROM THE PRISM. Study illustration 3-12. A prism of one diopter bends light to such an extent that when a refracted ray travels one meter beyond the prism it deviates a distance of one cm from the path of the incident ray. If a prism has a power of two diopters, for example, the deviation of the refracted light passing through it is 2 cm at a distance of 1 meter from the prism, and so on.

REFLECTING PRISMS

Most of the prisms used in optical systems are reflecting prisms. Deviation of light by a reflecting prism is brought about by internal, regular reflection. Some of the most common types of reflecting prisms are discussed in the following pages.

Right-Angled Prism

A right-angled prism (fig. 3-13) is a prism whose shape, from a side view, resembles an isosceles right-angled triangle. Prisms with this basic shape are used in many ways in optical instruments.

The name of a right-angle prism implies that it gives reflections of 90° only, but the prism can actually be used to give reflections at a great number of different angles. If a right-angle prism is rigidly mounted and only rays of light parallel to the normal on a side opposite the hypotenuse are permitted to enter it, the rays are not refracted upon entering and leaving the prism—they are merely reflected by the hypotenuse at a true 90° angle.

When a right-angled prism is mounted so that the reflecting hypotenuse can be tilted at various angles, it can be used to elevate and depress the line of sight as illustrated in figure 3-14. This arrangement is used in optical periscopes and the angular displacement of the line of sight is double the angular tilt of the prism. With the prism used in this manner, the incident light may strike the reflecting surface at an angle less than the critical angle and

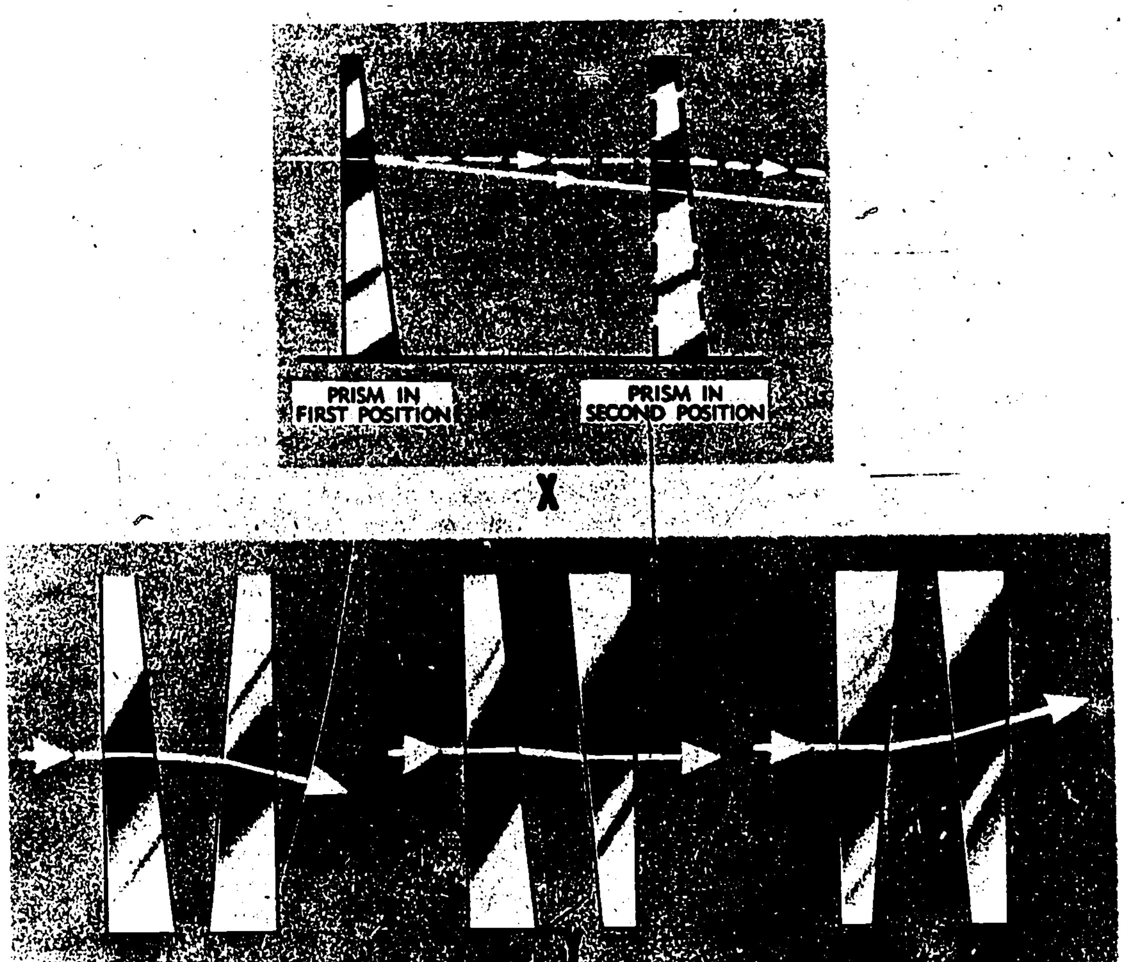


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Figure 3-11.—Path of light changed by pairs of prisms rotating in opposite directions.

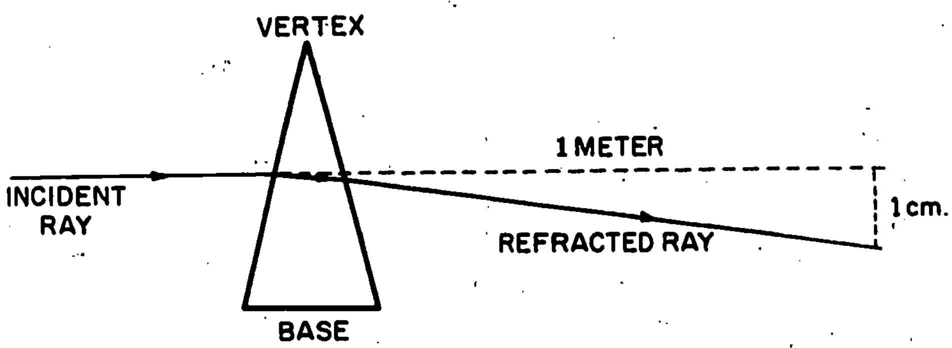

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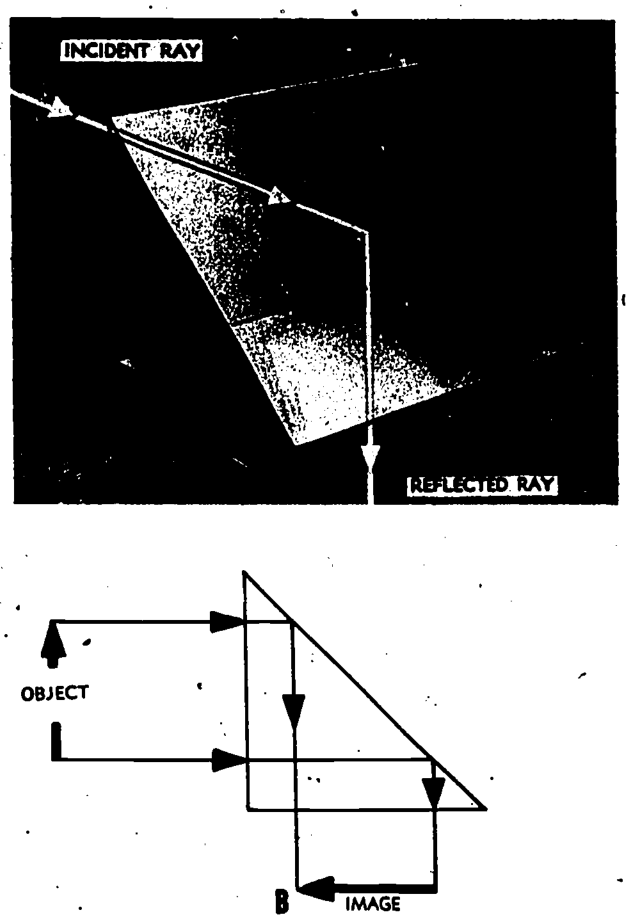
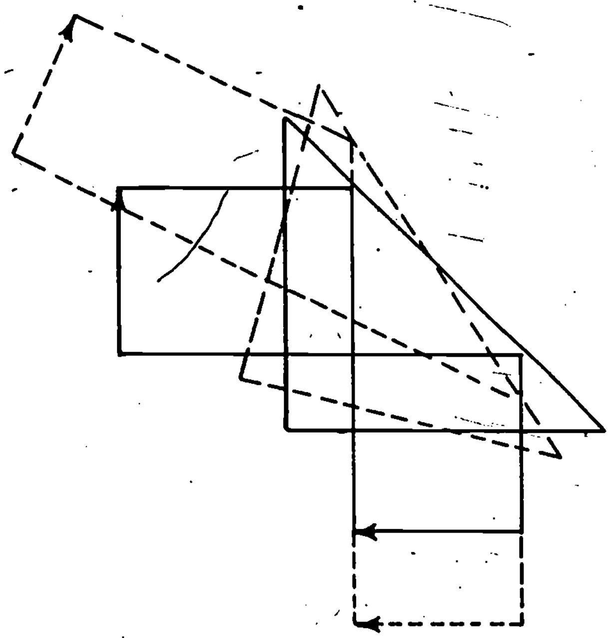
Figure 3-12.—Prism diopter.



137.115
Figure 3-13.—Right-angled reflecting prism.



137.495
Figure 3-14.—Right-angled prism as elevation prism.

emerge from the prism. For this reason, the reflecting surface is silvered so that all light striking the reflecting surface will be usable.

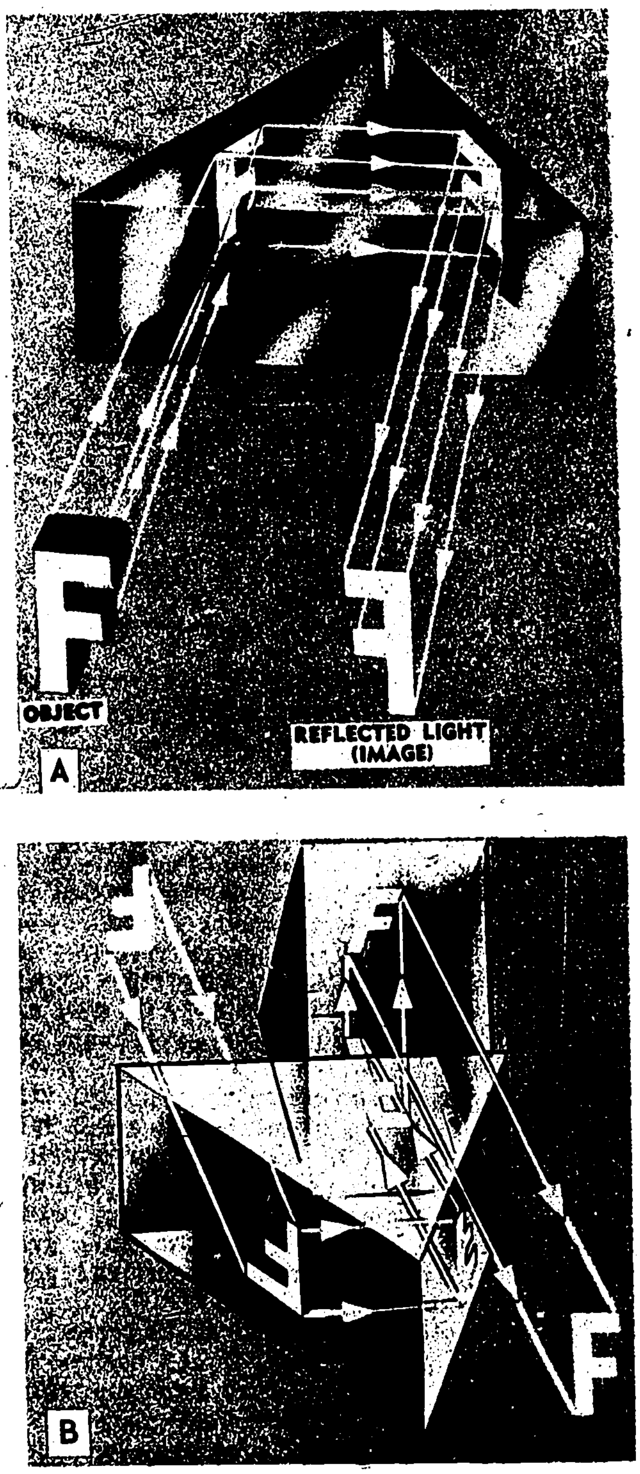
If you hold a right-angle prism so that your line of sight is deviated 90° to the left or right, all the objects you observe will appear ERECT and REVERTED (reflection in the horizontal plane). When you hold the right angle prism so that your line of sight is deviated 90° up or down, all objects that you observe will appear NORMAL and INVERTED (reflection in the vertical plane).

Porro Prism

A porro prism is actually a right-angled prism used in a different manner. When the hypotenuse of a right-angled prism is used to receive incident rays of light and exit the same rays after the other two faces of the prism reflects them TWICE, the prism is called a Porro prism. Study figure 3-15, and observe that the line of sight is reflected a total of 180°. Note also that the image of F appears reverted; but when we apply the IMAGE ATTITUDE RULE to it, we find that it is NORMAL. You can prove this is true by using the experiment explained next.

Porro prisms are never used singly, they are mounted in pairs as shown in figure 3-15B. This arrangement is called a porro prism cluster and an object viewed through it will appear inverted and reverted. The porro prism cluster is used effectively as an erecting system in many optical instruments such as binoculars and gunsights.

An interesting experiment can be performed with a single porro prism. Hold a book so the printed pages are facing away from you. Hold a porro prism in the horizontal plane as in figure 3-15 and lay the hypotenuse face on a page so that half the prism is extended over the edge of the book. When you look into the exposed face of the prism, the printing you see is completely normal. Now rotate the prism 90°



137.116:110.38.1
Figure 3-15.—Image formed by a reflecting prism.

so that half the prism extends over the top of the book. When you view the printing in this manner everything appears to you inverted and reverted.

The surface of porro prisms act as plane mirrors and transmit images in practically the same manner as two mirrors placed at right angles, as you saw in figure 3-9. The surfaces require a silver coating ONLY when the angle at which light strikes them is less than the critical angle of the material from which the prisms are made.

Dove Prism

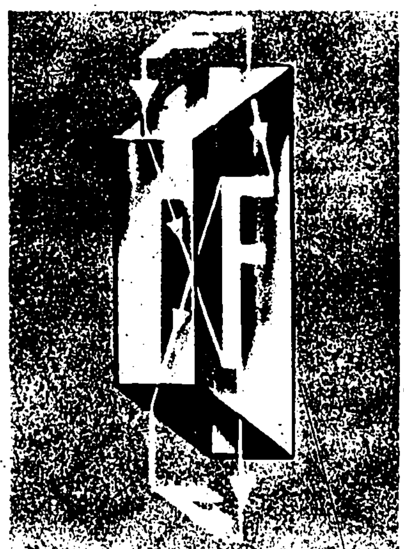
A Dove prism (fig. 3-16) resembles a right-angled or porro prism with its 90° angle sliced off. Light rays which enter one end of the prism are refracted to the longest face and reflected to the opposite face, from which they are refracted out of the prism in the same direction they were traveling before they entered the prism.

An object viewed through a dove prism, when the base (reflecting surface) is down, will appear INVERTED. When the prism is rotated 90° in either direction, the same object will appear ERECT and REVERTED. If the prism is now rotated 90° so the base is up, the object will again appear INVERTED. Notice that the prism has been rotated through 180° and at the same time the attitude of the object has changed 360°. Any object viewed through a rotating dove prism will appear to rotate twice as fast in the same direction. To provide the best possible view of an object, the reflecting surface of the dove prism is silvered.

RHOMBOID PRISM

A Rhomboid prism consists of two right-angled reflecting prisms built as one piece. You may also consider it as a block of glass with the upper and lower and opposite faces cut at an angle of 45° and parallel to each other. Study illustration 3-17.

A rhomboid prism has two parallel reflecting surfaces which provide two reflections in the same plane and transmit the image unchanged. It does NOT INVERT OR REVERT THE IMAGE OR CHANGE THE DIRECTION OF LIGHT RAYS, but it OFFSETS the light rays from their original direction. This action results from double reflection without reversal of the direction of light.



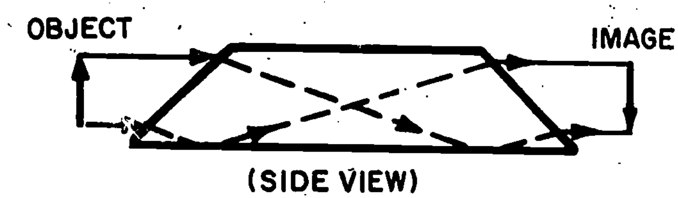


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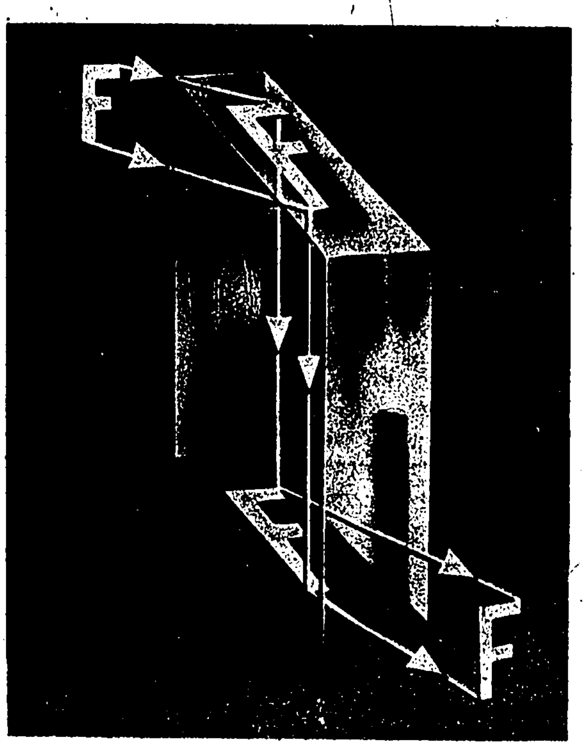
Figure 3-16.—Dove prism.



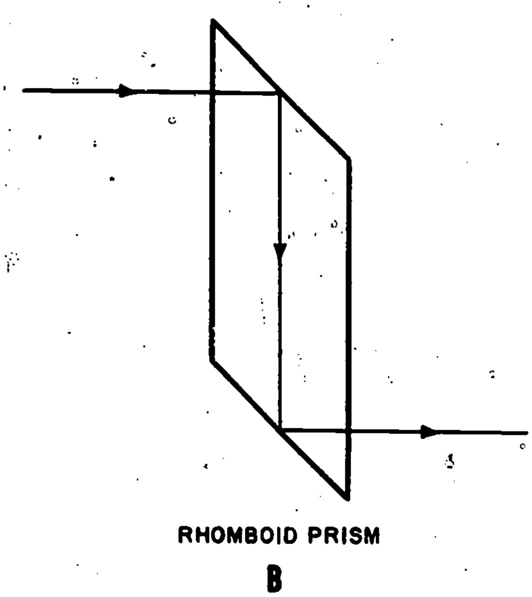


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Figure 3-17.—Rhomboid prism.

Regardless of the manner in which you hold or rotate a Rhomboid prism about the line of sight, the image it produces is ALWAYS ERECT AND NORMAL. The only purpose this prism serves is to OFFSET the line of sight, in order to make the new line of sight parallel to the old line of sight.

PENTA PRISM

A penta prism, shown in figure 3-18, reflects light from two reflecting surfaces by an amount equal to twice the angle between the reflecting surfaces. See figure 3-18B. If the angle between the silvered surfaces is 45° (prism angle), the deviation will be 90°, if the prism angle is 43°, then the deviation of the prism will be 86°. (Remember that deviation is measured from where the incident light would have gone to where the emerging light goes.) When a penta prism is held so that reflection takes place in the horizontal plane or vertical plane, all objects viewed will be NORMAL and ERECT.

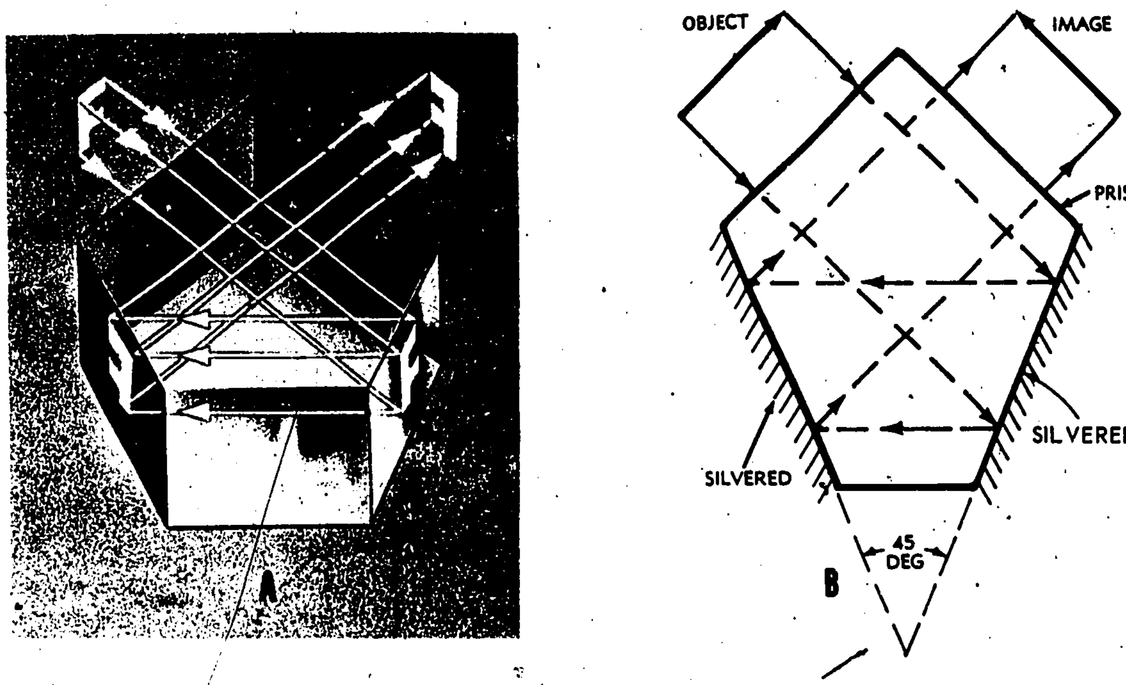

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Figure 13-18.—Penta prism.

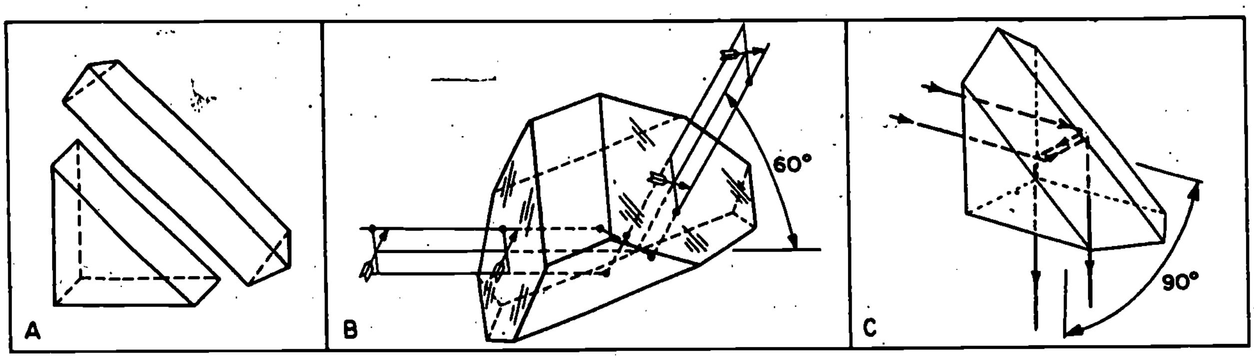

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Figure 3-19.—Roof edge prism.

The prism may even be rotated slightly without changing the apparent position of the object viewed. This is called Constant Deviation. The constant deviation feature of the penta prism is very useful in rangefinders which rely on optical wedges to measure the deviation of the line of sight.

Roof Edge Prism

The construction of the roof edge prism will be easy to understand by referring to Part A of figure 3-19. Basically the roof edge prism behaves as if it were composed of two right-angle prisms, as shown in Part A and Part C of figure 3-19. Light enters perpendicular to one surface, reflects left to right and right to left from the roof edge, and is also reflected to emerge perpendicular to the second surface. Light reflected from the roof edge in this manner will cause objects to appear INVERTED and REVERTED.

The roof edge prism may be ground so that deviation of the line of sight is 90° (Part C, fig. 3-19) or 60° (Part B, fig. 3-19). Whatever the deviation of the prism, light will always enter and leave the prism perpendicular to the entrance and emergence faces.

The reflecting surfaces are not silvered, but the roof edge of the reflecting surface must be protected against chipping. Any chips to this edge will show up in the line of sight.

CHAPTER 4
LENSES

The basis for the construction of all optical instruments is to control the light traveling from an object, so that we may view the object more effectively with the instrument than we can with our naked eye. Of all the various optical elements used to control light, LENSES are the most important and most widely used. Like the prisms and mirrors that you studied in the previous chapter, lenses are made from high quality optical glass.

Ordinary and optical glass differ greatly in their chemical composition, and also in the manufacturing process. The only common characteristic of all glass is that it is AMORPHOUS. This means that glass does not have a definite or crystalline structure as solid bodies do.

The properties of glass are explainable only by assuming that they have the same molecular arrangement as a LIQUID. When a crystalline body passes from the liquid to the solid state, the transition takes place at a definite temperature and is accompanied by considerable heat which temporarily halts solidification. With glass, on the other hand, the transition from the liquid to the solid state is so continuous and gradual that the most delicate instruments have failed to record either evolution of heat or retardation of the solidifying process, which is a GRADUAL STIFFENING WITHOUT CHANGE OF STRUCTURE. All glass, however, assumes a crystalline structure (devitrification) if while in the vitreous state the temperature is maintained too long at the critical state (crystallization point). Crystalline glass gives DOUBLE refraction, and a lens made from it forms TWO SEPARATE IMAGES at the same time.

Glass has NO melting point. When heat is applied to it gradually, it gets soft and can be molded into a thread; when it is red hot, it flows in a thick mass. A temperature of several thousand degrees turns glass into a fluid.

In a liquid state, glass is a MIXTURE of certain chemicals in solution. The most common chemicals used for this purpose are the silicates and borates. Under ordinary conditions of cooling, these chemical solutions remain mutually dissolved.

Although glass is a liquid, it is also a solid, which scientists generally describe as AMORPHOUS. Solids are characterized by definite shape and volume. Crystalline solids, for example, have a regular arrangement of particles; amorphous solids, on the other hand, have a random arrangement of particles—large, long-chain, entangled molecules.

You perhaps wonder how anything as SOLID as glass can be a LIQUID or in an AMORPHOUS state. The reason for this condition of glass is that the molecules are held together in crystals by VAN DER WAALS FORCES, which means that the electric field of the atoms of one molecule causes a similar variation in the electric field of the atoms of another molecule to generate attraction between them.

You can prove for yourself that GLASS IS AN AMORPHOUS STATE by placing a thin-walled glass tube five feet long (approximately) on two nails driven equidistant from the deck on the bulkhead of your shop and observing the bend in the tube during a five or six months' period. Hold the glass tube against the bulkhead and mark its original position with a pencil, so that you will be able to measure the amount of bend which develops during the period.

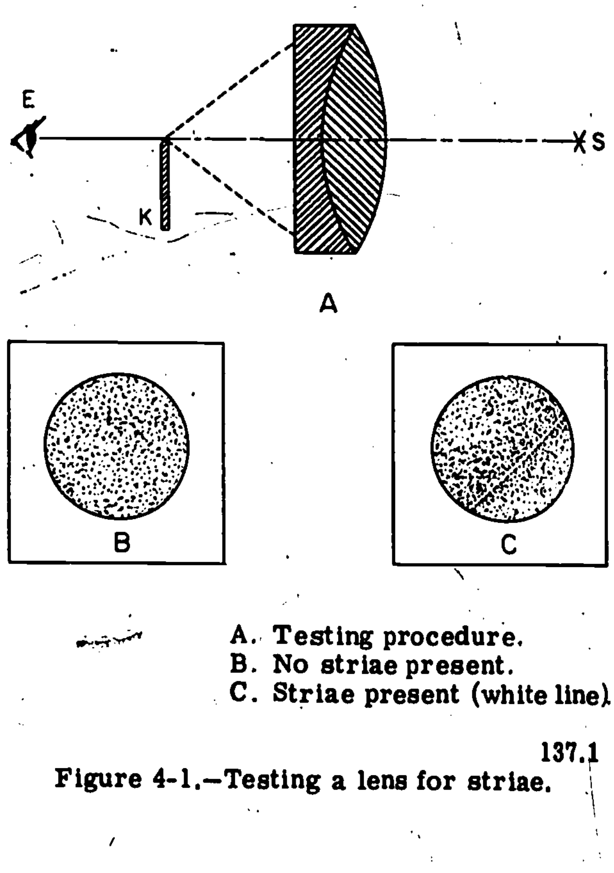
One interesting thing about this test is that when you first place the tube of glass on the nails it shows a slight bend, which immediately disappears if you then remove it from the nails. At the end of your test, however, the bend will remain in the tube when you remove it from the nails; because the liquid glass has ACTUALLY FLOWED to its new position.

The PURELY OPTICAL PROPERTIES which directly influence light as it passes through glass include: (1) homogeneity, (2) transparency, (3) freedom from color, (4) refraction, and (5) dispersion.

Homogeneity is the most important property of optical glass. If you examine a thick piece of ordinary glass, you will find that the layers of difference densities show clearly in the form of internal irregularities, known as VEINS or STRIAE, little streaks with a higher or lower index of refraction (bending) than the other part of the glass. Many times the striae are also so small that they cannot be detected until the glass is ground (as a lens, for example) and polished. Because these striae affect the sharpness of an image formed by the lens, it cannot be used in an optical instrument.

You can test a lens for striae in the manner illustrated in figure 4-1. If you place a light (S) behind a screen with a hole in it directly in front of the light and then hold a lens (L) with one hand and a knife blade (K) at the point indicated in the other hand, you can look along the optical axis (central point) of the lens and detect the absence or presence of striae. If the lens has no striae, the field appears dark (part B, fig. 4-1); if striae are PRESENT, they show as bright lines (part C, fig. 4-1).

To be homogeneous, a lens must also be free of dust, dirt, and bubbles. A few bubbles in a lens stop the passage of light through the lens at their location, but they do not hurt the quality of the image. The best lenses may have ONE or TWO bubbles, but inspectors of precision lenses reject lenses with more than THREE bubbles; and they also reject a lens with ONE bubble as BIG as half a millimeter in diameter.



A. Testing procedure.
B. No striae present.
C. Striae present (white line).

137.1
Figure 4-1.—Testing a lens for striae.

The degree of absorption of light by glass varies with the color of the light. Optical glass must be free from color. When white light passes through glass, the glass absorbs more of one of its component colors than the other colors, thus causing the emergent light to have a slight color tint. In thick pieces, purest and whitest glasses always show a distinct blue or green tint.

Refraction and dispersion of light are two of the most important properties of any optical element. Refraction is the bending of a ray of light when it enters a lens or prism; dispersion is the separation of light into its component colors as it passes through a prism or lens. This occurs in an uncorrected lens or prism, because the index of refraction (ratio of speed of light in a vacuum to speed of light in a medium) of glass is different for each wave length.

Chemical stability is an essential feature of optical glass, because the best lenses would soon be useless if they were affected by moisture and traces of chemical fumes in the atmosphere. Condensed water on glass absorbs carbon dioxide and forms carbonic acid, which dissolves glass. Distilled water, for example, must be kept in specially made glass containers or bottles; because it dissolves ordinary glass. High-quality optical glass (HARD CROWN and BORO SILICATE CROWN) resists chemicals and is therefore durable.

ANOTHER IMPORTANT FEATURE OF OPTICAL GLASS IS MECHANICAL HARDNESS (generally accompanied by a low refractive index) because lenses must be HARD ENOUGH to resist the effects of cleaning, which must be accomplished as necessary.

You will learn a little later in this chapter that HARD CROWN GLASS is harder than DENSE FLINT GLASS. This difference in degree of hardness is necessitated by the elements used by the manufacturer in order to get desired OPTICAL QUALITIES in the glass.

Although desirable, ENTIRE FREEDOM from internal strains is essential ONLY for special optical purposes. Manufacturers of glass know from experience the amount of STRAIN PERMISSIBLE in glass intended for various purposes.

Strains in glass result from annealing (cooling and setting). When glass cools, it contracts;

and if it cools TOO RAPIDLY, the surface becomes cool while the center is still hot, resulting in strains which usually cause breakage during grinding and polishing.

Strains in optical glass can be detected by polarized light. Perfectly annealed glass, entirely free from internal strains, produces no effect on a beam of polarized light which passes through it. A serious amount of double refraction indicates strain in the glass.

You can test for strain in optical glass by doing the following: (1) mount two polaroid filters in line with a light, one inch apart; (2) look through the filters toward the light and turn one of the filters until the field is dark; and (3) while looking into the dark field, hold the glass you desire to test between the two polaroid filters. If the field remains dark, the glass is free from strains. Strained glass, on the other hand, rotates the plane of polarization, causing you to see RINGS or BANDS of colored light.

Because the transparency of glass enables one to see in the finished products defects of COLOR and QUALITY, raw materials selected for making optical glass must be PRACTICALLY FREE from impurities. Although volatile and combustible substances are usually completely eliminated (by high temperature) during the melting step, all FIXED (stable) substances which compose the mixture appear in the finished glass. The selection of raw materials for optical glass is therefore most important.

One thing to remember about optical glass components is: CROWN GLASS—fairly low index of refraction and dispersion—contains phosphorus, barium, or boron, but NO lead; FLINT GLASS—higher index of refraction and dispersion than crown glass—may contain a small quantity of barium or boron, but it DOES contain lead—the greater the amount of lead used, the higher the index of refraction of the glass.

THIN LENSES

Optical lenses are grouped into three categories: (1) thin lenses; (2) thick lenses; and (3) compound lenses. Basically stated, a THIN lens is one that is so constructed as to make its thickness unimportant in measuring the distances from the lens to the image and to the object. A THICK lens is one that, because of its thickness being so large, allowances must be made when measuring the distances to the image and the object. A COMPOUND lens is one that is composed of two or more separate optical lenses.

There are several more technical considerations made in the grouping of lenses, but only those affecting your work as an optical repairman will be discussed in this manual.

PHYSICAL DESCRIPTION

A lens is a transparent optical element that has two polished major surfaces opposite to each other. One of which is CONVEX or CONCAVE in shape and usually spherical.

Some types of thin lenses are illustrated in figure 4-2. Note the shapes of the opposing surfaces of these lenses and also observe that they are divided into two groups. A convergent lens is one which will add convergence to incident light rays by refraction. Convergent lenses are thicker at the center than at the edge.

A divergent lens is one that adds divergence to incident light rays and they are always thicker at the edge than at the center.

One important rule to remember when describing a lens is: READ THE SURFACES OF THE LENS ACCORDING TO THE DIRECTION OF THE INCIDENT LIGHT. In this manual, we always illustrate the path of light as going from left to right and in our discussions it will be assumed that light initially travels the same.

LENS TERMINOLOGY

Before we go on with the study of lenses it is important that you understand some of the terms and phrases that apply to lenses and their use in optics. Refer frequently to the illustrations that are listed in these discussions.

OPTICAL AXIS.—Line AB in illustration 4-3 is the optical axis (principal axis), which is an imaginary straight line passing through the centers of curvature of both surfaces of a lens. Point A is the center of curvature of curve ab; point B is the center of curvature of curve a'b'.

PRINCIPAL PLANE.—Both thin and thick lenses have two principal planes which are in fact imaginary planes at the point where the incident ray, if prolonged, would intersect the prolonged emergent ray. In a thin lens the two planes are so close that they are considered as one plane. In figure 4-3 this plane is represented by line CD. Observe that incident ray B, parallel to the optical axis, is refracted upon entering and leaving the lens. If both the incident ray

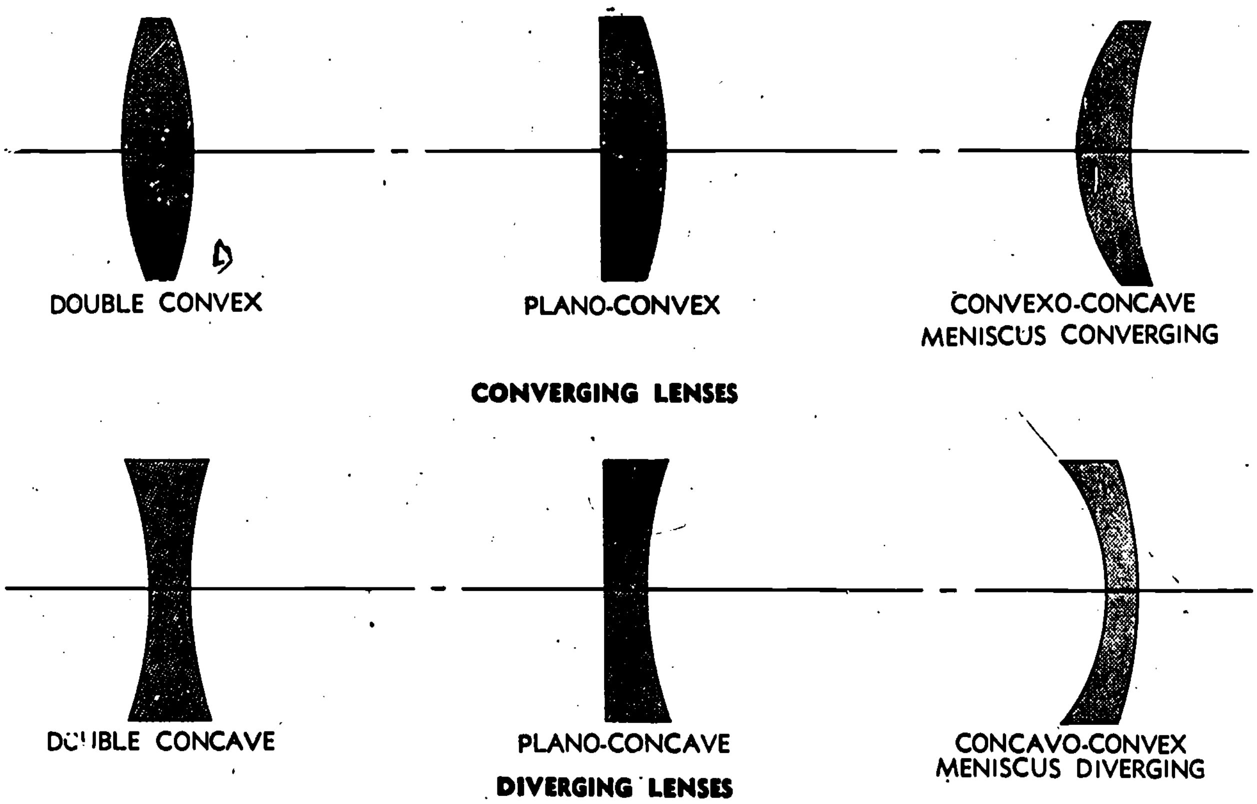


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Figure 4-2.—Types of thin lenses.

and the emergent ray are extended, as indicated by the dotted lines, they would intersect at "d" on the principal plane.

OPTICAL CENTER.—The point in a lens through which light rays pass without deviation is the optical center. In thin lenses the optical center is located on the optical axis, HALFWAY BETWEEN THE TWO CURVED SURFACES OF THE LENS. This is indicated by the letter O in figure 4-3 and in a thin lens the optical center will be intersected by the principal plane.

PRINCIPAL FOCAL POINT (Principal Focus).—The principal focus is the point where parallel incident rays converge after they pass through a convergent lens. Every convergent lens has two points of principal focus, one on each side. The point of principal focus on the left side of the lens is the PRIMARY FOCAL POINT, (F_1-fig. 4-3); the point of principal focus on the right of the lens is the SECONDARY FOCAL POINT (F_2). The incident ray (B) is parallel to the optical axis and, after it is refracted by the lens, passes through the SECONDARY focal point (F_2). Ray (C) passes through the optical axis at the primary focal point (F_1), and is refracted by the lens and becomes parallel to the axis.

This may seem confusing but if you refer back to Chapter 2 where you studied the LAW OF REVERSIBILITY the fact that a lens can have two principal focal points is understandable.

PRINCIPAL FOCAL PLANE.—The principal focal plane is an imaginary line (HI and H'I') perpendicular to the optical axis at the points of principal focus. (Fig. 4-3.)

PRINCIPAL IMAGE PLANE.—The principal image plane is an imaginary line (LM, fig. 4-3) perpendicular to the optical axis at the point where the image is formed. The principal image plane may be located anywhere along the optical axis of the lens from its focal point to infinity.

Curvature

The amount of departure from a flat surface, as applied to lenses, is termed curvature.

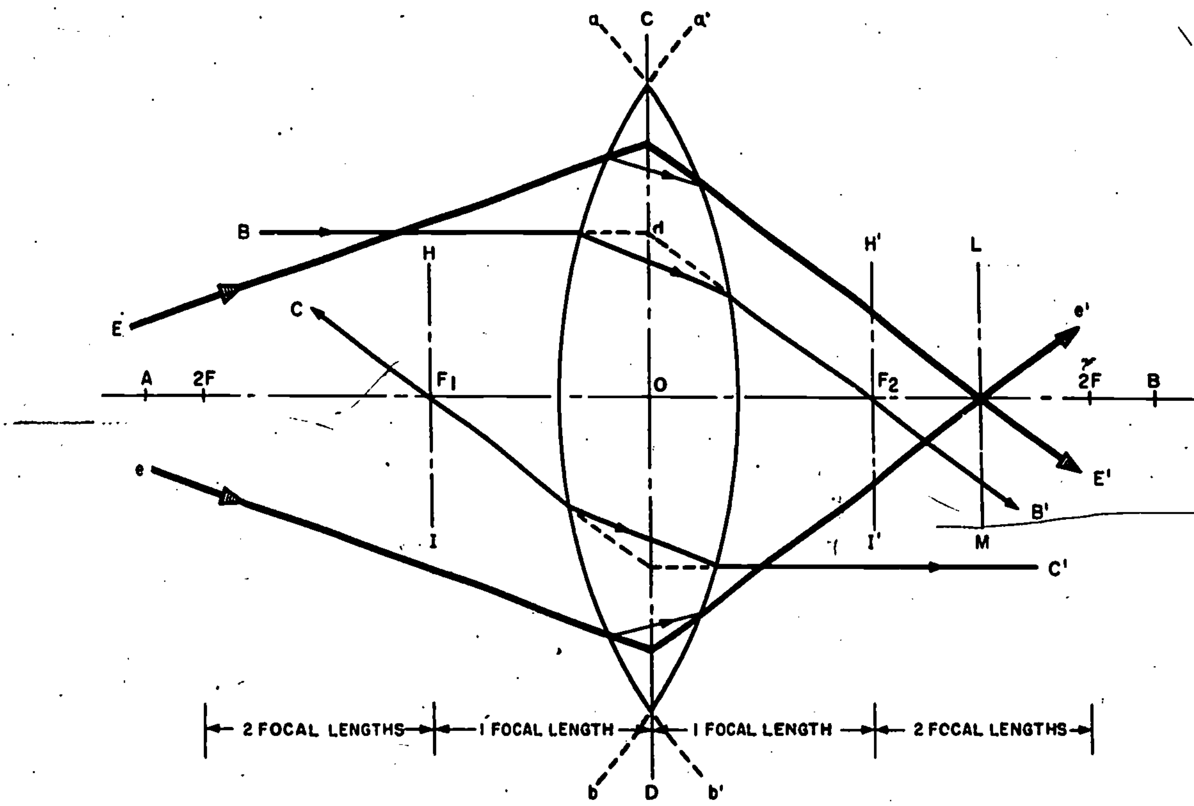

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Figure 4-3.—Lens terminology.

When we speak of the curvature of a lens, we are referring to the curve that the surface of the lens has. Refer again to figure 4-2 and note the curvature of the lens surfaces. In this illustration, the surfaces appear to be only curved lines but in effect lens surfaces are spherical in shape. In order to visualize more clearly the surface of a lens, refer to figure 4-4 which illustrates a segment of a sphere.

If you consider this segment as being a lens, you would describe the two surfaces as being Plano on the flat surface and convex on the spherical surface. The curvature of a lens surface is described as convex or concave. Convex surfaces are rounded like the exterior surface of a sphere and concave surfaces are rounded inward like the interior surface of a sphere.

Radius of Curvature

In optics, the term "radius of curvature" is used to describe the amount of curvature a lens surface has. The radius is a line segment extending from the center of the sphere to the curved surface.

Refer again to figure 4-4 which illustrates a sphere with a diameter of 3 inches. The line segment, as measured from the center of h the sphere, is 1.5 inches and the radius of curvature is also measured as 1.5 inches. The radius of curvature is the primary factor in determining a lens refracting ability.

Focal Length

As shown in figure 4-3 the focal length of all lenses is the distance from the principal focus (F_1 or F_2) to the principal plane (CD). Illustration 4-5 shows the focal lengths of a convergent lens; figure 4-6 gives the focal length of a divergent lens.

You can determine approximately the focal length of a convergent lens by holding the lens as necessary in order to focus the image of an object at infinity on a sheet of paper or ground glass. When the image is CLEAR and SHARP, you have reached the point of principal focus;

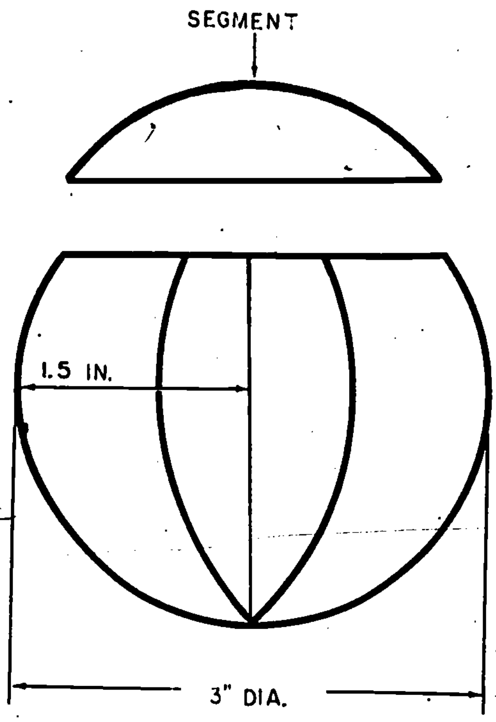

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Figure 4-4.—Sphere and segment.

Positive Lenses

Refer again to the group of converging lenses in figure 4-2. These lenses are commonly referred to as POSITIVE lenses because they will produce an enlarged virtual image when the incident rays of light are parallel. Included in the group of positive lenses is the DOUBLE-CONVEX (both opposing surfaces curved like the exterior of a sphere), PLANO-CONVEX (the left surface plain or flat and the opposing surface convex), and CONVEXO-CONCAVE (the left surface convex and the opposing surface hollowed or rounded inward).

Refer now to illustration 4-7, which shows light rays passing through two prisms of the same size and shape, placed base-to-base. Observe that the rays of light pass into the prisms and bend toward the bases of the prisms as they pass through. After the light rays emerge from the prisms they cross at the points indicated.

A convergent lens may be thought of as two prisms (fig. 4-7) arranged so that each directs rays of light to the same point. The lens bends light rays in the same manner as a prism; but, unlike a prism, it brings the light rays to a single point. Picture a convergent lens, therefore, as two prisms with surfaces rounded into a curve.

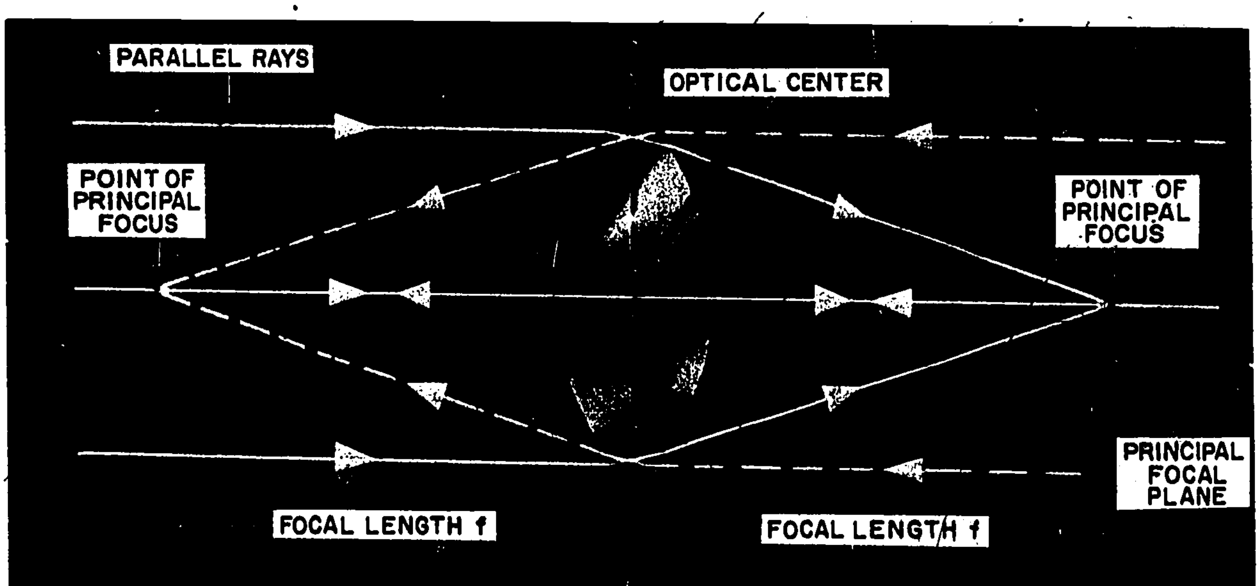

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Figure 4-5.—Focal lengths of a convergent lens.

and if you then measure the distance from the image to the optical center of the lens, you get the focal length.

Observe, next, in illustration 4-8 how a convergent lens deviates light rays. When parallel rays of light strike the front surface (left) of a

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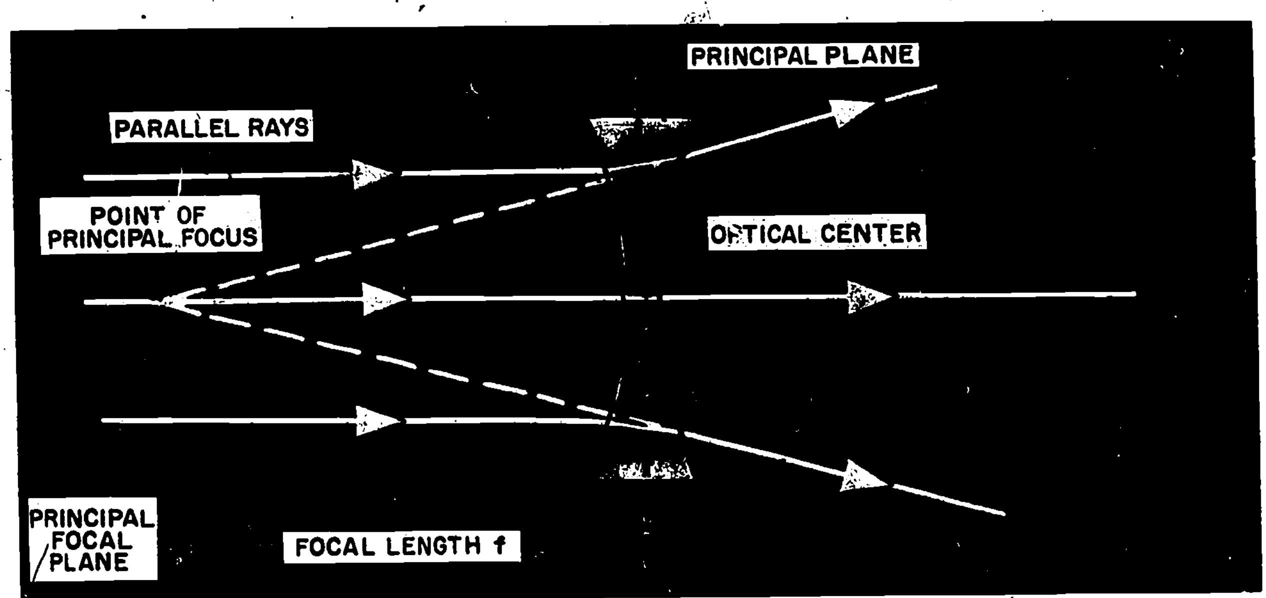

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Figure 4-6.—Focal length of a divergent lens.

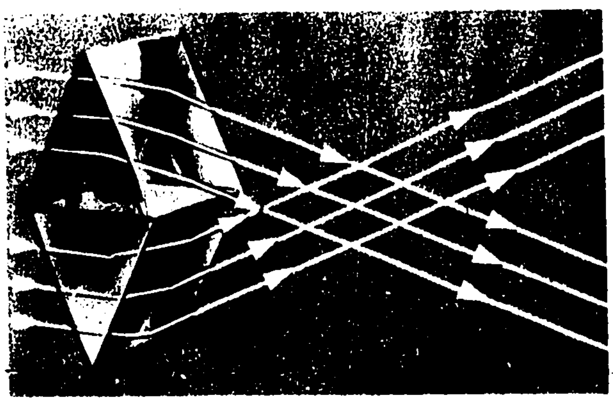

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Figure 4-7.—Deviation of light rays by prisms.

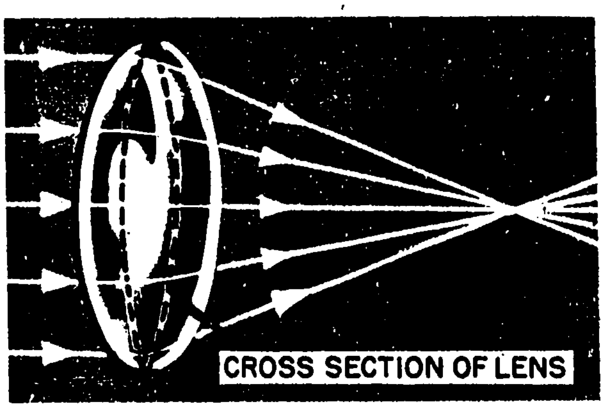

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Figure 4-8.—Deviation of light rays by a convergent lens.

convergent lens, they pass through the lens and CONVERGE AT A SINGLE POINT.

If you apply the law of refraction to the ray in figure 4-9, you can understand what happens when it passes through a convergent lens. When an incident light ray enters the top of a convergent lens (a medium more dense than air), it bends toward the normal; when the refracted ray (emergent ray) goes back into the air, it bends away from the normal.

Incident light rays which enter the bottom of a convergent lens bend toward the normal. The two sets of light rays (top and bottom) which enter a convergent lens therefore cross AFTER THEY EMERGE from the lens. If the incident rays are parallel when they enter the lens, they cross the optical axis at a single point called the focal point.

Negative Lenses

The diverging lenses shown in figure 4-2 are called NEGATIVE lenses because they produce a diminished virtual image when the incident light is parallel.

Take another look at the different types of simple divergent lenses shown in illustration 4-2.

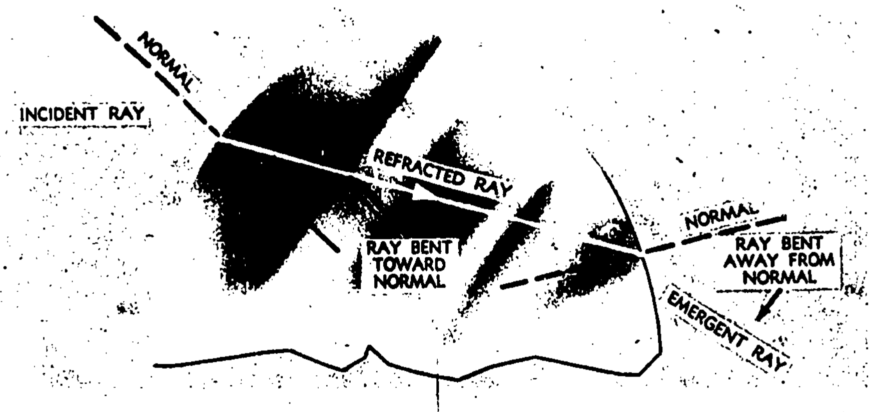

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Figure 4-9.—Refraction of light rays by a convergent lens.

Suppose that we now take two prisms like those shown in figure 4-7 and place them apex-to-apex, in the position illustrated in figure 4-10. What we do here is construct a different type of lens, a divergent lens. When rays of light strike the front surfaces (left face) of the prisms, the rays pass through in the manner illustrated, in accordance with the laws of refraction.

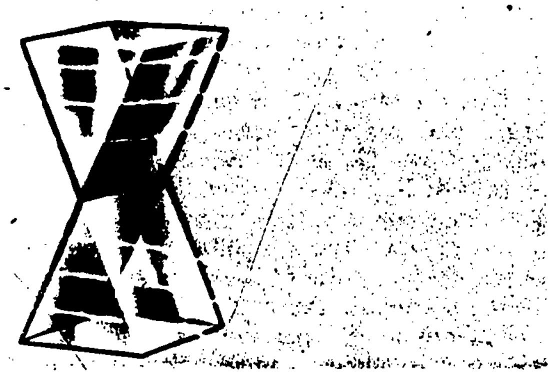

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Figure 4-10.—Deviation of rays by two prisms placed apex-to-apex.

Observe that the light rays in the top prism refract away from the normal; whereas, the light rays which pass through the bottom prism refract toward the base, away from the normal.

If you now assume that the front and rear surfaces of these two prisms have been ground into spherical surfaces, you have a simple divergent lens. Study illustration 4-11.

Divergent lenses are always thinner in the middle than at the edges, just the opposite to convergent simple lenses. The optical center

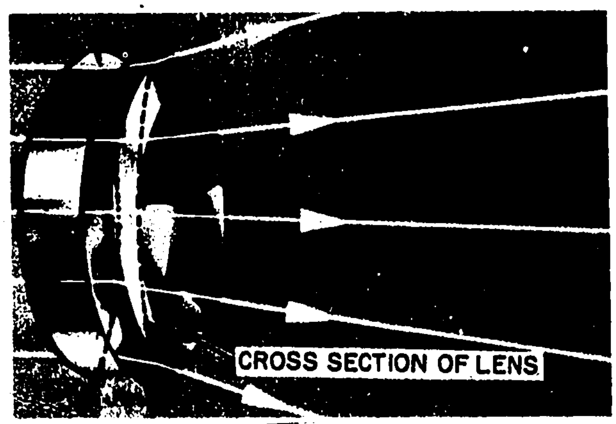

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Figure 4-11.—Deviation of rays by a divergent lens.

of a divergent simple lens is at the thinnest point of the lens, and the lens causes convergent light to be less converging, parallel rays to diverge, and divergent light to be more diverging.

The two surfaces of a divergent simple lens may differ in shape. Both surfaces may be concave (double concave), one surface may be plane and the other concave (planoconcave), or one surface may be concave and the other convex (concavoconvex) meniscus diverging.

To learn how the law of refraction applies to a divergent lens, study illustration 4-12. Observe the one incident ray used to illustrate the refraction of light as it passes through the top of a divergent simple lens, and the manner in which it is bent on both faces—toward the normal on the first face, away from the normal on the second face.

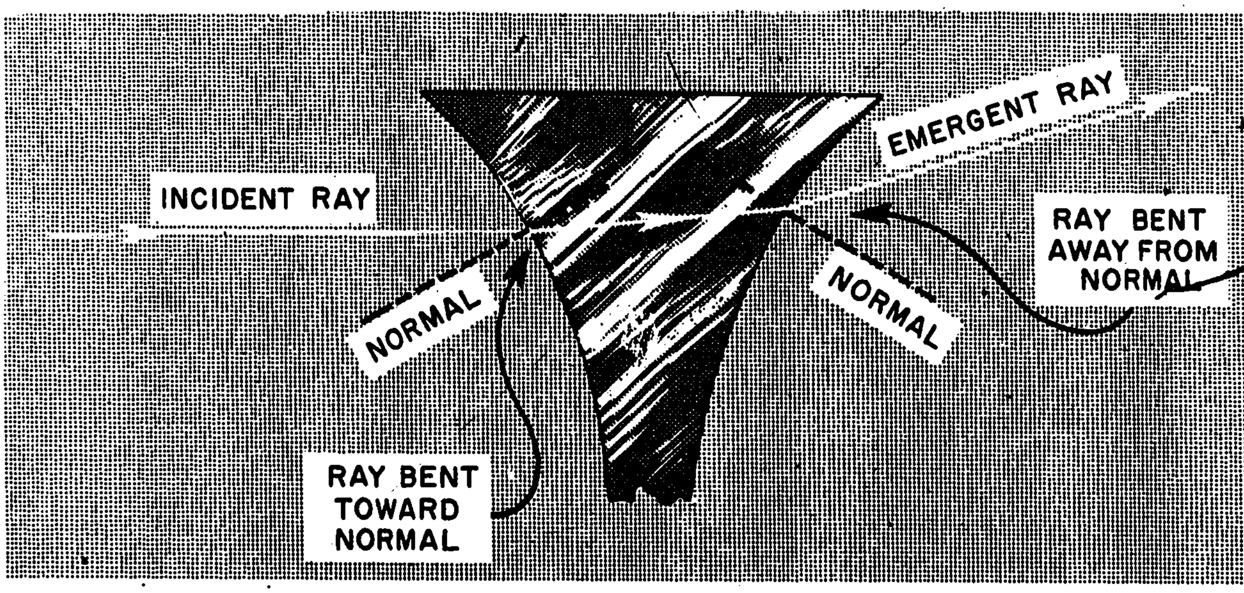

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Figure 4-12.—Application of the law of refraction to a divergent lens.

Light rays which pass through divergent lenses off the optical axis ALWAYS refract toward the thickest part of the lenses.

IMAGE FORMATION

As you know, light rays in the form of pencils emanate from all points on an object and pass through a lens to a point of convergence behind the lens. This point is called the IMAGE POINT WHEN THE OBJECT IS AT A DISTANCE GREATER THAN THE FOCAL LENGTH OF THE LENS.

Review at this time illustration 4-9, for it shows how the laws of refraction may be applied to plot the path of any light ray through any types of lens. Then study illustration 4-13, which shows how light rays pass through a convergent lens and converge at a single point.

Millions of light rays may come from every point of light on an object, but we use in illustration 4-13 only three such rays to show how they pass through a convergent lens. As you learned previously in this chapter, the light rays which strike a convergent lens on either side of the optical axis bend toward the thickest part of the lens, and bend again toward the thickest part of the lens when they emerge from it. As shown in the illustration, they converge at a single point.

A light ray which passes along the optical axis through a lens does not bend, because it strikes the surfaces of the lens at and parallel to the normal.

Study illustration 4-13 carefully. The central ray in the top portion (A) of this illustration passes through the optical center and does not refract as it continues through the lens. The other light rays (2) refract toward the thickest portion of the lens as they enter it, and as they emerge, and form an INVERTED and REVERTED image (F) at the IMAGE PLANE. The other part of F is on the optical axis.

The image is inverted and reverted because two similar rays from a point at the bottom of the object form a point of the image corresponding to the bottom of the object; and every point on the object forms its point of light on the image in the same manner. Rays from the upper part of the object form points of light on the corresponding image, thereby causing the image to be transposed diametrically and symmetrically across the optical axis from the object. THIS IMAGE IS REAL.

Principal Rays

Refer now to illustration 4-14 which shows the FOUR PRINCIPAL RAYS of light which pass through any lens, THICK or THIN. When these light rays pass through a lens, they ALWAYS follow the rules which pertain to each. Line XY in the illustration is the optical axis (sometimes called principal axis) of the lens.

A

B

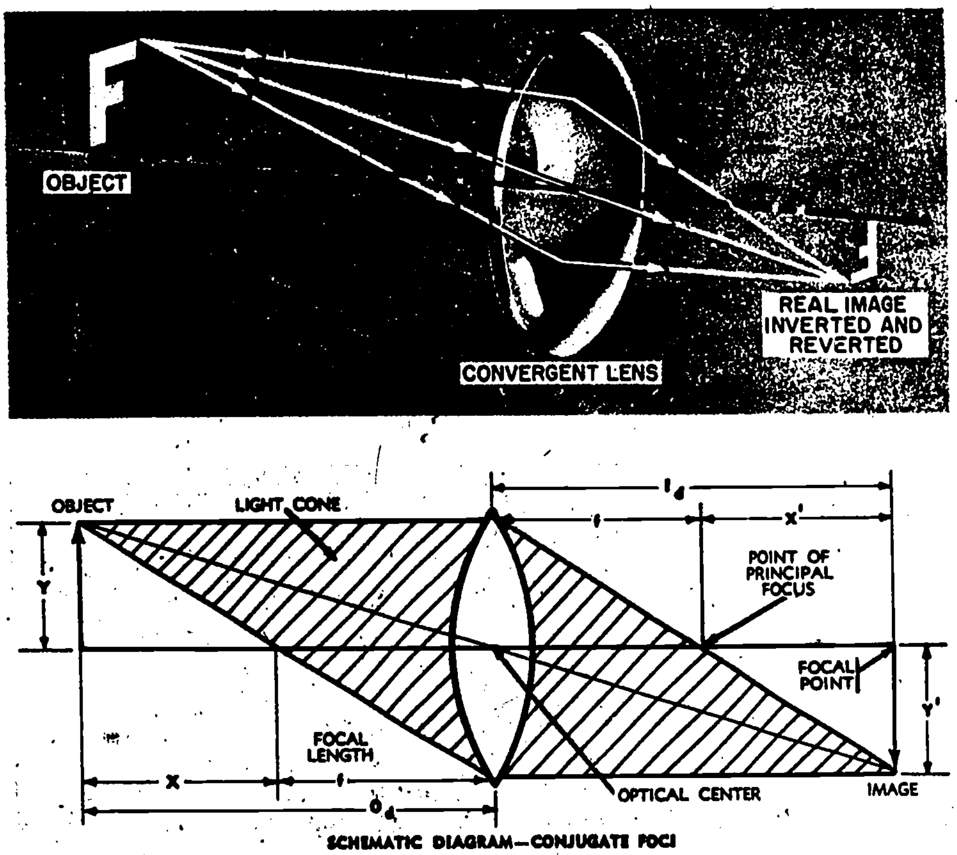

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Figure 4-13.—Image formation by a convergent lens.

The optical axis passes through the center of a lens and perpendicular to its principal plane (illustrated).

LIGHT RAY A.—An incident ray (one entering a medium) passes through the optical center (0, fig. 4-14) of a lens and emerges from the lens without deviation from the path it was following before entering the lens. This is true because the incident ray strikes the surface of the lens parallel to the normal. (The normal of an incident ray at any point on a lens is an imaginary line at right angles to the surface of the lens at the point where the ray enters.) When the ray reaches the second surface of the lens, it is still traveling parallel to the normal. (The normal of an emergent light ray is an imaginary line at right angles to the surface of the lens at the point where the ray emerges from the lens.)

When an "A" light ray passes through a lens at an angle to the optical axis but through the optical center, it is slightly refracted before it reaches the optical center. After it passes through the optical center and strikes the second surface, it is slightly refracted again, but at the same angle at which the incident ray struck the first surface. The emergent ray is parallel and offset to the incident ray, but it is offset so slightly that in actual theory the ray is said to have passed directly through the thin lens without refraction or deviation.

LIGHT RAY B.—Any incident light ray which travels parallel to the optical axis of a lens strikes the lens and is refracted to the principal focal point, the one behind the lens.

LIGHT RAY C.—Any ray which passes through the principal focal point and strikes the lens is refracted and emerges parallel to the optical axis. NOTE: The C ray is the opposite of ray B, because it enters the lens from the opposite edge, through the principal focal point, and does not pass through the principal focal point behind the lens, as does ray B.

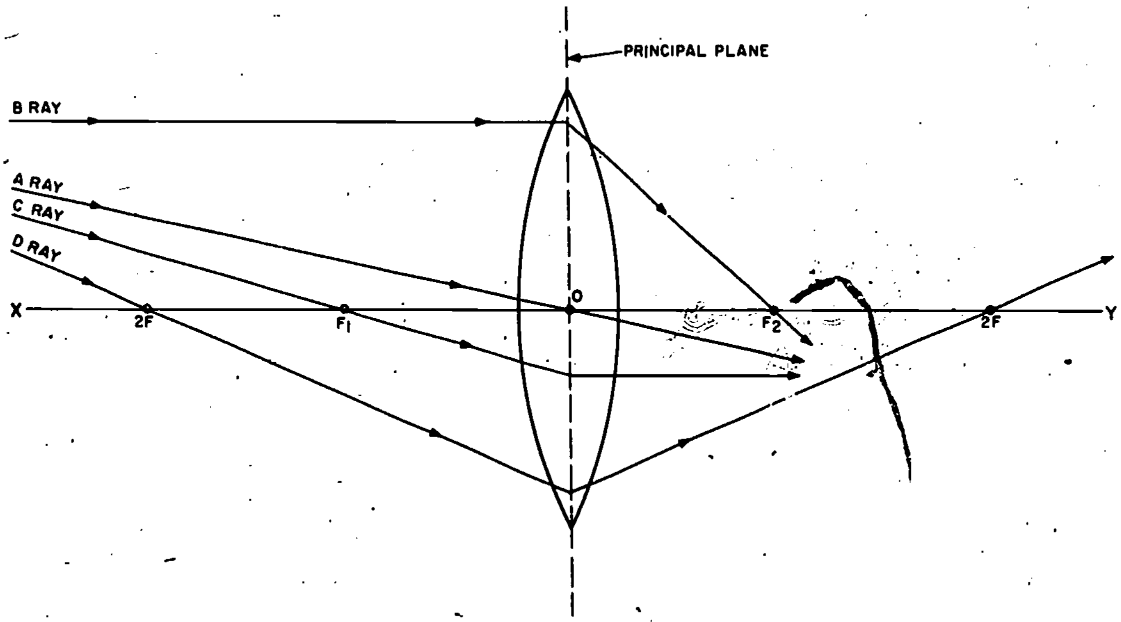

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Figure 4-14.—Principal light rays.

LIGHT RAY D.—Any ray which passes through a point two focal lengths in front of a lens and strikes the lens is refracted and converges to a point two focal lengths behind the lens. In accordance with the Law of Reversibility, this ray (and all other rays) could be reversed in direction.

NOTE: The four principal light rays just discussed can travel to the lens in any direction or angle, as long as they follow the rules which pertain individually to them.

Observe in illustration 4-14 that refraction appears to take place in the lens at the principal plane, but this is true for illustrative purposes only. A light ray refracts toward the normal as soon as it strikes the surface of the lens, and away from the normal as it leaves the surface of the lens.

Illustration 4-14 is important to you primarily because you can use rays A, B, C, and D to PLOT ANY IMAGE OF AN OBJECT WITH GREAT ACCURACY, provided your measurements are accurate.

Positive Lenses

When an object is at a great distance (infinity), incident rays of light from it are parallel and the image is real, inverted, reverted, and diminished; and it is formed by the light rays at the secondary focal point, as shown in part A of figure 4-13.

If the object is at a DISTANCE BEYOND TWO FOCAL LENGTHS BUT LESS THAN INFINITY (fig. 4-15), a real, inverted image is formed by light rays from the object between the secondary focal point and 2F on the opposite side of the lens. Note the size of the image in each illustration shown, as compared with the object. When the object is brought closer to the lens, the image formed by it is larger than images formed by the object at greater distances from the lens; but the image is still smaller than the actual object.

In illustration 4-16 you see an object placed at two focal lengths in front of the lens; so the image formed of this object by the lens is real, inverted, reverted, equal in size, and located at 2F on the other side of the lens.

When an object is at a distance between one and two focal lengths from a lens, as illustrated in figure 4-17, 1 1/2F, the IMAGE IS REAL AND LARGER THAN THE OBJECT, inverted, reverted, and at a distance of 3F on the other side of the lens.

Illustration 4-18 shows an object at the principal focus of a lens, in which case the emerging light from the lens is parallel and therefore

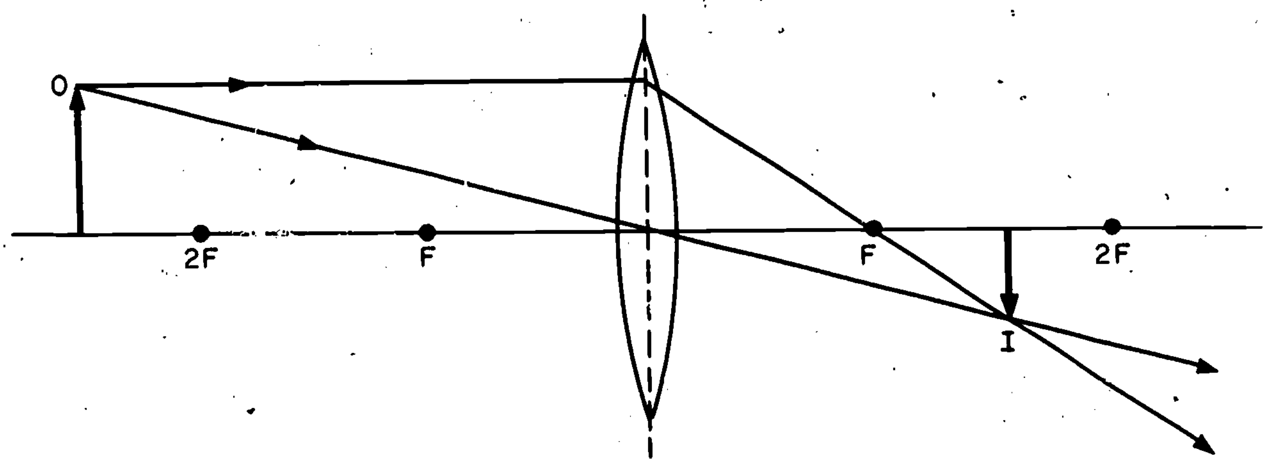

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Figure 4-15.—Position of an image formed by a convex lens when the object is more than two focal lengths distant.

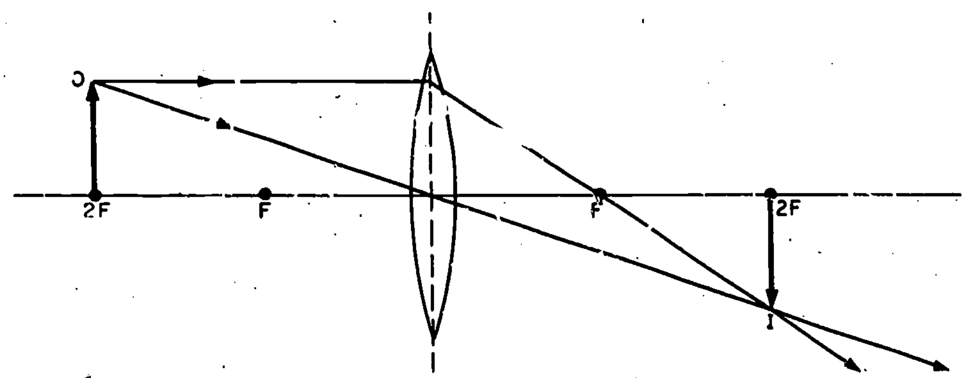

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Figure 4-16.—Position of an image formed by a convergent lens when the object is at a distance equal to twice the focal length.

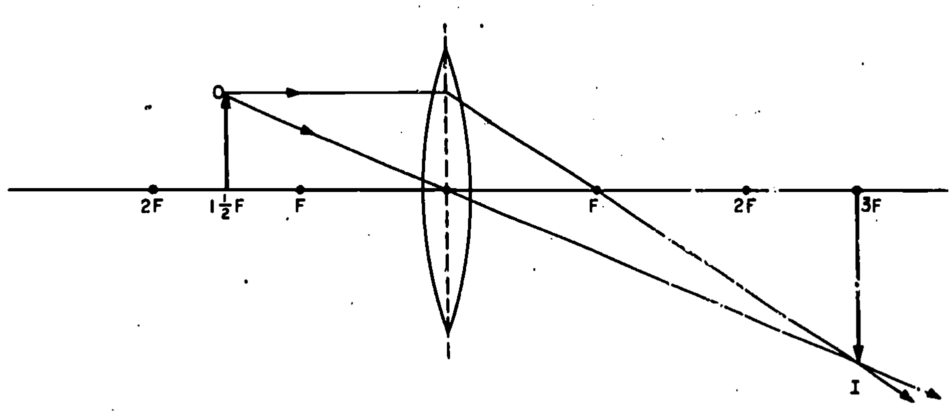

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Figure 4-17.—Position of an image formed by a convex lens when the object is between the first and second focal lengths.

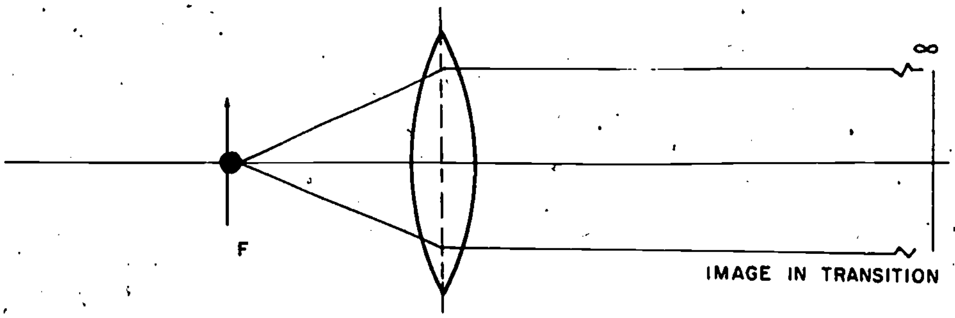

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Figure 4-18.—Image formation by a convergent lens when the object is at the principal focus.

cannot converge to form an image. The image in the illustration is IN TRANSITION AT INFINITY. A searchlight is an example of this type of image formation.

When an object is closer to a lens than the principal focus, divergence of the incident light is so great that the converging power of the lens is insufficient to converge or make it parallel. The emerging light is therefore merely less divergent than the incident light, and the rays appear to come from an object at a great distance than the actual distance of the object. See figure 4-19. These rays thus appear to converge behind the object to produce an ERECT, NORMAL, ENLARGED, and VIRTUAL IMAGE, located on the same side of the lens as the object.

From this discussion of images created by objects, we derive the following conclusion: As you move an object closer to a lens, the image created by the object moves away from the lens, and it becomes increasingly larger as it moves. When you move the object to the principal focal point of the lens, the image BECOMES VIRTUAL AND IS FORMED AT INFINITY.

Negative Lenses

Refer again to illustration 4-2 and study the types of simple divergent lenses.

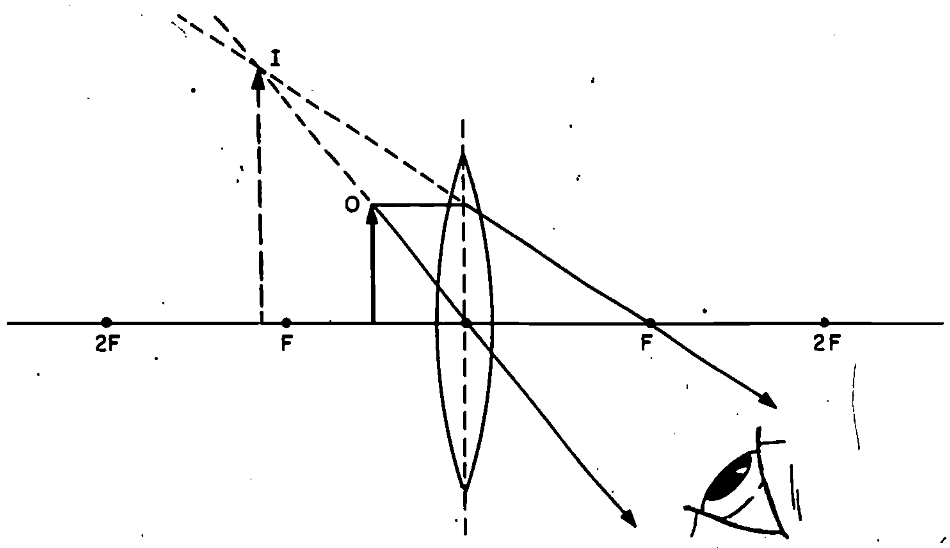

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Figure 4-19.—Formation of a virtual image by a convex lens when the object is closer to the lens than the focal point.

Divergent lenses have negative dioptric strength, and they are always thinner in the middle than at the edges. The optical center of a divergent lens is at the thinnest point of the lens, and the lens diverges parallel rays of light.

The point of principal focus, focal points, and focal planes resulting from the nearness of an object or light source to a simple divergent lens are located on the side of the lens toward the light source or object. The point of principal focus and other focal points are located where the emergent rays should intersect on the optical axis if they were extended backward as imaginary lines toward the side of the lens on which the light strikes. Review figure 4-6 for some terminology and focal length of a simple divergent lens.

If you use a page of this book as an object—at arm's length—and look at it through a divergent lens, this is what happens:

1. When the lens is in contact with the page (object), the image you see is erect, normal, and slightly smaller than the object.

2. If you move the lens closer to your eye, the image becomes even smaller.

3. When you have the lens quite close to your eye, you can see only a blur, REGARDLESS OF THE POSITION IN WHICH YOU HOLD THE OBJECT.

You will understand what took place when you held the divergent lens in the positions just described and looked at the page after you study the next few pages, dealing with the construction of a divergent lens and image formation by it.

Suppose, now, that we construct a divergent lens like the one shown in figure 4-6. Proceed as follows:

1. Sketch the double concave lens on paper.

2. Draw a dotted line through the middle of both ends of the lens, to represent the PRINCIPAL PLANE.

3. Then draw a straight line through the OPTICAL CENTER of the lens, PERPENDICULAR TO THE PRINCIPAL PLANE, to represent the OPTICAL AXIS.

4. Next, draw two lines, to represent rays of light, near the ends of the lens to the left face, through the lens (refraction indicated), and out into space.

5. With your ruler, draw the dotted lines along the straight portion of the emergent light ray to the optical axis. Where the two dotted lines intersect the optical axis is the POINT OF PRINCIPAL FOCUS, as indicated by the terminology and arrow.

6. Draw a dotted line downward from the POINT OF PRINCIPAL FOCUS, and then draw the two arrows in the positions indicated and insert FOCAL LENGTH.

Now sketch another double concave lens on paper (fig. 4-20) and draw a line through the OPTICAL CENTER, perpendicular with the PRINCIPAL PLANE, to represent the OPTICAL AXIS. Then draw two other lines (parallel) above and below the optical axis, as shown, to represent FOUR LIGHT RAYS.

The light rays you just drew show the PROCEDURE for TRACING LIGHT RAYS THROUGH A DIVERGENT LENS. Rays which pass along the optical axis and through the optical center do not refract (deviate), as you know; rays which pass through the lens at points other than through the optical center are deviated in the manner shown in the illustration.

When you look through a divergent lens (fig. 4-20), extensions of the refracted rays of light appear to converge at a point (POINT OF PRINCIPAL FOCUS) on the same side of the lens as the object, as shown in illustration 4-6. In order to learn how an image is created by a divergent lens of this type, draw (sketch) the lens on paper and then do the following:

1. Draw a dotted line through the middle of each end of the lens to represent the principal plane.

2. Draw another dotted line perpendicular to the principal plane and through the optical center to represent the optical axis. See figure 4-21.

3. Using a focal length of 2 inches, put a dot on the optical axis to represent the focal point (F).

4. Next, draw 3 arrows 1 inch high on the optical axis in the positions indicated by O_1, O_2, and O_3. Observe that one arrow is INSIDE THE FOCAL POINT (F), one arrow is ON THE FOCAL POINT, and the third arrow is BEYOND THE FOCAL POINT.

5. Along the tips of the arrow heads, draw a line to the principal plane to represent a parallel ray of light (parallel to the optical axis). Note how this ray diverges up after it contacts the principal plane. If you were to look at this ray from the opposite side of the lens, it would appear to emerge from the first focal point; so extend this line (dotted portion) to the focal point (F).

6. At the point where the ray of light which passes through the optical center from arrow O_1 intersects the dotted extension to the focal

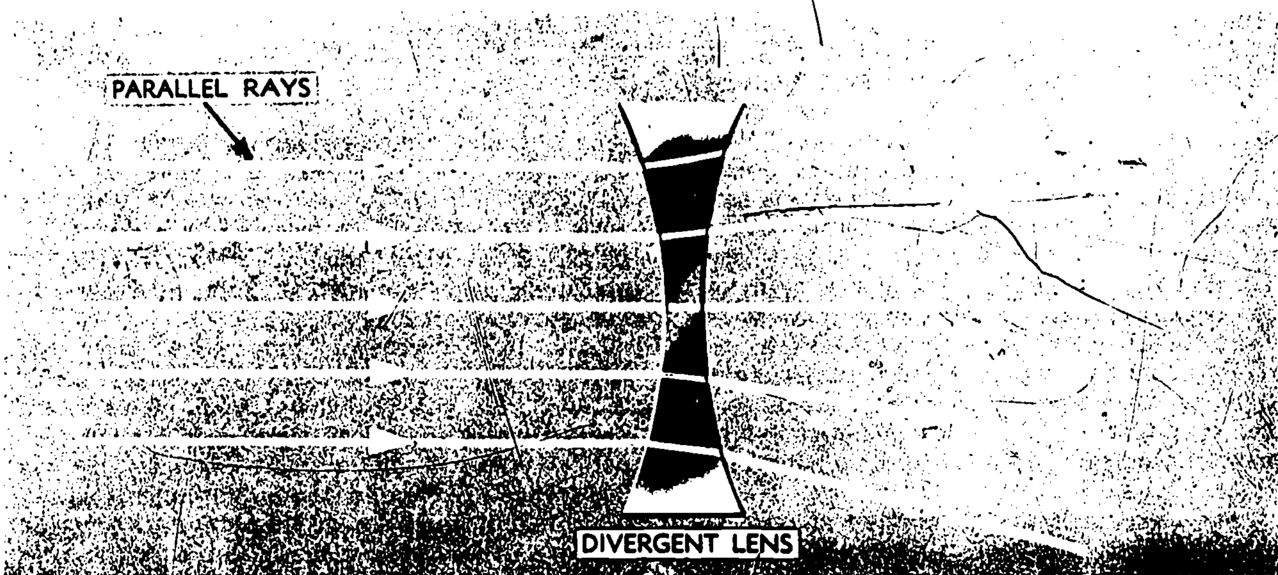

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Figure 4-20.—Effect of parallel rays on a divergent lens.

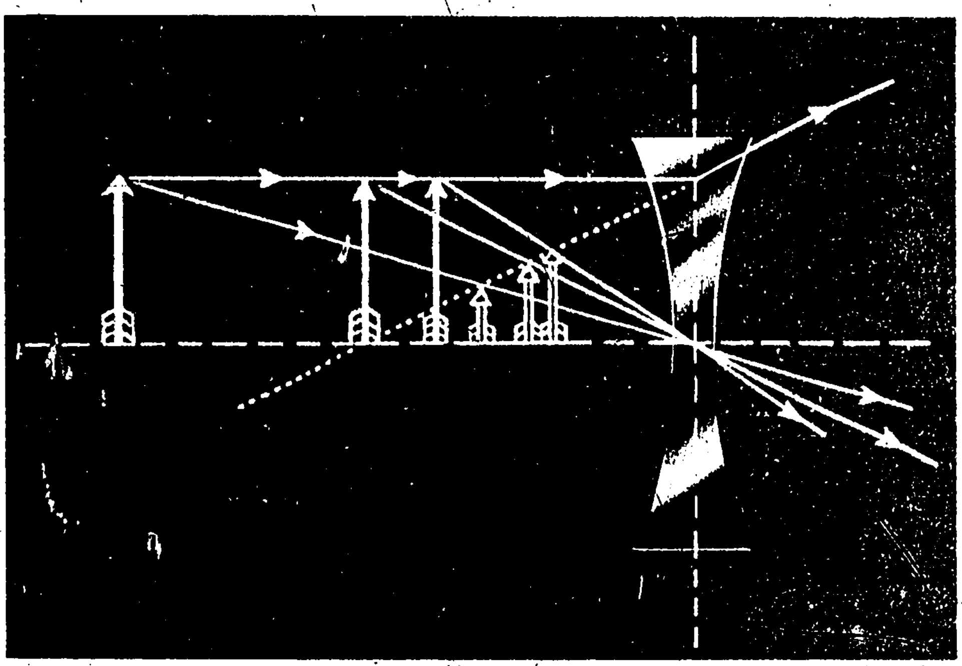

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Figure 4-21.—Image formation by a divergent lens.

point of the refracted ray you drew along the tips of the arrow heads, construct an arrow (erect) between this point and the optical axis. This arrow is designated I_1. Then draw arrows I_2, and I_3 to represent the other images made by the objects (O_1, O_2, and O_3).

SIZE OF IMAGE.—Observe that the images you constructed in illustration 4-21 are erect and normal, between the lens and its focal point, SMALLER THAN THE OBJECTS WHICH CREATED THEM, and VIRTUAL.

CYLINDRICAL LENSES

A cylindrical lens is a lens whose surfaces (one or both) are portions of a cylinder. The power of this lens to converge light rays when its axis is in a vertical position is in the horizontal meridian only; no refraction is produced in the VERTICAL PLANE. When the same lens is turned through a 90° angle, the axis is horizontal and its power to converge light rays is exercised ONLY IN THE VERTICAL PLANE. There are two types of cylindrical lenses, positive and negative, or convergent and divergent.

Convergent cylindrical lenses are used rather extensively for magnifying vernier scales on instruments and also for eyeglasses and the azimuth circle in the 90° prism housing.

A convergent cylindrical lens is shown in part X of illustration 4-22. The shaded portions of the illustration represent planes. In planes which pass through the object point (0) and parallel to the cylindrical surface of the lens, there is NO CONVERGENCE OF LIGHT RAYS. In planes perpendicular to the central plane through the center of the object point (0), light rays are refracted as they pass through the lens and converge at a point beyond the lens with the plane through the middle of the lens.

Observe A, B, and C on the lens. They represent the points at which the planes emerge from the lens. Ray OB in this lens passes straight through the center of the lens and is not refracted; rays OA and OC are refracted as they pass through and converge at I, the focal point. All light rays which come from point O and are refracted by the lens as they pass through it also pass through line I_1I_2, which is a real image of O.

If the refracted light rays were projected back through the lens (dotted lines), they would pass through line I_3I_4 and create a virtual image of object O.

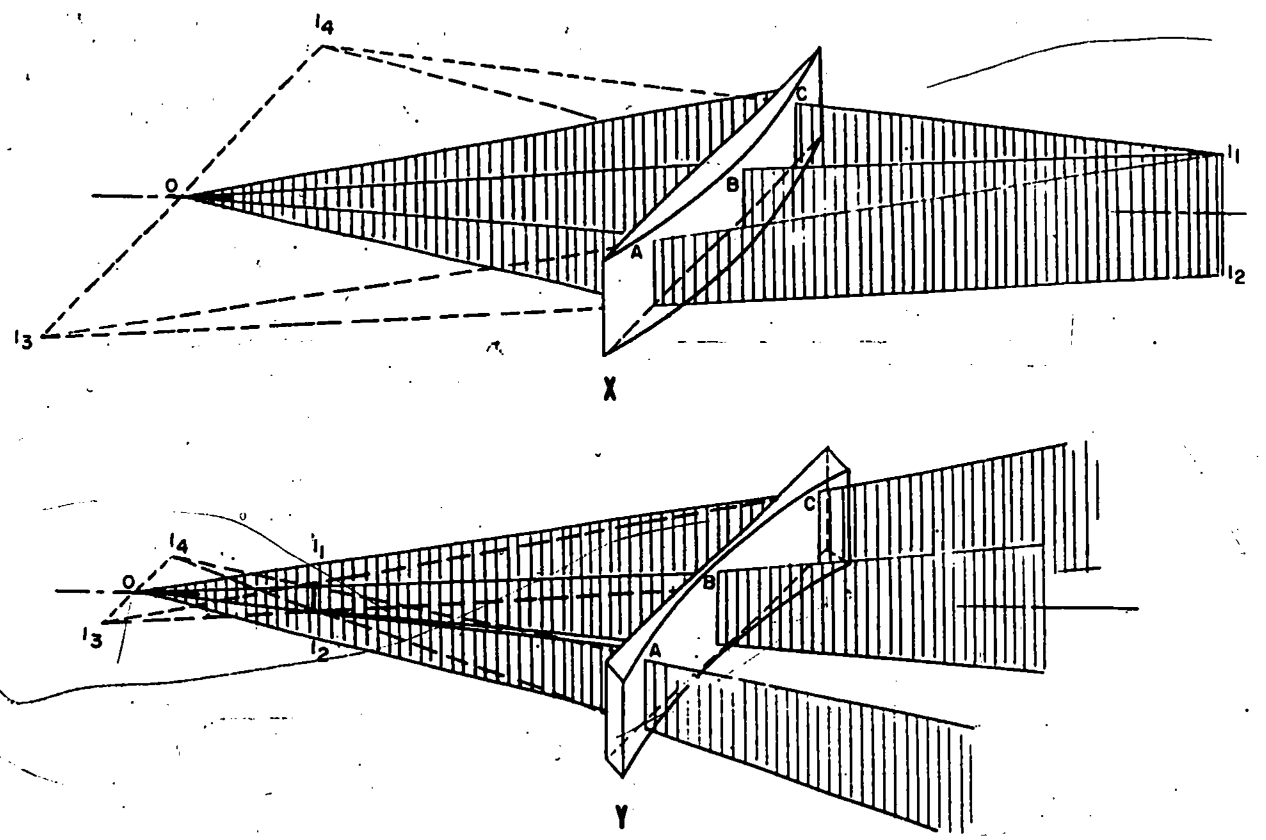

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Figure 4-22.—Cylindrical lenses.

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Refer now to part Y of illustration 4-22 to learn what happens to light rays as they pass through a divergent cylindrical lens. Note the object (O), the plane through the lens at B, and also the planes through A and C. Rays of light incident through plane O and B are not refracted. Rays of light incident through points OA and OC are diverged toward the edge of the lens and do not converge to any central point on the central plane, as did the rays through A and C in the convergent lens.

If the rays of light from O through A and C were projected back through the lens, they would pass through the central plane at I_2 and I_1, respectively, and create virtual images where they intersected line I_3I_4.

SPHERICAL MIRRORS

You perhaps have been at an amusement park where a building designated as FUN HOUSE had curved mirrors used to make you look ridiculously tall or disgustingly fat. Convex rear-view mirrors are also used on automobiles and trucks to give the drivers a wide view (field of vision).

A curved mirror either increases or decreases a wave front and changes its curvature. Such a mirror is called a SPHERICAL MIRROR (outside, convex mirror; inside, concave mirror).

Concave Spherical Mirrors

It is important at this time that you learn the procedure for constructing a concave mirror. Refer to illustration 4-23 as frequently as necessary during your study of the following discussion.

The shape of the curvature of a spherical mirror varies in accordance with the purpose for which it is intended. The procedure for making one must therefore be made accurately in accordance with a specific formula.

Begin the construction by measuring the length of the radius of a circle which will produce the desired curvature of the surface of the mirror. Line CV in figure 4-23 represents the radius of the size of a circle necessary to produce the reflecting surface of the mirror you are constructing. Draw this line after you make the circle with a compass. Point C, where you

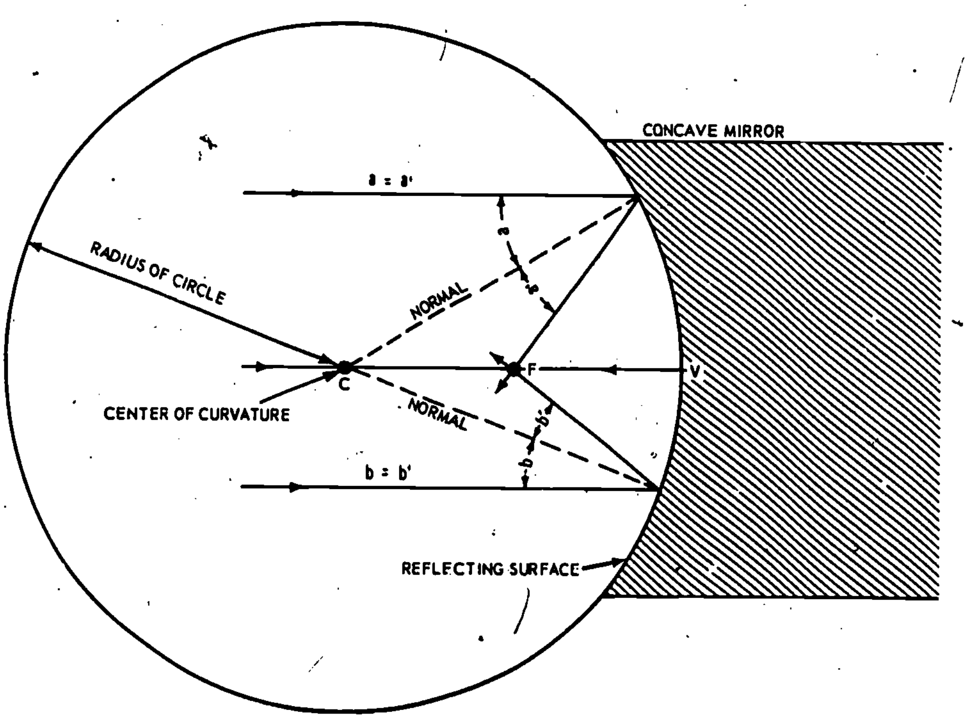

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Figure 4-23.—Construction of a concave mirror.

placed the metal point of the compass, IS THE CENTER OF CURVATURE OF THE SPHERE OF WHICH THE SURFACE OF THE MIRROR IS A PART. Line CV (Radius of the circle) IS THE OPTICAL AXIS OF THE MIRROR.

In order to locate the focal point of the concave mirror you just constructed, bisect line CV, represented by F (focal point) in the illustration. The focal point of a concave mirror is halfway between the center of curvature and the vertex (V) of the mirror. The focal point, or PRINCIPAL FOCUS, IS THE POINT TO WHICH PARALLEL RAYS ARE REFLECTED WHEN THEY STRIKE THE SURFACE OF THE MIRROR.

THE NORMAL OF A CONCAVE MIRROR IS A RADIUS drawn from the CENTER OF CURVATURE, to the point of contact OF THE INCIDENT RAY ON THE SURFACE OF THE MIRROR. Observe that the angles between an incident ray of light parallel with the optical axis form an angle with the normal which is equal to the angle formed by the reflected ray and the normal (angles a and a').

Regardless of the number of parallel incident rays which strike the surface of a concave mirror, their reflected rays always converge at the principal focus (focal point). Observe that angle b equals angle b'. As you know, the angle of reflection (b') equals the angle of incidence (b). These angles are measured FROM THE REFLECTED RAY TO THE NORMAL, and FROM THE INCIDENT RAY TO THE NORMAL.

The normal is erected perpendicular to the surface of the mirror by drawing a straight, dotted line from the center of curvature to the point of contact of the incident ray.

To learn how the law of reflection applies to a concave mirror, study illustration 4-24. The center of curvature of this mirror is in front. Note also the PRINCIPAL FOCAL POINT where the reflected rays converge. If imaginary lines are run from this center to the points of incidence of the incident rays, they indicate the NORMALS of individual light rays. Observe the N's on the edge of the lens. When these lines are drawn, the reflected rays can be so plotted that each forms an angle of reflection equal to the angle of incidence of the corresponding ray.

When diverging rays of light strike a concave mirror, they come together or converge; but the rays of light reflected from a concave mirror are more convergent than the incident rays.

The outer surface of a concave mirror is a part of the arc of a sphere, and the center of this sphere is the CENTER OF CURVATURE OF

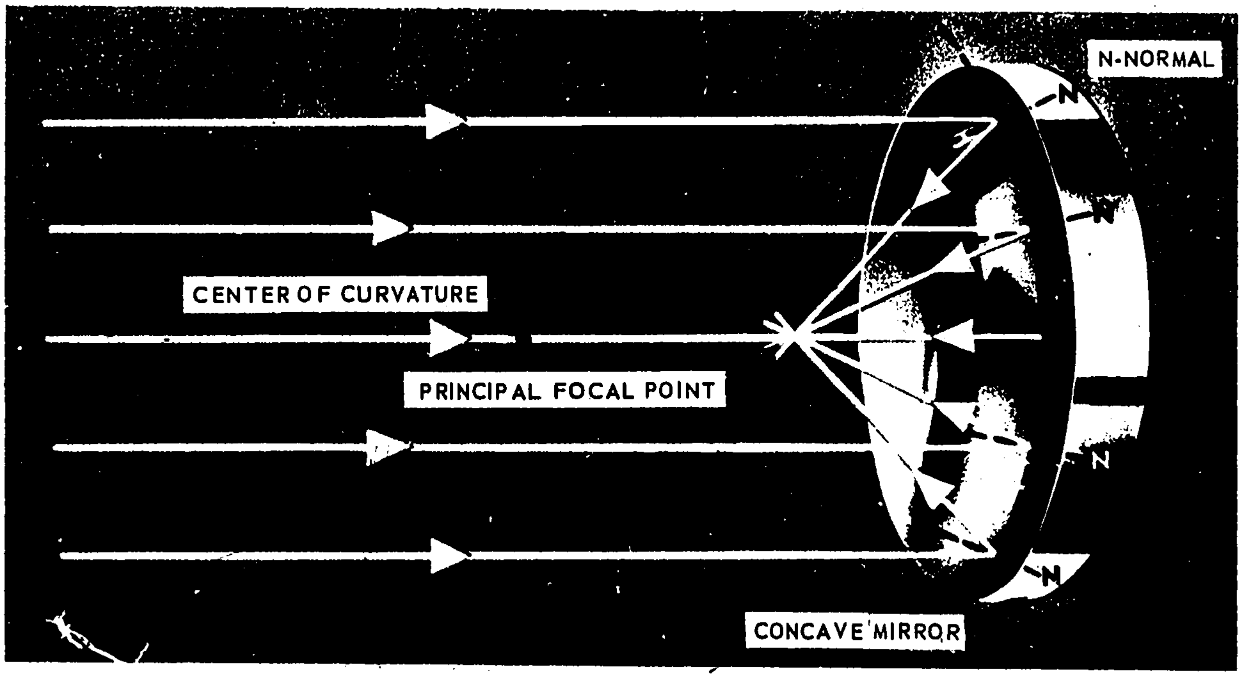

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Figure 4-24.—Reflection of parallel rays of light from a concave mirror.

THE MIRROR. The distance from the center of curvature to the surface of the mirror is the RADIUS OF CURVATURE. Take another look at illustration 4-24. Note that the focal point is exactly halfway between the center of curvature and the surface of the mirror.

If you place a small source of light at the focal point of a concave mirror, the light which strikes the mirror is reflected in a narrow beam of parallel rays. For this reason, a curved mirror is used as a reflector in a flashlight, or in a searchlight which throws an intense beam of light.

Refer now to figure 4-25 which shows how rays of light from an object form an image when they are reflected from the surface of a concave mirror. The object (located between the center of curvature and infinity), arrow AB, actually transmits billions of rays of light in all directions; but for our purpose, a few rays of light are sufficient to give you a general understanding of image formation by a concave mirror.

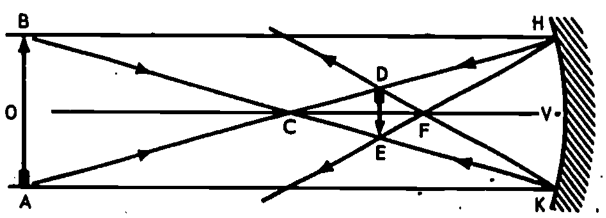

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Figure 4-25.—Image formation of an object by reflected rays of light from a concave mirror.

Ray BH travels parallel to the axis (OV) and strikes the surface of the mirror at H, from which point it is reflected through the focal point (F). Ray BCK, drawn through the center of curvature (C), intersects the reflected ray from ray BH at E. Since ray BCK is drawn through the center of curvature, it coincides with the normal to the mirror and is therefore reflected back in the same direction. Where the reflected rays of ray BH and ray BCK intersect (E) is the location of the image of the top of the arrow. In the same manner, the reflected rays AK and ACH give the location of the bottom of the image at D. Note that this image is located between C and F.

Because this image is formed by an actual intersection of reflected rays of light, it is considered a real image (smaller than the object, normal, and inverted).

The formation of images, by concave mirrors may be grouped by cases as explained next, with the object at varying distances from the surface of a mirror.

OBJECT AT INFINITY.—When an object is at infinity (fig. 4-26), light rays from it are diverging in all directions; but before they arrive at the mirror, they have become so nearly parallel that we may say they are parallel. The surface of the mirror converges the rays of light to the focal point to form a real, normal, and inverted image of the object (diminished in size).

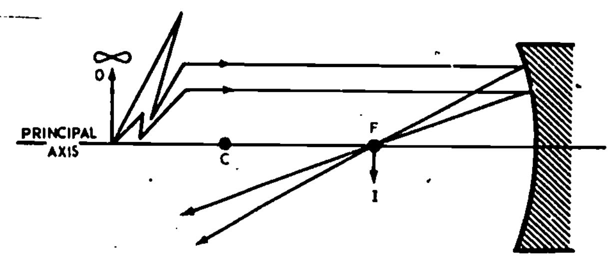

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Figure 4-26.—Position of image formed by a concave mirror when the object is at infinity.

OBJECT BETWEEN INFINITY AND CENTER OF CURVATURE.—When an object is placed at some point between infinity and the center of curvature of the mirror, the image is real, normal, inverted, and diminished in size; and it is located between the center of curvature and the focal point of the mirror, as shown in figure 4-27. NOTE: In this case, the image IS LARGER THAN the image formed in illustration 4-26, but it is still smaller than the actual object.

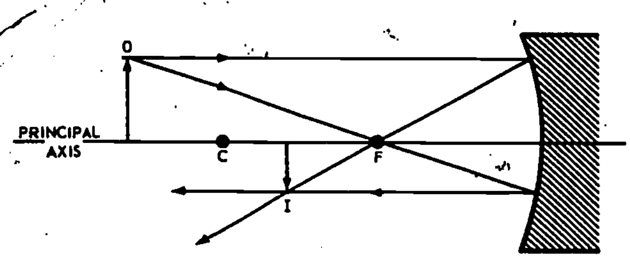

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Figure 4-27.—Position of image formed by a concave mirror when the object is between infinity and center of curvature.

OBJECT AT CENTER OF CURVATURE.—If an object is located at the center of curvature

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of a concave mirror, the mirror forms a real, inverted, normal image of the same size as the object, at the center of curvature. See figure 4-28.

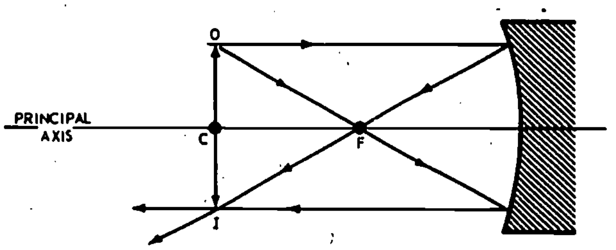

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Figure 4-28.—Position of image formed by a concave mirror when the object is at the center of curvature.

OBJECT BETWEEN CENTER OF CURVATURE AND FOCAL POINT.—When an object is placed between the center of curvature and the focal point of a mirror, the image formed by the mirror is real, inverted, normal, and enlarged (larger than the object); and it is located between the center of curvature and infinity, as shown in illustration 4-29.

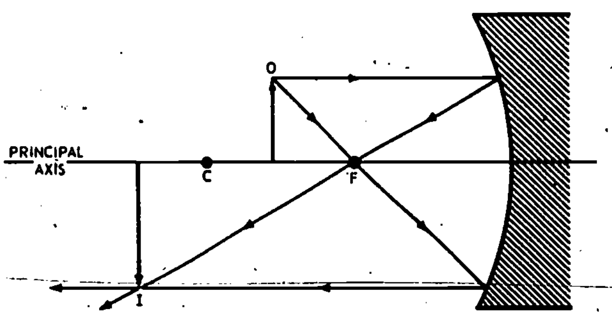

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Figure 4-29.—Position of image formed by a concave mirror when the object is between the center of curvature and the focal point.

OBJECT AT FOCAL POINT.—If an object is placed at the focal point (fig. 4-30) of a concave mirror, reflected rays from the mirror are parallel and a real image IS NOT FORMED. If an eye in the front area before the mirror catches the reflected parallel rays, they appear to be coming from infinity behind the mirror; and the eye sees a virtual, erect, reverted, and enlarged image at infinity.

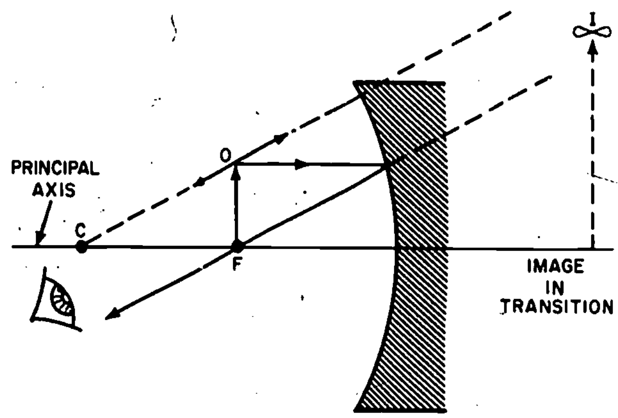

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Figure 4-30.—Position of an image formed by a concave mirror when the object is at the focal point.

OBJECT BETWEEN FOCAL POINT AND REFLECTING SURFACE.—When an object is placed between the focal point and the reflecting surface of a concave mirror, the reflected rays are divergent. Study illustration 4-31. As seen by an eye in front of the mirror, the rays appear to meet a short distance behind the mirror to form a virtual, erect, reverted, and enlarged image of the object. NOTE: The closer the object is moved toward the mirror, the larger is the image formed; and the image moves farther away from the mirror until the object reaches the principal focus. After passing this point, the image changes from REAL to VIRTUAL and decreases in size as the object approaches the surface of the mirror. The virtual image of a concave mirror is never smaller than the object.

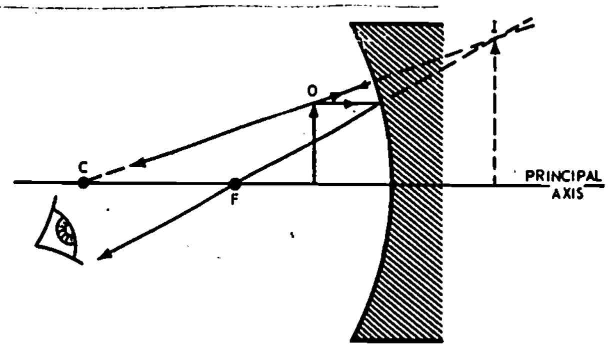

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Figure 4-31.—Position of an image formed by a concave mirror when the object is between the focal point and the reflecting surface.

Convex Mirror

Illustration 4-32 shows the procedure for constructing a convex mirror. Note the angles of incidence and the angles of reflection formed by the parallel rays of light which strike the mirror. These angles are equal, as you know; and the normals from the center of curvature of the mirror bisect these two angles. Observe the radius of the circle; all normals to the face of the mirror are actually radii of the circle. THE PRINCIPAL FOCUS OF A CONCAVE MIRROR IS REAL; THE PRINCIPAL FOCUS OF A CONVEX MIRROR IS VIRTUAL.

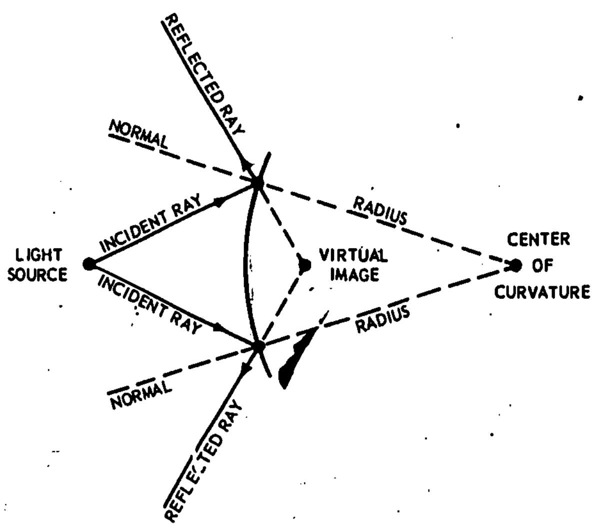

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Figure 4-32.—Procedure for constructing a convex mirror.

Illustration 4-33 shows how rays of light strike and reflect from the surface of a convex mirror. Note the angles formed by reflected rays, the radius to the center of curvature, the normals in relation to the radii, and the position of the virtual image formed by the extensions behind the mirror of the reflected rays of light. Now take another look at illustration 4-33, which shows rays of light striking different portions of the surface of a convex spherical mirror. The principle of reversibility is illustrated by the central ray.

The law of reflection holds true for all surfaces—convex, concave, and plane. The amount of reflected light from curved surfaces depends upon the distance of the light source and the amount of curvature of the reflecting surface.

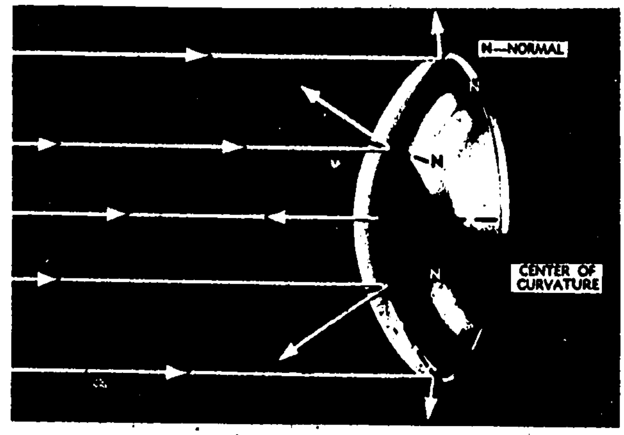

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Figure 4-33.—Reflection of light rays by a spherical mirror.

If light from a distance source such as the sun strikes a convex mirror, the rays are reflected in a convergent manner. The reason for this can be determined by plotting the angles of reflection of individual rays in relation to their angles of incidence and the normals for each light ray. In this case, the normal for each ray is an imaginary line drawn FROM THE CENTER OF CURVATURE OF THE MIRROR TO THE POINT OF INCIDENCE OF THE RAY. The angle of reflection, of course, is equal to the angle of incidence for each ray.

When a light source is close to a mirror, the rays are divergent when they strike the mirror and are also reflected in a divergent manner. In this case, the rays are reflected at different angles from parallel rays of light which strike the mirror, but always equal to the angle of incidence.

Study illustration 4-34, which shows three objects (arrows 0_1, 0_2, and 0_3) of the same size but of different distances from a convex spherical mirror. These arrows are of the same height, because they are constructed between a line parallel with the optical axis. The ray of light which passes along the tips of the three arrows strikes the mirror and is reflected in the manner indicated by arrow AF. The dotted extension of this line behind the mirror contacts the optical axis at the focal point.

Rays of light from the three arrow heads to the CENTER OF CURVATURE OF THE MIRROR ARE SECONDARY AXES, and the image formed by each lies between them and the optical axis. (Any straight line which passes

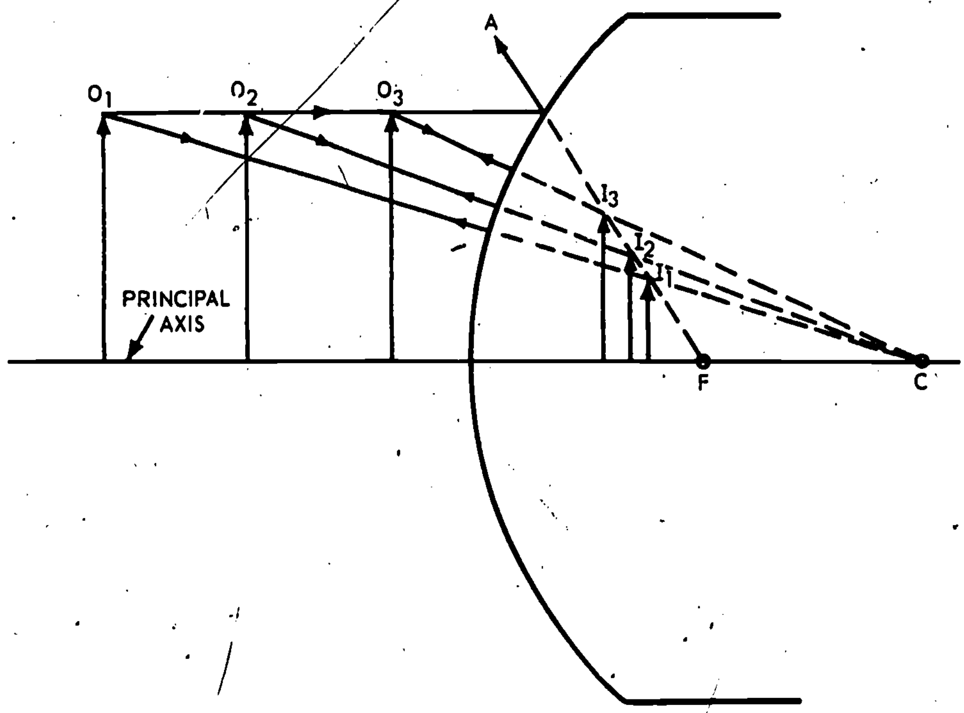

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Figure 4-34.—Image formation by a convex mirror.

through the center of curvature of a mirror to its surface is called a normal.) Object O_1 creates I_1, and so forth. Observe that the size of the image is larger when the object which formed it is moved nearer to the mirror, but an image can NEVER BECOME AS LARGE AS ITS OBJECT.

As you can see, these images are virtual, erect, reduced in size, and located behind the mirror between the principal focus and the vertex.

The radius of curvature of a convex mirror is negative and the image is always virtual. The focal length (F) and the image distance (D_i) are therefore negative quantities.

A spherical mirror will, in effect, produce the same convergence or divergence in light transmission as a lens. A concave spherical mirror is considered to be a positive mirror and the reflected light from a parallel beam will be convergent. Study figure 4-35 which illustrates a comparison of virtual images formed by a concave mirror (A) and a positive lens (B). Concave mirrors will form an image in the same MANNER as a convex lens, but the

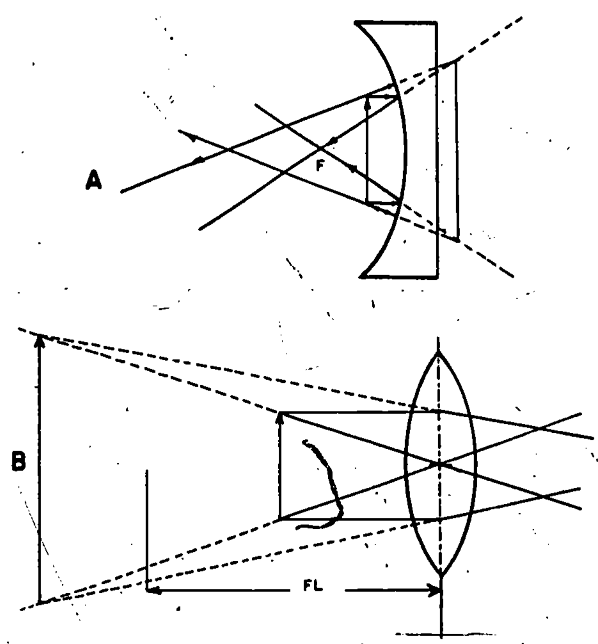

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Figure 4-35.—Virtual image comparison with concave mirror and positive lens.

image formed by a mirror is located on the opposite side of the element.

A negative or convex spherical mirror will have the same effect on light rays as a negative lens. It will form a virtual erect and diminished image. Study figure 4-36 which shows a comparison of virtual images formed by a negative lens (A) and a convex mirror (B).

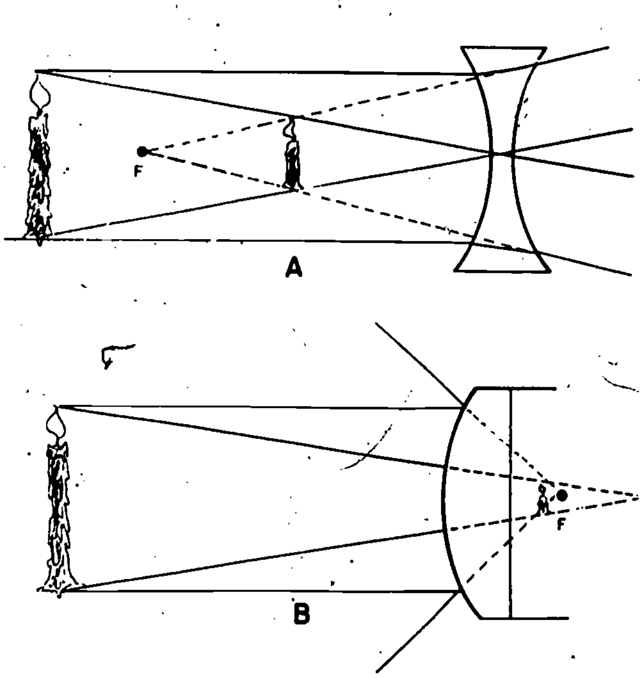

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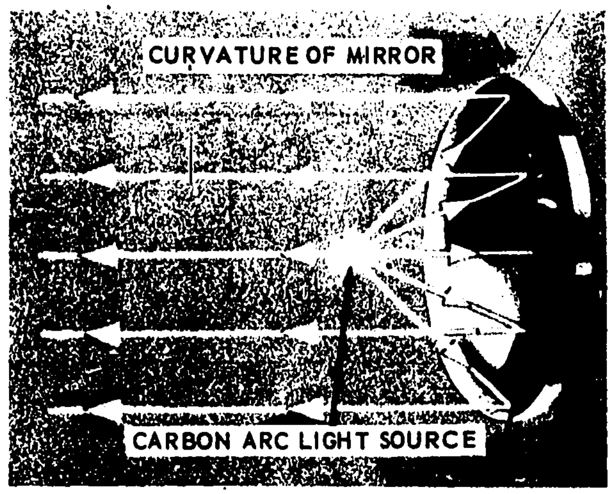
Figure 4-36.—Virtual image comparison with negative lens and convex mirror.

Parabolic Mirrors

If a very small luminous source is located at the principal point of focus, light rays are almost parallel after they reflect from a mirror—provided the curvature of the mirror is VERY SLIGHT. The rays actually have a slight convergence, particularly those reflected near the edges of the mirror (fig. 4-33). For this reason, a parabolic mirror is used whenever parallel reflected rays are desired. Study illustration 4-37.

A parabolic mirror is a concave mirror with the form of a special geometrical surface—a paraboloid of revolution. Light rays which emanate from a small source at the focal point of a parabolic mirror are parallel after they reflect from its surface.



137.66
Figure 4-37.—Reflection of light rays by a parabolic mirror.

The source of light (usually a filament or arc) is located in the principal point of focus and the rays diverge, because THERE IS NO TRUE POINT SOURCE. All rays which strike the parabolic mirror (except those which are diffused or scattered) reflect from the mirror toward the focal point and nearly parallel with each other, thereby providing for the formation of a powerful beam of light which diverges only slightly. Most searchlights have parabolic mirrors, as do automobile headlights.

Spherical mirrors are generally used for ordinary purposes because the grinding process is easy; but other types of mirrors are used for special purposes. A CYLINDRICAL MIRROR is part of a cylinder—not part of a sphere. When parallel rays reflect from a concave spherical reflecting surface, they form a CONE-SHAPED BEAM which converges to a point. When parallel rays of light reflect from a concave CYLINDRICAL reflecting surface, they form a WEDGE-SHAPED BEAM which converges to a line; and when light converges to a line, it is called ASTIGMATIZED LIGHT. Think of a CYLINDRICAL MIRROR as a silvered portion of the inside of an ordinary tin can. If you silver the inside curved surface of the can and then split the can lengthwise, you have an example of a concave cylindrical mirror.

LENS FORMULAS

So far in this chapter, we have been primarily concerned with describing lenses and spherical mirrors and how they form images. At this point, we will study the set rules (formulas) that are used to determine FOCAL LENGTH, MAGNIFICATION, IMAGE SIZE, IMAGE DISTANCE, and RELATIVE APERATURE.

FOCAL LENGTH

We have previously discussed a way to approximate the focal length of a convergent lens by measuring the distance from the lens to the real image formed with an object at infinity. The relationship between the image and the focal length of a lens is expressed in a formula called the lens law:

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

F = focal length

D_o = Distance of object

D_i = Distance of image

If you have a lens with a focal length of 4 inches and the object is at infinity (∞), you would substitute in the following manner. NOTE: WHEN THE DISTANCE OF THE OBJECT IS INFINITY (∞) $1/D_o$ IS CONSIDERED AS 0.

$$\frac{1}{4} = 0 + \frac{1}{D_i}$$

$$D_i = 4 \text{ in.}$$

Thus, you have just proven that with an object at infinity the focal length of the lens is the same as the image distance.

CALCULATING IMAGE POSITION.—Now use the lens formula to calculate the positions of the images you constructed in illustration 4-21. The lens formula is:

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

The focal length of a divergent lens is negative, because the image is on the same side of the lens as the object and the image distance is negative.

The focal length of the lens used in the illustration is 2 inches TO THE LEFT of the principal plane of the lens, so the focal length of the lens IS MINUS 2 INCHES.

To find the image distance for arrow O_2 (object) drawn at the focal point some substitutions must be made in the formula (lens law), as follows:

$$\frac{1}{-2} = \frac{1}{2} = \frac{1}{D_i}$$

$$2D_i = -2D_i - 4$$

$$4D_i = -4$$

D_i = -1, image distance for arrow O_2

The answer you got by solving the formula means that the image is 1 inch from the principal plane of the lens, but is ON THE SAME SIDE of the lens as the object.

You can calculate the distances of the other images in illustration 4.21 in the manner just described.

MAGNIFICATION

Magnification is the apparent enlargement of an object by an optical element. This can be easily understood when we consider a single positive lens that is used as a simple magnifier.

A positive lens works as a magnifier because it makes the light rays subtend a larger angle at an observer's eye than is possible with the unaided eye.

This is shown in figure 4-38 which illustrates an object viewed by an unaided eye, (A) and an object viewed through a magnifier, (B).

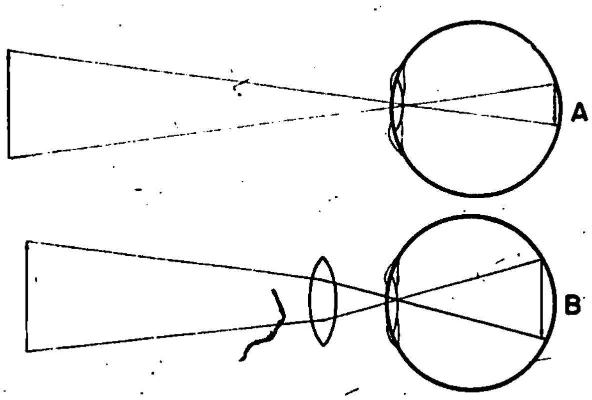


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Figure 4-38.—Object viewed with the unaided eye and through a magnifier.

When we technically define magnification by an optical element, we must consider it under two conditions of magnification: LATERAL and ANGULAR.

Lateral Magnification

The ratio of the linear size of the image to that of the object is LATERAL MAGNIFICATION.

Lateral magnification of an image is a variable amount controlled by the distance of the object to the lens and the focal length of the lens. The numerical relationship between lateral magnification and the lens or mirror is expressed in the following formula:

$$M = \frac{S_i}{S_o} = \frac{D_i}{D_o}$$

This formula shows that lateral magnification (M) is equal to the size of the image (Si) divided by the size of the object (So) and also equal to the distance of the image (Di) divided by the distance of the object (Do).

In order to firmly fix the formulas and the relationship between focal length magnification, the size and distance of object and image, let's put the formulas to use by constructing a convergent lens on paper.

Draw a convergent lens that is 3 inches high with the optical axis and the principal plane shown by dotted lines. Next, measure off 2 inches along the axis on each side of the optical center and mark them with the letter "F" to remind you that they are the focal points. Your drawing should now look like figure 4-39. Now draw an arrow one inch high, with its tail on the optical axis and placed 3 inches to the left of the principal plane.

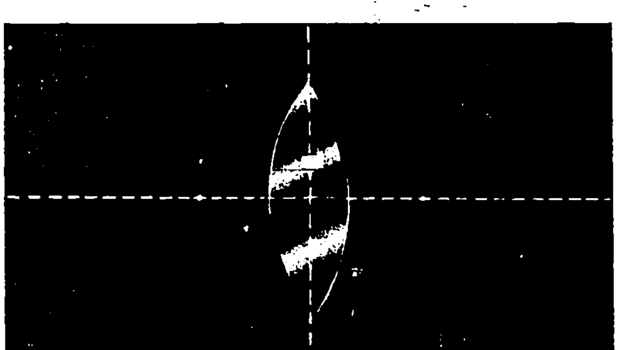

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Figure 4-39.—Convergent lens.

You know, of course, that each point on the arrow is radiating light in all directions, and that many of the rays will strike the lens. And you know that all the rays that reach the lens from any point on the object will bend and meet at a corresponding point on the image. So to plot the image of any point on the object, all we'll have to do is draw two rays, and find the ~~point where they cross.~~ Then we'll have the corresponding point on the image.

To find the image of the arrowhead, draw a ray from the arrowhead to the principal plane of the lens, and make the ray parallel to the optical axis. What do we know about rays parallel to the optical axis? We know that they bend as they pass through the lens, and after they leave the lens they pass through the principal focal point on the other side. From the point where your first ray meets the principal plane, it will pass through the second focal point. So add that refracted ray to your drawing. We know that the image of the arrowhead is somewhere along that ray. Your drawing should look like figure 4-40.

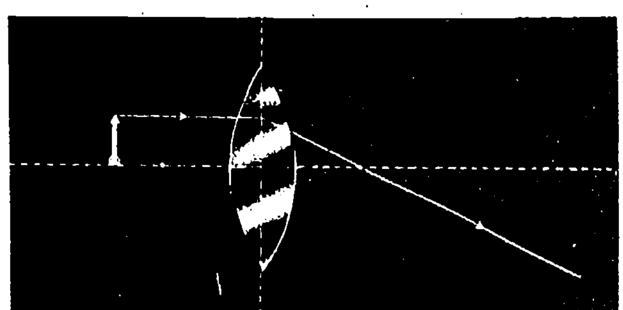

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Figure 4-40.—Convergent lens with ray passing through focal point.

Now, for your other ray, use the one that passes through the first focal point. Draw a ray from the arrowhead through the first focal point, and continue the ray until it meets the principal plane of the lens. (If this line goes below the lens you've drawn, don't worry about it. This plotting method will work anyway. Just continue the line that represents the principal plane until it meets the ray.) What do we know about rays passing through the focal point? We know that they bend when they pass through the lens, and that they emerge parallel to the axis. So, from the point where your second ray meets the principal plane, draw the refracted ray on the right side of the lens, and make it parallel to the optical axis. The image of the arrowhead is at the point where that ray crosses the first one you drew.

There's another ray you can plot, if you want to. Any ray passing through the optical center of the lens will be refracted at each surface (unless the ray is traveling along the axis). But the two refractions will be equal, and they'll be in opposite directions. So for a ray passing through the optical center, the total deviation is zero. When you're plotting images, you can draw any ray that passes through the optical center of a lens as if it went through the lens in a straight line. So now add this third ray to your drawing: Draw a line from the arrowhead to the optical center and continue it in a straight line on the other side of the lens. If you've made your drawing carefully, all three rays will meet at the image point.

You've found the image of the arrowhead. You know, of course, that the image of the tail is on the optical axis, because rays traveling along the axis are not refracted. Since the arrow is at a right angle to the axis, the image will be at a right angle to the axis too. So draw a line from the image of the arrowhead to the axis, and there's your image of the arrow. Your drawing should look like figure 4-41.

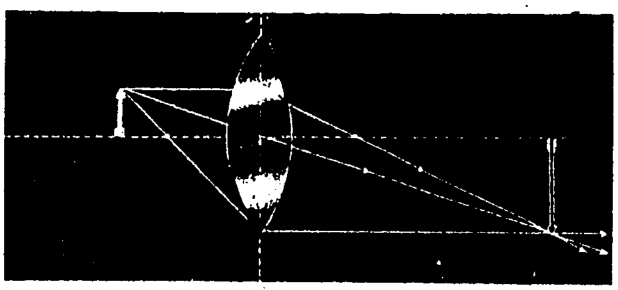

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Figure 4-41.—Convergent lens with object and image.

Now let's try it again. Use the same focal length, 2 inches, but this time put the arrow 4 inches to the left of the principal plane. And this time let's make the arrow 2 inches long, with part of it above the axis, and part of it below. Now locate the image. Find the point that's the image of the arrowhead, and then find the point that's the image of the tail. When you connect the two, there's the image of your arrow. Remember that for each point there are three different rays you can plot. Any two of them will locate the image. Use whichever two rays are most convenient for you. When you've finished your drawing, it should look something like figure 4-42.

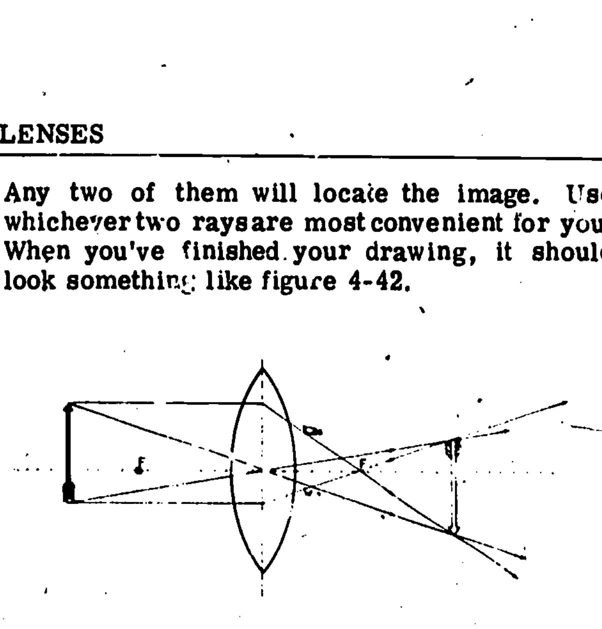

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Figure 4-42.—Convergent lens with object 4 inches to the left of principal plane.

Now you've plotted two images formed by a convergent lens. If you've made the drawings carefully, you can use them to check the formulas for image size and distance. In your first drawing, you have an object 1 inch high, 3 inches from a lens of 2-inch focal length. Let's use the LENS LAW to find the image distance.

The formula is:

$$\frac{1}{D_o} + \frac{1}{D_I} = \frac{1}{F}$$

Substitute:

$$\frac{1}{3} + \frac{1}{D_I} = \frac{1}{2}$$

Solve for D_I:

$$2D_I + 6 = 3D_I$$

$$D_I = {}^{-}6$$

So, in your first drawing, the image should be 6 inches from the lens. Measure and see if it is. Hold the ruler on the optical axis, or parallel to the axis, and measure the distance from the image to the principal plane of the lens. The more careful your drawing, the closer the distance will be to 6 inches.

Now use the same drawing to check the formula for magnification. The formula is:

$$M = \frac{S_I}{S_o} = \frac{D_I}{D_o}.$$

Substitute:

$$\frac{S_I}{1} = \frac{6}{3}$$

80

Solve for S_I:

$$3S_I = 6$$

$$S_I = \frac{6}{3} = 2$$

The image is 2 inches high. Does that check with your drawing? If not, look the drawing over carefully to see what's wrong with it. If it checks, then use both formulas to test the accuracy of your second drawing—the one with the object 2 inches high.

Now you know two methods for finding the distance and size of the image formed by a convergent lens: A graphic method, in which you make a scale drawing to plot the image, and a mathematical method in which you use formulas to calculate the distance and size of the image.

So far, we've been talking about objects a short distance outside the focal point of the lens. Before we go on, let's work out a more practical problem. Suppose you're looking at a ship through a telescope. The objective lens of your telescope (that's the one in front—the one nearest the object) is a convergent lens. Let's say that the objective lens has a focal length of 10 inches. Let's say that the ship you're looking at is 200 yards long, and that it's 5,000 yards from your telescope. Then how far from the objective lens of the telescope is the image of the ship? And how long is the image? Before we can substitute in the formula, we have to get all the distances in the same units. Since we want the answer to be in inches, let's get the other units in inches too. The ship is 200 x 36 inches long, or 7,200 inches long. And its range is 5,000 x 36, or 180,000 inches. Now use the lens law:

$$\frac{1}{D_O} + \frac{1}{D_I} = \frac{1}{F}$$

Substitute:

$$\frac{1}{180,000} + \frac{1}{D_I} = \frac{1}{10}$$

Solve for D_I

$$10D_I + 1,800,000 = 180,000D_I$$

$$179,990D_I = 1,800,000$$

$$D_I = \frac{1,800,000}{179,990} = 10.00055 \text{ inches.}$$

The distance of the image is just a trifle over 10 inches. And the focal length of the lens is 10 inches. So you can see that the image of a distant object is practically in the principal focal plane. What about the length of the image? The formula is:

$$\frac{S_O}{S_I} = \frac{D_O}{D_I}$$

Use 10 inches for the distance of the image, and substitute:

$$\frac{7,200}{S_I} = \frac{180,000}{10}$$

Solve for S_I:

$$72,000 = 180,000S_I$$

$$S_I = \frac{72,000}{180,000} = .4 \text{ inch.}$$

The image of the ship is just four-tenths of an inch long.

Here's another case we haven't considered yet. Suppose the object is at one of the focal points of a convergent lens. Then where's the image? You won't need pencil and paper, or even a formula, to answer that one. You know that if the object is at infinity, then all its rays will be parallel, and they'll bend and meet at the focal point after they pass through the lens. If the object is at infinity, its image is at the focal point. So you know that if the object is at the focal point, its image is at infinity. That's the law of reversibility again.

Angular Magnification

Angular magnification is the ratio of the apparent size of the image seen through an optical element to that of the object viewed by the unaided eye, when both the object and the image are considered to be at the distance of distinct vision.

In order to fully understand this, let's reconsider the single positive lens used as a magnifier. Without a magnifier, an observer can make an object appear larger only by bringing it closer and closer to his eye. As an object is moved closer to an observer's eye, it is necessary for the eye to increase its refractive power in order to continue to focus the image. The minimum distance at which the eye can increase its refractive power to its maximum capability is called "the distance of distinct vision" and for the average observer to make an object appear larger, it is necessary to add refractive power to the eye. The magnifier provides the extra refractive power required.

We have seen where lateral magnification is a variable that will change as the object and image distance changes. When we consider angular magnification, we find that the object and image distance are fixed at the distance of distinct vision (10 inches). At this distance, we have, in effect, reached the PRACTICAL LIMIT OF MAGNIFICATION for the optical element and it is commonly referred to as the MAGNIFYING POWER.

When computing the magnifying power of a lens the following formula is used:

$$MP = \frac{10 \text{ inches}}{\text{fl inches}}$$

If you have a lens with a focal length of 5 inches and you want to find the magnifying power, you would substitute in the following manner:

$$MP = \frac{10''}{5''}$$

$$MP = 2.$$

LENS DIOPTER (generally called diopter)

A lens diopter is the UNIT OF MEASURE OF THE REFRACTIVE POWER (dioptric strength) of a lens or a lens system. It is based on the metric system of measurement. All optical diagrams give focal lengths and diameters of lenses in millimeters.

A lens with a focal length of 1 meter has the refractive power of 1 DIOPTER. Study illustration 4-43. The refractive power of a converging lens is POSITIVE; the refractive power of a diverging lens in NEGATIVE.

The refractive power of lenses which do not have focal lengths of 1 meter is the reciprocal of the focal lengths in meters, and it varies inversely as the focal length. This means that a converging lens with a focal length of 20 centimeters (1/5 meter) has a power of +5 diopters; whereas, a diverging lens with a focal length of 50 centimeters (1/2 meter) has a power of -2 diopters. A lens with the shortest focal length has the greatest positive or negative dioptic strength.

A lens with a focal length of 25 centimeters has a positive idoptric strength of 4 diopters. When converted to meters, the 25 centimeters equal .25 meter. The reciprocal of .25 meter equals 4 diopters. The equation for this is as follows:

$$\text{Diopters} = \frac{1}{f} \text{ (in meters)}$$

$$\text{Diopters} = \frac{1}{.25} \text{ meters}$$

$$\text{Diopters} = 4$$

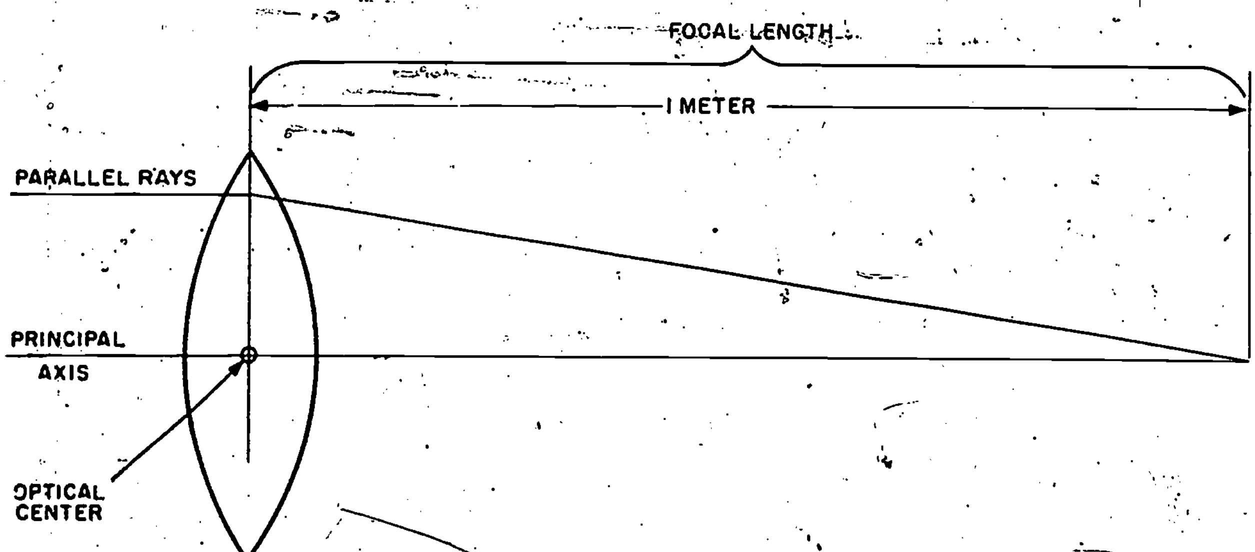

Figure 4-43.—Lens diopter. 137.86

Another formula for determining the dioptric strength of a lens when its focal length is in millimeters is:

$$\text{Dioptric strength} = \frac{1{,}000 \text{ millimeters (mm)}}{\text{F (in millimeters, mm)}}$$

If the focal length of a lens is in inches, the formula is:

$$\text{Dioptric strength} = \frac{39.37 \text{ (or 40) inches}}{\text{F (in inches)}}$$

RELATIVE APERTURE

The aperture of a lens is the largest diameter through which light can enter a lens. The light-gathering ability of a lens is determined by: (1) its aperture, and (2) its focal length.

Take a look now at the lenses in illustration 4-44, both of which have the same diameter but not the same focal length. The arrows on the left, the objects, have the same size; and both lenses receive the same amount of light from the objects, because their apertures are equal.

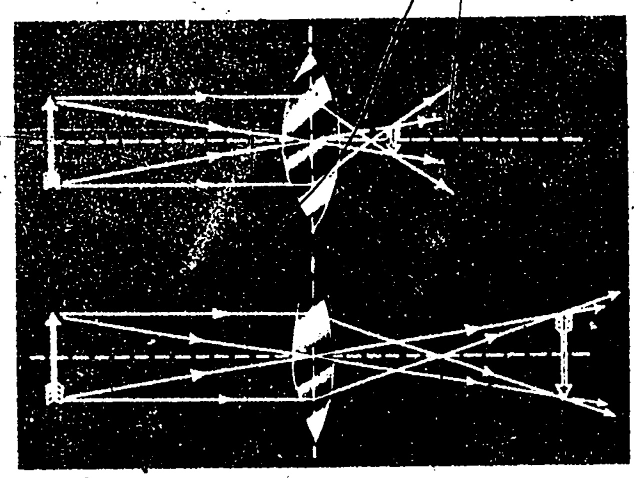

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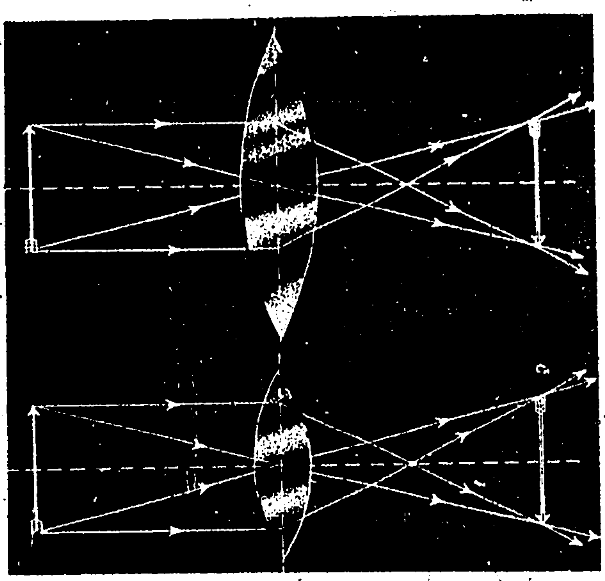
Figure 4-44.—Passage of light through lens aperture.

The bottom lens in the illustration, however, has a longer focal length than the top lens and therefore makes a larger image of the arrow, because the light it receives is spread over a larger area. If the diameters of the two lenses were equal, the lens with the shorter focal length would form a brighter image than the lens with the longer focal length, because the light it receives is concentrated in a smaller area.

Study next illustration 4-45 which shows two lenses with the same focal length but of different diameters. The larger lens at the top therefore forms a brighter image of the object, because it has a greater aperture than the bottom lens and receives more light from the object.

When you compare the light-gathering ability of one lens with another, take into consideration the relative aperture (focal length divided by diameter) of both lenses. To find the relative aperture of a lens, divide its focal length by its diameter. For example, the formula for finding the relative aperture of a lens with a diameter of 2 inches and a focal length of 8 inches is:

$$\text{Relative aperture} = \frac{F}{\text{diameter}} = \frac{8}{2} = 4$$



137.98
Figure 4-45.—Image brightness increased by enlarged lens aperture.

The relative aperture of this lens is therefore, generally written as f:4.

If you have two lenses with different relative apertures, you can tell which one will form the brighter image by using the formula: Suppose, for example, that you have two lenses with relative apertures of f:4 and f:2, respectively. If both lenses have the same diameter, the focal length of the f:4 lens is twice that of the f:2 lens. Use F_1 for the focal length of the f:2 lens and F_2 for the focal length of the f:4 lens in the formula and solve and you get:

$$\text{Relative aperture} = \frac{F}{\text{diameter}}$$

$$2 = \frac{F_1}{d}, \text{ and } 4 = \frac{F_2}{d}$$

$$F_1 = 2d, \text{ and } F_2 = 4d$$

If the focal lengths of these two lenses were equal, the f:2 lens would be twice the diameter of the f:4 lens. Let d_1 represent the diameter of the f:2 lens and d_2 represent the diameter of the f:4 lens in the formula and solve and you get:

$$2 = \frac{F}{d_1}, \ \& \ \ 4 = \frac{F}{d_2}$$

$$d_1 = \frac{F}{2}, \ \& \ d_2 = \frac{F}{4}$$

RELATIVE IMAGE BRIGHTNESS

In both examples, the f:2 lens forms the brighter image; because BRIGHTNESS OF THE IMAGE is proportional to the light-gathering ability of the lens, and the relative image brightness of two lenses is inversely proportional to the square of their relative apertures.

The relative image brightness of the two lenses just considered (f:2 and f:4) may be determined by using the formula, as follows:

$$\text{Relative image brightness} = \frac{(4)^2}{(2)^2} = \frac{16}{4} = 4$$

This means that the image formed by the f:2 lens is four times as bright as the image formed by the f:4 lens.

LENS ABBERATIONS

Aberration in a lens is an image imperfection which prevents the lens from forming a true reproduction of an object, because the light rays do not converge to a single focus. Aberrations result from a variety of conditions, some of which you studied in chapter 2, Nature of Light. The general types of aberration are: (1) chromatic, (2) spherical, (3) astigmatism, (4) coma, (5) curvature of the field, and (6) distortion.

CHROMATIC ABERRATION

You learned in chapter 2 that when white light is refracted through a prism it disperses the light into rays of different wavelengths to form a spectrum. The rays of different colors are refracted to different extents, as illustrated in figure 4-46. Observe that violet rays are refracted most and that red rays are refracted least.

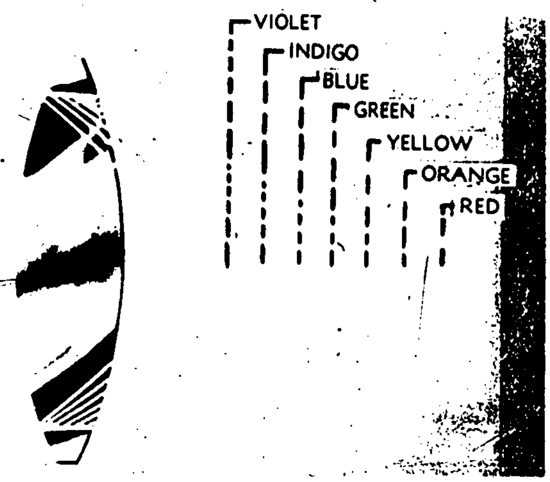


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Figure 4-46.—Chromatic aberration in a lens.

Because a lens may be considered as composed of an infinite number of prisms, as shown in figure 4-47, dispersion also occurs in a lens when light passes through it. Dispersion in a lens produces an optical defect known as chromatic aberration, which is present in every uncorrected single lens. The violet rays focus nearer to the lens than the red rays, and the other rays focus at intermediate points. The lens therefore had different focal lengths for different colors of light and an image created by the lens is fringed with color.

Chromatic aberration may be corrected by proper spacing between lenses, and also by adjusting the curvatures of the lenses. See figure 4-48, part A of which shows how a portion of the aberration can be diminished by equalizing the deviation at the two surfaces of a lens. Part B of this illustration shows how chromatic aberration in a lens can be corrected by a compound lens, one part of which is positive (convergent) and the other part of which is negative (divergent). As you learned previously in this training course, a lens with positive dioptric strength is made of crown glass and a lens with negative dioptric strength is made of flint glass.

Since crown glass is more strongly convergent for blue rays than for red rays, and the

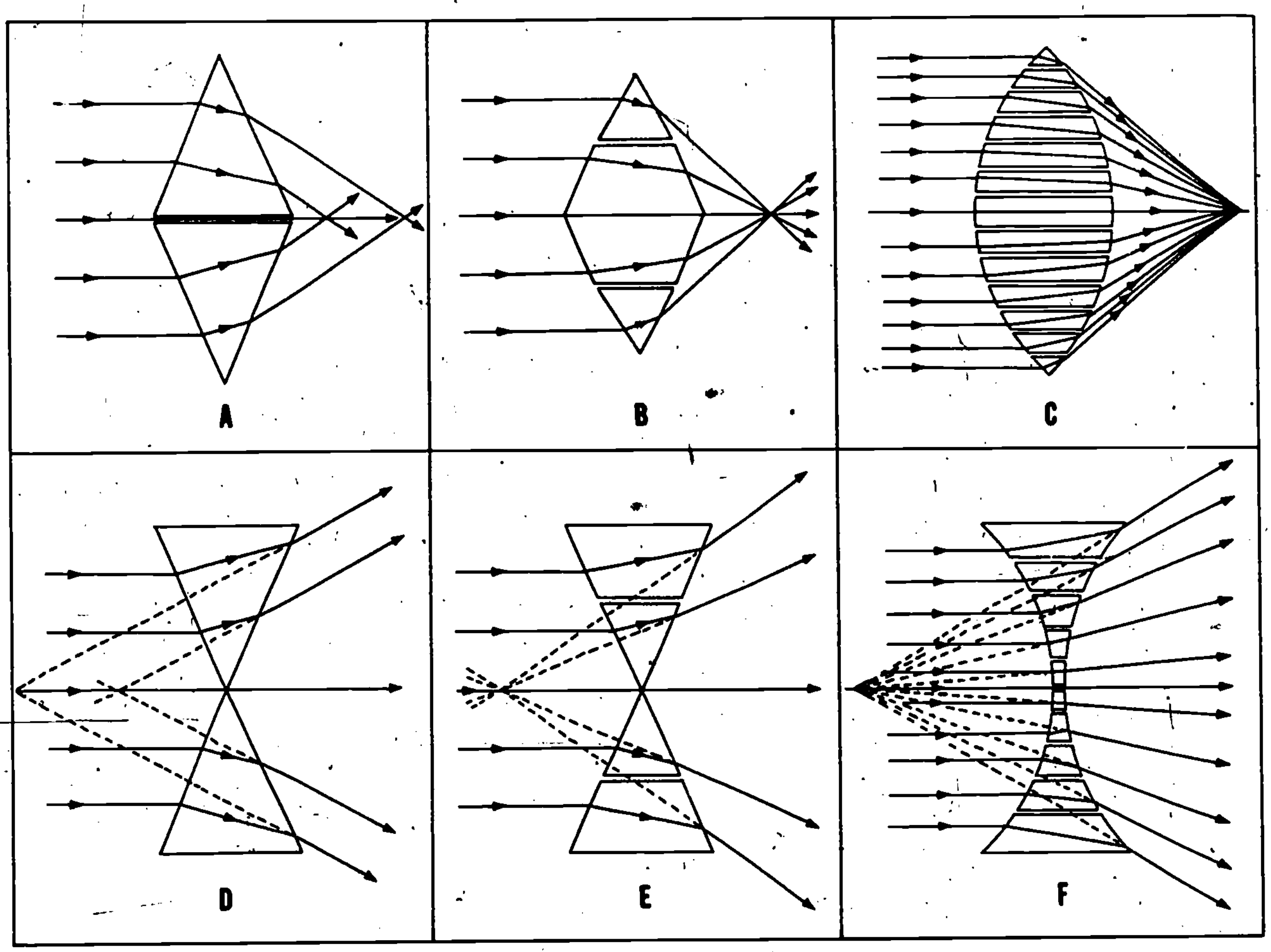

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Figure 4-47.—Lenses constructed from prisms varying in number, size, and shape (principle of refraction shown).

flint glass is more strongly divergent for blue rays than for red rays (fig. 4-46), the high color dispersion of the flint divergent lens sufficient to compensate for the lower color dispersion of the crown convergent lens, without complete neutralization of its refractive power. Note in part B of illustration 4-48 that the two rays come to a focus. A compound lens designed in this manner is called an achromatic lens.

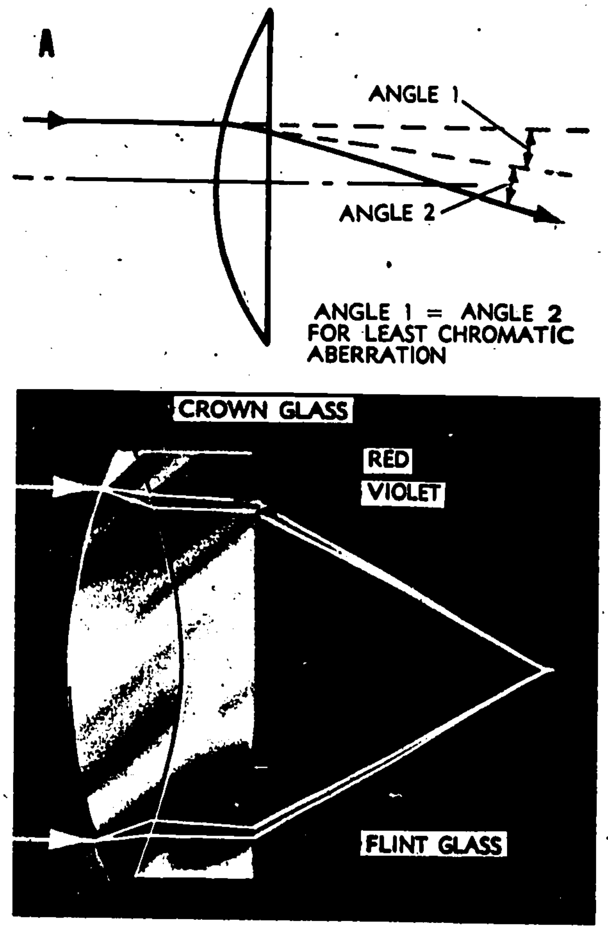
SPHERICAL ABERRATION

Spherical aberration is a common fault in all simple lenses. In a convergent lens, refracted light rays through its center do not intersect rays refracted through other portions of the lens at a single point on the optical axis. Study figure 4-49.

The outer rays of light in illustration 4-49 intersect the optical axis closer to the lens; the more central rays intersect the optical axis at a greater distance from the lens. Failure of the refracted rays passing through the lens to intersect the optical axis at a central point causes a blurred image.

Take a look now at illustration 4-50, which shows rays of light passing through a divergent lens and the imaginary extension of the refracted rays. Intersection of outer and inner rays of light on the optical axis of this lens is opposite that of refracted rays from a convergent lens.

The amount of spherical aberration in either a convergent or divergent lens is influenced by: (1) thickness of the lens, and (2) its focal length. A thin lens with a long focal length has less aberration than a thin lens with a short focal length.



A. Correction for least chromatic aberration by curvature of the lens.
B. Correction for chromatic aberration by a

137.101

Figure 4-48.—Correction of chromatic aberration in a lens.

One method of reducing spherical aberration, at the expense of light intensity, is to test a lens to find out how much of the area around the optical axis (where the lens is most free of aberration) may be used to form a sharp image, and then to mask out with a field stop all rays which pass through the lens beyond this circle. Study illustration 4-51.

Observe in figure 4-51 the rays blocked by the field stop from passage through the lens. This field stop is a flat ring or diaphragm made of metal (or other suitable opaque material) to mask the outer portion of the lens. The stop prevents rays from striking the lens and thus reduces the amount of light which passes through it.

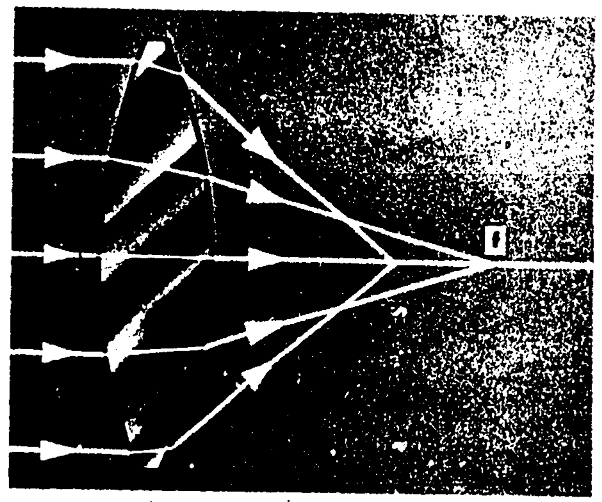


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Figure 4-49.—Spherical aberration in a convergent lens.

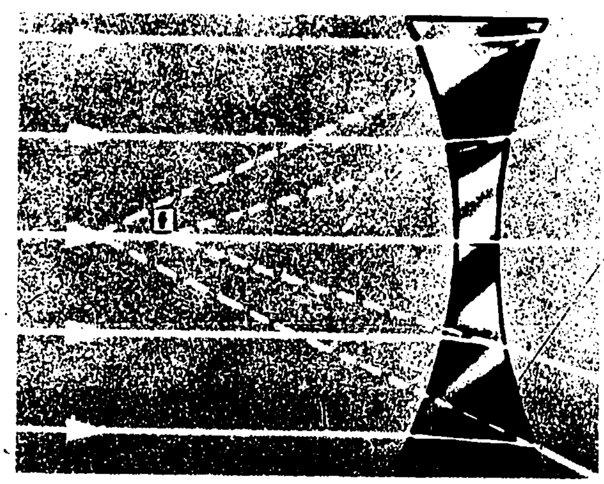

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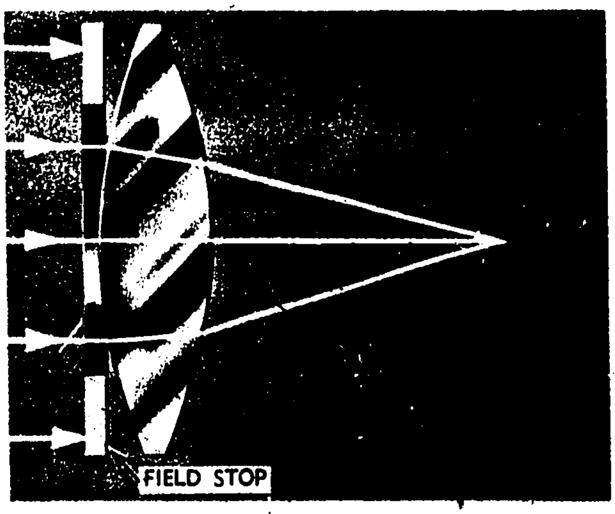
Figure 4-50.—Spherical aberration in a divergent lens.

Spherical aberration in a lens can be minimized also by BENDING THE LENS, which can be accomplished by increasing the curvature of one surface and decreasing the curvature of the other surface. This process retains the same focal length of the lens but reduces the amount of aberration.

In telescopes, spherical aberration is reduced by placing the greater curvature of each lens toward the parallel rays to make the deviation of the rays at each surface nearly equal. In order to reduce the amount of spherical aberration to



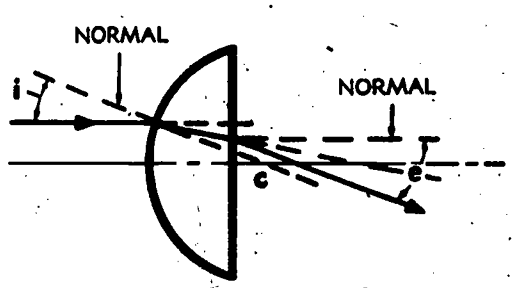


Figure 4-51.—Reduction of spherical aberration by a field lens. 137.104

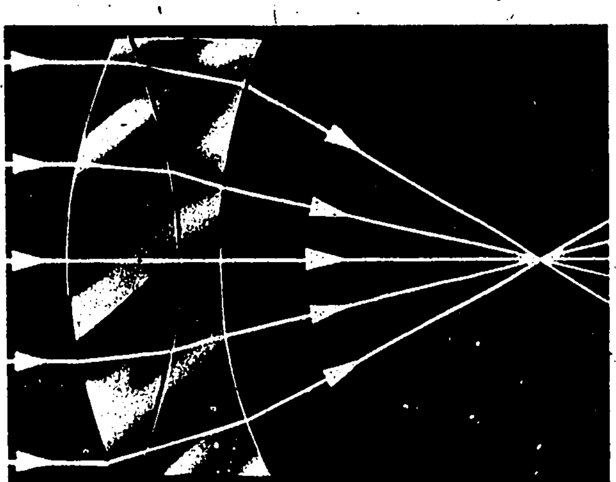


Figure 4-52.—Elimination of spherical aberration by a compound lens. 137.105

a minimum, the angle of emergence of a ray (e, fig. 4-51) must equal its angle of incidence (i). In keeping with this rule, telescope objectives are assembled with the crown side facing forward.

Spherical aberration in fire control instruments is generally eliminated by a compound lens (fig. 4-52). The concave curves of the divergent lens neutralize the spherical aberration of the convex curves of the convergent lens. Proper refractive power of the compound lens, however, is retained by selecting two single lenses with correct indices of refraction to form the compound lens.

CURVATURE OF FIELD

Even with the absence of spherical aberration, coma, and astigmatism, the point images of point objects can lie on a curved surface, instead of a plane. This aberration is called "curvature of field" and is illustrated in figure 4-53. Curvature of field can be detected in an instrument or element by checking the sharpness of an image at its center and also the edges. When curvature is present, the center of the image will be sharp and the edges blurred. Conversely, if we adjust the element to bring the edges into sharp focus, the center will be blurred.

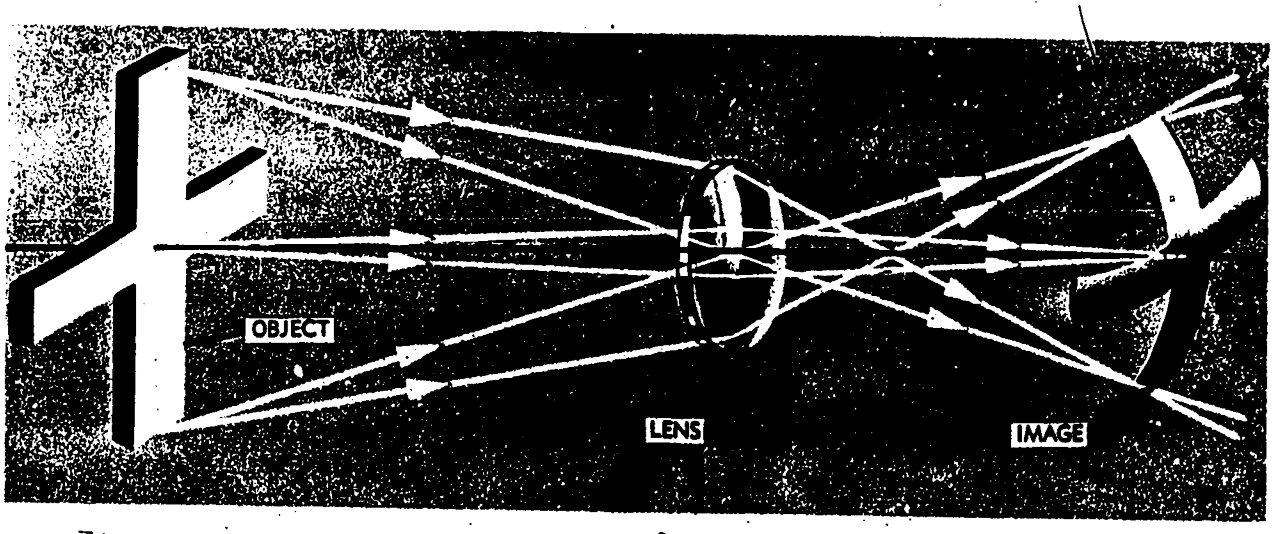
The most common method of correcting this aberration is by using a suitable combination of lenses called "field flatners."

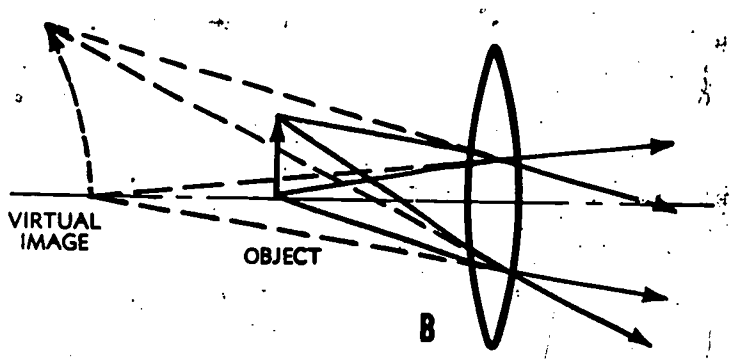
COMA

Coma is caused by unequal refracting power of concentric ring surfaces or various zones of a lens for rays of light which come from a point a distance off the optical axis. Rays from various surfaces come to a focus at slightly different points, resulting in a lack of superimposition of the rays. Coma appears as blurring of the image for points off the optical axis.

The image of a point of light is formed by a cone of light rays refracted through a relatively wide portion of a lens. In order for them to form a sharply defined point of light, the rays which pass through the concentric circular zones (or rings of varying thickness of the lens) must come to a focus at exactly the same place in the focal plane.

In a lens which is producing coma, rays of light originating at a point located off the optical





A. Curvature of real image.
B. Curvature of virtual image.

137.111

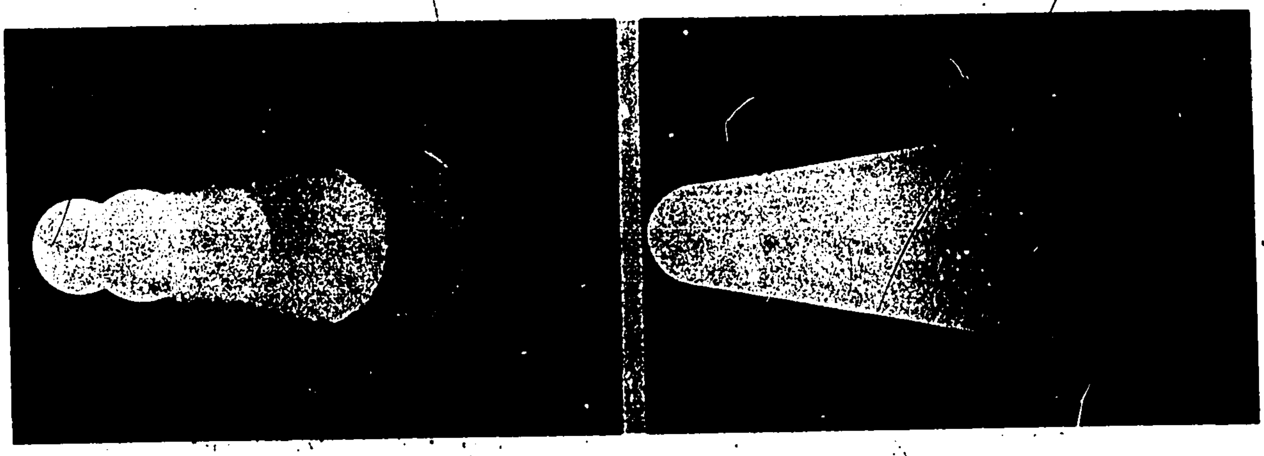
Figure 4-53.—Curvature of the image.

axis and refracted through the inner zone form a well-defined image of the point. Rays refracted through the next zone, however, form a larger, less-defined image of the point, which is offset slightly from the first. The image formed by each successive zone is larger, less-defined, and farther removed from the initial point of light, as illustrated by part A of figure 4-54. Displacement of the successive images is in a direction TOWARD OR AWAY FROM the center of the lens.

The total image of the point offset from the optical axis may be a blur in any of a wide variety of patterns—egg, pear, or comet. See part B of illustration 4-54. The name COMA COMES FROM the resemblance of the blur to a comet.

When viewed under a microscope, a point of light influenced by coma may have a very fantastic shape, as a result of the effects of all types of aberration upon it. Because coma causes portions of points of light to overlap others, the result is BLURRED IMAGES OF OBJECTS IN THE PORTION OF THE FIELD AFFECTED BY COMA.

Coma can be corrected by compound lenses made of the proper type of glass for each part and with correct curves of the faces. A lens which has been corrected for chromatic and spherical aberration, plus coma, is called an APLANATIC LENS.



A. Formation.
B. Appearance after formation.

137.106

Figure 4-54.—Coma.

ASTIGMATISM

Astigmatism is a lens aberration which makes it impossible to get images of lines equally sharp when the lines run at angles to each other. This optical defect is found in practically all lenses except some relatively complex lenses designed to eliminate this condition.

A perfect lens would refract rays from a point of light to a sharply defined point of light on the image. Rays of light which form the image are refracted as a cone (fig. 4-55). Cross sections of these cones are circular; and successive circles become smaller and smaller until the focal point (illustrated) is reached.

A lens with properly ground spherical or plane faces DOES NOT show astigmatism for points near the optical axis, but it DOES show astigmatism for points at a considerable distance from the axis. The face of the lens is then at an oblique angle to incoming light rays. Cross sections of cones of light refracted by the lens become successively narrow ovals until they are a line in the vertical focal plane. They then are broader ovals and eventually are circular, at which time they again become a line in the horizontal focal plane at right angles to the first line. Study illustration 4-56 carefully. Between the two focal planes (horizontal and vertical) is an area known as the CIRCLE OF LEAST CONFUSION, in which plane the MOST SATISFACTORY IMAGE is formed.

The best way TO REDUCE ASTIGMATISM in a lens is through the use of a combination of several lenses, in the same manner explained for eliminating spherical and chromatic aberrations. When lenses made of optical glasses with different indices of refraction are ground to different curvatures, the various types of aberration CANCEL EACH OTHER.

A lens designer has a difficult task in his endeavors to eliminate aberration in a lens. Anything he does to correct one type of imperfection usually affects other types of aberration. He must consider many variables, including:

1. Index of refraction of different kinds of glass.
2. Difference in dispersion in various types of optical glass.
3. Curvature of refracting surfaces.
4. Thickness of lenses and distance between them.
5. Position of stops along the optical axis.

DISTORTION

All of the other aberration affect the sharpness of the image, but an image can be perfectly sharp in all respects and still be DISTORTED. This is caused imperfect centration or irregularity of optical surfaces and produces a change in magnification from the center of the field, to any other point in the field, as measured in a radial direction. Thus objects off the optical

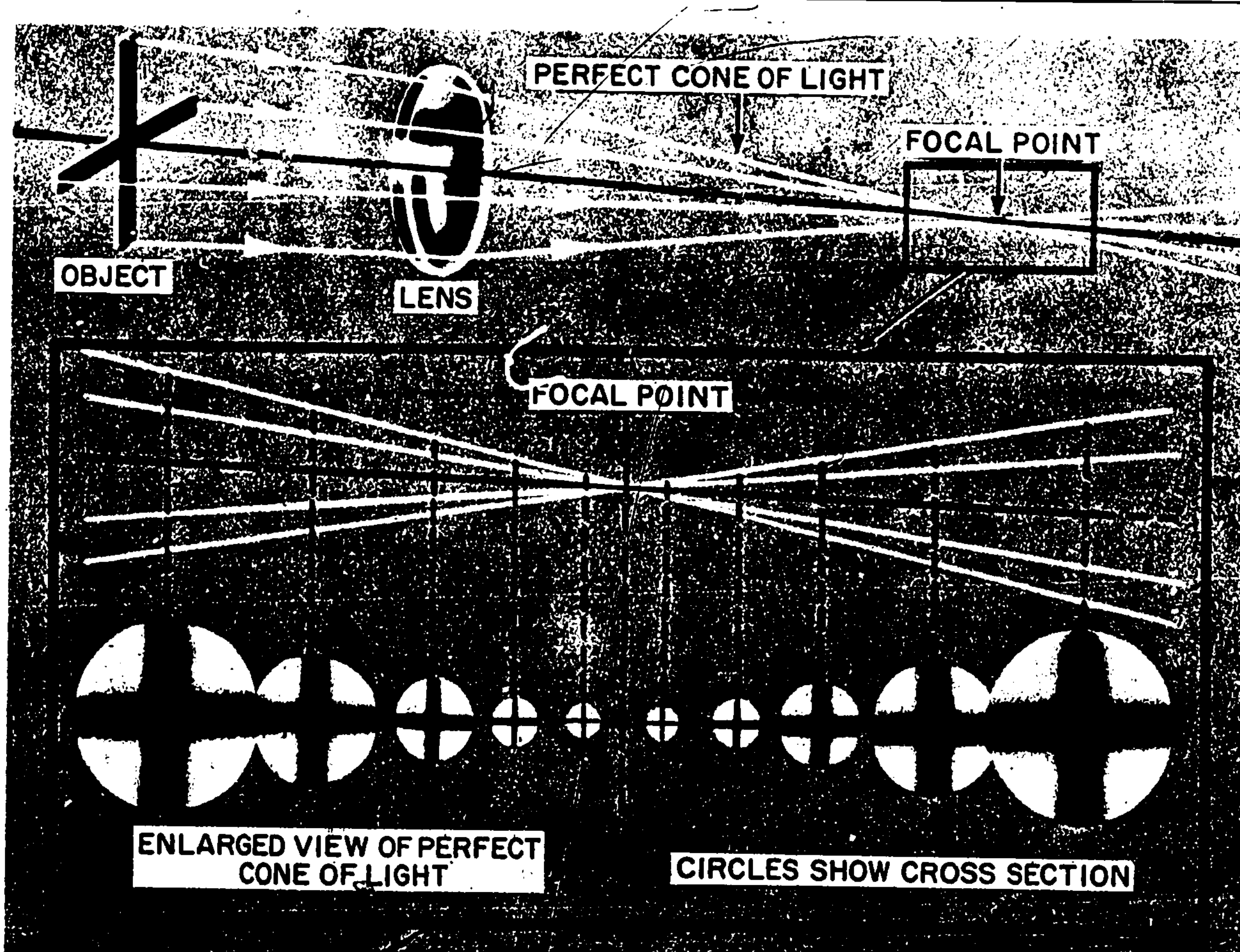


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Figure 4-55.—Refraction of light by a perfect lens.

axis will have a different magnification than objects on the optical axis.

If magnification is less for objects off the axis, you have BARREL distortion (A of Fig. 4-57). If magnification increases as you leave the axis you have PIN CUSHION distortion (C of Fig. 4-57).

A single, thin lens will form an undistorted image, but when you must put a stop on the axis, you will introduce distortion. Placing the stop in the front of the lens will cause the image to have barrel distortion and placing the stop behind the lens will cause pin cushion distortion. When a stop must be used in an instrument the manufacturer will use a compound lens, with the stop placed between the two elements, letting the distortions cancel each other.

NEWTON'S RINGS

If convergent and divergent lenses of slightly unequal curvature are pressed against each other, irregular COLORED BANDS or patches of color appear between the surfaces. See figure 4-58. The pattern you see in this illustration is called NEWTON'S RINGS, after Sir Isaac Newton, who first called attention to it. These rings constitute a defect in a compound lens; but the rings can be used advantageously for testing the accuracy of grinding and polishing lenses.

Light waves from an object never focus perfectly at a corresponding point on an image created by them—they form instead a diffused image with a central white spot surrounded by

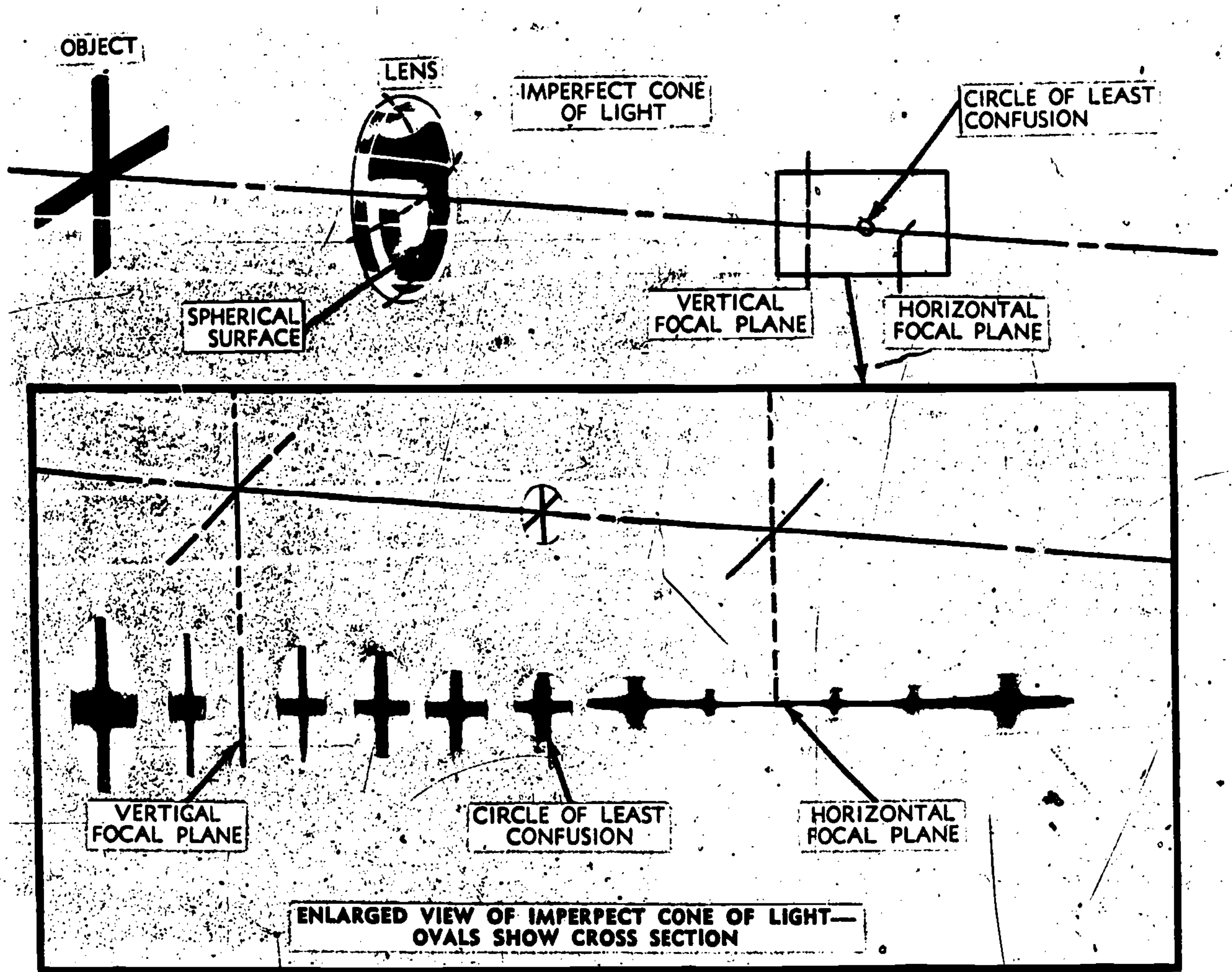

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Figure 4-56.—Astigmatic refraction of light.

a series of concentric rings of light which fall off rapidly in intensity. THIS IS CALLED A DIFFRACTION PATTERN. See illustration 4-59. Diffraction sets the final limit to the sharpness of the image formed by a lens, resulting from the natural spreading tendency of light waves; and it occurs in images formed by all lenses, regardless of the perfection with which they are constructed. The diffraction pattern (blurred image) created is directly proportional to the wavelength of the light, and inversely proportional to the diameter of the beam of light which enters the optical instrument.

THICK LENSES

Thus far our discussion on lenses has dealt with thin lenses, and it is now important that we explain the difference in light transmission through a thick lens.

Because light is refracted at both surfaces of a lens, all lenses have two principal planes. A lens is considered thick when its axial thickness is so large that the principal planes and optical center cannot be considered as coinciding at a single point on the axis.

There are three types of thick lenses that you will be concerned with in the Navy:

- SINGLE THICK LENSES
- COMPOUND LENSES
- TWO THIN LENSES COMBINED TO MAKE A THICK LENS

Two equi-convex lenses are illustrated in figure 4-60. Both lenses have the same index

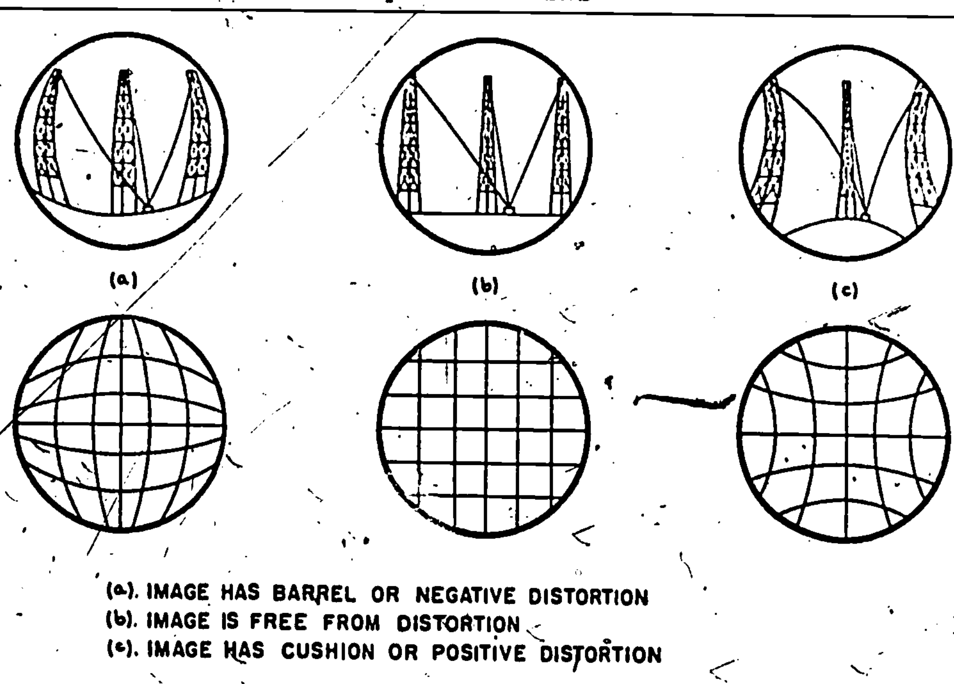

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Figure 4-57.—Images formed by a lens.

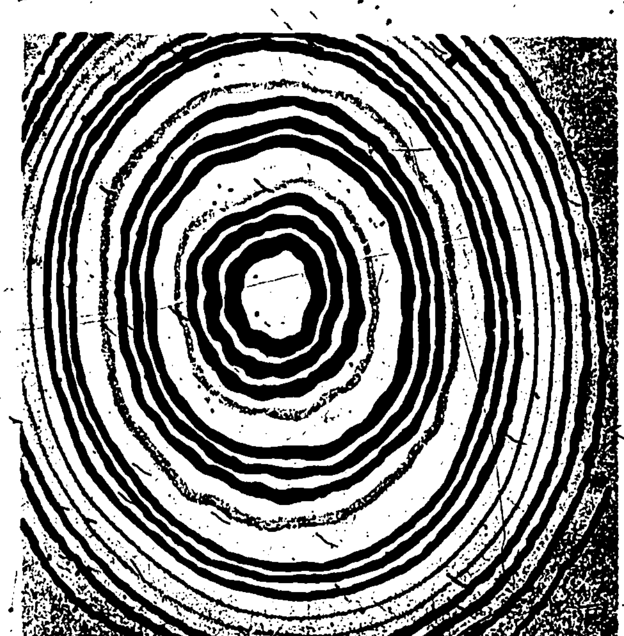

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Figure 4-58.—Newton's rings.

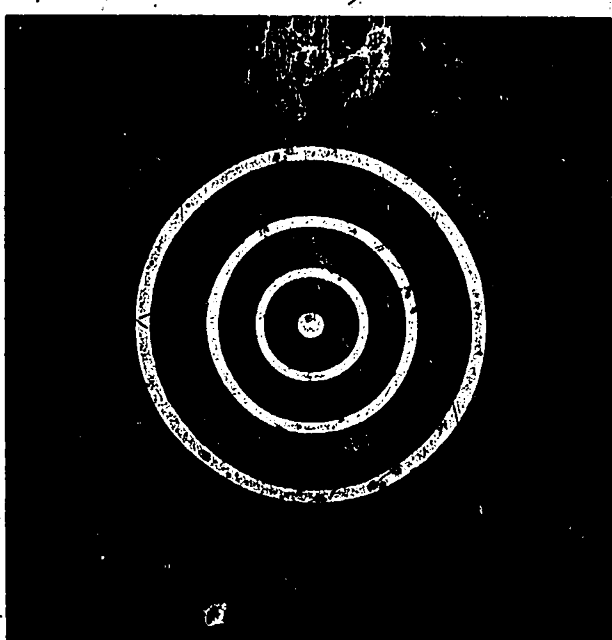

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Figure 4-59.—Diffraction pattern (greatly magnified).

of refraction and radius of curvature; their diameters are equal, but their thicknesses are unequal.

As you know, an A ray is any ray which passes through the optical center of a lens and

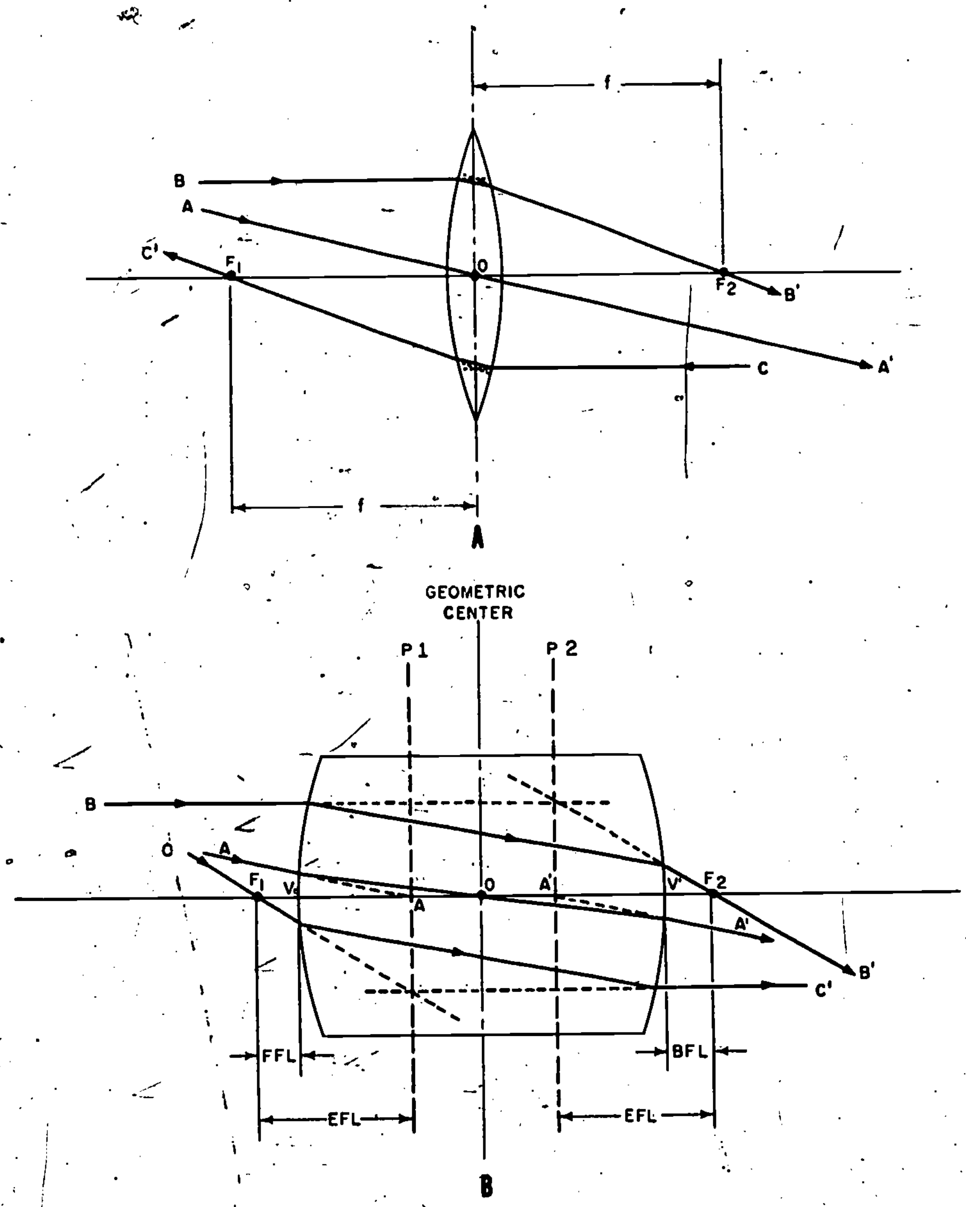

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Figure 4-60.—A thin lens and a single thick lens.

emerges from the lens parallel to the incident ray without deviation. This rule applies to BOTH THICK AND THIN LENSES; but note the difference in the A rays of the two lenses in illustration 4-60. In the thin lens in part A, the A ray is traveling toward the optical center and passes directly through without refraction or deviation.

In order for a ray of light to pass through a thick lens without deviation, it must travel along the optical axis, or travel in the direction of the first principal point (where the principal plane intersects the optical axis). When it strikes the lens, it is refracted in accordance with the laws of refraction and passes through the optical center. Upon emerging from the second surface, the emergent ray appears to have come from the second principal point (A') and is parallel to the incident ray, slightly offset (NOT DEVIATED) from its original path.

If a lens is VERY THICK, the degree of convergence or divergence of rays is changed by the DISTANCE the rays travel through the glass. If the light is converging after passing through the first surface of the lens, the degree of convergence is increased before the second surface of the lens is reached. If the lens is thick enough, the light could converge to a focus on the second surface, or within the lens itself.

Observe that the refraction of the B rays in the two lenses in figure 4-60 is the same; but the ray in the thicker lens converges more and travels a greater distance than the ray in the thinner lens. Observe also that the principal plane (P') of the B ray is now located to the right of the optical center of the thick lens.

Now compare the b rays of the two lenses. The refracted ray in the thin lens appears to be refracted at the same plane where the B ray refracted; but ray b of the thick lens does not appear to be refracted at the same point as the B ray—it traveled a greater distance and is more convergent than in the thin lens. The location of the principal plane (P) for the b ray is to the left of the optical center. Refraction, therefore, DOES NOT TAKE PLACE IN THE EXACT CENTER of the thick lens as it does in thin lenses.

Observe in (fig. 4-60) that the A ray deviates slightly as it strikes the face of the lens, passes through the optical center, and then REFRACTS AGAIN as it leaves the left face of the lens. Note, also, that the B ray refracts exactly the same amount as the b ray as it strikes the left face of the lens, as it passes through, and as it leaves the face of the lens. Both of these rays pass through the optical axis of the lens at EXACTLY THE SAME DISTANCE FROM THE LENS.

Because the principal planes of a thin lens bisect the optical axis in the center of the lens, we measured the focal length as the distance from the principal plane to the principal focus. As shown in figure 4-60, the principal planes of a thick lens do not lie in the center, so we must consider the focal length as three separate factors: (1) front focal length; (2) equivalent focal length; and (3) back focal length.

FRONT FOCAL LENGTH

Abbreviated FFL, the distance measured from the principal focal point in the front space to the vertex of the front surface is the FRONT FOCAL LENGTH (F1 to V in fig. 4-60).

EQUIVALENT FOCAL LENGTH

Abbreviated EFL, the distance measured from a principal plane to its corresponding principal focal point is the EQUIVALENT FOCAL LENGTH (P1 to F1 and P2 to F2 in fig. 4-60).

BACK FOCAL LENGTH

Abbreviated BFL, the distance measured from the vertex of the back surface of the lens to the focal point in the back space is the BACK FOCAL LENGTH (V^1 to F2 in fig. 4-60).

COMPOUND LENSES

Because an optically perfect lens cannot be produced as a single lens, two or more lenses made from different types of glass are frequently combined as a unit to conceal defects that are present in a single lens. These are called compound lenses and will often be thick enough to be classified as a thick lens (fig. 4-61).

Two elements that are cemented together with their optical axis in alignment are called

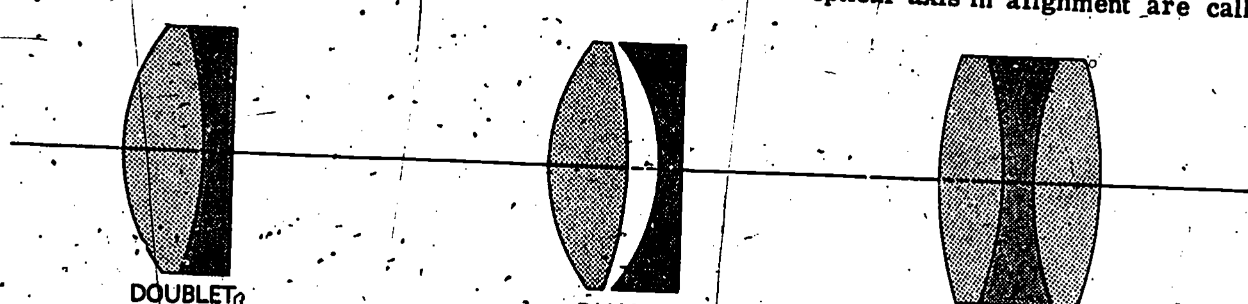

Figure 4-61.—Compound lenses. 137.95

a doublet. Three elements cemented together are called a triplet.

Cementing the contact surfaces of lenses used in a compound lens is generally considered desirable, because it helps to maintain the two elements in alignment under sharp blows, keeps out dirt, and decreases the loss of light as a result of reflection where the surfaces contact.

NOTE: The lenses of DOUBLETS TOO LARGE in diameter to be cemented together (even if their inner surfaces match) form a lens combination called an AIR-SPACED or UNCEMENTED DOUBLET.

In a dialyte compound lens, the inner surfaces of the two elements do not have the same curvature, which means they cannot be cemented together. The two lenses are separated by a thin spacer ring, or tin foil shims, and are secured in a threaded cell or tube.

LENS COMBINATIONS

If you arrange two thin lenses in proper position they will perform as a single thick lens. Study figure 4-62 which illustrates two symmetrical thin lenses used as a thick lens. All the laws of refraction apply here as they did in figure 4.60. The only variation in the two systems is the way you measure focal distances. Because the two lenses are very thin, the principle plane of each lens lies in the geometrical center and for this reason we must measure the focal distance for each lens from the individual principal planes. The equivalent focal length is measured from the principal plane of the combination.

When thin lenses used in combination are identical in optical characteristics, FFL and BFL are equal; but if the focal length of one lens differs from that of the other, the FFL and BFL are unequal. When the thin lenses differ optically, the equivalent focal on each side will still be equal because of the principal planes in the combination.

The formulas for computing the three focal distances are:

$$EFL = \frac{F_1 \times F_2}{F_1 + F_2 - S}$$

$$BFL = \frac{(F_1 \times F_2) - (S \times F_2)}{F_1 + F_2 - S}$$

$$FFL = \frac{(F_1 + F_2) - (S \times F_1)}{F_1 + F_2 - S}$$

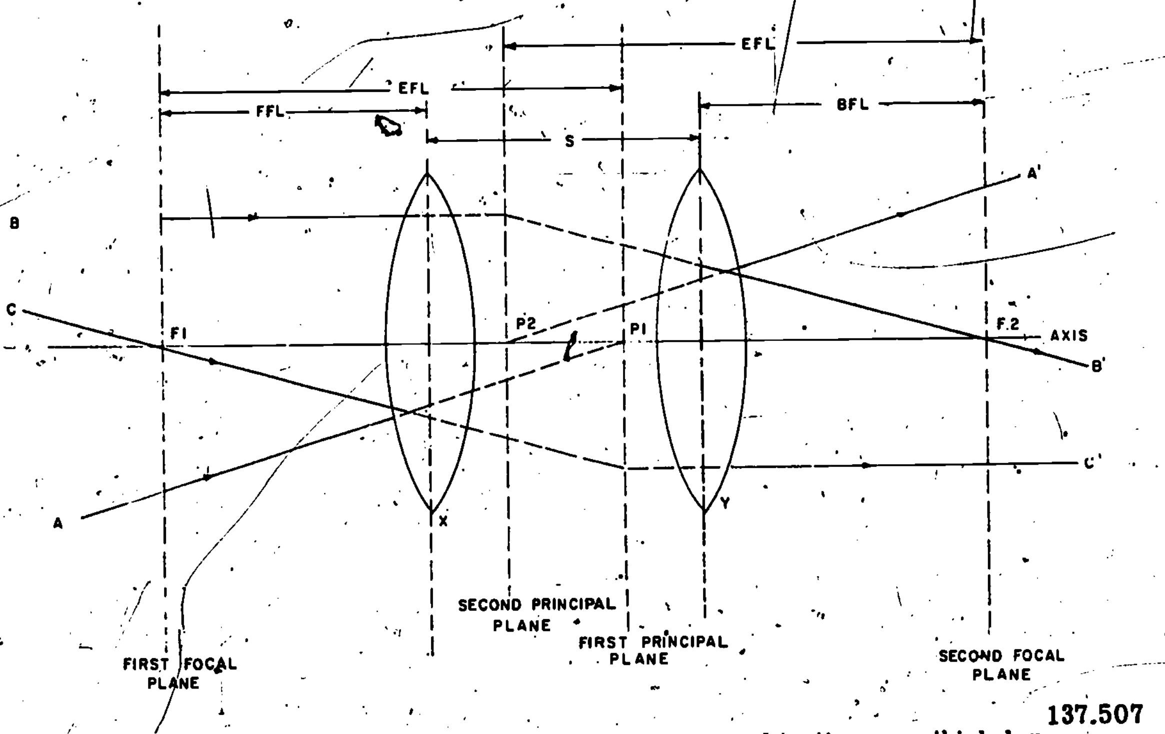

Figure 4-62.—Symmetrical thin lenses used in combination as a thick lens.

F_1 = focal length of lens A (in combination)

F_2 = focal length of lens B (in combination)

S = separation of the two lenses (X & Y, or left and right) in a combination, measured from their principal planes.

Refer now to figure 4-63 which illustrates the use of two thin lenses in combination when making an eyepiece of a telescope. You will study eyepiece systems in detail in chapter 5, but the application is very appropriate at this point.

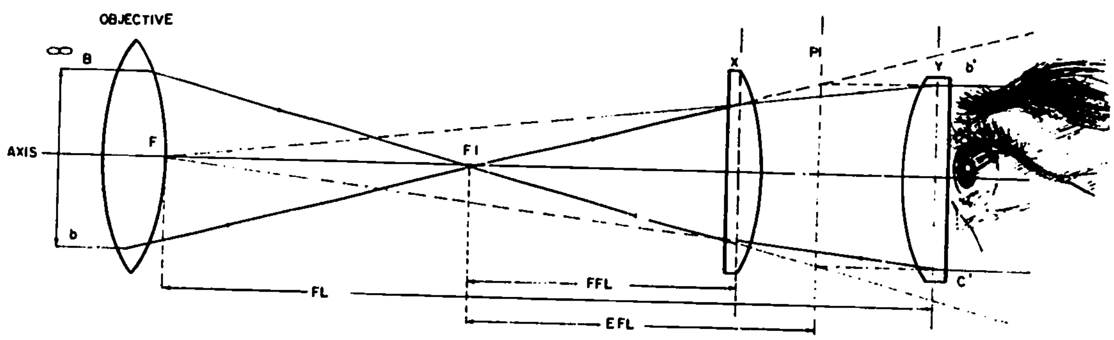

Figure 4-63.—Two thin lenses used as an eyepiece.

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As you study the illustration, you will notice that lens X is within the focal length of lens Y and it makes the diverging rays from focal plane F2 less diverging. Also notice that the focal length of lens Y is longer than the EFL. This helps to illustrate the fact that each thin lens in a combination has a definite focal length, but when used together the resulting EFL of the combination is shorter than the F1 of either lens.

MISCELLANEOUS OPTICAL ELEMENTS

In addition to the optical elements studied thus far there are three additional elements that have an effect on light transmission in an instrument. These elements are RETICLES, COLOR FILTERS, AND POLAROID FILTERS.

Reticles

Most reticles used in optical instruments are glass disks with plane parallel surfaces, on one of which appropriate markings are engraved or etched. In some instances, a planoconvex lens is necessary at the point where a reticle is generally mounted and the markings are therefore engraved on it. The function of a reticle is to SUPERIMPOSE reference marks on the view of a target.

Colored Filters

Filters (sometimes called ray filters) are colored glass disks (with plane parallel surfaces) placed in the line of sight in optical instruments to reduce glare and light intensities. They are separate elements and may be attached or detached (A & B of fig. 4-64), or they may be mounted on a rotating disc which makes insertion and removal from the path of light easy. Part C of figure 4-64 shows a disc with three colored and one neutral filter mounted.

Some of the different types of colored filters employed in optical instruments in order to improve visibility under varying conditions of light and atmosphere are amber, blue, green, red, smoke, and yellow.

Amber and red filters are generally used under varying conditions of fog and ground haze. Red filters are also employed for observing tracer fire. Amber and yellow filters protect the eyes from reflections of sunlight on water and glare from various sources. Blue filters are helpful in determining when objects and/or areas camouflaged.

Greenish-yellow filters have both green and yellow colors in their composition, and they can serve the same purpose as amber and smoke. A smoke filter is a dark filter used to protect the eyes from a bright sun or a searchlight. This type of filter is usually too dark for other purposes.

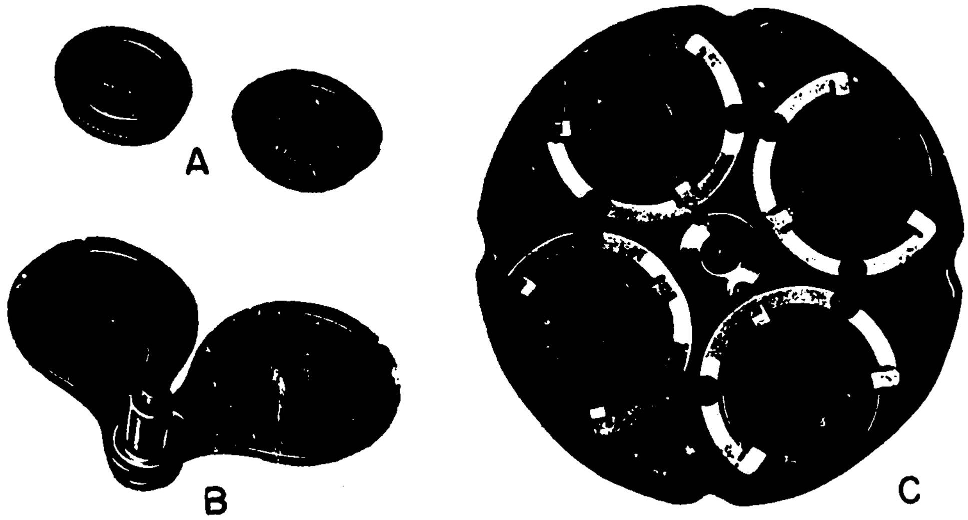

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Figure 4-64.—Color filter mountings.

Polaroid Filters

Polaroid filters can do three things: (1) increase image contrast; (2) cut glaring reflections; (3) control the amount of light passing through the optical system.

To understand how they work, we'll have to go back to the wave theory of light. We showed you how to make wave motion in a rope by securing one end, and shaking the other end up and down. But that doesn't represent the wave motion of light. You'd get a clearer picture of light waves if you had a number of parallel ropes, and shook some of them up and down, and some of them sideways, and some at various angles in between. Light waves vibrate in all possible directions at right angles to their line of travel.

Let's suppose you're shaking a rope to make a wave motion in it. Let's say that somewhere along its length, the rope passes between two vertical slats, an inch apart. If you shake the rope up and down you'll make vertical waves in it, and these vertical waves will pass easily between the vertical slats. But if you shake the rope sideways, you'll make horizontal waves. And the vertical slats will stop them dead.

Now let's suppose you have a number of parallel ropes, passing between a whole series of parallel vertical slats. Let's say that you shake some of the ropes up and down, some of them sideways, and some of them at angles in between. Then your ropes, like light, will have wave motions in all directions at right angles to the line of travel. What happens when your rope waves reach the vertical slats? The vertical waves will pass through, and the horizontal waves will stop. What about the "diagonal" waves? A part of the wave energy will pass through, the waves on the other side will be smaller, and they'll be vertical. Beyond the slats, all the wave motion will be in one direction. When wave motion is all in one direction, we say it's POLARIZED.

Ordinarily, light waves vibrate in all directions. But when light strikes a series of microscopic parallel "slats," all the light that passes through will be vibrating in one direction. We'll have POLARIZED LIGHT. Polaroid filters polarize the light that passes through them. Look at figure 4-65.

Polaroid filters contain a microscopic "grid" to polarize the light. Figure 4-65(A) represents a polaroid filter with the grid vertical. The light that passes through it will be polarized in a vertical plane. If we turn the filter through 90 degrees the grid will be horizontal, as in figure 4-65(C). Then all the waves that pass through will be polarized in a horizontal plane.

In figure 4-65(B) we have a beam of light, vibrating in all directions, striking a polaroid

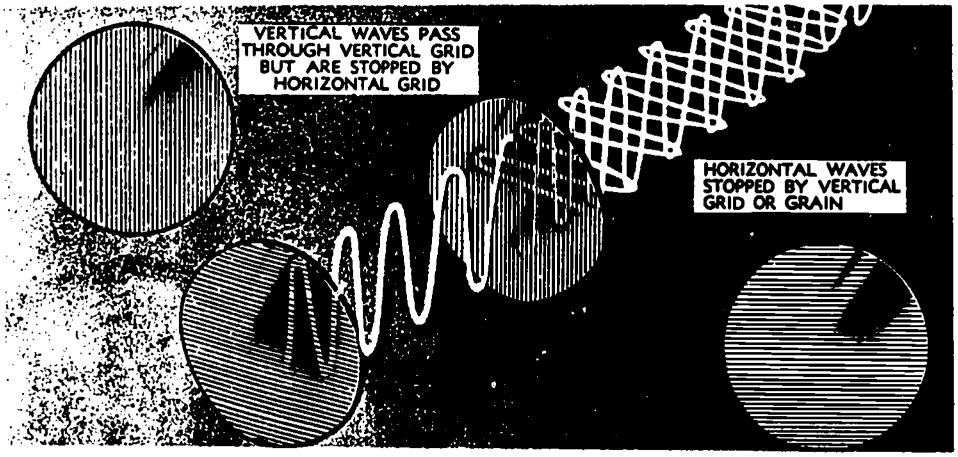

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Figure 4-65.—The polarization of light.

filter with a vertical grid. (In this diagram, the light is coming from right to left. To keep it simple, we've shown only the vertical and horizontal waves.) All the light that passes through the filter will be polarized, and its vibrations will be vertical. What happens when this polarized light strikes a second polaroid filter? If the grid of the second filter is vertical, the light will pass through. If the grid is horizontal, as in the diagram, the light will stop. If you turn the grid to some angle in between, a part of the light will go through.

A polaroid filter is a film of plastic, either by itself or cemented between thin sheets of glass. Suspended in the plastic film are millions of tiny crystals of a dichroic mineral (iodoquinine sulfate). Since all these crystals are lined up in the same direction, they polarize all the light that passes through the film.

By now, you've probably figured out why a polaroid filter is useful on a telescope. Suppose your target is still a gray ship against a background of sea and sky. The light from sea and sky is partly polarized; the light from your target is not. If you look through a polaroid filter, and turn it so its grid is vertical, you'll reduce the brightness of your target to about half. But you'll reduce the brightness of sea and sky to much less than half. You've increased the contrast of your target, and cut down the glare on the water.

Here's your last experiment for this chapter. Put two polaroid filters together, and look through both of them. Hold one of them still, and turn the other. When the two grids are parallel, the two filters will transmit about half the light. When you get the grids crossed, the filters will absorb practically all the light. By turning one of the filters to the proper angle, you can get any intensity of transmitted light you want—between 50 percent and less than 1 per cent.

That arrangement comes in handy on an instrument like the sextant, where you have to look at an image of the sun.

CHAPTER 5
BASIC OPTICAL SYSTEMS

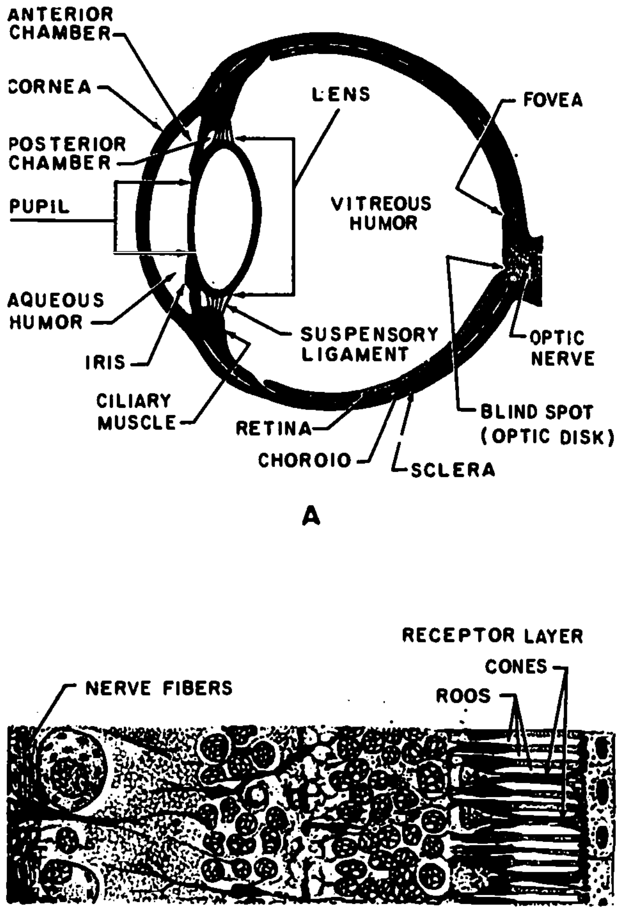
In previous chapters we discussed the formation of images through the use of various optical elements. We will now combine some of those elements into basic optical systems. An optical system as defined by MIL-STD-1241A is, "A COMBINATION OF OPTICAL COMPONENTS ARRANGED SO AS TO PERFORM ONE OR MORE OPTICAL FUNCTIONS." Of all the optical systems that we will come in contact with, the most important is the HUMAN EYE, and an understanding of its function will therefore help you to comprehend more clearly the operation of optical instruments in the Navy.

THE HUMAN EYE

A complete study of the human eye involves physiological and psychological aspects since any image formation must be interpreted by the human brain. The human eye is in effect a physical image-forming system that has lenses of certain curvature and measurable indices of refraction. The eye conforms to the usual laws of image formation when producing an image on a sensitive screen in the back of the eye known as the retina (fig. 5-1). To see an object, light of suitable quality and intensity from the object must form an image on the retina which transforms the light energy to nerve energy, and the nerve impulses are then conducted to the brain by the optic nerve. Thus we are able to distinguish the object.

EYE STRUCTURE

The human eye, as illustrated in figure 5-1, is a nearly spherical organ held in shape by a tough, outer, whitish sclerotic coat, called the sclera, and the pressure of its viscous content. The cornea, the transparent front part of the sclera, protrudes slightly as it has a greater curvature. Inside the sclera is the choroid containing blood vessels, the opaque pigment (not shown), and the ciliary process. The ciliary process includes the iris and the muscles which focus the lens of the eye. The pupil is the opening in the center of the iris. The retina covers the inside of the choroid up near the ciliary muscle.



B

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Figure 5-1.—Construction of the human eye.

The space between the cornea and the iris is called the anterior chamber and between the iris and the lens is a posterior chamber. Both are filled with a fluid called the aqueous humor.

The space back of the lens and the ciliary process is filled with the vitreous humor. The lens is attached to the ciliary muscle by many fibers called suspensory ligaments (fig. 5-2A). Except for the opening in the iris, called the pupil, the pigmentation of the sclera and iris

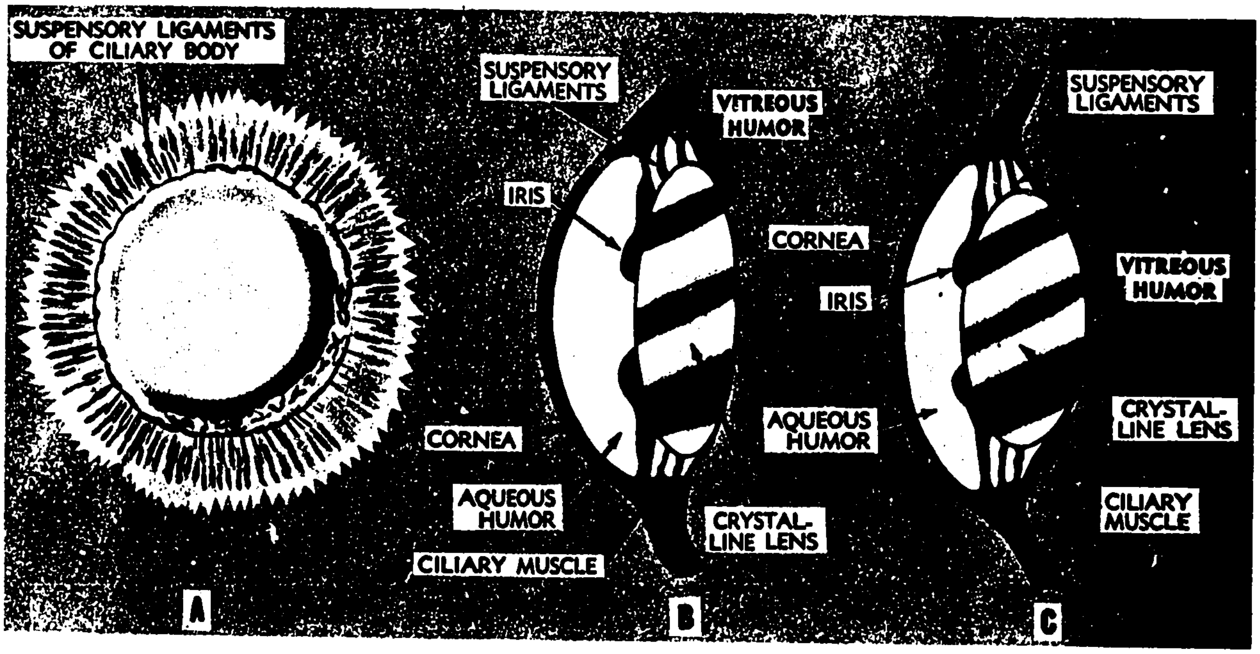

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Figure 5-2.—Suspension and action of the lens.

normally makes the eye light tight. Without proper pigmentation, vision is impaired by glare from light leakage onto the retina.

AN OPTICAL INSTRUMENT

The German astronomer Johannes Kepler is credited with being the first man to compare the eye to an instrument like a camera. In 1604 he wrote, "Vision is brought about by pictures of the thing seen being formed on the white concave surface of the retina." The eye has been compared to the camera in numerous textbooks throughout the world. This comparison has been misleading and often gave the wrong impression of how the eye functions. Figure 5-3 illustrates the human eye superimposed on a camera, and we suggest that you study this illustration as you read this section.

The camera is a completely physical optical instrument that forms an image on the sensitized film which, when processed, becomes a photograph. The formation of an image by the human eye is a physical optical instrument only to the point of refracting light. From the formation of an image on the retina of the eye, the balance of seeing is a psychological processing dealing with nerve impulses and the brain.

The only comparison of physical properties of the eye that can be made with the camera are LENS with LENS, IRIS with DIAPHRAM, and SCLERA with LIGHTPROOF HOUSING of the camera.

REFRACTING MECHANISM

The cornea and the lens act together as a convergent lens system to form a real image on the retina of the eye. The cornea (fig. 5-1) is the first refracting surface for light entering the eye and is responsible for about 75 percent of the refracting power of the eye. The cornea is transparent and the refracting power is due to its curvature and refractive index difference between it and air on one side, and the aqueous humor on the other. The two surfaces of the cornea usually are of similar curvature. Changes in focus to adjust the eye for various object distances are made by the lens which changes to make the adjustment. The lens is a transparent elastic body with a less dense outer layer and a denser inside core. The lens changes curvature to focus light from near and far points onto the retina brought about by action of the ciliary muscle changing the tension of the suspensory ligaments. Figure 5-2 shows the ciliary

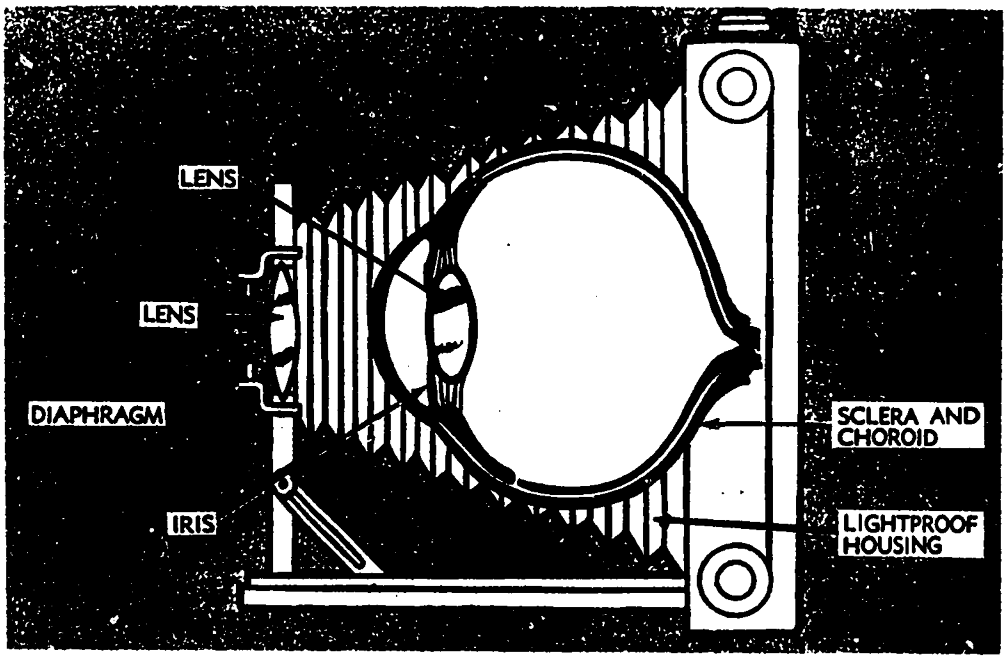

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Figure 5-3.—Comparison of the eye and camera.

process in detail with the eye focused on a near object in B, and the eye relaxed and focused on a distant object in C. Notice the difference in the curvature of the two lenses. The process of changing focus from a near point to a far point is referred to as accommodation, and the normal eye has the ability to focus on an object at a near point of about 5.9 inches and a far point of infinity. This decreases with age, as a result of loss of elasticity of the lens.

IRIS FUNCTION

Built into this optical system named the eye, is an adjustable diaphragm designated as the iris. It acts as an aperture stop for the lens, just as the diaphragm of a camera does (fig. 5-4). The iris opens and closes automatically, contracting under very bright light and expanding in dim light. The opening in the center of the iris (fig. 5-1) is called the pupil. The size of the pupil will vary in young eyes from 8mm in dim light to about 2mm in bright light. The iris is composed of radial and circular muscle fibers, over which we have no control. The opening and closing of the iris is an automatic function of the nervous system and it thus tends to hold the illumination on the retina constant regardless of image brightness.

VISION

Light energy striking the retina of the eye enables us to see, but the optical image formed on the retina is only the starting point of a complicated process of visual perception and visual memory. The fact is that you do not see the retinal image; you see with the aid of this image. The incoming light forms a pattern that gives information for the nervous system to pick up. This information is then used by the viewer to guide his movements, to anticipate events, and to construct a mental experience. The visual process is then supplemented by our memory which stores the information in the brain. The retinal images are constantly changing in position, size, and shape as the viewer moves his eye or the object being viewed is moved. Usually we are not aware of our eye movements as they are moved by the contraction of one or more pairs of opposed muscles triggered by the nervous system. Such eye movements are necessary because the area of clear vision available to the stationary eye is severely limited. To see this for oneself all one needs to do is fixate on a point of some unfamiliar picture or printed page. Only a small region around the fixation point will be clear. Most of what is being viewed will be hazily visible. This is due to the structure of

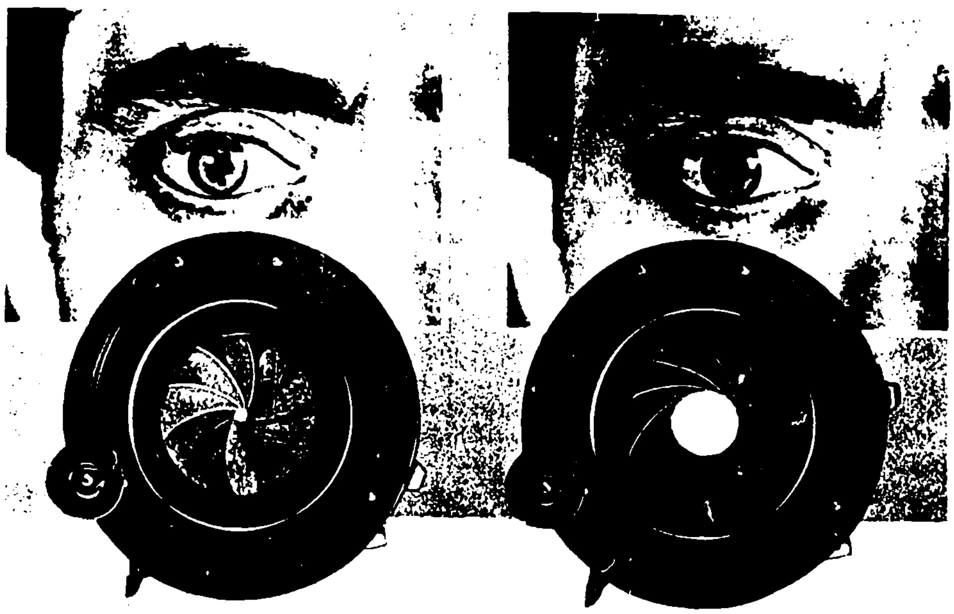

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Figure 5-4.—Iris and diaphragm of a camera.

the retina and the placement of its sensitive elements. The retina which covers most of the area behind the ciliary process, translates light energy into nervous energy and contains the first coordinating nerve cells in the visual system. The front part facing the lens is composed of blood vessels, nerve cells, enrve fibers, and connective tissues.

"B" of figure 5-1 shows a cross section of the human retina, magnified about 500 times. In this picture, light is coming from the left. The light-sensitive elements are specially developed nerve cells, of two different kinds. Because of their shape, we call them RODS and CONES. The light-sensitive layer of rods and cones lies at the BACK of the retina. Before light can reach that layer, it must pass through several layers of tissue, containing a network of nerve fibers and blood vessels. These layers are extremely thin, so they don't absorb much light. But, they do affect the sharpness of the image.

In some of the lower animals, the sensitive layer is at the front of the retina, with the nerve and blood supply behind it. Those animals probably see more clearly than we can. But the human retina has this advantage: the sensitive layer is in contact with the rich blood supply of the choroid. That helps to keep the efficiency of the retina at a high level, over a long period of time.

As illustrated in figure 5-1, the entrance of the optic nerve means a disc that is a blind spot where there are no light sensitive cells. The retina thins at the visual axis because there are no blood vessels or nerve fibers over the fovea. The fovea is the most sensitive part of the retina. The center of the fovea contains only cones that are longer, thinner, and more densely packed than cones elsewhere in the retina. From here to the edge of the retina the number of cones per unit area decreases and the number of rods increases. The sensitivity of the retina to light varies, and since the fovea is the most sensitive, it is used to see fine detail and color. The cones of the fovea are individually connected to a single nerve fiber and have a direct path into the optic nerve. Because the fovea is highly sensitive and small, we must constantly shift our eyes when we look at an object in fine detail.

Animals with non-foveated eyes, such as horses, do not fine this necessary. It is also the reason why the eye must make several fixations on each line while reading and why our eyes rove widely over pictures.

The overall condition of the eye determines the degree of sharpness of vision. Eye specialists have devised a means of measuring the sharpness of vision called visual acuity. Various charts are used for measuring vision. They usually consists of letters of different sizes. The standard is a 5-minute square letter, the individual details of the letter subtending at the observer's eye 1 minute of arc. Figure 5-5 gives an illustration of this. The reference line on the chart is normally constructed of details for viewing at 20 feet. Other lines on the chart have graded sizes of letters for various distances. For example, the line marked 40 feet would subtend an angle of 2 minutes, and the line marked 10 feet would subtend an angle of 1/2 minute.

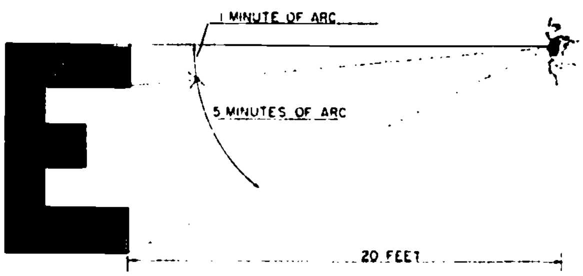

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Figure 5-5.—Standard 5-minute square letter.

VISUAL ACUITY is expressed as a fraction, the numerator of which is the design distance for the chart and the denominator is the line which can be read at that distance. With such a chart, 20/20 vision would be normal, 20/15 would be better than normal, and 20/30 would be subnormal. Vision 20/30 would mean that the observer can only read at a distance of 20 feet the line normally read at a distance of 30 feet; and 20/15 vision means the observer can read at 20 feet the line normally read at 15 feet.

Night Vision

Cones appear to be a factor in acute vision, as the eye tends to rotate in order to bring the image nearer to the area where cones are most concentrated. It also appears that the rods in the retina are associated with night vision. Some facts that support these statements are:

- Animals that hunt at night and sleep in the daytime (such as bats) have retinas composed almost entirely of rods.
- Animals that go to sleep as soon as it gets dark (such as pidgeons) have retinas composed almost entirely of cones.
- Humans beings who get around both day and night have retinas composed of both.

The structure of the rods and cones is complex and the exact mechanism of vision is not fully known. We do know that the retinal rods contain a red colored photosensitive pigment called RHODOSPIN, which is bleached when exposed to light. The product of this bleaching is a stimulation of the nerve cells in the eye making the rods sensitive to very small amounts of light.

The retinal cones contain a violet-colored photosensitive pigment called IODOPSIN that is similar to rhodospin but more capable of undergoing physical change. Even though the cones respond more quickly to light, it takes a greater amount of intensity to trigger this response. An example of the change taking place in the eye is when a person goes from bright sunlight into a darkened room, it takes the eye several minutes to adjust to the lower illumination level. It is because the retinal rods, even though they are more sensitive to low illumination, do not respond as quick as the cones. The reverse procedure holds true when we again emerge from a darkened room into bright sunlight.

Color Vision

We know that white light is a combination of all the wavelengths of the visual spectrum, and when we see an object in color we know that the object is reflecting or emitting waves of a certain range. As an example, red objects reflect wavelengths greater than 640 angstrom units (mu) and blue objects reflect wavelengths between 410 and 480 mu.

Aside from the cone cells being less sensitive than the rods, the cones are also the sensitive cells in color vision. This is proven by the fact that at very low levels of illumination all radiation regardless of wavelength give rise to colorless sensations. The normal human eye can match any color with a mixture of three primary colors; red, green, and blue. The brightness of color in the objects that we see depends on the radiant energy in the light.

Color Blindness

The inability of a person to distinguish colors, that is, having only gray visual sensations, is called color blindness and is very rare in humans. More common is the condition of deficient color vision. One in ten men and one in one hundred women have various degrees of color deficiencies. The most common deficiency is poor red-green discrimination, and relatively rare are defects in blue-yellow vision.

With a color deficiency, one is unable to distinguish certain colors, and the type of color confusion indicates the kind of irregularity. A person who has red deficiency would see red, brown, dull green, and bluish green as the same color when they have the same brightness. A person with green deficiency would confuse purplish red, brown, olive, and green. A mild deficiency is only a small handicap and may not even be known by the person. Medium deficiency would exclude a person from working where medium color discrimination is important, and seriously deficient individuals should be excluded from all occupations where color recognition is important.

Resolving Power

The RESOLVING POWER of the eye or an optical system is its ability to distinguish between two adjacent points. It is often expressed as the ability to distinguish between small lines and fine angles. Since resolving power is a measure of the ability of an optical system to distinguish fine detail, it is an important property of the system. After all, what good would an instrument be in the Navy if we had a magnified image, but we could not distinguish any of the details in the image?

Figure 5-6 illustrates what we mean by two adjacent points forming an angle with the eye. The average eye can resolve details subtending 1 mintue of arc. This is brought about by the image falling on the retina and stimulating more than one cone, with a separation of at least one unstimulated cone between them. So we can see that the normal eye can distinguish between two equally bright objects, separated by an angle of only 1 minute.

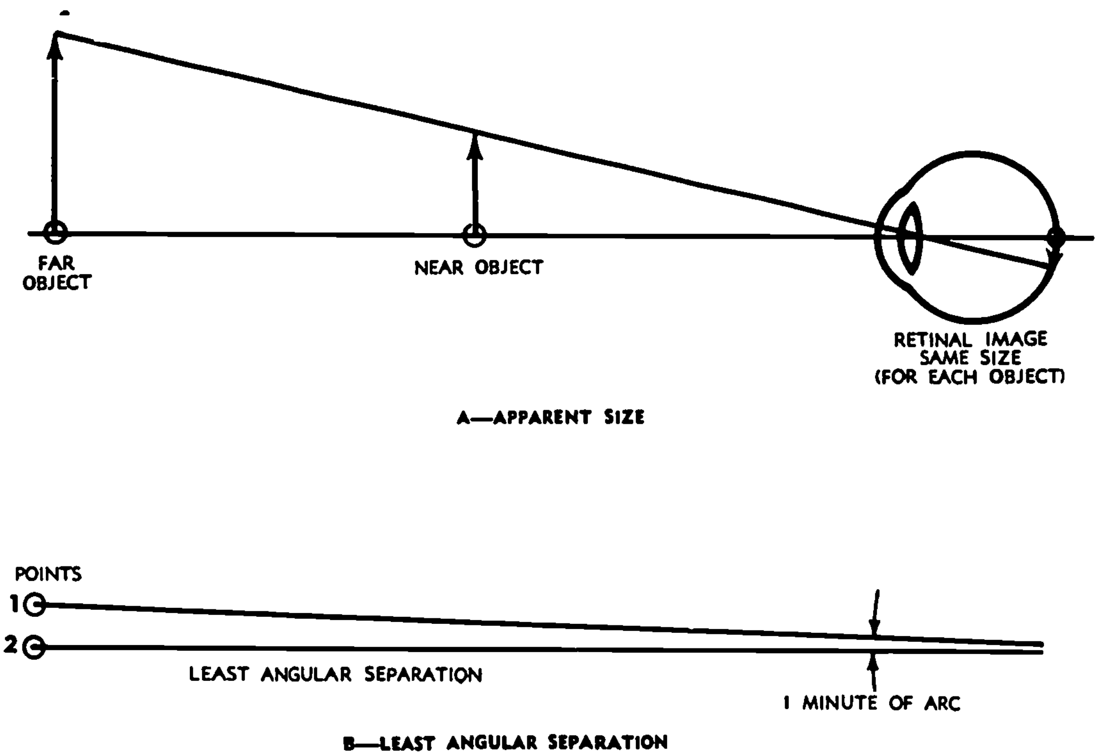

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Figure 5-6.—Visual limitations.

The rods and cones give the retina a mosaic structure that determines resolution. Maximum resolution depends on three factors: (1) retinal location of the image, (2) the nature of the image, and (3) adequate time for stimulation. Now let's break this down into more detailed terms.

By "retinal location of the image," we mean that the image must fall on the fovea of the retina where vision is most acute. The resolving power of the eye decreases as the image moves away from the fovea.

By "nature of the image," we mean its brightness. Brightness is the light necessary to stimulate the retina. The smallness of a light or bright spot that can be seen will depend solely on its brightness.

The final factor is "adequate time for stimulation." This means simply that an image must fall on the retina long enough to cause stimulation of the nerve cells. Bright objects will stimulate quicker than dim objects.

All of these factors can be fully realized when we look out to sea at night. If we see a small but very bright light, we have quick stimulation and the light is very noticeable. If, when looking out, we see a dim light, we must concentrate for a much longer period of time in order to discern it.

STEROSCOPIC VISION

The fact that we have two eyes to guide us is a decided advantage in seeing, and both eyes act as a team to feed information to the brain where it is fused into a single mental image. Both eyes usually operate under the same light conditions and converge on the same object for binocular vision. One of the advantages of two eyes, or binocular vision, is the apparent increase in brightness of about 20 percent above that of an object viewed with just one eye. Figure 5-7 shows the normal field of view with both eyes and also the binocular field. The field of view with both eyes is normally about 160° on the horizontal, and 70° on the vertical. This includes the area seen by the left eye, the right eye, and that seen by both eyes. The binocular field exists only in that area of the field of view where the fields of the separate eyes overlap.

Another and more important advantage of binocular vision is the experience of depth, which is called stereoscopic vision. The basis of stereoscopic vision is horizontal dissimilarity of retinal images on corresponding points of the two retinas.

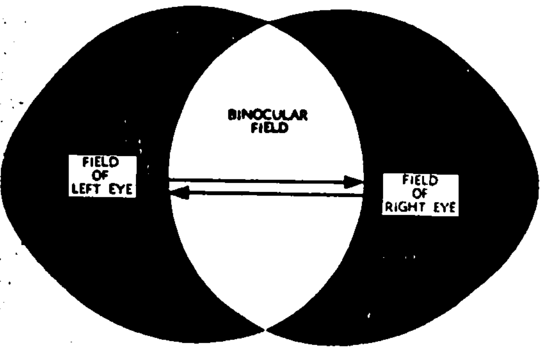

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Figure 5-7.—Field of view with two eyes.

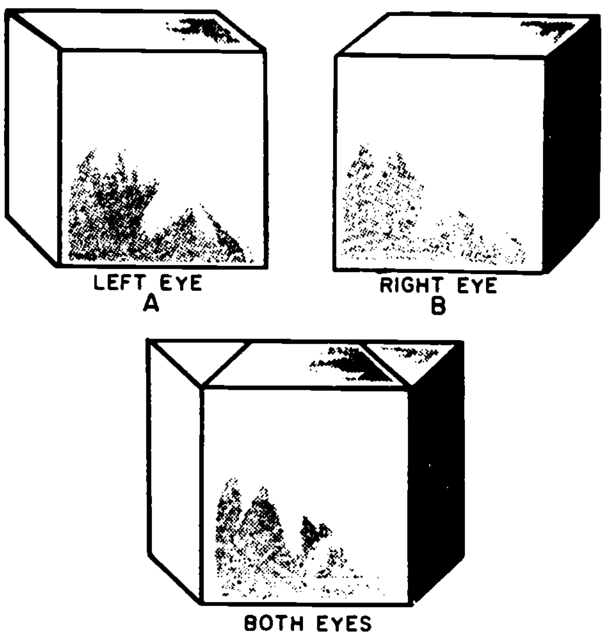

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Figure 5-8.—Stereoscopic vision.

Figure 5-8 shows a cube demonstrating the stereoscopic effect when looking at a near object. In studying this illustration we can see the difference in the retinal images of the two eyes. This difference is brought about by the spacing of our eyes, which allows us to see objects from slightly different angles. The spacing between the human eyes is measured from the pupil and is called INTERPUPILLARY DISTANCE (IPD). Normally in humans, it is about 64 millimeters. Stereoscopic vision can be stated as the ability to see in depth or in three dimension. When you view an object in three dimension, you see height, width, and depth.

In a like manner, when you observe two objects simultaneously, stereoscopic vision enables you to judge the relative distance of one object from the other, in the direction AWAY FROM YOU.

Your ability to distinguish the relative position of two objects stereoscopically depends upon the interpupillary distance of your eyes, the distance of the object from you, and their distance from each other (see fig. 5-9). Other factors of depth perception being equal, the wider your interpupillary distance, the better the appreciation of depth perception you secure through stereovision. In order for you to distinguish the position of two objects stereoscopically, the distance of the second object from the first object must be approximately equal to the distance of the first object from you.

When you look at two objects and attempt to determine which is farther away, the lines of sight from both eyes converge TO FORM

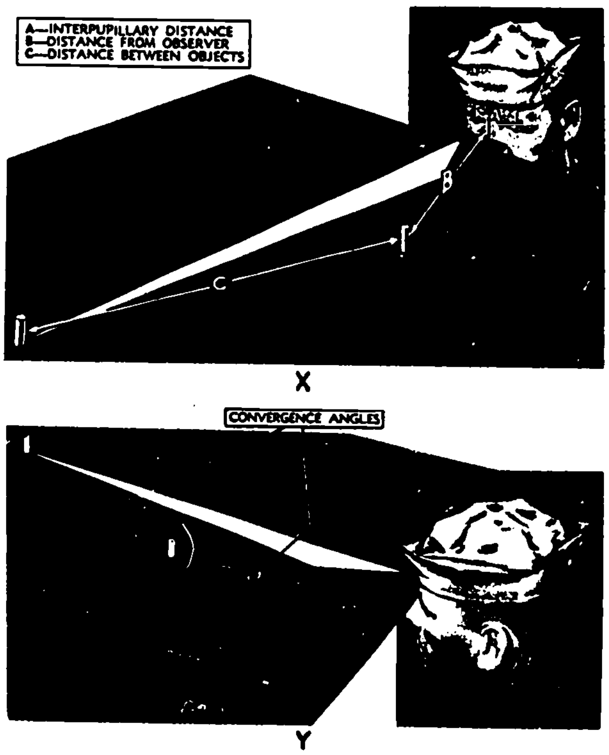

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Figure 5-9.—Distinguishing the distance between two objects.

ANGLES OF CONVERGENCE ON BOTH OBJECTS (fig. 5-9). If the angles of convergence to both objects are identical, the objects appear to be the same distance away, but if there is a difference in the angles of convergence to the two objects, one object appears more distant than the other.

Even though the distance between angles of convergence is slight, the brain has the ability to distinguish the difference. Your ability to see stereoscopically, therefore, depends upon your capacity to discern the difference between these angles. Figure 5-10A shows graphically the difference between the angles of convergence shown in figure 5-9.

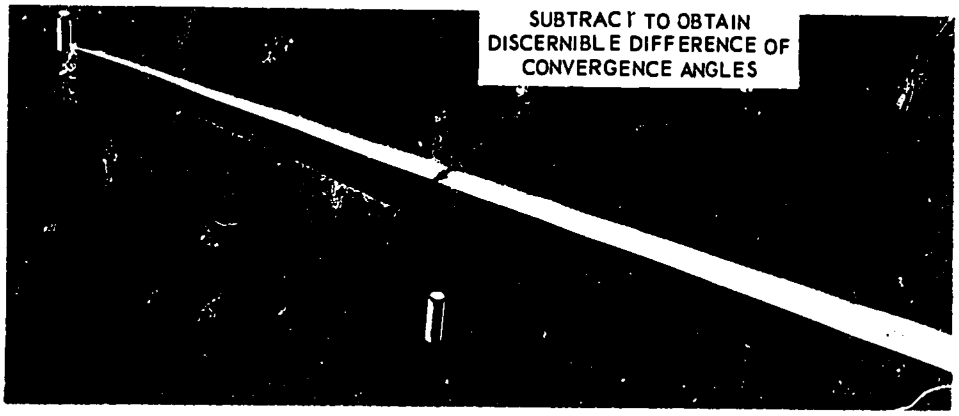
Angles of convergence become smaller, and the difference between them becomes less discernible, as the objects are moved farther away from you, or as the distance between them is decreased. THIS DIFFERENCE IS KNOWN AS DISCERNIBLE DIFFERENCE OF CONVERGENCE ANGLE (fig. 5-10B), AND IT IS MEASURED IN FRACTIONS OF MINUTES AND SECONDS OF ARC. STEREOSCOPIC VISION FOR THE UNAIDED EYE IS EFFECTIVE UP TO 500 YARDS ONLY. This distance, however, can be increased through the use of binoculars or rangefinders, which increase the interpupillary distance between the eyes and therefore increases stereoscopic vision.

STEREOACUITY, IN CONTRAST WITH VISUAL ACUITY, IS SHARPNESS OF SIGHT IN THREE DIMENSIONS, OR THE ABILITY TO GAGE DISTANCE BY PERCEPTION OF THE SMALLEST DISCERNIBLE DIFFERENCES OF CONVERGENCE ANGLES. The minimum difference which you can discern between two angles of convergence is dependent upon your quality of vision, your training, and conditions which affect visibility.

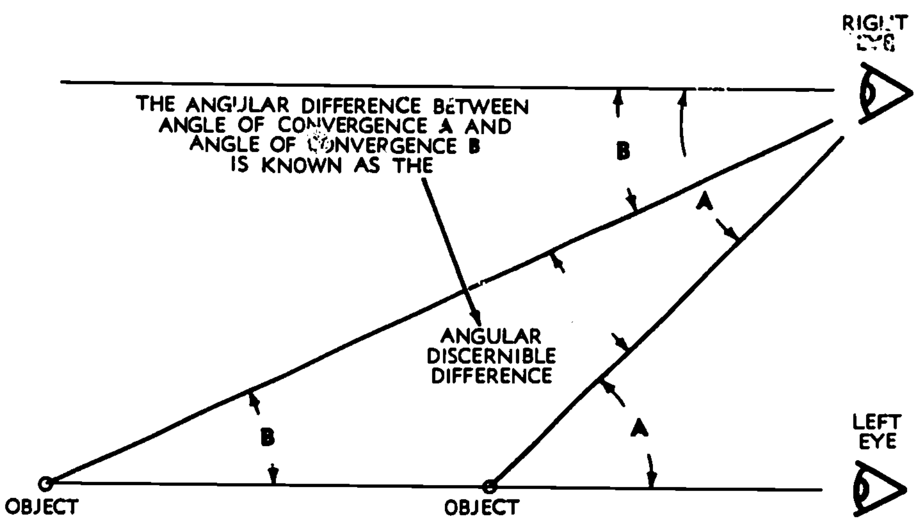
A well-trained observer can discern an average difference of about 12 seconds of arc, at times, under excellent conditions of observation, this difference may be reduced to 4 seconds of arc for a series of observations. An average, untrained observer should be able to distinguish a minimum difference of 30 seconds of arc between two angles of convergence under normal visibility conditions.

ABERRATIONS OF THE EYE

The optical system of the eye suffers from some of the same aberrations as an optical system made up of glass lenses. The eye is partly



A GRAPHIC VIEW OF DIFFERENCE BETWEEN CONVERGENCE ANGLES SHOWN IN X AND Y



B CONVERGENCE ANGLES IN STEREOSCOPIC VISION

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Figure 5-10.—Angular discernible difference.

corrected for spherical aberration because its refracting surfaces (especially the front surface of the lens) are not quite spherical.

The eye has a strong curvature of field, but that is an advantage because of the curvature of the retina.

The chromatic aberration in the human eye is much worse than you might think. When you look at an object, you automatically focus the green and yellow light on your retinas, but the blue light falls short of the retina, and the red light falls beyond it.

If you have divergent lens of about minus 2 diopters and a good blue light, it is very easy to demonstrate the chromatic aberration in your eyes. Just turn out all but the blue light in the room. When the blue light is on an object it appears to be wrapped in a fuzzy blue blanket. Because of the chromatic aberration in your eyes, you cannot focus the short blue rays, and the image falls short of your retinas. Now look at the object through the divergent lens and see how much clearer the object is.

The normal aberrations of the eye do not cause any significant problems in life but there are three chief defects that must be corrected with eyeglasses for comfortable vision. These are ASTIGMATISM, MYOPIA, and HYPEROPIA.

Astigmatism in the eye is caused by a defect of the cornea whereby the surface is more strongly curved in one place than in another. For an example let's say that your cornea has a normal curve in the vertical plane, but is more strongly curved in the horizontal plan. You will be able to focus clearly on vertical lines, but the horizontal lines will be refracted too much and their image will fall in front of the retina.

Corrective eyeglasses for astigmatic conditions must be worn over long periods of time for comfortable vision. In recent years, optical designers have made instruments with the eye point far enough away from the lens so that the whole field can be seen with the aid of corrective eyeglasses.

Myopia

In nearsightedness, or myopia, the image is formed in front of the retina because the refracting mechanism of the eye is too strong. Figure 5-11A shows how the image plane fails to fall on the retina. The defect is corrected by placing a minus lens in front of the eye as shown in figure 5-11B.

Hyperopia

Farsightedness, or hyperopia (fig. 5-12A), is caused be the refracting mechanism being too weak and the image plane falls behind the retina. This is corrected by placing, in front of the eye, a plus lens of proper strength to replace the image on the retina (fig. 5-12B).

Usually in the case of only nearsightedness of farsightedness, eyeglasses are removed when an optical instrument is used and the instrument is refocused to correct for the eye defect. Focusing eyepieces should have sufficient range to take care of this defect. A range of -4 diopters will cover about 98 percent of eyeglass prescriptions.

Eye Strain

Optical instruments may be classified as: (1) monocular, for use by one eye; and (2) binocular, for use by both eyes. Because optical instruments affect functioning of the eyes, certain adjustments must be made to the instruments in order to accommodate them to each eye. A monocular optical instrument, for example, must be so focused (proper positioning of eyepiece) that the amount of light enters the instrument from an object is sufficient to form a distinct image on the retina without undue effort by the muscles of the observer's eyes. The exit pupil (rear opening of eyepiece, illustrated later) must be large enough to admit a maximum amount of light to the pupil of the eye; and stray light must be kept out of the eye.

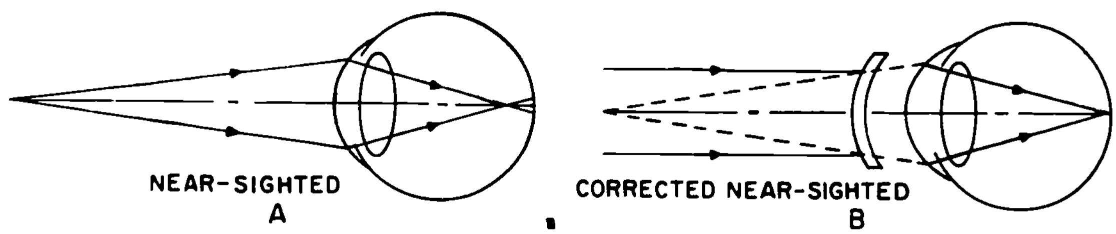

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Figure 5-11.—Nearsighted vision and correction.

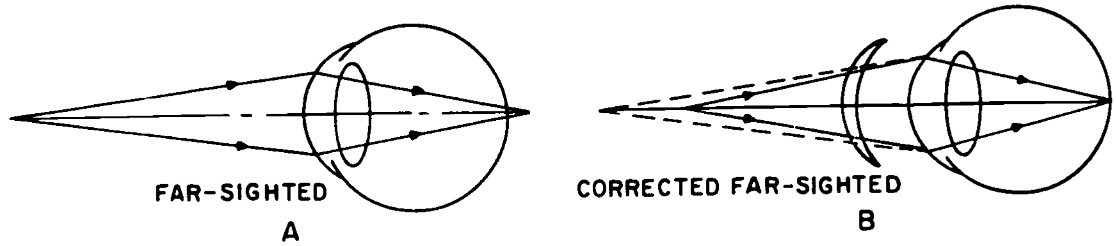

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Figure 5-12.—Farsighted vision and correction.

Adjustment of a binocular optical instrument requires that the two optical systems of the unit be properly aligned with each other and conform to the interpupillary distance of the eyes of the observer. Precise focusing of the instrument changes the position of the eyepiece so that it is in correct relation to the focal plane of the objective and the angles at which the light rays are brought to a focus. The eyepiece of a focusing-type telescope, for example, is generally designed to accommodate the refracting qualities of the eyes of an observer.

Because telescopes with a magnifying power of 4x or less have a sufficiently wide range of accommodation, a single-focus setting is satisfactory. These telescopes have fixed-focus eyepiece which cannot be adjusted during operation; hence the name FIXED-FOCUS TELESCOPES, usually with a minus 3/4 to minus 1 dioptric setting.

Eye tension or fatigue causes the eyes to blink, which is muscular rather than retinal action and is least apparent when the eye is relaxed, as when accommodated for distant objects. In most telescopes, the eyepiece mount is adjustable; and by adjusting the position of the eyepiece you can adapt the instrument to compensate for the inherent refractive errors of the eye. If a person has perfect vision, the light rays which leave the eyepiece of a telescope must be parallel and enter the eye parallel; but the rays which leave the eyepiece must be SLIGHTLY DIVERGENT before entering the eye of a person who is slightly nearsighted. The eyepiece of a telescope for the person must therefore be moved in (toward the objective lens) to bring the final REAL image of the telescope within the focal length of the eyepiece, and moved out (away from the objective) for a farsighted person.

REMEMBER: You CAN SOMETIMES bring the viewed object within focus on your retinas by accommodation of your eyes, as well as by adjusting the eyepiece of the instrument (fig. 5-13). A serious error often made by a novice is accommodating with his eye.

When you allow your eyes to accommodate on an object before the instrument is set for proper focusing, the eyes will be under a constant strain. Focusing the eyepiece from the PLUS to the MINUS setting prevents the eye from accommodating on the object before the eyepiece is properly set.

The correct way to focus an instrument with an adjustable eyepiece is:

- Allow your eye to become completely relaxed by viewing a distant area.
- Move the eyepiece to the extreme PLUS diopter position (all the way out).
- After placing the eye in a comfortable viewing position, move the eyepiece slowly in until the image of the target is sharply defined. If you go past the point of sharp definition to a point where the image becomes blurred, DO NOT attempt to refocus from this position. Instead, back the eyepiece out again to the full PLUS position and start over.
- When you are focusing an instrument, DO NOT squint your eye or in any way put a strain on its muscles. If you do, errors in setting the eyepiece will result and cause eye strain all the while the instrument is being used.

EYEPIECE SYSTEMS

As we learned in chapter 4, a positive lens forms a real image at its focal plane by converging the light rays to a focus. This image is rather small and usually too close to the eye

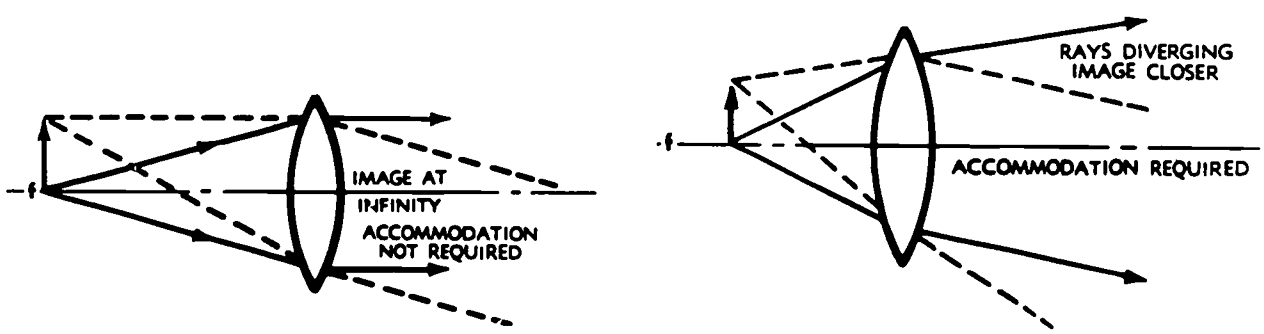

Figure 5-13.—Eye accommodation.

to be clearly seen. Thus we must add extra lenses to magnify the objective image and form an image far enough away from the eye to be seen. The lens or combination of lenses that are added to do this are called the eyepiece system of the instrument. The eyepiece works satisfactorily if it will form a virtual image between the point of the most distinct vision of the eye (usually 10 in.) and infinity. Figure 5-14 shows the construction of a simple telescope with the eyepiece placed in a position where the focal plane of the objective and the focal plane of the eyepiece coincide.

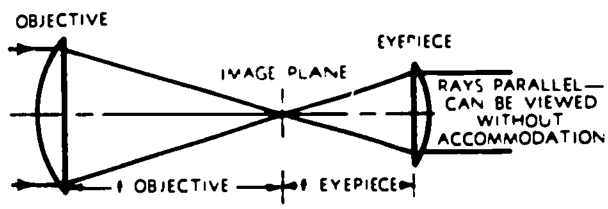

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Figure 5-14.—Simple telescope.

BASIC FUNCTION

In general, the eyepiece has three basic functions in a visual instrument (fig. 5-14):

- It must, with the objective, form a good image of the object being viewed.
- It must serve as a magnifier if the instrument has a retical.
- It must be designed so that the observer's eye can be placed in the exit pupil. Hence the exit pupil must be located at least 10mm to 12mm away from the last glass surface, this being the nearest the normal eye can approach the eyepiece surface with comfort.

The objective takes nearly parallel light from a distant object and converges it to a focus, turning it into diverging rays. The eyepiece takes these diverging rays and directs them as a parallel beam into the entrance pupil of the eye. The eyepiece forms an image of the objective at the point at which the eye is placed.

NOMENCLATURE

The simplest and most common forms of eyepieces usually consist of one, two, or three lenses, of which any or all may be compound lenses. The lens nearest to the eye is known as the eyelens. The element that is nearest to the objective is called the field lens and its purpose is to gather light rays from the objective and divert them to the eyelens (fig. 5-15). If it were not for the field lens, much of the marginal light gathered by the objective would not be brought into the field of the eyelens.

TYPES

General types of eyepieces used in optical fire control instruments will be discussed in the following paragraphs, however, the student

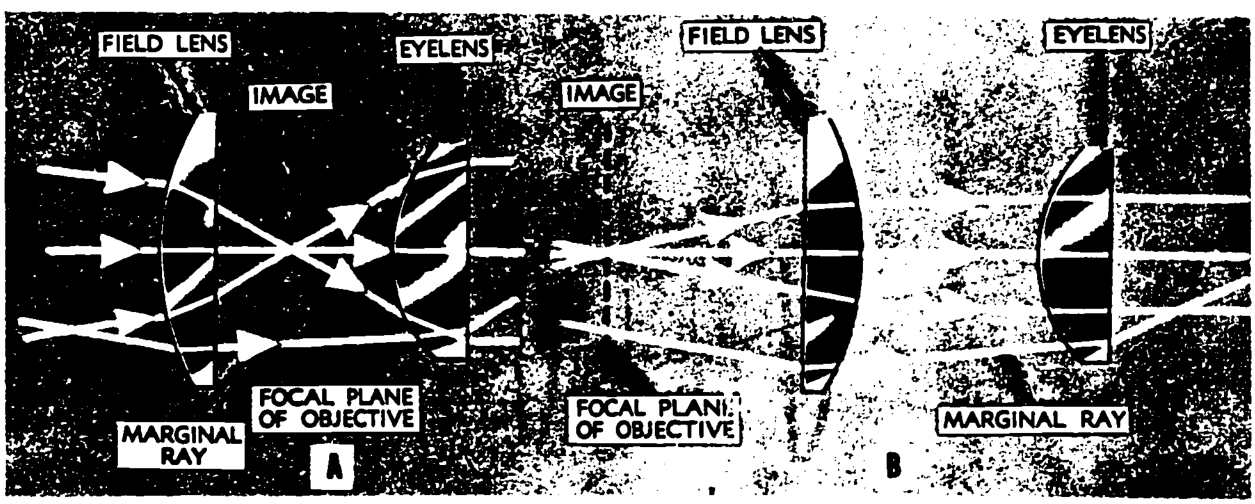

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Figure 5-15.—Path of light through eyepiece lenses.

must bear in mind that when working on an optical instrument he will often find modifications to these eyepieces. The designer of instruments will use the basic types as they are shown in this chapter, but he will often find it necessary to make some modifications to them in order to produce a quality instrument. One of the prime concerns of an instrument designer is the elimination of aberrations in an instrument. The proper design and use of the eyepiece can be very useful in this function and will be discussed under the separate types of eyepieces.

Huygens

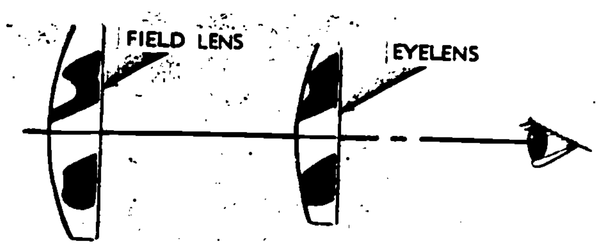
The HUYGENS EYEPIECE (fig. 5-16) is made of two single lenses. (Usually they're both convexo-plano, and both made of crown glass.) The diagram shows three rays converging toward a real image. The field lens deviates these rays slightly, and sends them toward the eyepiece. You can see that without the field lens, some rays will miss the eyelens entirely. In any eyepiece, an important function of the field lens is to collect the rays and send them to the eyepiece. This ensures that all the light passing through the system will be used to form the final image.

The Huygens eyepiece minimizes chromatic aberration, in a way we mentioned in an earlier chapter, by making the distance between the two lenses equal to half the sum of their focal lengths. The Huygens eyepiece has some spherical aberration, but it isn't very noticeable at relative apertures less than about f:7. If you want to use it at an aperture greater than f:7, you have to overcorrect the objective to compensate for the spherical aberration of the eyepiece.

The Huygens eyepiece can be made entirely free from coma. It shows some pin-cushion distortion, but in many instruments that isn't objectionable. It has a NEGATIVE astigmatism, which helps correct the astigmatism of the objective.

This eyepiece has one outstanding disadvantage: since the image is inside the eyepiece, you can't use a reticle. The aberrations of the ocular as a whole are corrected, but those of the eye lens alone are not. So if you put a reticle in the image plane, its image would be distorted and show color fringes.

The magnifying power of the Huygens eyepiece is limited to about 10. (If you made the focal length shorter than about 1 inch, the exit pupil is too close to the eyelens.)



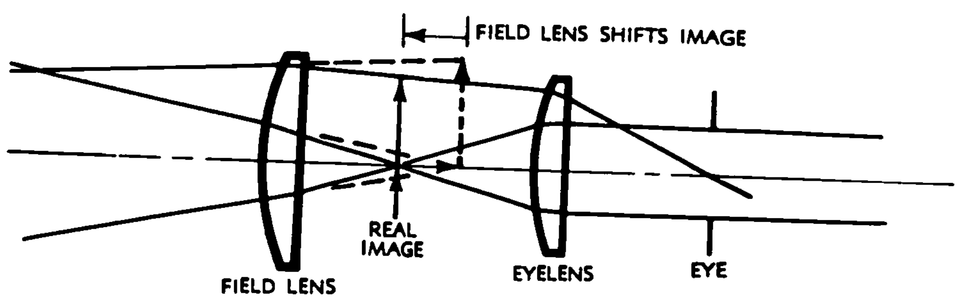


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Figure 5-16.—Huygenian eyepiece.

Ramsden

Figure 5-17 shows the RAMSDEN EYEPIECE. It's made of two plano-convex lenses of equal focal length. The distance between them is equal to about two-thirds of that length. The arrow is the real image formed by the erecting lens. As you can see, the eyepiece forms an enlarged virtual image at infinity.

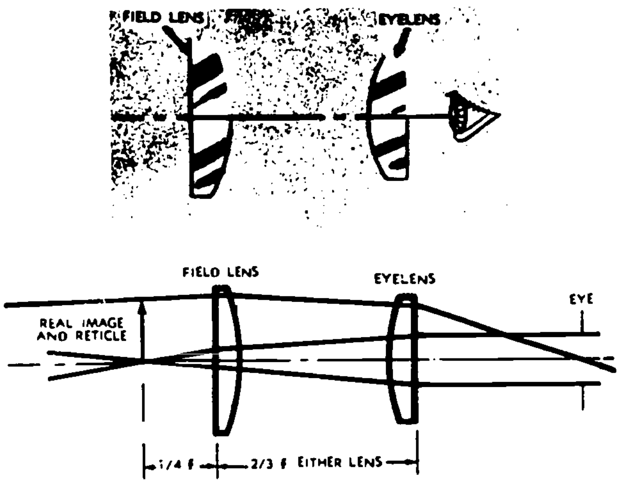

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Figure 5-17.—Ramsden eyepiece.

The Ramsden eyepiece has one outstanding disadvantage: its chromatic aberration is rather serious. It has no coma, and all its other aberrations are less than those of the Huygens eyepiece. Besides controlling all the aberrations except color, the Ramsden has this advantage over the Huygens: since the real image is outside the eyepiece, you can put a reticle in the image plane.

Except for its chromatic aberration, the Ramsden is a desirable eyepiece. For any given focal length, its eye distance is about 1.5 times that of the Huygens, so you can use a higher magnifying power. And the aberrations of the Ramsden are increased less than those of the Huygens by slight variations in the focal length of the objective. But the only way you can eliminate the chromatic aberration is by forming the image inside the eyepiece, and then you can't use a reticle.

Kellner

The Kellner eyepiece is a modification of the Ramsden. Figure 5-18 will serve to illustrate the Kellner; the only difference is that the eye lens is a doublet. The Kellner keeps most of the advantages of the Ramsden, and reduces the chromatic aberration. Spherical aberration is slightly greater, but distortion is less. To eliminate the chromatic aberration completely, you'd have to put the field lens in the plane of the real image. And then you couldn't use a reticle. Most instruments that use a Ramsden eyepiece have the field lens a short distance beyond the image plane. They sacrifice a part of the color correction in order to use a reticle.

Symmetrical and Two Doublet Eyepieces

Symmetrical and two-doublet eyepieces are constructed of two cemented, achromatic doublets (fairly close together) with their positive elements facing each other. If the doublets are identical in every respect (diameters, focal lengths, thickness and index of refraction), the eyepiece is symmetrical. If the doublets differ in one respect or another, however, they are considered as a TWO-DOUBLET eyepiece. The eyelens of the two-doublet eyepiece is generally slightly smaller in diameter and has a shorter focal length than its field lens. Doublets in a symmetrical eyepiece, on the other hand, ARE IDENTICAL IN EVERY RESPECT AND CAN BE INTERCHANGED (fig. 5-19).

Symmetrical and two-doublet eyepieces are often used in fire control instruments which recoil. The eye distance on these instruments must be fairly long, to prevent the eyepiece from striking the gunner's eye. These eyepieces may also be used in terrestial telescopes (not only in gunsight telescopes), or in any other telescope designed to carry them.

A symmetrical eyepiece provides long eye relief, because it has a large exit pupil and low magnification, qualities which ensure eye relief. For this reason, symmetrical eyepieces—along with Kellner—are used extensively in optical instruments, particularly rifle scoped and gunsights.

Orthoscopic

The orthoscopic eyepiece is illustrated in figure 5-20. It employs a planoconvex triplet field lens and a single planoconvex eyelens with the curved surface of the field lens facing the curved surface of the eyelens. It is free of distortion and is useful in high-power telescopes

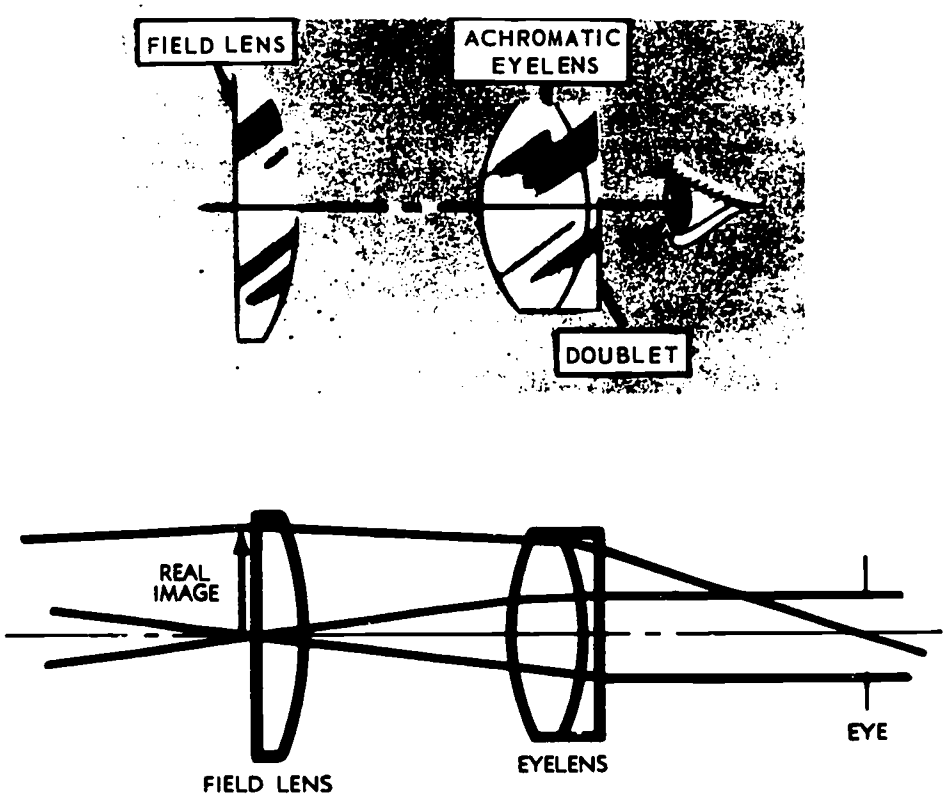

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Figure 5-18.—Kellner eyepiece.

because it gives a wide field and high magnification with sufficient eye relief. It is also a very useful eyepiece for rangefinders because it permits the use of any part of the field. It was named ORTHOSCOPIC because of its freedom from distortion.

Internal Focusing

Very often it is mandatory that an instrument be completely sealed to keep out moisture and dirt. In order to do this and still be able to accommodate for the visual variations between different observers, designers have developed several types of internal focusing eyepieces. These usually consist of three elements, and one type is illustrated in figure 5-21. The eyepiece has a field lens, intermediate lens, and eyelens, all of which are cemented doublets.

The field lens and intermediate lens are mounted in a cell which can be moved longitudinally by rotation of the focusing knob. The eyelens is fixed and acts as a seal for the eyepiece. Figure 5-22 is a mechanical schematic of the focusing operation.

Internal focusing eyepieces are not limited to the three doublet combination as used in telescopes Mk 102 Mods 2 and 4. In fact, the Mk 102 Mod 3 telescope employs a triplet field lens, doublet intermediate and singlet eyelens. The basic principle is the same in all combinations; the field lens converges light rays which otherwise would miss the intermediate lens, and the intermediate lens converges light which would otherwise miss the eyelens. The eyelens converges light to the exit pupil.

Moving the lens cell along the optical axis toward or away from the fixed eyelens allows the operator to adjust the focus of the eyepiece to suit his eye requirements.

SIMPLE TELESCOPE

A telescope is an optical instrument containing a system of lenses or mirrors, usually but not always, having magnification power greater than unity, which renders distant objects more

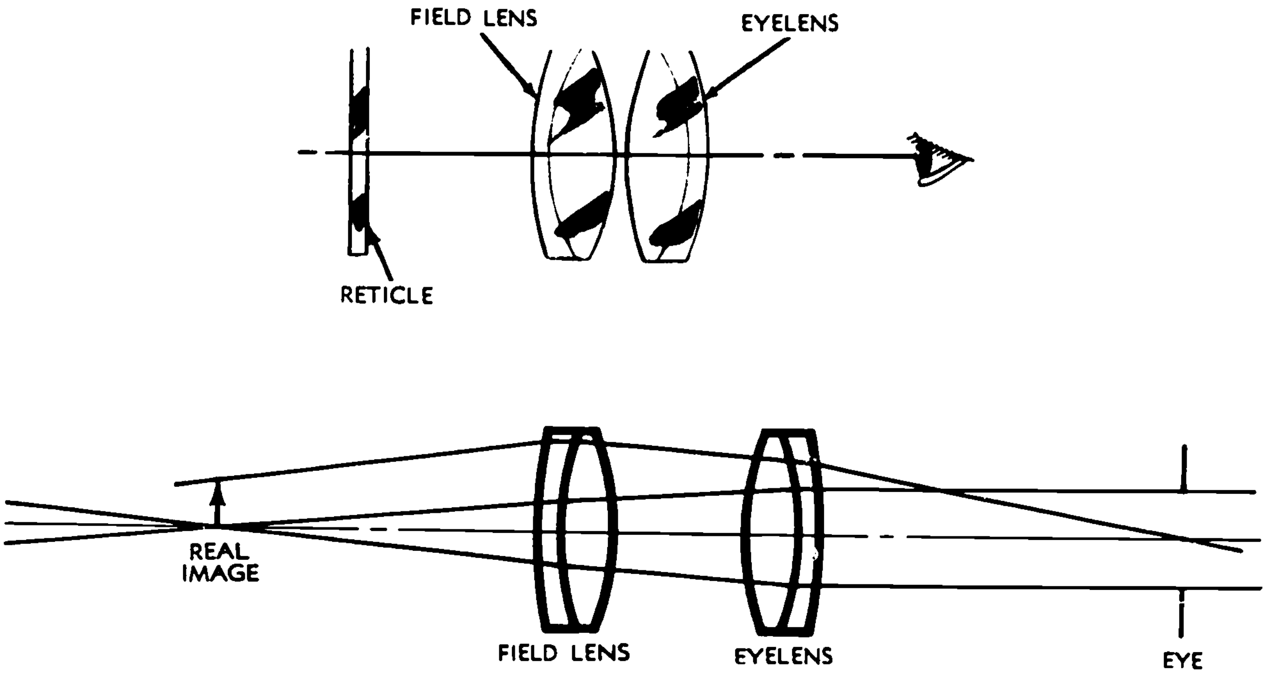

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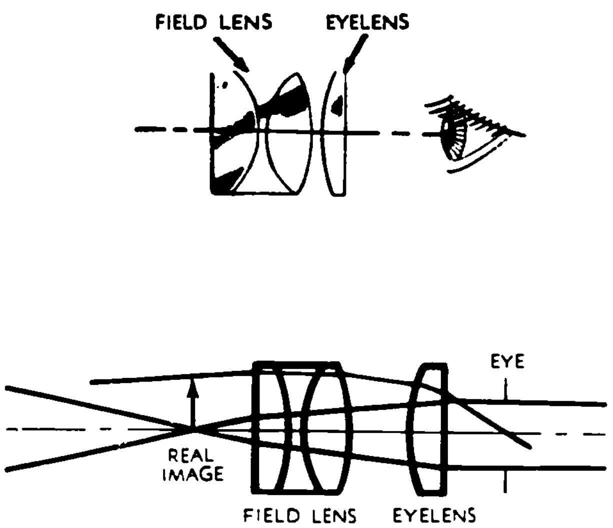
Figure 5-19.—Symmetrical eyepiece.



137.143
Figure 5-20.—Orthoscopic eyepiece.

clearly visible by enlarging or accentuating their images on the retina of the eye. In its simplest form, a telescope consists of two parts; a lens or mirror, called the objective, and an eyelens or eyepiece.

The function of the objective is to gather as much light as possible from the object and converge it to form a real image of that object. In some telescopes, the objective does not form a real image, and this will be explained later in the chapter.

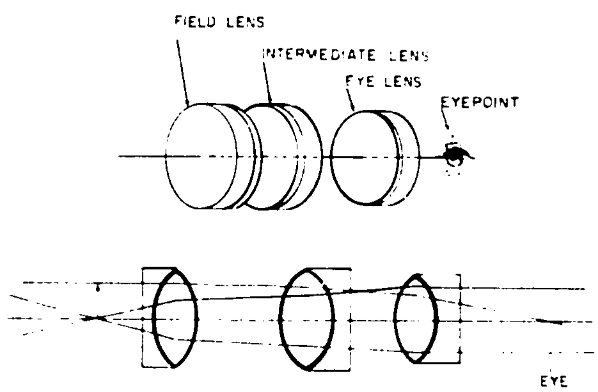


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Figure 5-21.—Internal focusing eyepiece.

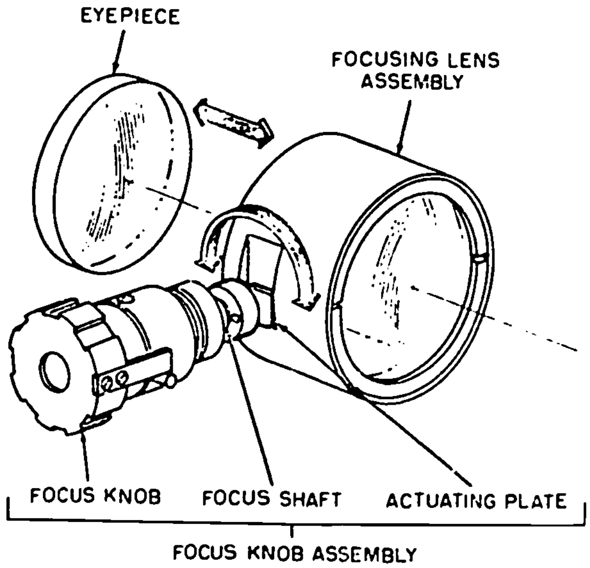

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Figure 5-22.—Mechanical schematic of focusing eyepiece.

ASTRONOMICAL

One of the most important branches of science is astronomy. Our interest is spurred during the modern age by our country's efforts in the space program. When man first started to study the celestial bodies, little did he realize that someday he would be placed on the moon. The ancient astronomers could observe the moon, sun, stars, and planets with the naked eye only and record their relative positions. The invention of the telescope, about 1600 AD, was a major breakthrough which has lead to the highly technical instruments that are used today.

In the process of refraction and reflection by a telescope system, the image becomes inverted. With astronomical bodies, it makes little difference whether or not the object is viewed upside down, which is true for some telescopes. Telescopes that give the observer an inverted view are named astronomical telescopes. Since they need no erecting system, they are thereby optically simpler, and for this reason we study them first in our attempt to understand the general nature of the telescope.

Reflecting

In chapter 4 we studied the effect that concave mirror has on light. In most astronomical telescopes—especially the big ones—the objective is a concave mirror instead of a lens. There are several reasons for this. When you're looking at distant stars, you want the image to be as bright as possible. And the brightness of an image depends on the diameter of the lens or mirror that forms it.

There's a practical limit to the diameter of a lens. The biggest refracting telescope we know about is at the Yerkes Observatory; the diameter of its objective is 40 inches. You couldn't make a lens much bigger than that and mount it in a telescope barrel. In the first place, you'd have a hard time casting a big enough piece of good optical glass. And in the second place, a lens bigger than 40 inches would sag under its own weight. (Remember, glass is a liquid.) The lens would have to be extremely heavy, and it would be supported only at its edges. It could easily sag 20 or 30 millionths of an inch. And that's all the sag you need to ruin the image.

And another thing: an objective lens must have at least two elements, to correct its aberrations. That means you have to grind and polish at least four surfaces. But with a mirror, you have to grind and polish only one surface. And of course a mirror has no chromatic aberration. And since the light doesn't pass through the mirror, the glass doesn't have to be optically perfect all the way through.

The biggest reflecting telescope in the world is in the observatory on Mt. Palomar, in southern California. Its objective is a concave mirror 200 inches—almost 17 feet—in diameter. The Corning Glass Company, at Corning, N.Y., made the blank for it out of Pyrex glass. (Pyrex expands and contracts less than ordinary glass when the temperature changes.)

To keep it from developing strains, the Corning Glass Company annealed the mirror in an electric furnace. They reduced its temperature just one degree a day. Interesting enough, the Cohocton River runs right beside the glass works, and in 1936 the river flooded. It didn't reach the mirror, but it took out the power line and cooled the annealing furnace. They had to start all over with a new mirror.

The California Institute of Technology spent four years grinding the mirror. Then they were interrupted by World War II. After the war they finished the grinding and polishing, and plated the reflecting surface with a thin film of aluminum. They also completed the telescope mount. The mount supports the weight of the objective, and the platform the observer stands on. It automatically—and very accurately—tracks the stars as they move across the sky.

A study of figure 5-23 shows that before the reflected rays of the concave mirror in this figure are brought to focus, a 90° prism is placed in the converging rays to deviate the rays at an angle of 90°, as shown. The purpose of this deviation is to prevent an observer who is viewing the image from cutting off a large part of the light before it reaches the mirror.

An eyepiece is placed at the point where the real image if formed to magnify the image. If you look through the eyepiece of a reflecting telescope, you see a VIRTUAL, INVERTED, ENLARGED image.

When there is a need for lengthening the focal length of a concave mirror, or when the design of a telescope is altered (Cassegranian reflecting telescope, for example), a small convex mirror can be used with the concave mirror (fig. 5-24).

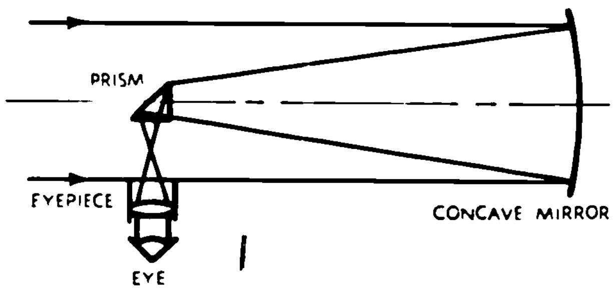

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Figure 5-23.—Reflecting telescope.

The concave mirror in a Cassegranian telescope has a small hole ground through the middle (center), and the convex mirror is placed in the converging rays in place of the 90° prism to reflect the rays and make them less divergent and focused at a point greater in distance than the original focal plane of the concave mirror. Study illustration 5-24 carefully.

When the rays are reflected from the convex mirror, they pass directly through the hole in the concave mirror and come to focus to produce an image like the one produced by the doublet lens. The eyepiece is placed behind the reflecting surface of the concave mirror to magnify the real image and give a VIRTUAL, INVERTED, and ENLARGED image of the object.

Converging mirrors with long focal lengths are used in telescopes as objectives to form real images. The light in this type of mirror is incident on the same side as the center of curvature of the sphere. The focal point is halfway between the center of curvature and the reflecting surface.

A real image created by a convergent mirror used as an objective in a telescope can be viewed through a magnifying eyepiece or photographed by a camera attachment.

Refracting

In a refracting telescope, the lens nearest to the object is called the objective lens. The

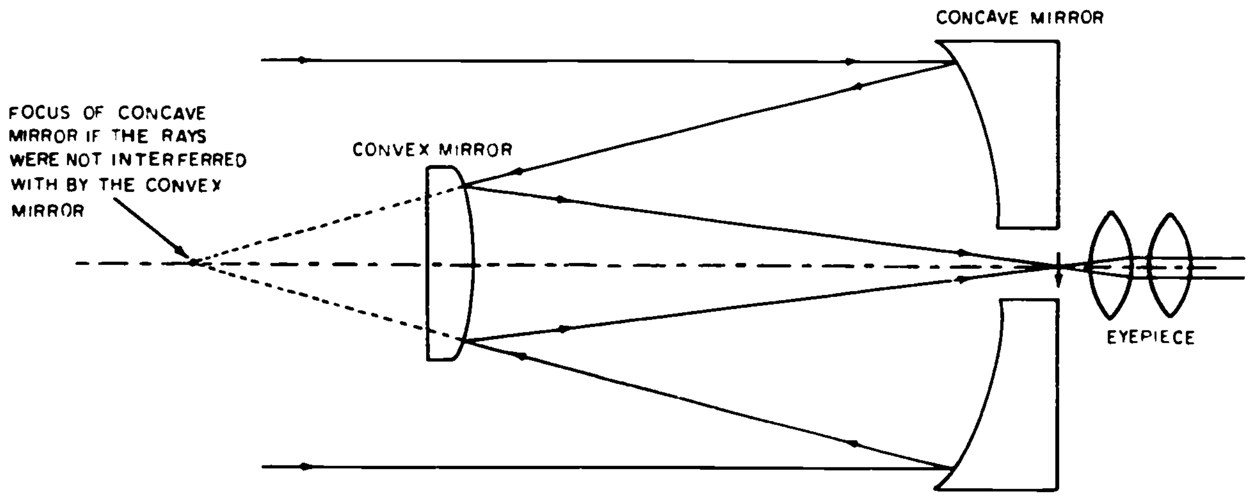

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Figure 5-24.—Cassegranian reflecting telescope.

majority of objective lenses are constructed of two elements, a double-convex positive lens of crown glass and a concave-plano negative lens of flint glass. When the elements are not too large in diameter and the curvatures are the same, the elements are cemented together (fig. 5-25-A).

When the elements of the objective are large in diameter or when the faces of the elements are of different curvature, the elements are not cemented but are held in their relative positions in a cell by separators and a retaining ring (fig. 5-25B). This construction permits giving the inner surfaces of the two elements different values and allows greater freedom in the correction of aberrations. An objective of this type is called a DIALYTE or GAUSS objective.

Certain objectives are composed of three elements (fig. 5-25C). This type of objective can have all three elements cemented together, or it can have two elements cemented with one mounted separately, or it can have all three elements mounted separately. Such objectives afford a total of six surfaces for the designer to work with in order to obtain the best possible correction for aberration.

A positive objective lens alone forms only real images of distant objects, but such real images in space cannot be brought to focus by the eye (fig. 5-26). In order for an eye to bring an image to a focus, the rays of light from the object which enter the eye MUST BE PARALLEL OR ONLY SLIGHTLY DIVERGING, as if from an object no closer than the near point (10 inches) of the eye. If another positive lens,

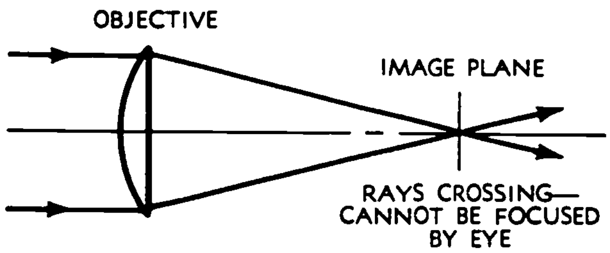

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Figure 5-26.—Passage of refracted rays from an objective lens.

however, is placed between an image and an eye, and the real image is at the primary (first) focal point of the eyepiece, the eye can see (without accommodation) a virtual image of the object picked up by the objective lens (see fig. 5-14).

Figure 5-14 also shows the position of an objective lens in relation to the eyepiece in telescope construction. Such an arrangement of optical elements is the simplest form of a refracting astronomical telescope. Observe that the parallel light rays entering the objective lens are refracted and converge to the focal plane of the lens. (The image plane and the focal plane coincide when parallel rays are refracted by any lens.) In the focal plane of the objective lens a real, inverted image of the object is formed. The eyepiece is so placed that the image formed by the objective lens is located on the primary focal point of the eyepiece. The diverging rays, diverging from the real image,

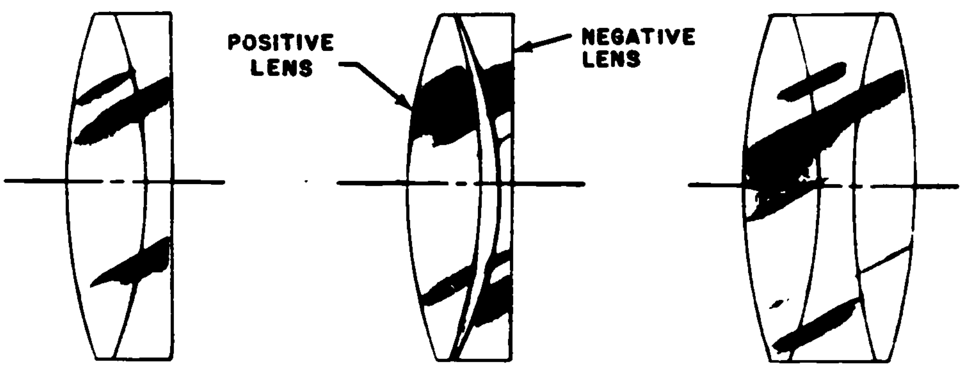

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Figure 5-25.—Types of objective lenses.

enter the eyepiece, are refracted, and emerge parallel to the optical axis of the telescope.

Since the real image formed by the objective lens is located at one focal length (at the primary focal point) of the eyepiece, the eyepiece acts as a magnifying lens to magnify the real image. If you look through the telescope eyepiece, you see a VIRTUAL, INVERTED, ENLARGED image which is formed at infinity.

In an astronomical telescope, in which the focal points of the objective lens and the eyepiece lens coincide, the length of the telescope is the SUM OF THE FOCAL LENGTHS OF THE TWO LENSES.

Before you can fully understand the telescope, you must have a thorough knowledge of several other optical terms.

• ENTRANCE PUPIL: This is a term used to denote the aperture of the objective and is limited by the diameter of the objective or the inside diameter of either the lens cell or the retainer ring as indicated in figure 5-27, and designated AP. The entrance pupil can be viewed as such from the objective end of the instrument and it can be approximated by measuring with a scale directly across the objective.

• EXIT PUPIL: This is a term given the diameter of the bundle of light leaving an optical system. This small circle or disk of light can be seen by looking at the eyepiece of an instrument that is directed at an illuminated area. The diameter of the exit pupil is equal to the diameter of the entrance pupil divided by the magnification of the instrument. The exit pupil is designated EP in figure 5-27.

• TRUE FIELD: The true field of view in a telescope is the width of the target area or field that can be viewed. More specifically, it is the maximum cone or fan of rays subtended at the entrance pupil that is transmitted by the instrument to form a usable image (fig. 5-28).

• APPARENT FIELD: The apparent field of view is the size of the field of view angle as it appears to the eye. It is approximately equal to the magnifying power of the instrument times the angle of the true field (fig. 5-28).

• EYE DISTANCE: Often called eye relief, this is a term given to the numerical measure of the distance from the rear surface of the rear eyelens to the fixed position of the exit pupil (fig. 5-29). In Galilean telescopes, the exit pupil is in the interior of the instrument, and its eye distance is a negative quantity.

TERRESTRIAL TELESCOPES

A terrestrial telescope gets its name from the Latin word terra, which means earth. A terrestrial telescope is used to view objects as they actually appear on earth.

Any astronomical telescope can be converted to a terrestrial telescope by inserting a lens or prism erecting system between the eyepiece and the objective to erect the image. Figure 5-30 shows the optical elements of the simplest form of terrestrial telescopes. Note the position of the REAL IMAGES.

A lens erecting system requires such positioning of the objective and the eyepiece that the erectors are between the focal point of the objective and the first principal focus of the

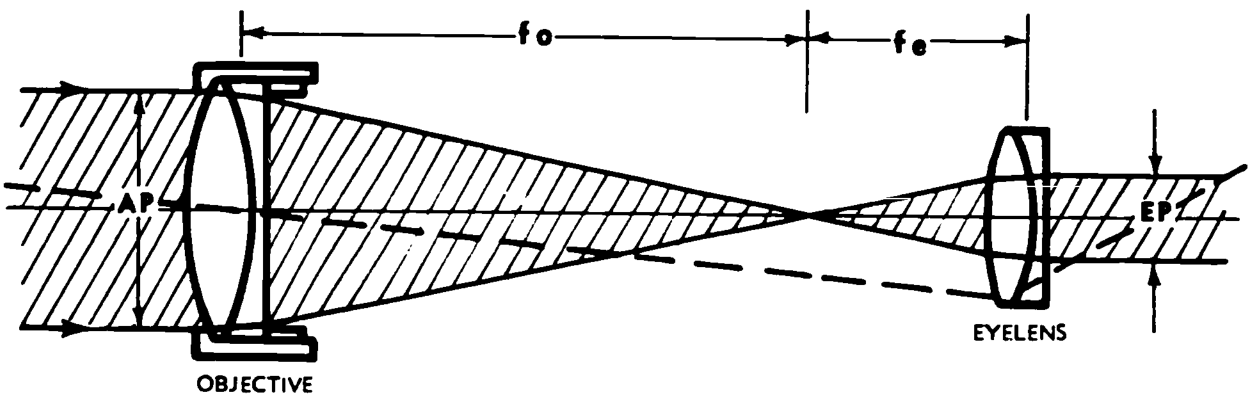

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Figure 5-27.—Entrance and exit pupils.

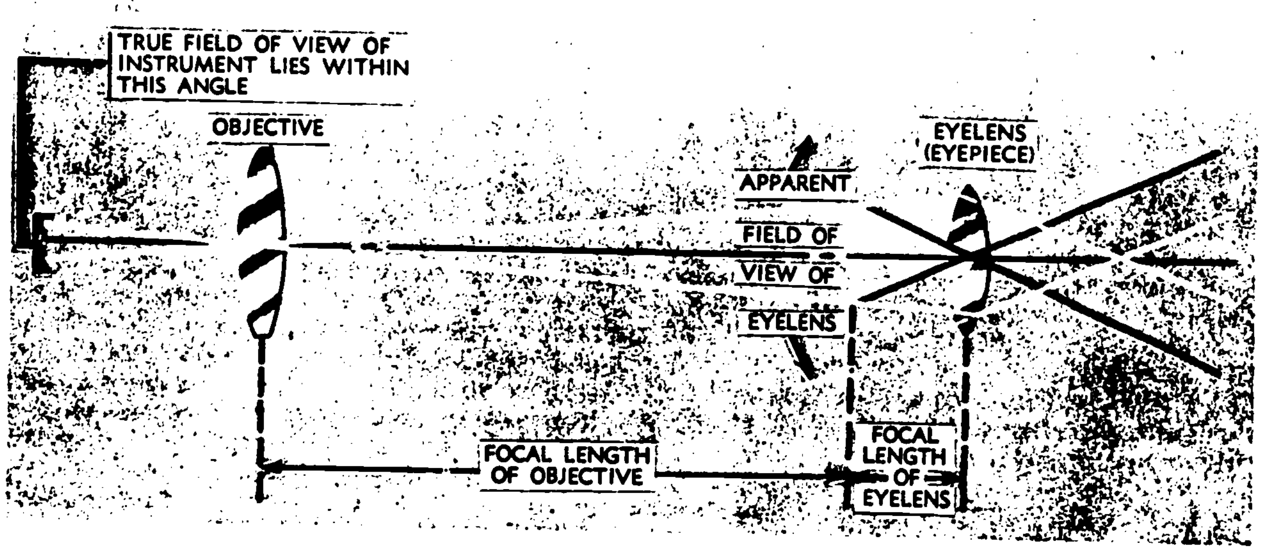

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Figure 5-28.—True field and apparent field.

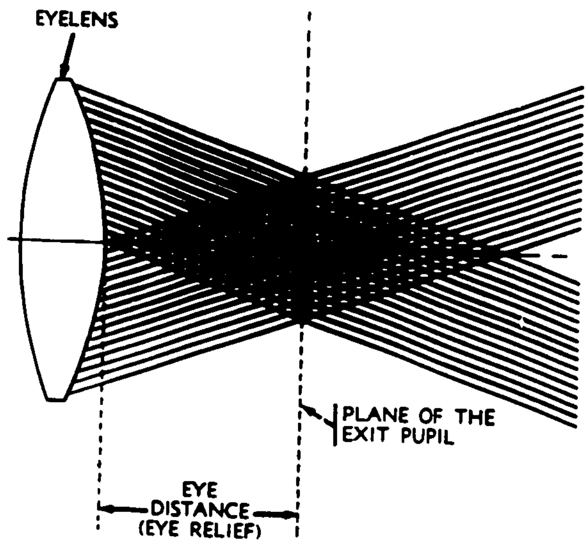

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Figure 5-29.—Eye distance and exit pupil plane.

eyepiece. A prism erecting system, on the other hand, must be placed between the objective and its focal point.

You will learn more details about the use of erecting systems when you study magnification of images in telescopes later in this chapter.

Galilean Telescopes

The first telescope Galileo made had a power of 3, but later he made one with a power of 30. It makes use of an eyepiece consisting of a negative eyelens positioned a distance equal to its focal length (fe, fig. 5-31B) in front of the objective focal point. Such positioning of the negative eyelens makes converging rays from the objective parallel before they converge to form a real image; so no real image exists in this optical system. The light rays do not converge to a point to form a real image; but if you look through the negative lens you see an enlarged, virtual image of the object, which appears to be at a point between 10 inches and infinity.

The virtual image viewed through the negative eyelens is therefore at infinity and can be viewed by the eye without accommodation.

The relation of the optical elements in a Galilean telescope (fig. 5-31B) is referred to as the ZERO DIOPTER SETTING, which means that ALL LIGHT RAYS FROM ANY POINT SOURCE LOCATED AT INFINITY EMERGE FROM THE EYEPIECE PARALLEL. If the eyelens is moved in and out, however, the emergent light rays converge or diverge and the instrument can therefore be adjusted for farsighted or nearsighted eyes, and also for distance.

The INVERTING EFFECT of the objective lens in a Galilean telescope is canceled by the

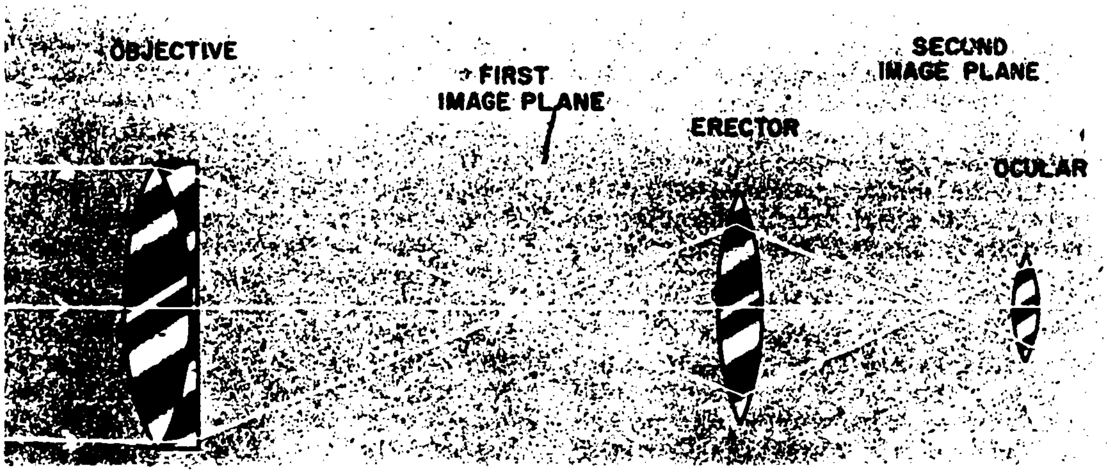

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Figure 5-30.—The terrestrial telescope.

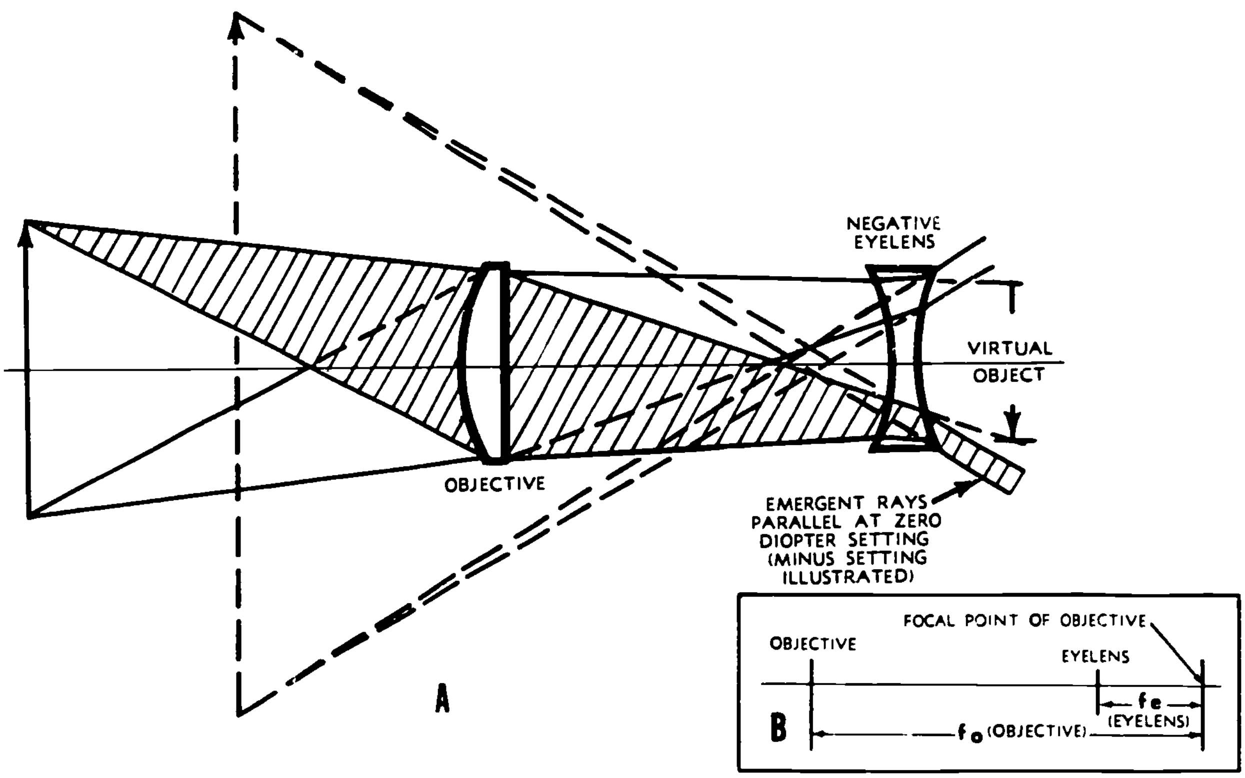

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Figure 5-31.—Galilean telescope.

negative eyelens, because the real image is not allowed to form; that is, the emergent rays from the negative eyepiece are refracted farther away from the axis instead of recrossing it. The virtual image of the object viewed is therefore ERECT.

The principle of the Galilean system is diametrically opposite to that of the astronomical system with a positive lens, which causes the emergent rays from the positive eyelens to recross the axis and form an INVERTED, VIRTUAL IMAGE of the REAL IMAGE formed by the objective lens.

A Galilean telescopic system is one in which the diameter of the objective controls the field of view (width of visible area), because the objective is both the field stop and the entrance window.

Single Erector

A lens erecting system is employed in an instrument to give the viewer an erect normal image. In addition to erecting the image, proper positioning of the erector system can also have a direct effect on the magnifying power of the instrument. The arrangement of optical elements in a single erector telescope is illustrated in figure 5-32A. Observe that the parallel rays entering the objective lens from an infinity target are refracted to form a real inverted image in the focal plane of the objective lens. Rays which leave the real image are diverging as though the image itself were an object. When we place an erector lens two focal (2F) lengths from the objective image, the erector receives the diverging rays and refracts them to form an image two focal lengths (2F) behind the erector. The image formed by the erector is the same size as the image formed by the objective. We can prove this by applying the formula for magnification of an image studied in chapter 4.

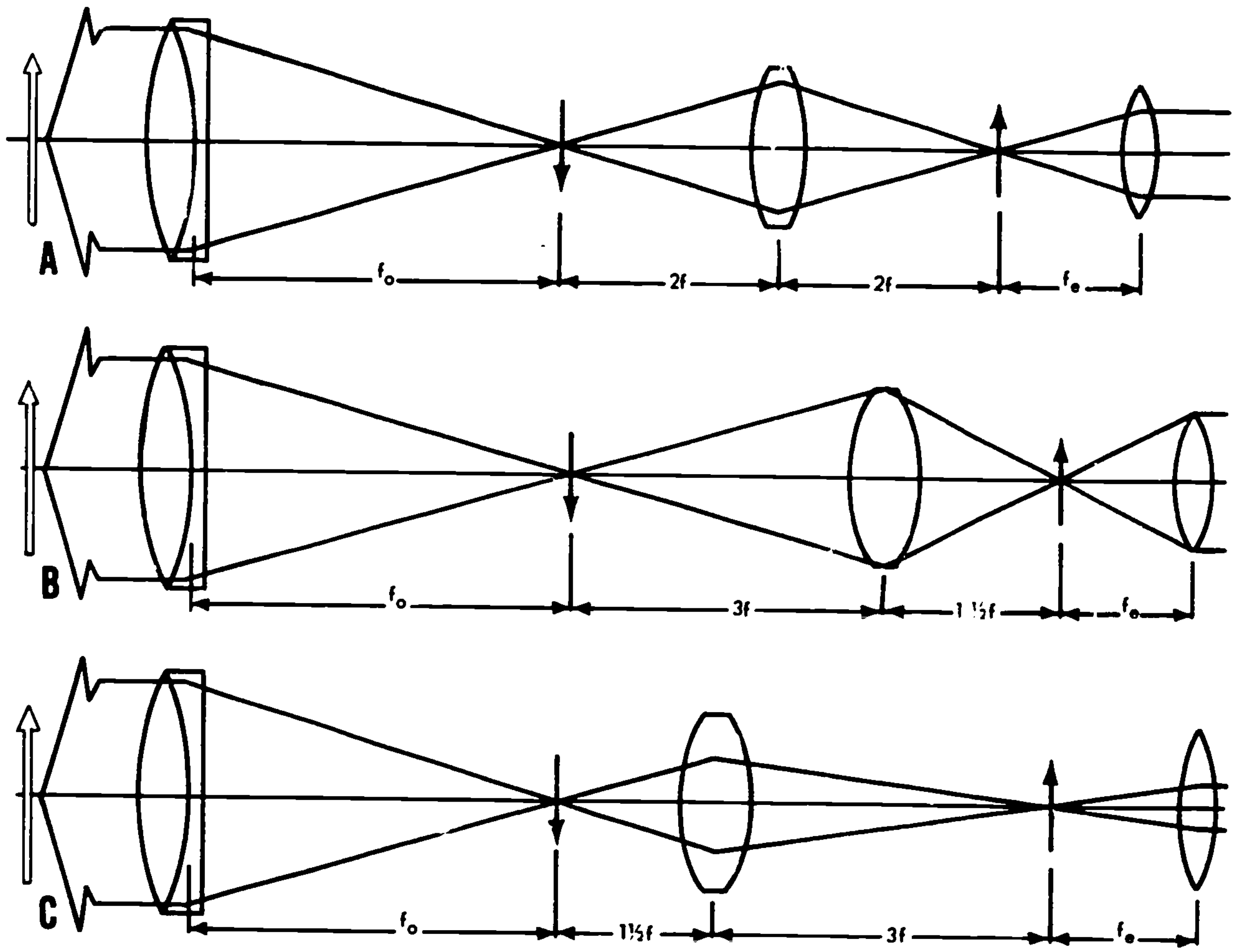

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Figure 5-32.—One erector telescope.

Suppose we give the erector (fig. 5-32A) a focal length of 1 inch. Magnification, as you recall, is Mag = Di/Do and since the object distance (in this case the image formed by the objective) is 2F or 2 inches, by substituting we get Mag = 2/2 = 1. Since there is no magnification, the image formed by the erector is the same size as its object.

Now let's change the position of the erector and move it further back from the objective (fig. 5-32B).

$$\text{Mag} = \frac{\text{Di}}{\text{Do}} = \frac{1.5}{3} = .5 \text{ or } -1/2$$

Our answer shows that the image formed by the erector is one-half the size of the object.

Now let's position the erector closer to the object as in figure 5-32C.

$$\text{Mag} = \frac{\text{Di}}{\text{Do}} = \frac{3}{1.5} = 2$$

We now have a magnification of two power and the size of the image is twice as large as the object.

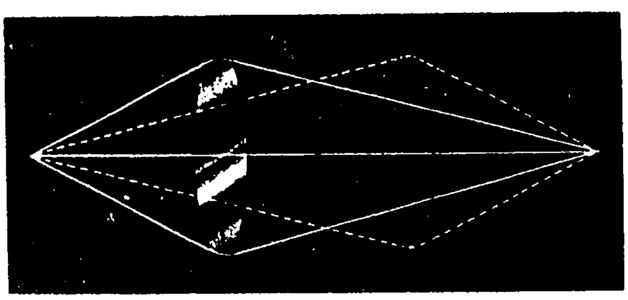

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Figure 5-33.—Conjugate points.

Observe in figure 5-33 the original position of the lens (C), the optical axis of the lens (AB), rays of light (white lines) from point A to the lens, and the refracted rays to point B. As illustrated, the distance the lens is from the object is 1 1/2 F, and the distance of the image from the lens is 3F.

When the lens is moved to position D, the distance of the object (A) from the lens is 3F, and the distance of the image from the lens is 1 1/2F.

According to the law of reversibility, you know that if the object were at B, its image would be at A. Points A and B are therefore conjugate points, because each is the image of the other. Suppose that the lens is 3 inches from point A and 6 inches from point B and you move the lens to D, 6 inches from point A and 3 inches from point B. POINTS A AND B ARE STILL CONJUGATE POINTS.

This lens, therefore, forms an image of A at B WHEN IT IS AT TWO DIFFERENT POSITIONS. If you place a real object such as an arrow in the plane at A, its image will be in plane B, regardless of whether the lens is at C or D; but WHEN YOU MOVE THE LENS FROM ONE POSITION TO ANOTHER, YOU CHANGE THE SIZE OF THE IMAGE. As you know, the relative size of the object and the image depends upon their relative distances. When the lens is at C, the image is TWICE AS BIG AS THE OBJECT; when the lens is at D, the image is ONLY ONE-HALF THE SIZE OF THE OBJECT.

If lenses in an erecting system are moved closer to the focal point of the objective lens and farther from the eyepiece, magnification is increased but the field of view is decreased. If the erecting lenses are located at the same distance from the focal points of the objective and the eyepiece, there is no additional magnification of the image. This method of changing the degree of magnification is used in optical instruments which have a change of power.

At this point, it is best that you learn the distinction between VARIABLE MAGNIFICATION and CHANGE OF MAGNIFICATION. Variable magnification is obtained in an optical system when the image STEADILY BECOMES LARGER AND LARGER throughout movement of the erecting lenses. Change of magnification in an optical system is obtained ONLY WHEN the instrument is changed FROM ONE POWER TO THE NEXT POWER. Between positions, the image is badly blurred.

Two-Erector

Refer now to figure 5-34 to see how a terrestrial telescope with two erecting lenses is constructed. The erectors (lenses) shown are SYMMETRICAL; that is, they are IDENTICAL in every respect—diameter, thickness, index of refraction, and focal lengths. ASYMMETRICAL erectors (with different focal lengths) may also be used in this type of telescope for design purposes or to help increase magnifying power, which the objective and eyepiece alone could not do.

As is true for all objective lenses, parallel rays from an infinity target are refracted and converge to the focal plane of the objective lens to form an INVERTED, REAL image. The first erecting lens is so positioned that the real image is in its focal plane. (The image is one focal length from the first erecting lens.) The divergent rays which enter the erecting lens are refracted and emerge parallel to the optical axis.

Since the rays which emerge from the first erecting lens are parallel, the second erecting lens may be placed at any reasonable distance from the first erector, because the rays which enter the second erecting lens are ALWAYS PARALLEL, regardless of the amount of lens separation. Separation of the erectors in fixed-power telescopes is generally THE SUM OF THEIR FOCAL LENGTHS, which is sufficient to ensure good eye relief. As separation of the erectors varies, eye relief of the eyepiece also varies.

Parallel rays which enter the second erecting lens are refracted and converge to the focal plane to form a REAL, ERECT image. If the erectors are SYMMETRICAL, the image produced by the second erector is of the same size as the image produced by the objective lens. If the erectors are ASYMMETRICAL, the size of the image produced by the second erector varies directly in proportion to its focal length—the longer the focal length of the second erecting lens, the larger the image produced by it.

The eyepiece of the telescope is again positioned as necessary in order to have the image of the second erector at its focal plane. When the eyepiece is placed one focal length from the image, divergent rays from the image are refracted by the eyepiece and emerge parallel to the optical axis. If you look through the eyepiece of the telescope, you see a VIRTUAL, ERECT, ENLARGED image formed at infinity.

A two-erector telescope can also be constructed as a change of power instrument, by moving the erectors together as a unit in the same direction (with their separation fixed). Their distance from the real image formed by the objective lens must be 1 1/2 EFL, or 3 EFL of the erecting lens combination. The two erecting lenses FUNCTION together as a single thick lens to produce an image in the same manner as the one-erector lens used for the same purpose.

You cannot continuously vary the power in a two-power telescope, because there are ONLY TWO positions of the erecting lens (one-erector lens, or a two-erector lens used as a unit) for which the TWO IMAGE PLANES ARE CONJUGATE.

Variable Power

In the two-power telescope (fig. 5-34), there are only two positions of the erecting lens for which the two image planes are conjugate, That means you can't vary the power continuously, because the image will be out of focus when the erecting lens is in an intermediate position. The only way to keep the two image planes conjugate throughout the travel of the erector lens is to change its focal length continuously while you move it. And that is exactly what a variable power telescope does.

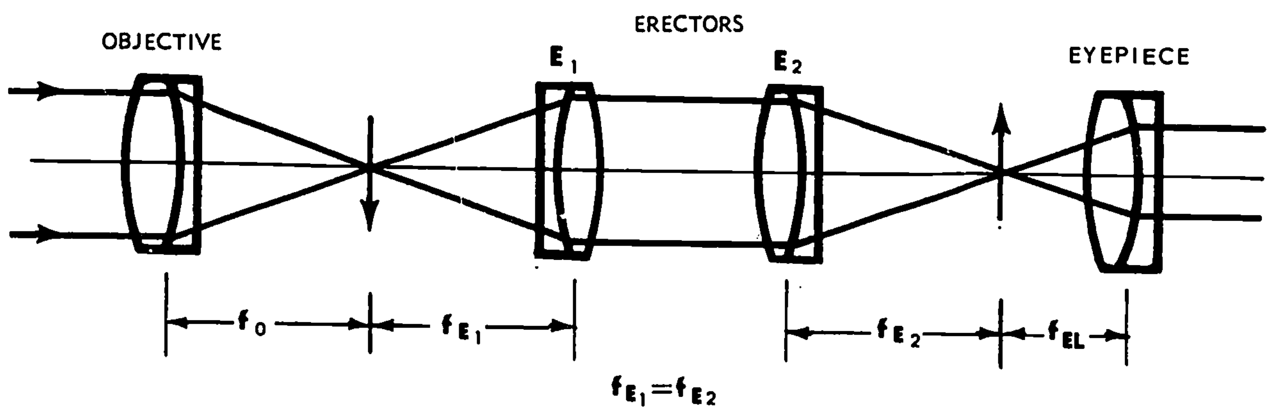

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Figure 5-34.—Two erector telescope.

How can you change the focal length of the erector? If it's a single lens, you can't change its focal length without changing its shape. But instead of a single lens, you can use a combination of two lenses for an erector. As you know, the focal length of a combination of lenses depends on the distance between them. So we can make a variable power telescope if we can figure out a mechanical arrangement that will change the distance between the two erector lenses when we move them. As you can probably guess, the mechanical system is pretty tricky.

With a VARIABLE POWER TELESCOPE, you can change the magnification continuously between two limits. If you look through a variable power instrument and gradually increase its magnification, you'll get the same effect that a television or movie cameraman gets when he ZOOMS in on an object. It appears as if the camera is moving toward the subject while the action is going on. Even the simplest home movie cameras have this feature.

Variable-magnification erecting systems used in variable-power telescopes provide two to three times as much power in the high-power position as in the low-power position.

Magnification of an erecting system composed of a COMBINATION OF LENSES can be varied by doing the following simultaneously:

1. Varying the position of the erecting system from its object.

2. Varying the separation between the optical elements of the erecting system.

Now study figure 5-35A, which shows two asymmetrical erectors in the low-power position. When these erectors are shifted toward the object, the position of the image shifts toward the eyepiece (fig. 5-35B), and magnification of the telescope is increased. If the distance between the two erectors in the forward position (toward object) is decreased by moving the second lens toward the first lens, magnification is slightly decreased and shifting of the resulting image position is also decreased (fig. 5-35C).

The image position CAN BE THE SAME for all possible magnifications produced by the optical system of a variable-power telescope. Separation between the erectors in a variable-magnification telescope is always such that the IMAGE POSITION REMAINS FIXED (fig. 5-35C).

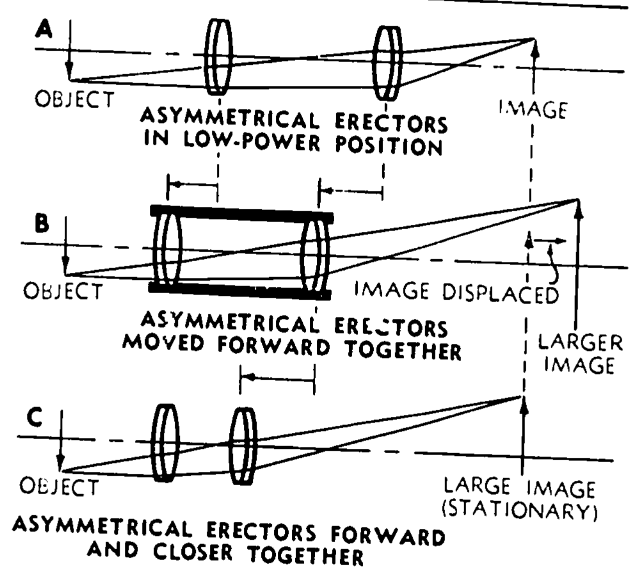

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Figure 5-35.—Variable magnification in two erector telescope.

GUNSIGHT TELESCOPES

The Navy employs a wide variety of terrestrial telescopes as gunsights, some of which are very complicated in their construction. This section will give the student basic knowledge needed to understand the function and design principles of the telescope used as a fire control instrument. Some of the simple gunsight telescopes are covered in more detail in another chapter of this book. When the opticalman is engaged in repair or overhaul of a particular gunsight, or any optical instrument, he must always use the technical manual that applies to that instrument.

The gunsight telescope is used to improve the observer's view of distant targets as follows: They gather and concentrate upon the lens of the eye a greater quantity of light from the target than the unaided eye can gather, thus, rendering the target more distinct. They erect the target image and superimpose a reticle upon it, thus sharply defining the line of sight to the target. They magnify the target image so that the distant target appears closer. These telescopes, in many instances, have the eyepiece inclined at an angle with respect to the line of sight, so that the observer can comfortably view targets at various angles.

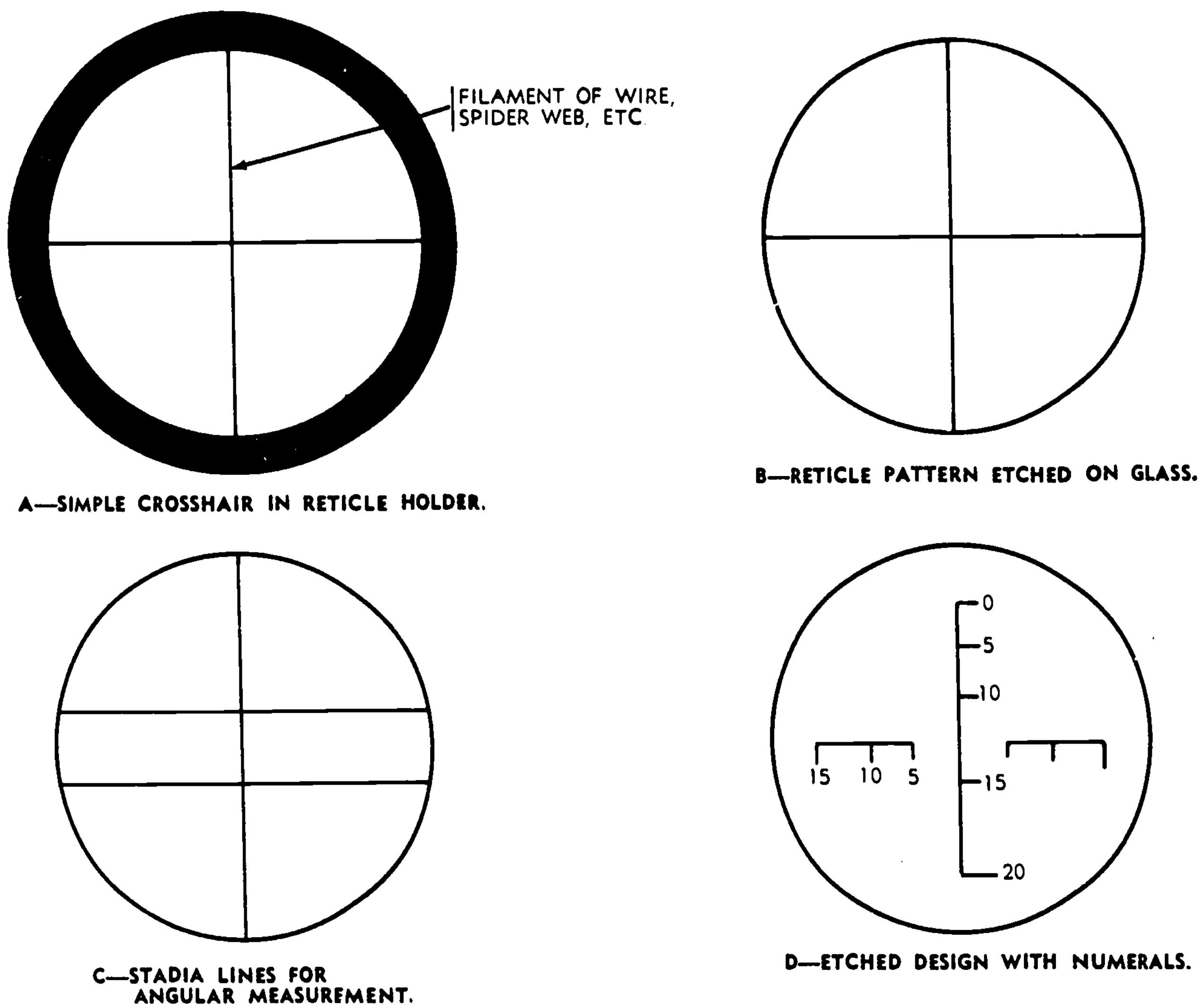

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Figure 5-36.—Examples of reticle patterns.

Reticles such as those shown in figure 5-36 are used in fire control instruments for superimposing markings or a predetermined pattern of range and deflection graduations on a target. When the reticle is placed in the center of the field of view, it represents the axis of the gunsight and then can be aligned with the axis of the bore of the weapon for short range firing, or it can be fixed at a definite angle to the bore for long range firing. A reticle is used as a reference for sighting or aiming, or it can be designed to measure angular distance between two points. Since the reticle is placed in the same focal plane as a real image, it appears superimposed on the target. In a gunsight employing a lens erecting system, there are two possible locations (fig. 5-37) where the reticle can be placed. If the erecting system increases magnification and the reticle is placed in the image plane of the objective, the reticle lines will appear wider than they were when placed at the focal point of the eyepiece. When a prism erecting system is used, the reticle usually is placed behind the erecting system.

Parallax

Parallax in an optical instrument is a defect of primary importance. In a correctly adjusted instrument, the image of the viewed object is

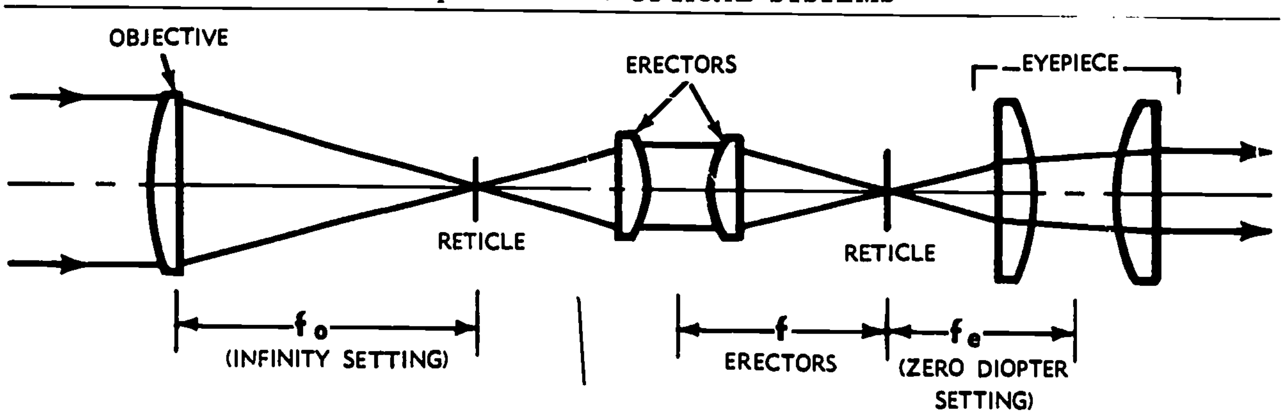

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Figure 5-37.—Reticle location in telescope with two erector lenses.

formed in the same plane as that in which the reticle lies. If this does not occur (fig. 5-38), parallax is said to be present and it can be detected by moving the eye back and forth across the eyepiece of the instrument. The appearance of relative motion between the reticle and the field of view indicates the presents of parallax (fig. 5-39).

The procedure for correcting this defect is to shift the optical elements of the telescope until the reticle lies in the precise plane of the real image. The technical manual for each type of instrument gives detailed procedures.

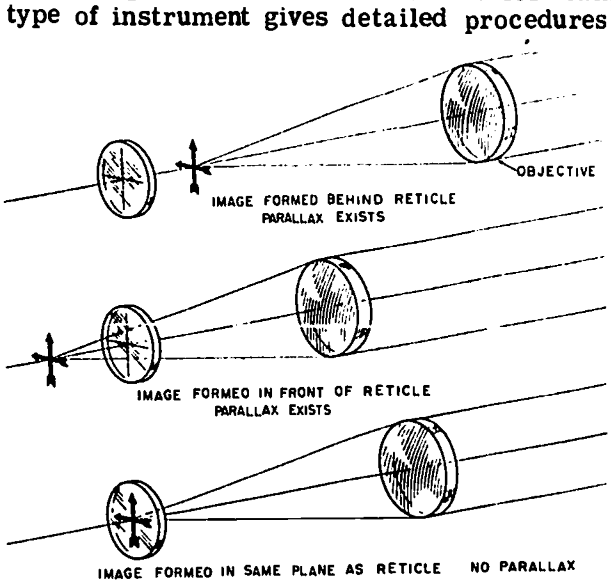

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Figure 5-38.—Optical parallax.

TELESCOPE MAGNIFICATION

The formula for computing the magnifying power of an astronomical telescope which has no erecting system is:

$$M = \frac{f_o \text{ (focal length of objective)}}{f_e \text{ (focal length of eyepiece)}}$$

This means that you can DETERMINE THE MAGNIFYING POWER of an astronomical telescope by dividing the focal length of the objective by the focal length of the eyepiece, provided the virtual image is at infinity, or the emergent light rays from the object are parallel. Remember the two conditions when this formula can be used for measuring magnifying power in an astronomical telescope. If the image is moved to the near point of the eye (10 in.), it increases slightly in size.

This formula can be used also for determining the amount of magnifying power produced by terrestrial telescopes which have PRISM ERECTING SYSTEMS; but it cannot be applied to terrestrial telescopes which have LENS ERECTING SYSTEMS, because such erecting systems can (and usually do) contribute to the power of the optical system.

Magnifying power in a one-erector optical system for a telescope is equal to the distance of the focal length of the objective divided by the focal length of the eyepiece, multiplied by magnification of the erecting lens.

You learned previously in this chapter that magnification in a variable-power telescope is accomplished by moving the erectors. When

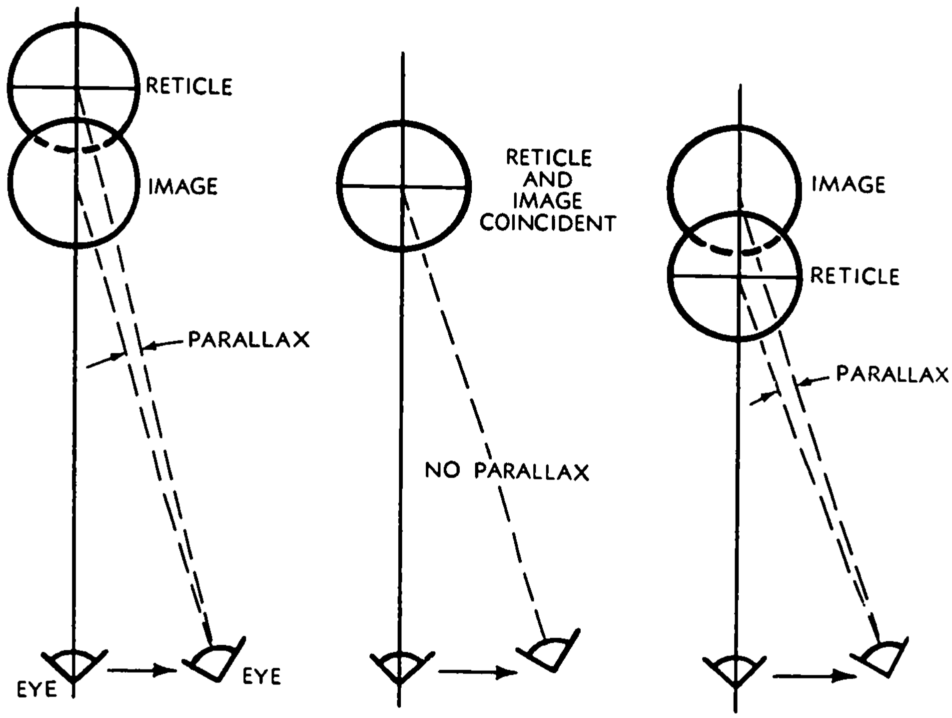

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Figure 5-39.—Relative motion in parallax.

the erectors are moved forward as a complete unit to increase magnification, or when the rear erector element only is moved forward, the image formed by the erectors moves back. This is the only case when the image position is not the same for all magnifications produced by the optical system of a variable-power telescope.

Power in an optical instrument is denoted by the letter x; for example, a 7 x 50 binocular is a 7-power instrument with an entrance pupil or objective size of 50 millimeters.

Another method for determining the magnifying power in all types of telescopes is this: DIVIDE THE DIAMETER OF THE ENTRANCE PUPIL BY THE DIAMETER OF THE EXIT PUPIL. The formula to use in doing this is:

$$MP, \text{ or } P = \frac{AP}{EP}$$

AP is the diameter or aperture of the entrance pupil, and EP is the diameter of the exit pupil (fig. 5-27). Observe the position of AP and also the position of EP. You will recall that ENTRANCE PUPIL means the CLEAR APERTURE OF THE OBJECTIVE; and that the EXIT PUPIL is the diameter of the bundle of light which leaves an optical system. The exit pupil is actually AN IMAGE OF THE OBJECTIVE LENS PRODUCED BY THE EYELENS.

You can measure the diameter of the entrance pupil with a transparent metric scale—directly across the objective. This method of measurement is sufficiently accurate for most purposes.

You can determine the diameter of the exit pupil of a telescope by: (1) pointing the instrument toward a light source (out a window, for example), (2) inserting a piece of translucent material in the plane of the exit pupil, and (3) measuring the diameter of the exit pupil on the paper.

The best way to measure the diameter of an exit pupil, however, is with a dynameter. See figure 5-40. This dynameter is essentially a magnifier or an eyelens with a fixed reticle on a frosted glass plate, both of which move as a unit within the dynameter tube.

To measure the exit pupil with a dynameter, place the dynameter between the eye and the eyepiece of the instrument and focus the dynameter until you have the bright disk of the exit pupil sharply defined on its frosted reticle. Then measure the diameter of the exit pupil

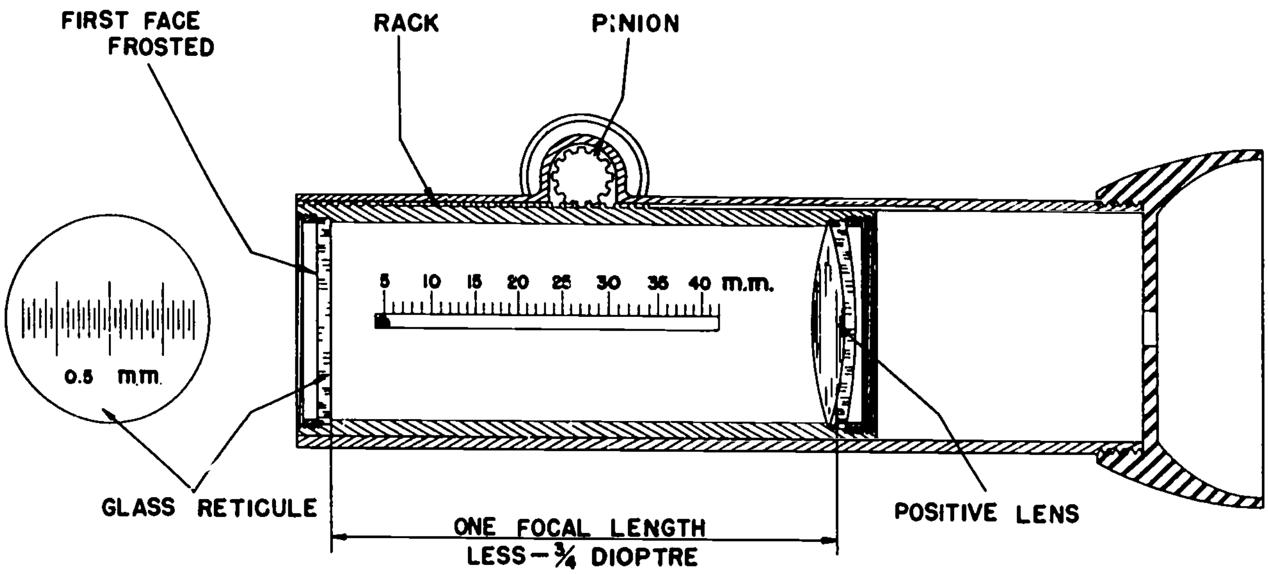

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Figure 5-40.—Dynameter.

on the dynameter reticle (usually graduated in .5mm) and read the eye distance on the scale on the dynameter tube. This means that in order to keep the image in focus the eyepiece must be moved a distance equal to the amount of shift of the image.

You will learn more details concerning the positioning of elements in the optical system of a telescope (and measuring magnification) when you study chapter 7, which deals with mechanical construction and maintenance of optical instruments.

$$MAG = \frac{\text{Diameter of entrance pupil}}{\text{Diameter of exit pupil}}$$

Suppose that the entrance pupil of an instrument is 50mm and the exit pupil diameter on the dynameter is 10mm. If you substitute these numbers in the formula and solve for MAG, you get 5, which is the magnification of the instrument.

You have already learned that the TRUE FIELD of an optical instrument is the width of the target area, or field, which you can see when you look through the eyepiece, expressed as either angular true field or linear true field; and you know that the objects you see are greatly magnified.

APPARENT FIELD is the opposite of true field, and it is the width of the target area, or field, which you can see when you look through the objective end of a telescope, expressed in either angular apparent field or linear apparent field. The objects you see through the objective end of a telescope are greatly MINIFIED; that is, they are not as large as they would be when viewed with the naked eye.

The apparent field is always larger than the true field, provided the optical instrument's original purpose was to magnify targets. You can therefore determine the angular magnification of an optical instrument by COMPARING THE RATIO BETWEEN the angular apparent field and the angular true field.

To determine the angular apparent and true field of an optical instrument, you must have some means for measuring these angles directly with the instrument. This you can do by placing the instrument on an angle-measuring instrument such as a bearing circle (chapter 10), or some other instrument by means of which you can measure the angular movement of the instrument when you have it positioned horizontally.

Place the instrument you are chekcing on the angle-measuring instrument in the normal viewing position (eyepiece toward you), and focus the instrument on a distant object (flag or telephone pole, for example). Then turn the measuring instrument (with the telescope on it) as necessary in order to have one side of the pole at one extreme edge of the field of view and take a reading on the measuring instrument. Next, turn the measuring instrument (with pole still in view) until you have the SAME SIDE OF THE POLE on the OPPOSITE EXTREME EDGE of the field of view and take another reading to find out how many degrees you moved the instrument to get from one reading to the other reading. This measurement is the TRUE FIELD.

Now turn the telescope around on the angle-measuring instrument, with the objective end toward you, and look through the objective lens at the same object. The object is MANY TIMES SMALLER than when you were looking at it through the eyepiece. Finally, turn the measuring instrument and telescope (with it) as necessary to have the same side of the pole on the same extreme edge of the field of view. When you now repeat the same steps you follow in measuring the true field, you will find that your measurement is much larger than the true field. This larger measurement in degrees is the APPARENT FIELD of the telescope.

To determine the magnification of this instrument, divide the apparent field by the true field. The formula follows:

$$MAG = \frac{\text{Apparent Field}}{\text{True Field}}$$

Now use the formula to determine magnification of an instrument with an apparent field of 50 degrees and a true field of 5 degrees. Substitute the measurement for each field in the formula and solve for MAG and you get 10, which means that the telescope is 10 power.

THE MICROSCOPE

An instrument that is used to produce an enlarged image of very small nearby objects is called a microscope. Microscopes are of two types, simple and compound. A simple microscope produces but one image of an object and consists of a convergent lens located at the first focal plane of the eye. In effect, this is just a

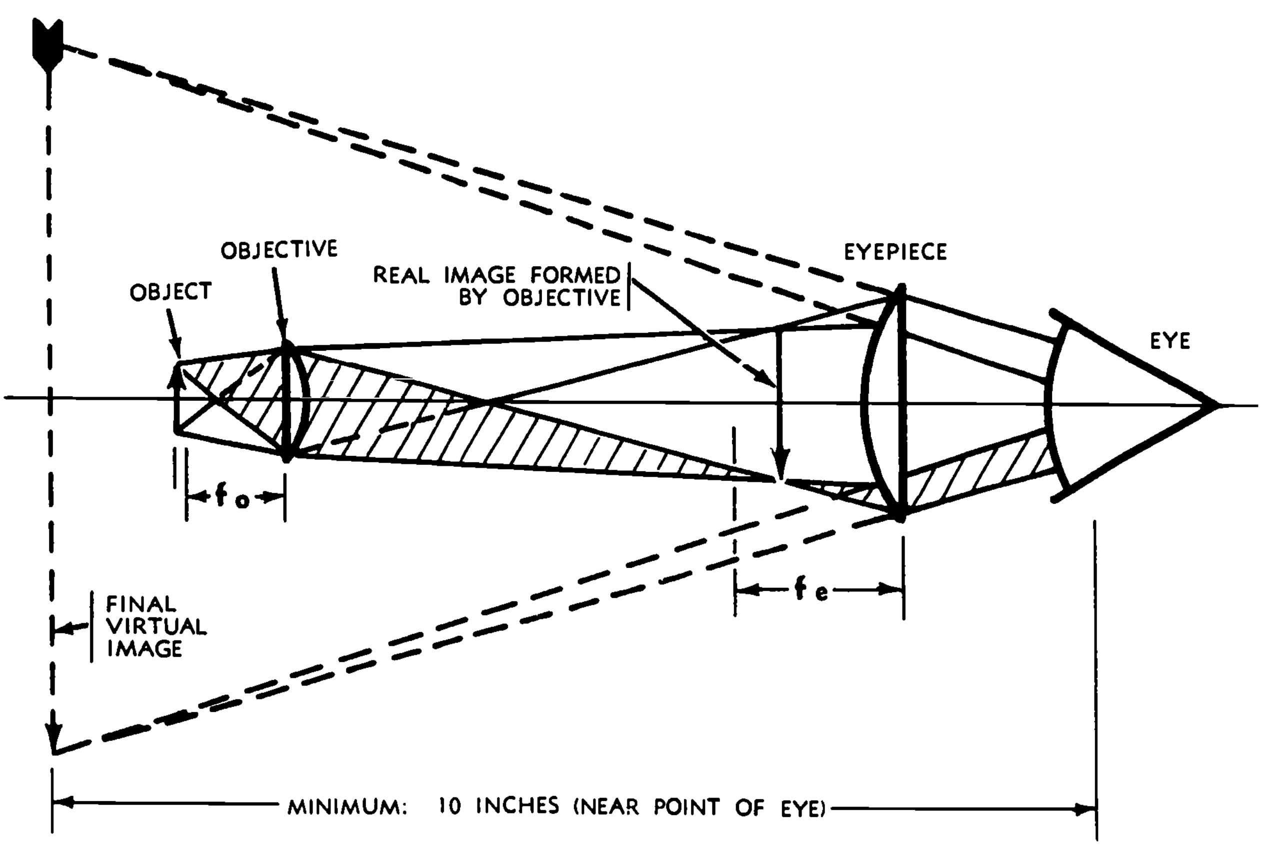


Figure 5-41.—Image creation by a compound microscope.

simple magnifying lens as covered in chapter 4. A compound microscope first forms an image by the objective lens, and this primary image is further magnified by an eyepiece.

You perhaps used a compound microscope to look at minute plants and animals when you were in high school. Such an optical instrument so magnifies small objects that it increases the usefulness of the eyes at short distances. The eyes, by nature, are long-range optical instruments of high acuity.

Refer now to figure 5-41, which shows one of the simplest types of compound microscopes. Study all details and the nomenclature. Note the position of the eye, the eyepiece, the objective, and the object. Then observe the positions of the real and virtual images.

Rays of light from the object strike the objective (closest lens to the object) and then strike the eyepiece, which refracts them in the direction of the eye. The objective of a microscope has an extremely short focal length, to ensure enlargement of the image formed on the retinas of the eyes. The image it forms is real, enlarged, and inverted, as shown. THE EXTREMELY SHORT FOCAL LENGTH OF THE OBJECTIVE IS REPRESENTED BY fo; the SHORT FOCAL LENGTH OF THE CONVERGING EYEPIECE IS REPRESENTED BY fe.

If the real image is at the first principal focus of the eyelens, the eyes see the image at infinity and no accommodation is necessary. The final, virtual image (large, broken arrow) may be formed at any distance which exceeds the shortest distance of distinct vision (about 10 inches). In this case, the image formed by the objective must be within the principal focus of the eyepiece, fe (fig. 5-41). Magnification in a microscope depends upon the focal lengths of the objective and the eyepiece, and the distance between these two optical elements. A compound microscope can magnify an object about 2,000 times (diameters); but little increase, if any, in the details of an object is obtained after the object has been magnified 400 times. Magnifying power of a compound microscope is equal to the magnification of the objective lens multiplied by the magnifying power of the eyepiece.

CHAPTER 6
DESIGN AND CONSTRUCTION

MECHANICAL FEATURES

Optical instruments used in the Navy are complicated, delicate, PRECISION instruments. A small error in alignment, a foreign particle, or a trace of moisture can render such an instrument ineffective or useless. These delicate instruments get almost constant use and are subjected to all kinds of weather conditions and rough treatment. To keep them in working condition, the Navy depends on your skill as an Opticalman and the mechanical design of the instrument. The mechanical design is important to the instrument's effectiveness because it controls the stability and cleanliness of the optical elements.

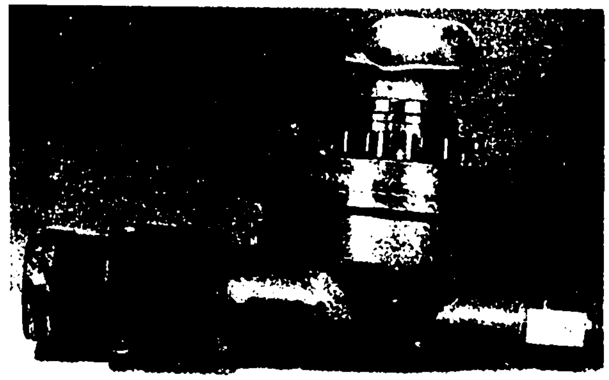
BODY HOUSING

The design of an instrument housing is influenced by three factors: the location of the instrument when in use; what the instrument is used for; and the location of the optical elements within the housing. The housing of a pair of binoculars is not subjected to the same pressures that a submarine periscope is, and a binocular's line of sight is not offset as much as that of a periscope.

Figure 6-1 illustrates a MK 74 gunsight whose housing is rather small and simple in construction. The housing weighs about 15 pounds and houses 11 optical elements, in a line of sight that is deviated 90°.

Figure 6-2 illustrates a MK 67 gunsight whose housing is large and very complex. The housing of the MK 67 gunsight weighs about 135 pounds, and houses 17 optical elements. These large telescopes, when fixed in position on a gun mount, offset the line of sight about two feet and enable the observer to follow fast-moving targets without changing body position. Elevation and deflection of the line of sight are accomplished by rotating prisms that are driven by shafts and gears in the sight mechanism.

Observe the differences in the housing of figure 6-1 and 6-2 and note the location of the optical elements in the two gunsights. All of these elements must be positioned and secured in the housing so that they will remain in place under normal circumstances and not impair the effectiveness of the instrument.



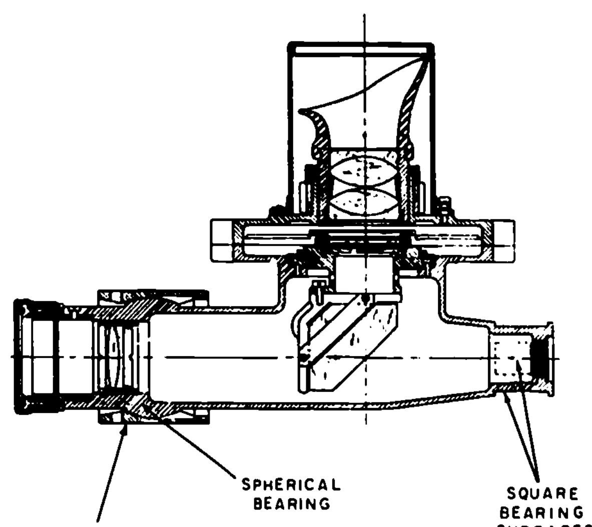


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Figure 6-1.—Housing features of MK 74 gunsight.

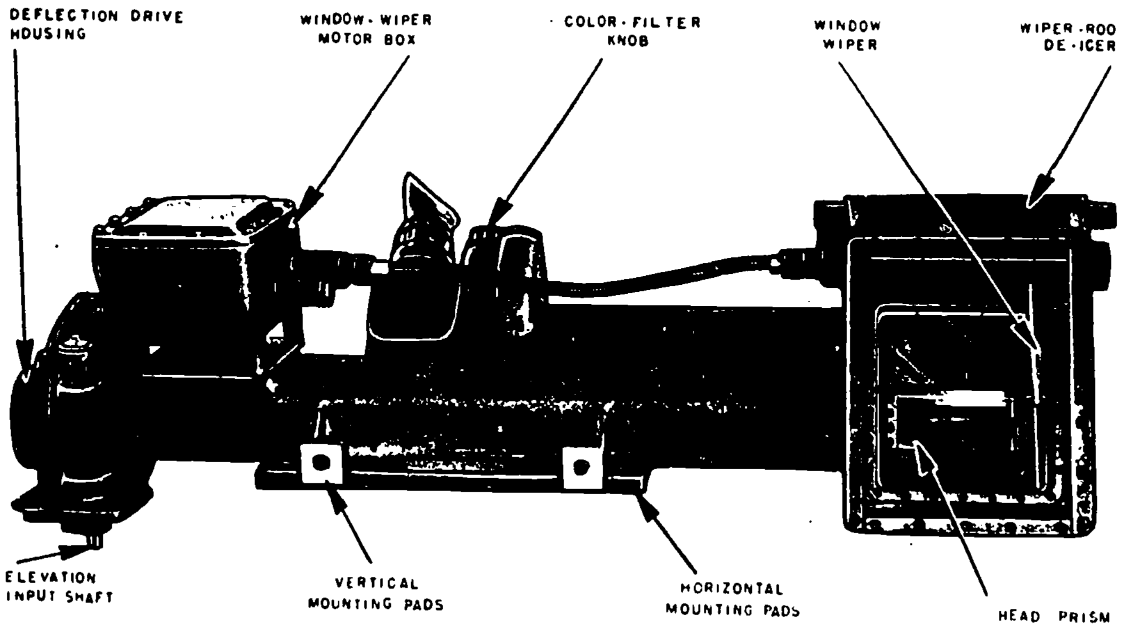

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Figure 6-2.—The Mark 67 telescope.

Material

The material used to construct the body housing is selected with reference to the specific instrument. If the instrument is to be hand held, and portable, the material must be lightweight and yet strong enough to withstand the shock and abuse it may be subjected to. Cast aluminum and magnesium alloys are usually used for binocular bodies and some portable straight line telescopes.

Gunsight telescopes are mounted directly on turrets and gun mounts where they receive large degrees of shock. Most housings of gunsight telescopes are made from cast bronze or steel alloys that have the strength to support and protect the optical and mechanical components of the telescope. The material specifications for a telescope housing is shown on the appropriate drawing, and the repairman should know the type of material he will be working with before he attempts any repairs to the housing.

Arrangement

The location of the optical and mechanical components of an instrument is a prime factor in determining how a housing must be arranged.

Figure 6-3 is a cutaway view of the MK 102 Mod 2 telescope and is used to illustrate the complexity and importance of housing arrangement. Refer to this figure often as you study the description that follows.

The telescope housing assembly is cast bronze and finish-machined with great precision and is open at the front and back. The front of the housing is closed by a window and the rear by a metal cover plate. The interior of the housing is divided, by an irregular vertical wall, into an optical chamber and a servo chamber. The gas-tight optical chamber is in front of the dividing wall and the water-tight servo chamber is to the rear. A square box shaped section rises toward the rear from the top as an integral part of the housing to position and support the optical tube, headrest assembly, and focus assembly. The housing is cast with four mounting pads, two on each side, which provide a vertical mounting surface; and four mounting pads on the bottom which provide a horizontal mounting surface. Both of these mounting surfaces are precision machined and located to provide accurate alignment of the telescope on the gun mount.

The front window of the telescope is secured by a window retainer and sealed by two gaskets. Stuffing tubes on the right side of the housing allow for passage of electrical cables without

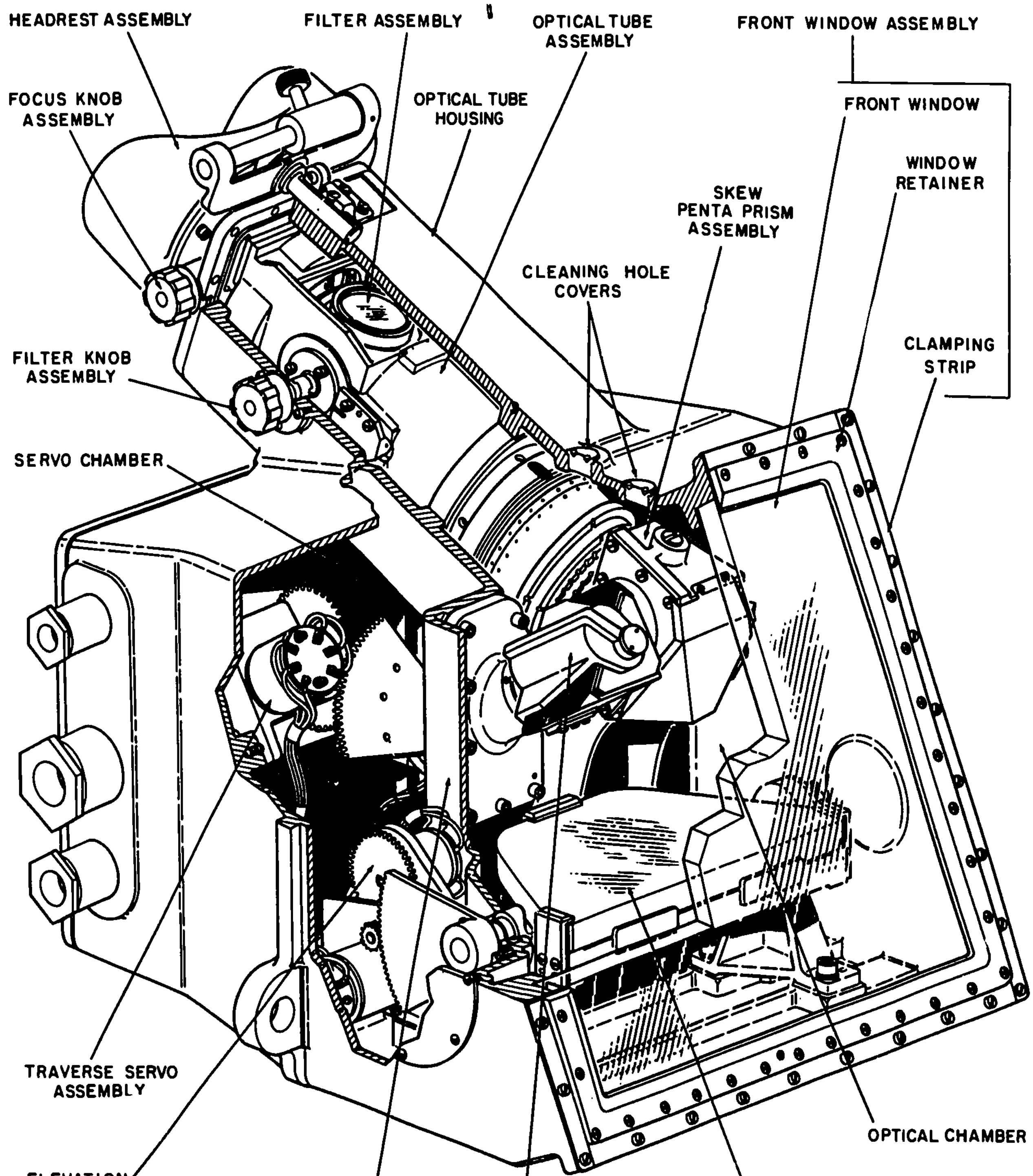

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Figure 6-3.—Telescope Mk 102 Mode 2; cutaway view.

loosing the water-tight seal in the servo chamber. The focusing knob and filter knob are sealed by a packing gland where the shaft passes through the housing.

The optical tube assembly is a brass cylinder about 12 inches long, which houses the objective lens, filter assembly, and reticle in position within the body housing.

The elevation mirror and skew pents prism assemblies are positioned in the optical chamber by brackets. Two servo assemblies mechanically connected to the mirror and prism allow the line of sight to be elevated and deflected.

Access and Adjustment

We have seen how the design of a housing is affected by the positioning of the instrument components, but another problem that a designer must consider is accessibility. A body housing must be made in such a way that all of the parts enclosed in the instrument can be assembled and adjusted in a convenient manner. This is accomplished by providing a number of access holes and cover plates. The number of openings in any instrument housing is always kept at a bare minimum, since each opening is a source for gas to escape and moisture or dirt to enter the instrument.

Refer now to figure 6-4 which shows a rear view of the MK 102 gunsight with the rear access cover removed. Notice how the servo chamber is exposed allowing the repairman to adjust or repair the electrical system of the sight.

When it is necessary to gain access to the optical chamber, the repairman would remove the front window shown in figure 6-3.

SHADES AND CAPS

When an optical instrument is not in use, it should be placed in a case that will protect the exposed optical elements such as objective and eyelenses. If the instrument is mounted in such a manner that using a case is not feasible, then some other form of protection is provided.

Lens Caps

A very effective and convenient way to protect an eye lens or objective lens is to use a lens cap. These caps are made of metal with a friction fit over the area to be protected or threaded onto the telescope. "A" of figure 6-5 illustrates a slip-on objective cap for an azimuth telescope, and "B" shows a threaded cover for a ship's telescope eyepiece. When a ship is at sea, the external optical surfaces are exposed to salt water spray, stack soot, and grime which will damage optical elements very easily. For this reason, the protective caps should always be utilized when the instrument is not in use.

Sun Shades

An optical instrument that is used extensively in sunlight will have a sunshade to reduce glare caused by sunlight directly striking the outer face of the objective lens. Sunshades, as illustrated in figure 6-5 are usually tubular sections of metal fitted around the objective, with a lower portion cut away. A sunshade will also protect the objective from falling rain and heat from the sun that would harm the thermosetting cement used to cement elements of a compound objective.

Eye Guards

Eye guards similar to those illustrated in figure 6-6 are used extensively on optical instruments. These guards are made from plastic or rubber and protect the observer's eye from gun fire shock or similar disturbances. In addition, an eye guard will maintain proper eye distance and keep out stray light rays.

DIAPHRAGMS

Diaphragms are rings of opaque material placed in an optical system so that the passage of light is limited to their center. When a diaphragm is used in this manner, it is referred to as a stop. Study figure 6-7 as various stops are discussed.

Field Stops

A diaphragm that is positioned so that it limits the field of an instrument to that area which is most illuminated, is called a "field stop." A field stop is placed at the image plane and helps produce a sharply focused image by eliminating the peripheral rays that cause poor imagery because of aberrations. Placing the field stop at the image plane not only limits the field, but also sharply defines the edge of the field and prevents the observer from viewing the inside of the instrument. When a field stop is used at each image plane, the second and succeeding field stops are larger than the image

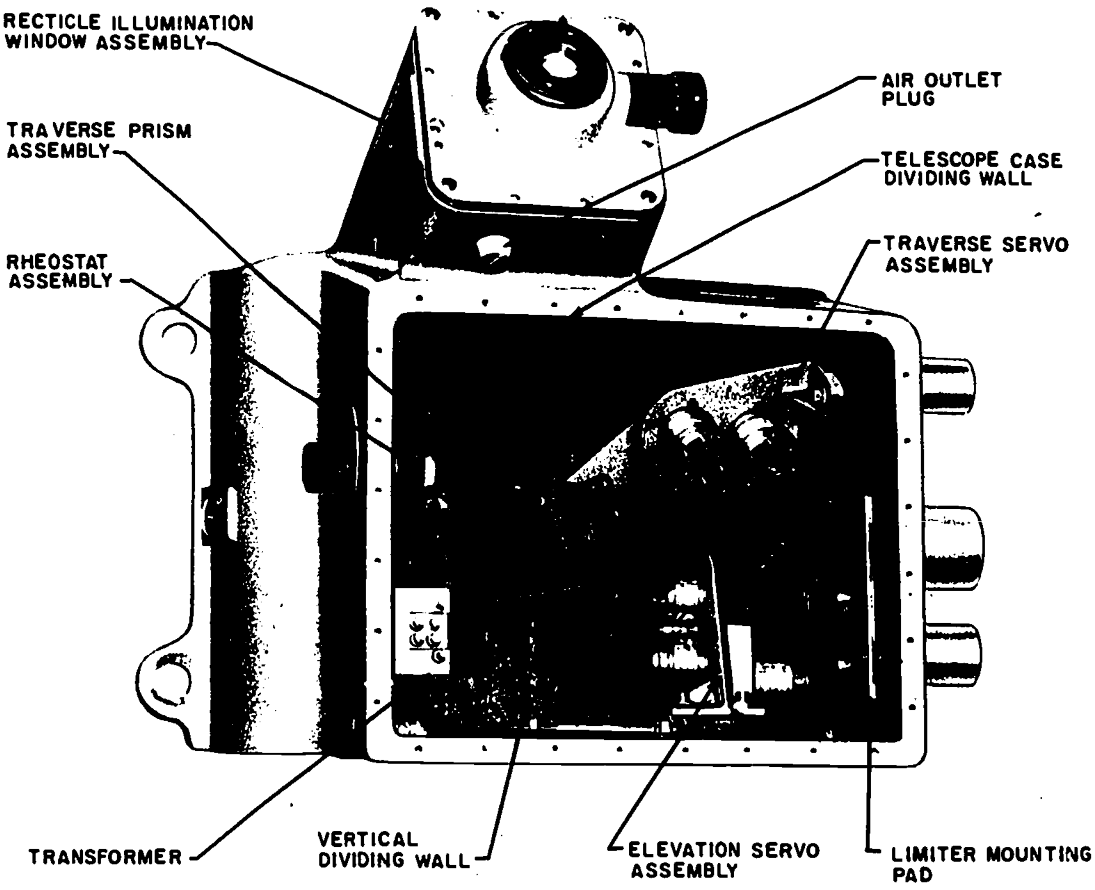

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Figure 6-4.—Telescope Mk 102 Mod 2; servo chamber.

of the first so that slight inaccuracy in size or positioning will not conflict with the sharply defined image of the first.

Aperture Stop

A stop that is so positioned as to limit the size of the aperture of a lens is called an "aperture stop." In most telescopes this is usually the objective lens mount or retainer ring as there is no reason for reducing the size of the aperture of the single compound objective lens used in such an instrument. A stop, in close proximity to a single compound objective, will only reduce the illumination and exit pupil size without reducing lens aberrations. In the event an instrument has an objective so complex that two or more separate lenses are used, an aperture stop located between the elements may serve to reduce aberrations.

Antiglare Stops

Diaphragms are placed in optical instruments within the focal length of the objective to prevent ray's exterior from reflecting off the interior of the instrument and causing glare. These are called "antiglare stops" and are finished with nonreflecting paint or oxide coatings.

In straight line telescopes, the stops could be merely washers on disks with a hole in the center. In the construction of a binocular, the prisms shelf is designed to act as a stop for stray light.

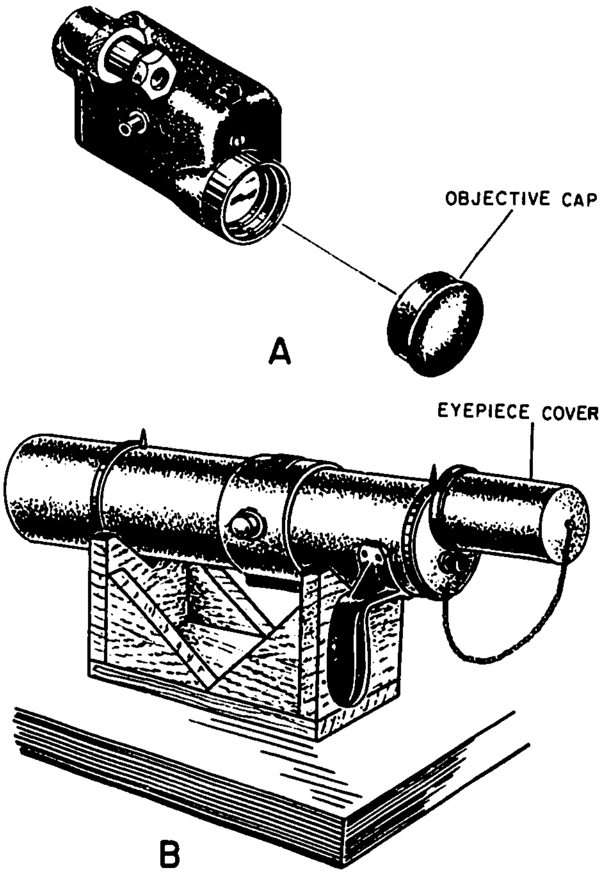

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Figure 6-5.—Lens caps.

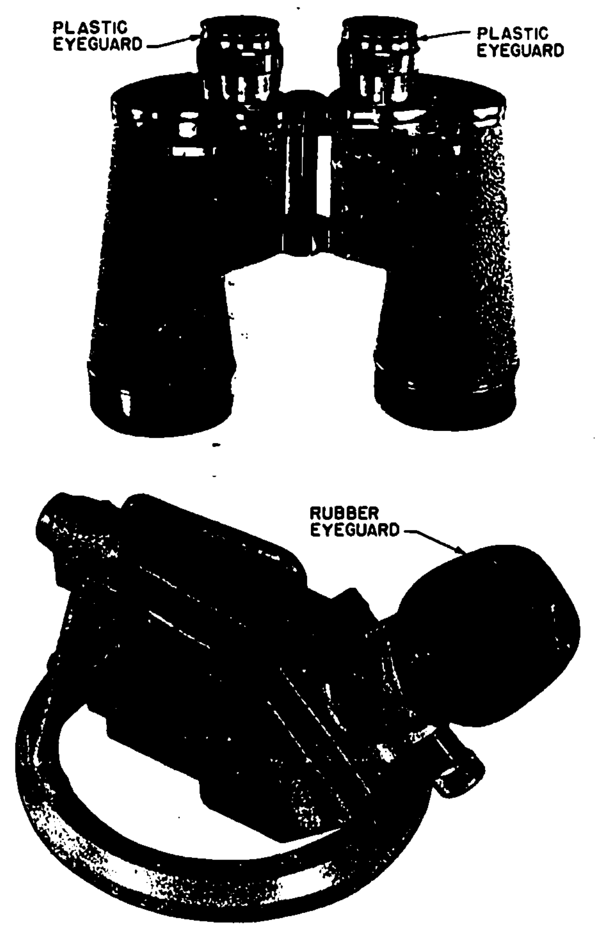

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Figure 6-6.—Eyeguards on instruments.

MOUNTING OPTICAL ELEMENTS

After a designer of optical instruments has decided where an element must be positioned. he must also solve the difficult problem of designing the proper mount for the element. The lens or prism must be held securely in place without putting a strain on it that will cause a distorted image or break the element. If the element is to be adjustable, he must design the mount so that it can be adjusted without looseness or play. The following discussion will cover the most common mounts that you will be working with as an opticalman.

LENS MOUNTS

After a lens has been ground and polished to the proper curvature, the lens is then ground on the edge to its final diameter. Since the edge of the lens will be used to position it in its mounting, the optical axis of the lens must coincide with its mechanical axis. Occasionally it is possible to machine the housing of an instrument so that a lens can be mounted directly in the housing. This is the case of the objective lens of the Mark 75 Mod 1 boresight telescope shown in Figure 6-8. The objective lens is mounted in a fixed position at the end of the body tube, against a seat ring, and held in place by a retaining ring.

When two or more lenses are positioned near each other, the designer will use a lens cell similar to that shown in fig. 6-9. The lens cell is made of tubular metal precisely machined to hold the lenses, separated by spacers, in a predetermined position. The spacers are machined with a bevel where they make contact with the lens and provide a snug fit with no sharp edges to mar the lens. The optical and mechanical parts are then secured in the cell by a retaining

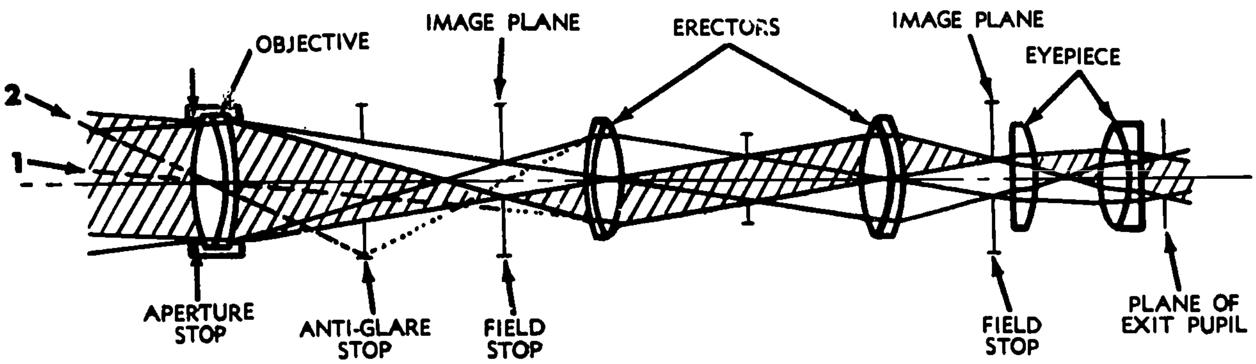

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Figure 6-7.—Diaphragm locations.

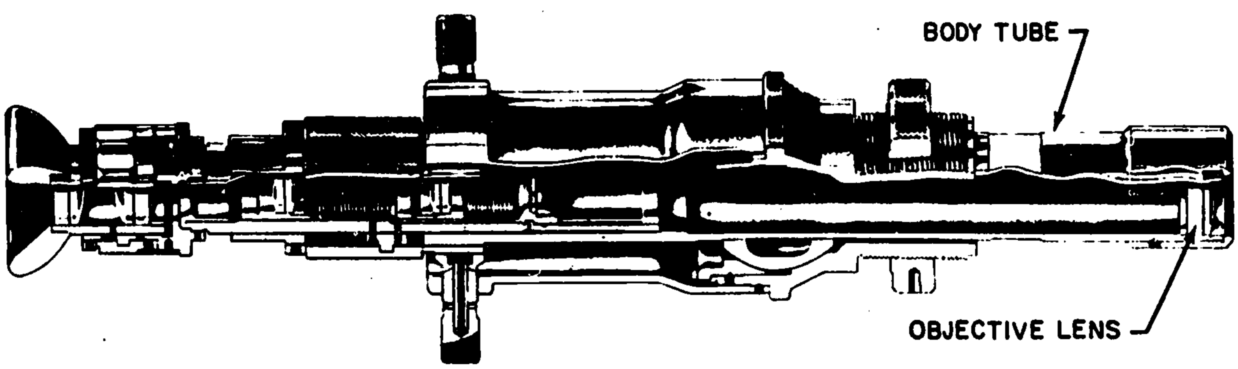

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Figure 6-8.—Cutaway view of a Mk 75 Mod 1, boresight telescope.

ring. Lenses mounted in a cell can be adjusted and placed in the instrument as an assembly.

In order to mount a single lens in an instrument so that it may be axially adjusted during assembly, an adjustable mount like that shown in figure 6-10 is often used. The lens is fitted snugly against a shoulder in the mount and held in place by a retainer ring. The mount is externally threaded so that it can be screwed into the telescope housing to its proper position, and locked in place by a lock ring or set screw.

Retainer Rings

In our discussion of lens mounts, we have frequently illustrated and referred to retainer rings. We have seen how they are used to hold a lens in a mount and how they are used to secure a mount in place. Every instrument that you work on in the Navy will have retainer rings and they are very important to an instrument. When a retainer comes loose, the lens will be loose and the instrument's effectiveness impaired or lost.

You will be working with rings that range from small and delicate to large and cumbersome, but they all must be handled carefully so as not to damage the fine threads or distort their shape. Most retainer rings and other threaded mechanical parts are locked in place by a set screw or locking compound that hardens when dry such as shellac. BE VERY SURE THAT ALL SET SCREWS AND LOCKING COMPOUNDS ARE REMOVED BEFORE TURNING THE RING. If not, you will damage the threads on the mount and the retainer, which will cause added repair work or ruin the part. Note figures 6-9 and 6-10 which illustrate set screws used to lock the retainer. Not all locking screws are so predominately located, so examine the retainer carefully for hidden locks.

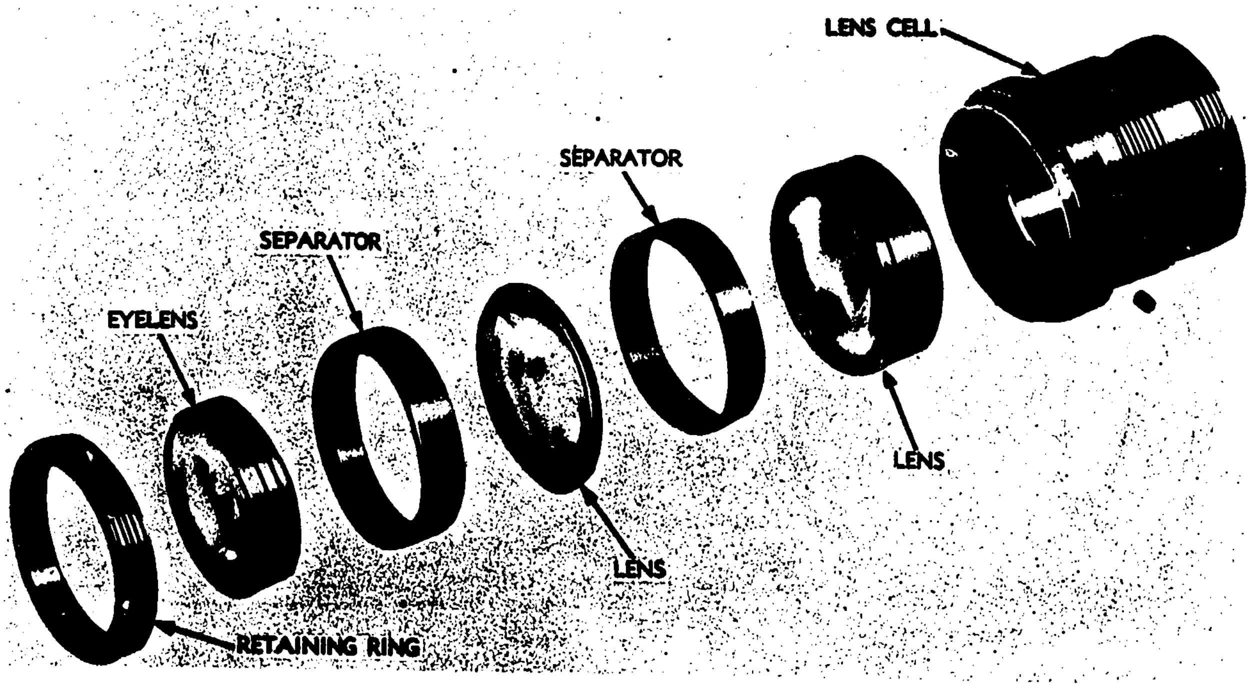

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Figure 6-9.—Lens cells, lenses, separator, and retaining ring.

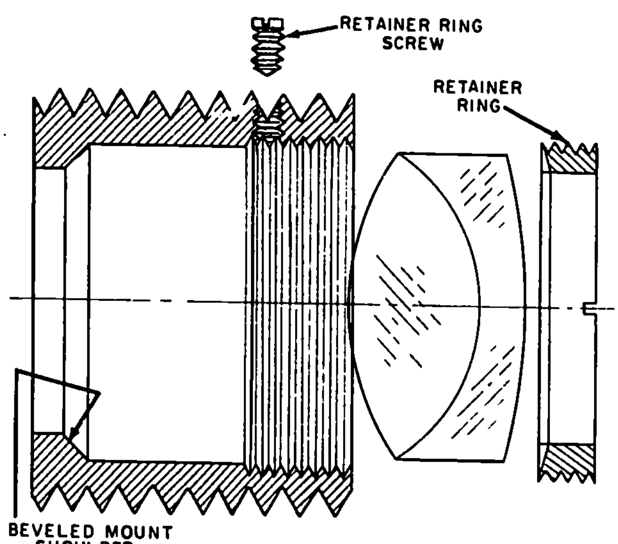

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Figure 6-10.—Adjustable lens mount.

Screw Adjusting Mounts

Occasionally it is necessary to have an element placed in an instrument in such a way that it can be adjusted after the instrument is assembled. For this you will find a screw adjusting mount similar to that illustrated in figure 6-11. This mount has four adjusting screws at 90 degree intervals for adjusting horizontally and vertically. The adjusting screws extend through the telescope body and can be either a slotted head (illustrated) or a thumb screw type. By letting out on one screw and taking up on the other, the element can be positioned with great accuracy. Care must be taken when tightening the screws so that no undue strain is placed on the mount or element.

Eccentric Mount

We have seen where the optical axis of an instrument must coincide with its mechanical axis if the instrument is to be in alignment. In order to assure alignment, lenses are sometimes placed in an adjustable eccentric mount that allows the lens and its optical axis to be moved in a plane perpendicular to the axis of the instrument. Figure 6-12 illustrates the eccentric objective mount of a binocular; refer to it as you read the following description. The eccentric mount has a concentric bearing surface (fig. 6-12) so machined that it is offset from the mechanical axis of the mount. A ring (fig. 6-12),

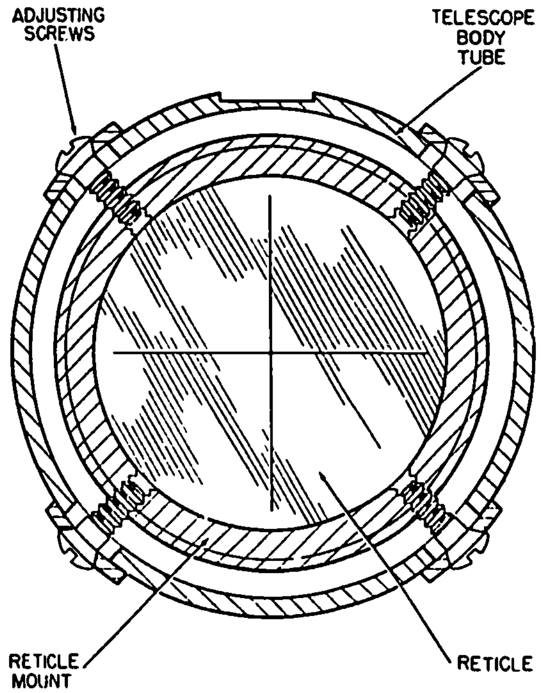

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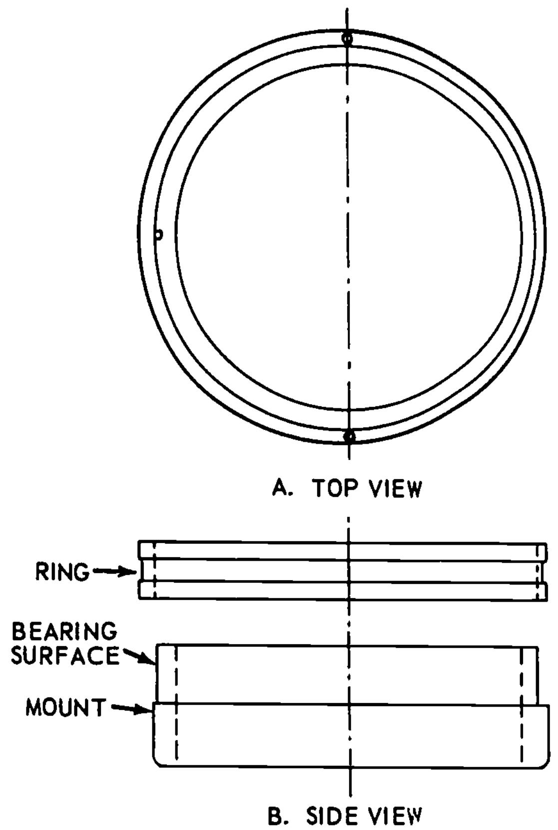
Figure 6-11.—Adjustable recticle mount.



137.521
Figure 6-12.—Eccentric lens mount assembly.

whose inner and outer surfaces are eccentric to each other, is placed over the bearing surface of the mount to act as a bushing to hold the assembly in the binocular body. By rotating the lens mount in the outer ring or by rotating the outer ring around the mount, the optical axis of the lens can be moved to any desired point within a relatively large area. Some additional movement may be obtained by rotating the objective lens in its mount since most lenses have some inherent eccentricity. The objective assembly is then locked in place by a combination of set screw and retainer ring.

PRISM MOUNTS

As with other optical elements, a prism in an optical instrument must be correctly positioned with respect to all other elements in the system. The problem of positioning a prism is compounded by the bulkiness and the varied shape of prisms. Practically all lenses are round and so the designer uses tubular mounts for most lenses, but prism mounts must be individually designed to fit the shape of the particular prism that is used. Space does not permit a full description of all the prism mounts used in Navy instruments, but a few are explained briefly.

Roofedge

The ROOFEDGE prism mount illustrated in part A of figure 6-13 consists of a right angled bracket on which the prism rests. Shoulders ground on the frosted sides of the prism act as mounting surfaces which are used to secure the prism in the bracket.

Two prism straps (one on each side) are placed against the prism shoulders, and then secured by screws to the bracket. The bracket is fastened to the telescope body with four screws which can be loosened when it is necessary to adjust the prism mount. Part B of the illustration shows disassembled parts.

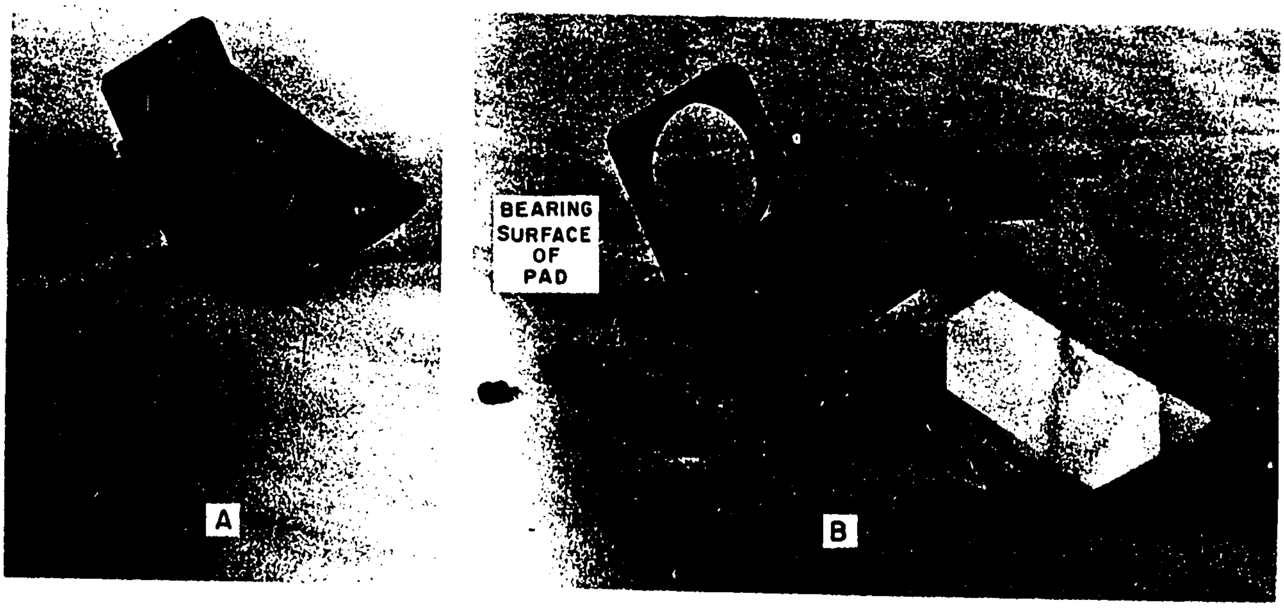


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Figure 6-13.—Roof-edge prism mount.

Right-Angled

Mounts for right-angled prisms vary in design in accordance with needs. One mount (fig. 6-14) holds the silvered or reflecting surfaces of prisms securely in place and properly aligned on bearing pads which prevent the surfaces from touching the base of the mount. Four prism straps, two on each side, hold the prisms in position. The straps also contain bearing pads which help to keep the prisms properly aligned without chipping.

Porro Prism Mounts

A porro prism mount (fig. 6-15) consists primarily of a flat metal plate shaped to the interior of a telescope body. It is machined to hold one prism on each side of the plate. The hypotenuse surfaces of the prisms are mounted parallel to each other, and they are set over holes machined in the plate to allow light to pass from one prism to the other.

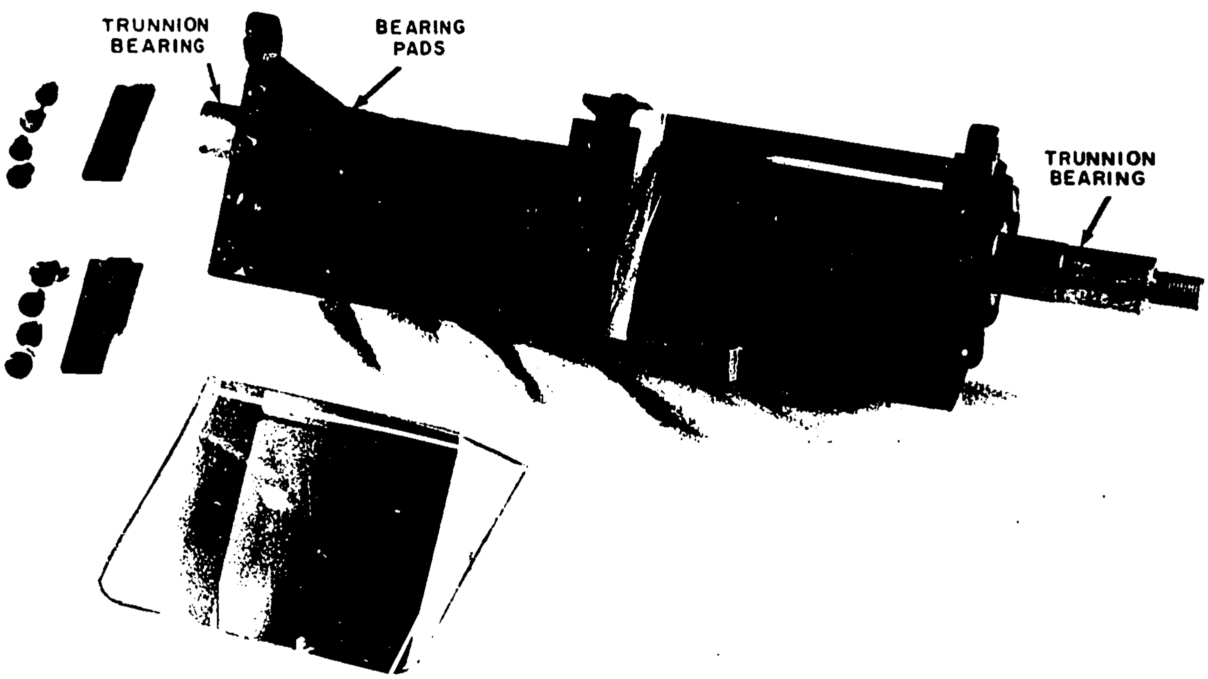
In order to maintain the APEX surfaces of the two mounted prisms at 90° angles with each other, a rectangular, metal adjustment ring (prism collar) is placed snugly around each prism. If the two prisms are NOT AT 90° ANGLES with each other, an effect CALLED LEAN IS CREATED IN THE PRISM CLUSTER, which means that the IMAGE APPEARS TO LEAN AT AN ANGLE IN COMPARISON WITH THE ACTUAL OBJECT.

Each prism is secured to the mount with a spring clip or prism strap, pressed against the apex of the prism. The strap itself is secured to two posts, one on each side of the prism; and the posts, in turn, are screwed into the prism plate. A metal shield placed over each prism under the prism strap prevents stray light from entering the other prism surfaces. These shields must be so placed that they do not touch the reflecting surfaces of the prisms; because if they touch, total internal reflection does not take place and some of the light is refracted through the reflecting surface and absorbed by the light shields.

FOCUSING ARRANGEMENTS

The majority of focusing arrangements that an opticalman comes in contact with are eyepiece assemblies, since most instruments must be adjustable to the individual observers eye.

Lenses in an eyepiece usually are secured in a tubular type mount. The field lens and the eyelens may be fastened separately, each with a retainer ring; or they may be secured together by the same retainer ring, with a separator placed between the field lens and the eyelens



137.172

Figure 6-14.—Right-angled prism mount.

to hold both at the correct distance from each other.

The distance between the reticle and the eyepiece in an optical instrument must be so adjusted to the observer's eye that the reticle and image of the object are sharply defined and eye fatigue is eliminated. In order to provide this adjustment, the lenses (2 or more) of the eyepiece are mounted in a single lens cell or tube, whose distance from the reticle (also focal plane of the objective) can be adjusted by a rack and pinion, a draw tube, or by rotation of the entire eyepiece during adjustment of the diopter scale.

Some of the focusing arrangements used on eyepieces are shown in figure 6-16.

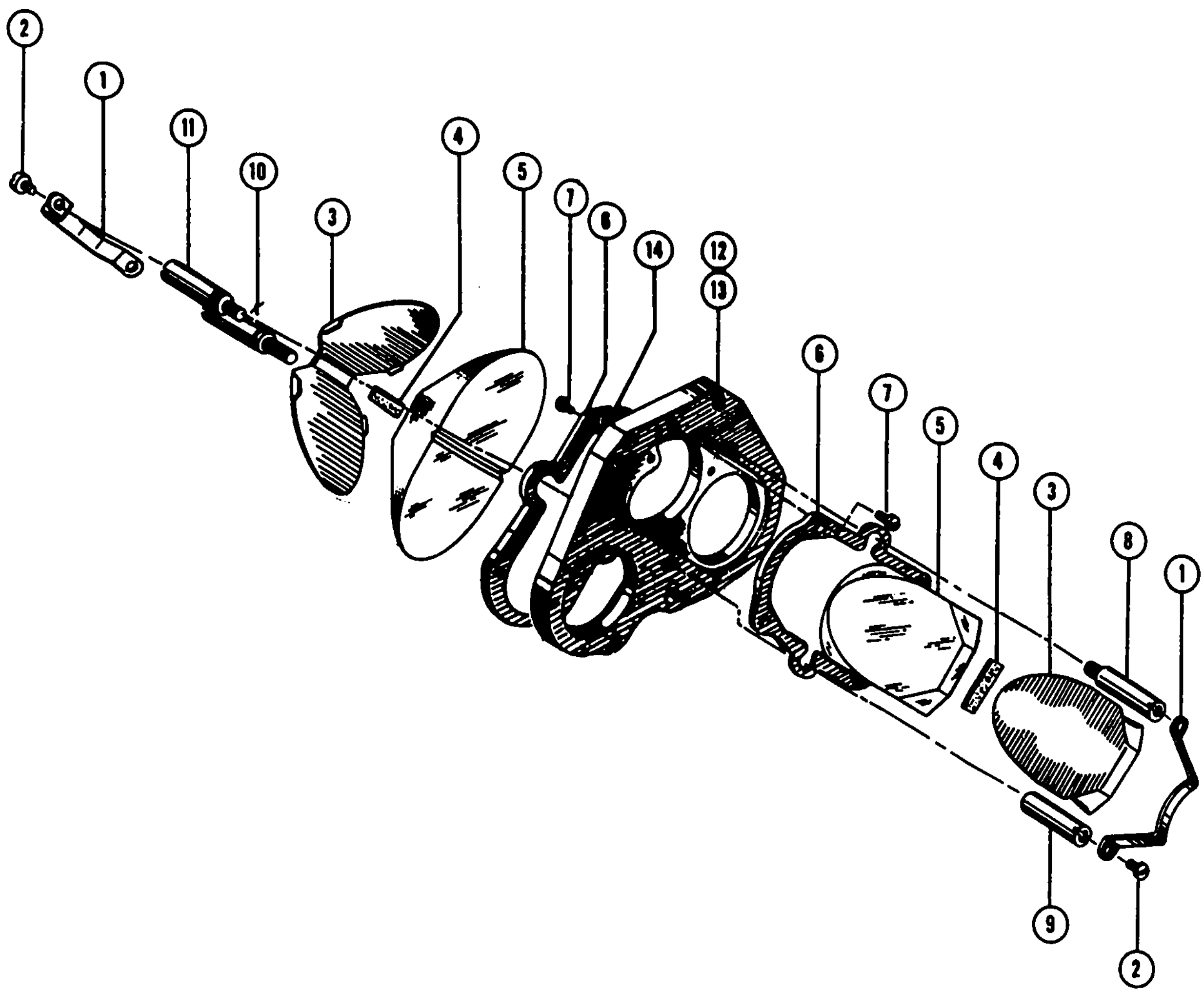
Draw Tube

A draw tube focusing arrangement E of (fig. 6-16) consists of a metal tube carrying the lenses and their retainer ring. The tube is focused manually by sliding it forward or backward in a guide tube at the rear of the telescope body or housing. The draw tube can be secured to the guide tube or withdrawn completely from it. This type of eyepiece focusing arrangement, however, is not widely used in the Navy, because the draw tube focus can be disturbed by a slight jar.

Spiral (Helical) Keyway

A spiral keyway focusing arrangement (fig. 6-17) is a modification of a draw tube. It is similar in construction to a draw tube, but has the additional following components: (1) a focusing key or shoe, (2) a focusing ring, (3) a retainer ring, and (4) a diopter-ring scale.

A straight slot which guides the focusing key is cut through the guide tube parallel to the optical axis of the telescope. The focusing key is fastened to the draw tube and protrudes through the straight slot to engage a spiral groove or keyway in the focusing ring. The focusing ring is permitted to turn on the guide tube, but it is prevented from moving along the optical axis by a shoulder on the guide tube and the retainer ring on the opposite side. The diopter-scale ring is mounted on the shoulder



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1. Prism clip.
2. Prism clip screw.
3. Prism shield.
4. Prism clip pad.
5. Porro prism.
6. Prism collar.
7. Prism collar screw.
8. Prism post A.
9. Prism post B.
10. Prism post C.
11. Prism post D.
12. Left prism plate and dowel pins.
13. Right prism plate and dowel pins.
14. Prism plate dowel pin.

Figure 6-15.—Porro prism mount.

137.170

of the eyepiece guide tube and is read against the index mark on the focusing ring.

The diopter scale is graduated on either side of 0 DIOPTER TO READ FROM PLUS TO MINUS DIOPTERS. The number of plus or minus diopter graduations depends upon the design of the instrument, but it usually runs from +2 to -4 diopters. When the focusing ring is turned either way, the focusing key follows the spiral keyway and moves the draw tube in or out to focus the eyepiece. If an operator focuses the eyepiece to his eye and notes the diopter scale reading, he can save time by adjusting to that reading each time he uses the optical instrument.

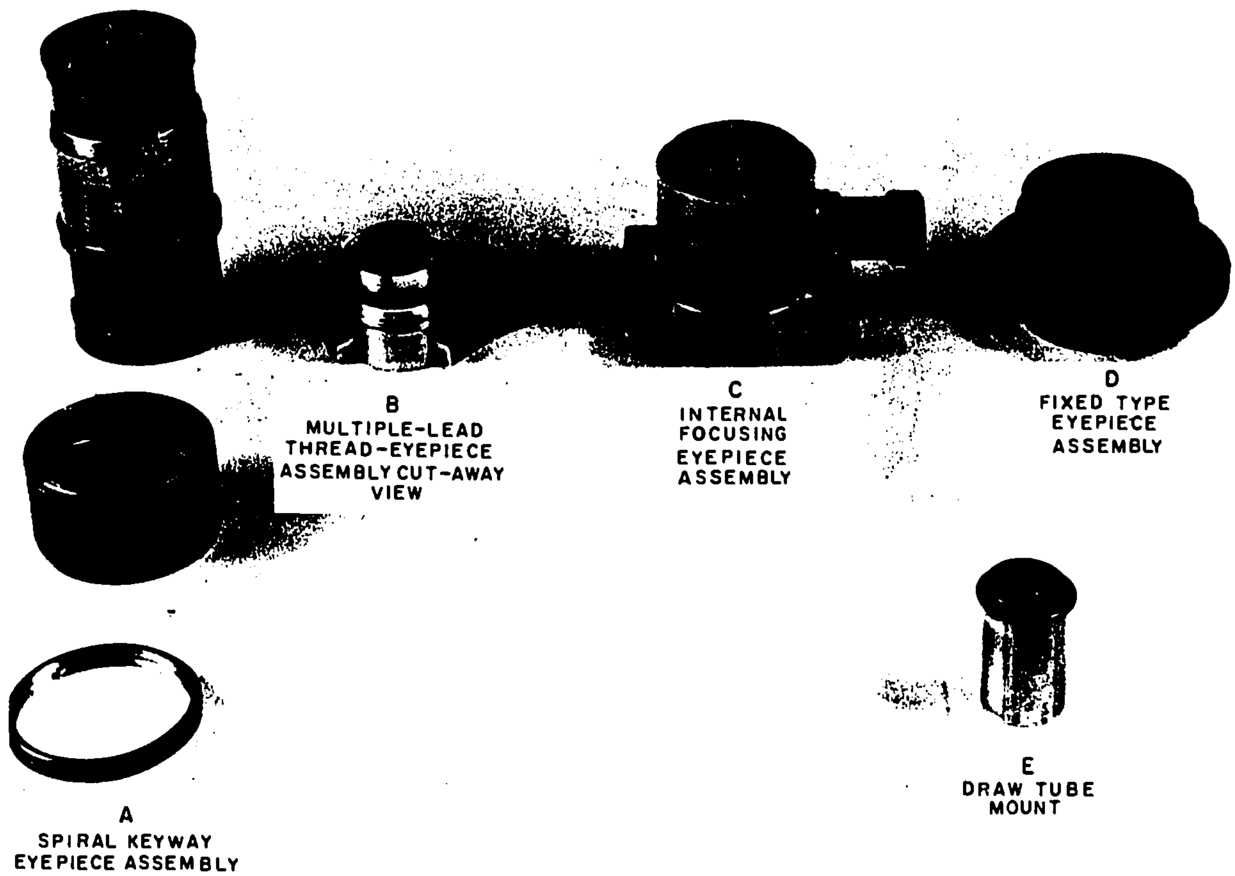

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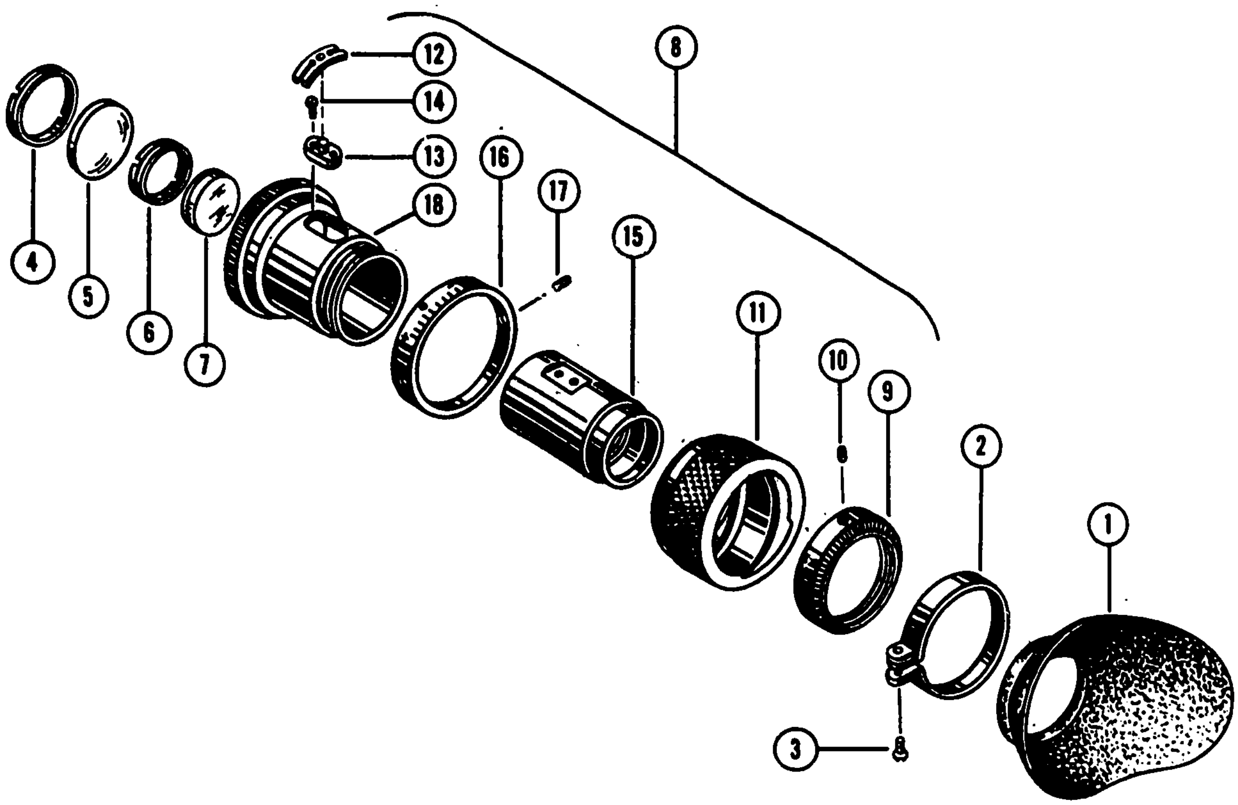
Figure 6-16.—Focusing arrangement.

Multiple Lead Thread

A multiple-thread eyepiece lens mount (fig. 6-18) is a tubular type with external multiple-lead threads, and it screws into a guide tube or eyepiece adapter with multiple-lead threads. When the eyepiece mount is screwed all the way into the adapter, it is stopped by a shoulder in the adapter. A stop ring is then screwed into the top of the adapter, which prevents extraction of the eyepiece mount when the threads reach the stop ring as the mount is screwed all the way out. A focusing ring with a diopter scale engraved on it is attached to the top of the eyepiece mount.

Internal Focusing Mount

An internal focusing eyepiece mount shown in figure 6-19 consists of a housing secured and sealed to the rear of the telescope body. The housing contains an eyelens secured by a retaining ring; and in the housing a movable lens mount or cell containing the field lens and an intermediate lens is free to move forward or backward when the focusing knob and shaft are activated. As the focusing knob rotates, it turns the focusing shaft and rotates an eccentrically mounted actuating plate which, in turn, slides the movable lens mount toward or away from the eyelens during focusing for individual



1. Eyeguard
2. Eyeguard clamp.
3. Eyeguard clamp ring screw.
4. Eyepiece collective retaining ring.
5. Eyepiece collective lens.
6. Eyelens retaining ring.
7. Cemented doublet eyelens.
8. Eyepiece focusing assembly.
9. Focusing ring stop ring.
10. Stop ring lock screw.
11. Knurled focusing ring.
12. Focusing shoe.
13. Focusing key.
14. Focusing key screw.
15. Eyepiece lens mount.
16. Diopter ring.
17. Diopter ring lock screw.
18. Eyepiece diopter.

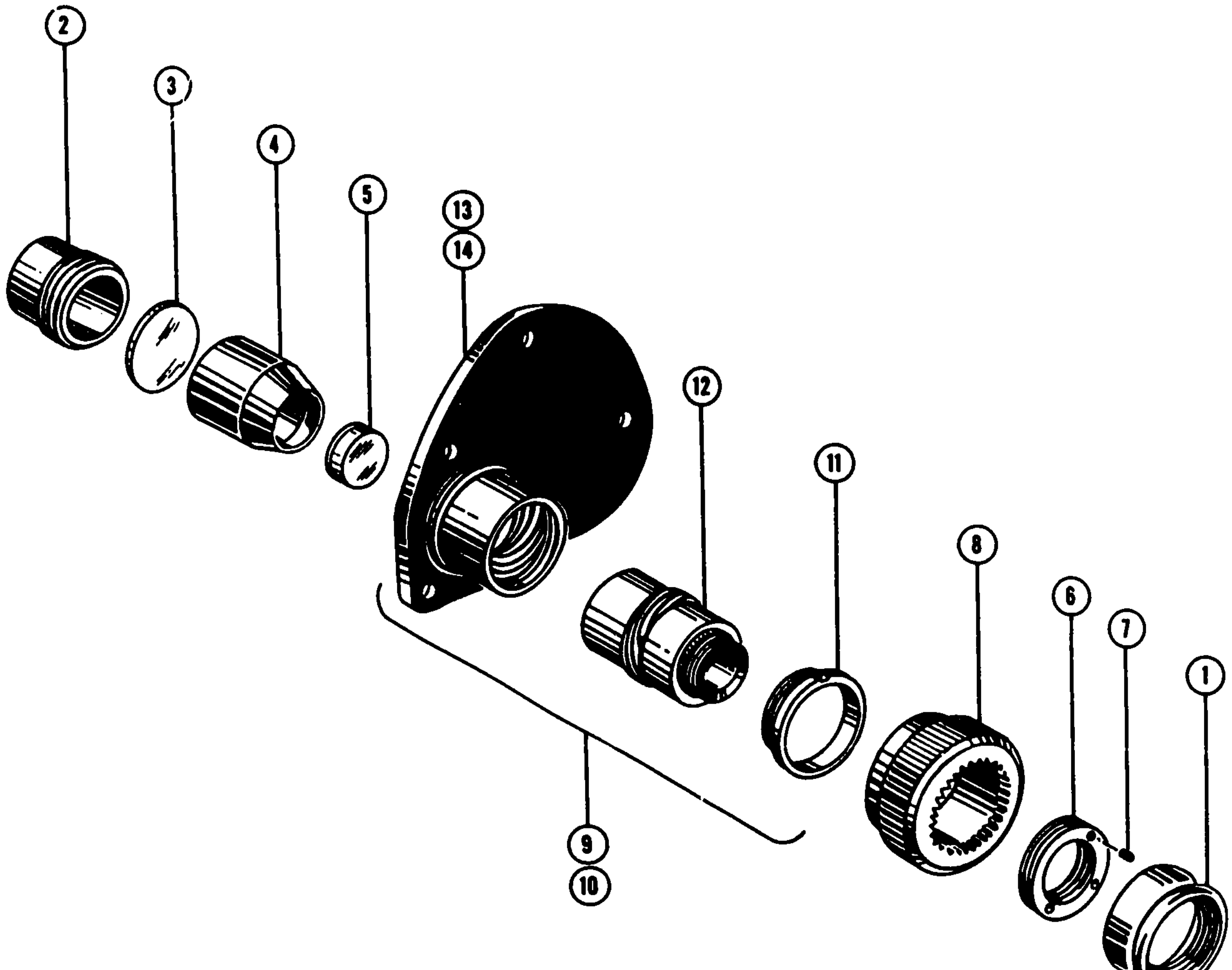
137.174

Figure 6-17.—Spiral keyway focusing arrangement.

eye corrections. The dioptric scale is on the focusing knob and the index mark is on the focusing shaft housing.

Focusing-type eyepieces are mechanically designed to provide fast focusing with minimum turning of the focusing ring or knob. This design permits the eyepiece (when turned completely out) to stopon the plus side of the diopter scale; and to be focused all the way in to the stop on the minus side of the scale, with one rotation (or less) of the focusing ring. Multiple-lead threads of eyepiece mounts, because of their long lead, are responsible for this type of focusing. In internal focusing eyepieces, the eccentric plate slides the lens mounts from maximum to minimum throw with a half turn (or less) of the focusing knob.

The lenses of the spiral keyway and internal focusing eyepieces do not rotate when they are focused, and this is an advantage over a multiple-lead-thread eyepiece. When multiple-lead-thread eyepieces are rotated, eccentricity in the lenses or their mounts (if present) causes the image of a target to appear to rotate in a small circle. For this reason, eyepieces with draw tubes which slide in and out without rotating



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1. Eyepiece cap.
2. Collective lens retaining ring.
3. Collective lens.
4. Eyepiece lens spacer.
5. Cemented doublet eyelens.
6. Eyepiece clamp ring.
7. Eyepiece clamp ring lock screw.
8. Knurled focusing ring.
9. Left cover and eyepiece mount assembly.
10. Right cover and eyepiece mount assembly.
11. Right eyepiece stop.
12. Eyepiece lens mount.
13. Right cover with eyepiece adapter.

137.175

Figure 6-18.—Multiple-thread eyepiece lens mount.

are generally preferred in instruments with reticles. NOTE: The reticle must be superimposed ON THE SAME SPOT OF THE TARGET ALL THE TIME, REGARDLESS OF THE MANNER IN WHICH THE EYEPIECE IS FOCUSED. If the eyepieces or lens mounts rotate with eccentricity in a telescope which has a reticle, the image of the target appears to move under the reticle image in a small circle.

One advantage internal-focusing and fixed eyepieces have over spiral keyway and multiple-lead-thread eyepieces is that they can be sealed

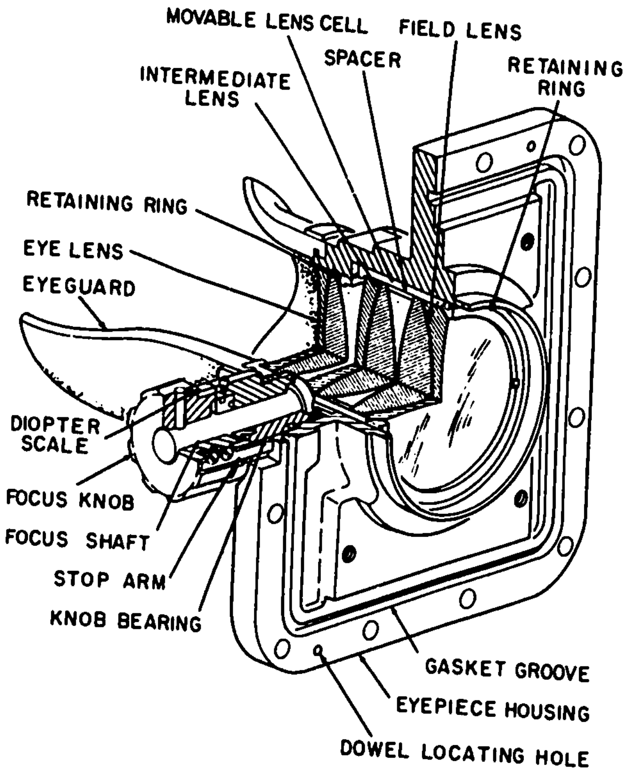

Figure 6-19.—Internal focusing eyepiece mount.

well enough to prevent entrance of foreign matter and moisture. Telescopes with these eyepieces can even be submerged under water, because they will not leak.

Spiral keyway and multiple-lead-thread eyepieces cannot be submerged under water, and they also BREATHE DURING FOCUSING; that is, WHEN YOU FOCUS THEM IN, THEY COMPRESS THE AIR WITHIN THE TELESCOPE AND FORCE IT OUT THROUGH THEIR JOINTS AND LOOSE FITTINGS. NOTE: Some telescopes have a small hole near the eyepiece mount which enables the air in them to escape freely. WHEN YOU FOCUS THESE EYEPIECES OUT, THEY DRAW AIR AND DUST INTO THE TELESCOPE. This breathing action can be caused also by changes in atmospheric pressure or temperature changes (day to night, for example). As time passes, dirt and moisture collected in the optical elements of the telescope diminish or obliterate vision through the instrument.

Multiple-lead-thread eyepieces have few mechanical parts and are therefore light in weight. Another advantage they have over some other types of eyepieces is that their threads reduce backlash, hold eccentricity to a tolerable minimum, and provide smooth focusing action.

On some optical instruments, fixed-type eyepieces must also be capable of withstanding a hydrostatic pressure test (subjected to water pressures applied externally) prior to approval for service in the fleet.

A fixed-type eyepiece (part D, fig. 6-16), as the name implies, is fixed in position and cannot be focused for individual eye correction. The eyepiece mount may consist of a housing secured and sealed at the rear of the telescope body, which contains the eyelens, separator, field lens, and the retainer ring. The eyepiece housing may also be part of the main telescope housing with its component parts. If the eyepiece housing is part of the main telescope housing, the lenses and the spacer slide into the eyepiece housing from the rear and are secured in place with a retaining cap screwed onto the rear of the housing.

Because this eyepiece cannot be focused for individual eye correction, the light rays which leave it are slightly divergent, with a value of -3/4 or - 1 1/2 diopters. It is set at this value because the majority of operators set focusing eyepieces slightly on the minus side of the dioptric scale.

One disadvantage of a fixed-type eyepiece is that IT DOES NOT PROVIDE MEANS FOR FOCUSING TO THE EYES. This is a fairly serious disadvantage to a slightly farsighted operator who requires that convergent rather than divergent light rays leave the eyepiece.

No two individuals, however, with or without eyes corrected by glasses, have the same diopter setting. An individual's setting can change from hour to hour during the day, in accordance with the amount of time spent looking through optical instruments.

BEARINGS

When a shaft is mounted in a device to hold it during rotation, friction develops at the contact point of the shaft with the device. Friction develops heat, and the amount of friction produced in a shaft housing must therefore be reduced to a minimum in order to obtain satisfactory performance and longer life of the shaft. Devices which reduce the amount of friction produced by shafts in their housings are called BEARINGS. A bearing may also be defined as a device used to guide and support RECIPROCATING and ROTATING elements which may be subject to external loads resolved into components possessing normal, radial, or axial directions, or two-dimensional loads in combination.

Unless it is a simple type such as a single lens reading glass, an optical instrument has many moving parts. Movement of these parts, however, must be so restricted that motion takes place. ONLY IN THE DIRECTION DESIRED. Freedom of movement is also essential, and it can be attained by reducing friction between moving parts. Movable parts of an optical instrument must therefore be supported and retained by some suitable means, so that friction-free movement in a specific direction may be obtained.

Before we get into the discussion of different types of bearings, it is a good idea to explain the different types of loads which bearings must carry, as follows:

1. NORMAL LOAD.—A normal load is one applied TOWARD and PERPENDICULAR to the bearing surface.
2. RADIAL LOAD.—A radial load is a load directed AWAY FROM a surface, the opposite of a normal load. Rotation of a wheel or object on an axis is an application of radial load.
3. AXIAL LOAD.—An axial load is one directed along the axis of rotation or surface of an object.

ANGULAR LOAD.—An angular load is a combination of the other loads just described.

Bearings are generally classified as: (1) SLIDING SURFACE, and (2) ROTATIONAL (sometimes called rolling contact bearings).

Sliding Surface Bearings

A sliding surface bearing usually has a stationary member which forms the base on which its moving part slides. A lathe, for example, has this type of bearing in the holding and guiding of the carriage, and tailstock on the lathe bed. The sliding surfaces are not always flat; they may be square, angular, or circular. The piston and cylinder bore of an internal combustion engine constitute a circular sliding surface bearing.

There are many variations of sliding surface bearings used in optical instruments, some of the more common of which are:

1. Cylindrical
2. Spherical
3. Square (quadrangular)

Cylindrical and spherical sliding surface bearings are used to mount some of the smaller gunsights in order that they may be easily boresighted (aligned with the gun). Refer to illustration 6-20 which shows these two bearings used in an assembly. The cylindrical sliding surface bearing is secured in its mating surface on the gun mount. The function of the spherical sliding surface bearing is to hold the front of the gunsight securely in the cylindrical sliding surface bearing; and at the same time to allow

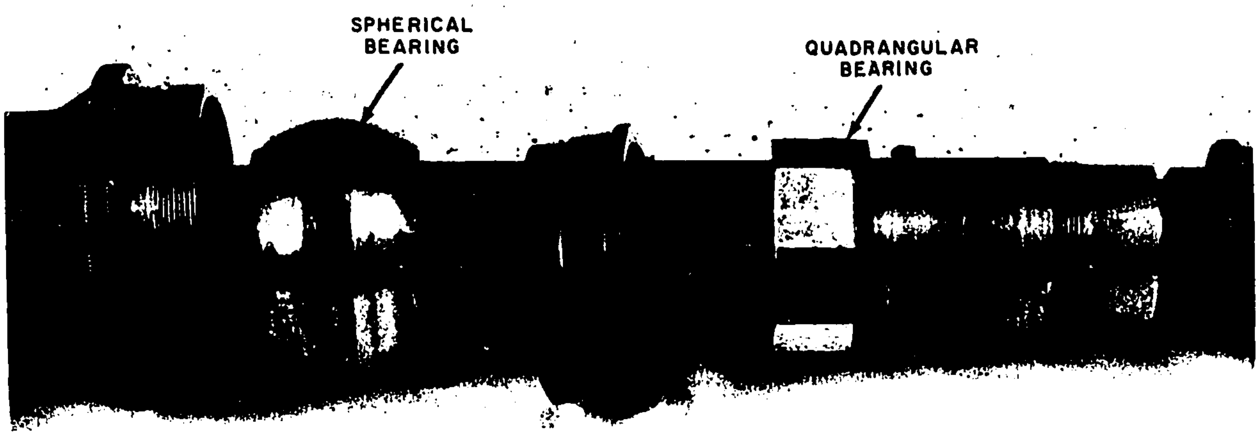

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Figure 6-20.—Cylindrical sliding surface bearing and square bearing in an instrument assembly.

radial movement of the rear end of the gunsight (within certain limitations imposed by the construction of the spherical sliding surface bearing).

The purpose of the SQUARE BEARING (quadrangular) is to move and to hold the rear portion of a gunsight. Study illustration 6-20 again, and then study figure 6-1 which shows the position of a spherical bearing and a quadrangular (square) bearing in an optical instrument. The bearing surfaces in this instance are subjected to NORMAL LOADS by four ADJUSTING SCREWS in an adjusting-screw mount. Each adjusting screw exerts pressure on its respective bearing surface; and by loosening and tightening opposing screws, as necessary, you can boresight the telescope. Adjusting-screw mounts are also good for holding and adjusting reticle mounts.

Although not a sliding surface bearing, the square bearing is used as a LOCATING BEARING SURFACE, with little sliding motion (if any) exerted upon it. When accurately machined, a square bearing is used as a bearing pad for holding large gunsights in gun mounts and directors, and for locating and holding parts inside optical instruments. During overhaul of a gunsight telescope, bearing pads become reference surfaces.

A rotational bearing generally has a stationary member for holding the rotating member. The stationary member is called the BEARING. The rotational member is usually in the form of a shaft, whose precision-finished surfaces are called TRUNNIONS and rotate in the stationary member. Trunnions are by necessity circular in cross section, but their profile may be cylindrical, conical, spherical, or an even more complex form. The most common TRUNNION PROFILE in use is cylindrical.

Trunnion bearings (fig. 6-14) such as those on the ends of a Mark 61 telescope, right-angled prism mount are used on MANY KINDS of telescopes. A trunnion is a shaft which rotates around a true horizontal axis in order to keep the optical axis of a telescope or prism mount in a true vertical plane during elevating or depressing operations.

Trunnions are attached permanently to the body casting at the central point of a telescope or mount; but they may be part of the body casting. The trunnions make it possible to rotate a telescope (or mount) during elevation or depression; and if the telescope is stopped at any position, it remains in that position, PROVIDED THE TELESCOPE IS PERFECTLY BALANCED.

Ball Bearings

Because their resistance to rolling friction is much less than for sliding friction, precision BALL BEARINGS are used extensively in optical instruments. Precision ball bearings in self-contained units are classified in accordance with design. Differences in design in ball bearings are generally not apparent externally. When making a design of these bearings, the OUTER RACE, the INNER RACE, and the STEEL BALLS (which roll between the races) must be taken into consideration.

As you study the most common designs of self-contained precision ball bearings in the following paragraphs, refer to illustrations 6-21 and 6-22 to determine their differences.

Radial ball bearings (part A, fig. 6-21) are designed to carry loads applied to a plane perpendicular to the axis of rotation in order to prevent movement of the shaft in a RADIAL DIRECTION. Thrust ball bearings (part C, fig. 6-21) are designed to take loads applied in the SAME DIRECTION as the axis of the shaft in order to prevent free ENDWISE MOVEMENT.

Radial and thrust ball bearings are therefore designed to carry loads in a specific direction: PERPENDICULAR OR PARALLEL TO THE AXIS OF SUPPORTED SHAFTS.

An angular ball bearing (part B, fig. 6-21) supports an ANGULAR LOAD—a load which has components of radial and axial thrust—and it is exemplified by the bearing in the front wheel of a bicycle. Angular ball bearings are NORMALLY USED IN PAIRS, in a manner which enables the ANGULAR CONTACT SURFACES of the outer and inner race of ONE BEARING to oppose the ANGULAR CONTACT SURFACES of the OUTER and INNER RACE of the OTHER BEARING. This arrangement of the bearings provides a technique designated as PRELOADING, which REMOVES what is called GIVE or SOFTNESS before the bearings are subjected to their normal loads.

The principle of PRELOADING is illustrated in figure 6-22. Preloading can be obtained (and normally is) by subjecting the inner races to a STATIC THRUST directed axially TOWARD the angular contact surfaces of the OUTER RACES.

In some cases, individual precision steel balls are used as a bearing between two parts.

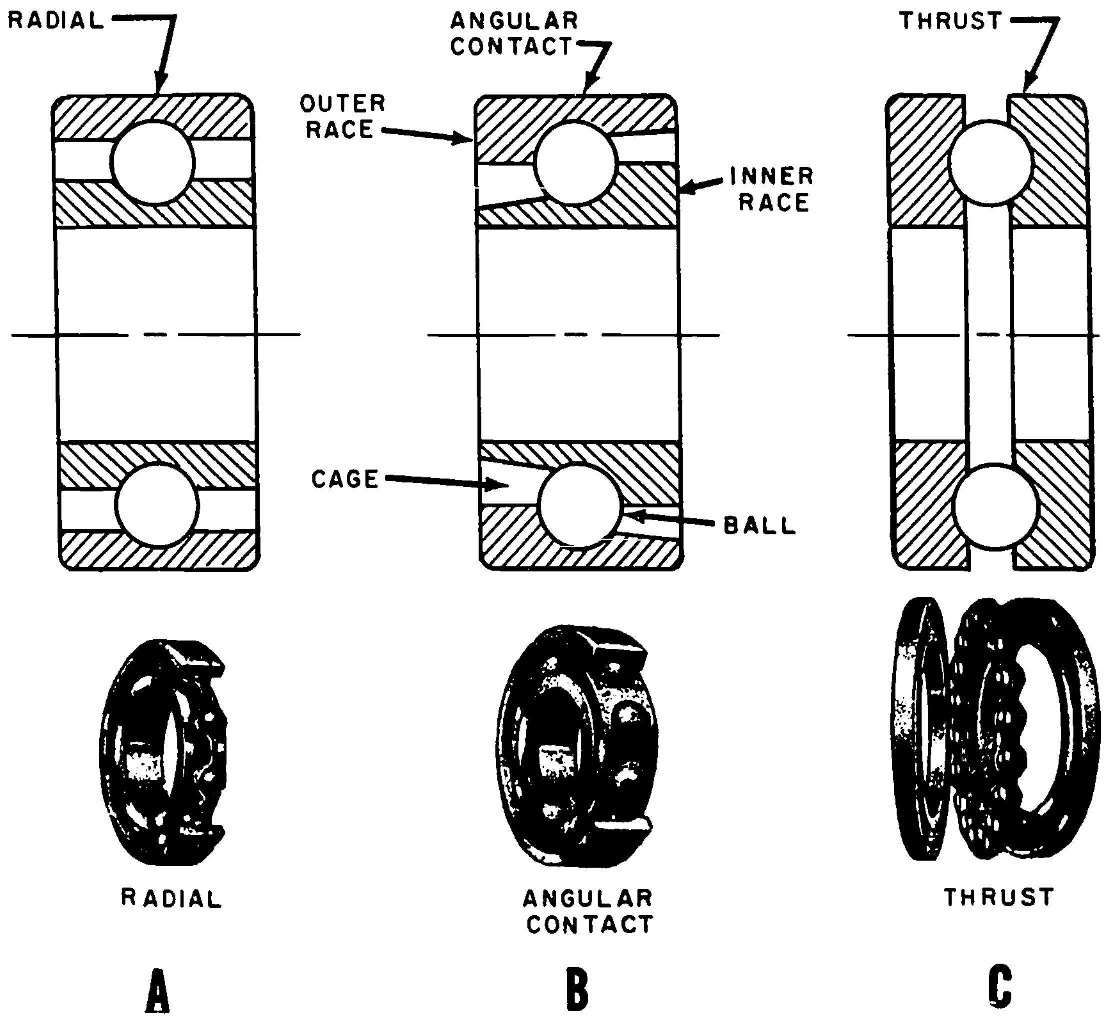

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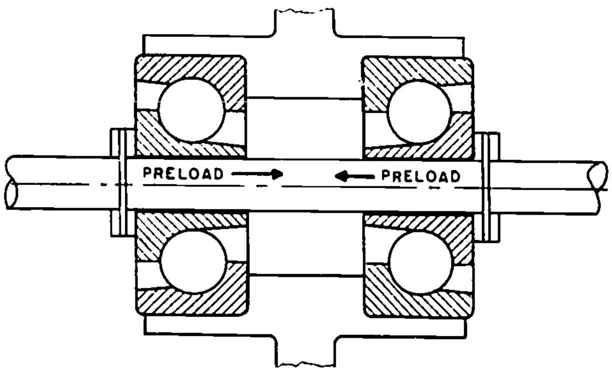
Figure 6-21.—Different types of ball bearings.

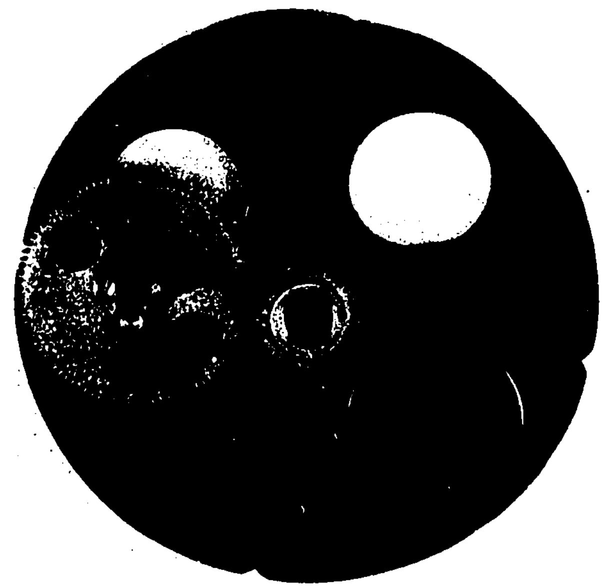
When this is true, the parts themselves act as the BEARING RACES, with the desired number of steel balls rolling between them. Such a bearing is used between polaroid filter plates in optical instruments, in order to secure SMOOTH and FREE rotation.

The RAY FILTER ASSEMBLY in a ship's telescope uses ONLY ONE precision steel ball as a detent, which starts or stops the movement. The steel ball in this assembly is held against the ray filter plate by a recessed spring and follower. When each glass filter is correctly positioned in the line of sight, the detent ball is thrust into a groove on the plate to hold the desired filter in the line of sight.

CAUTION: Dry metallic surfaces under an appreciable load, though smoothly machined, will not slide over each other without abrasion; so they must be kept covered CONTINUALLY with an approved lubricant, which actually keeps them separated and prevents abrasion and friction. Like metals do NOT RUB TOGETHER WELL unless completely covered with a film of lubricant. If properly lubricated, precision-made ball bearings wear very little. When wear does occur in ball bearings, replace them. Adjustment is impossible.



137.180
Figure 6-22.—Preloading produced by pairs of angular ball bearings.



5.22.1
Figure 6-23.—Types of spur gears.

OPTICAL INSTRUMENT GEARS

An instrument designer must know what types of gears to use for a specific function in order to provide the TYPE OF MOTION and SPEED required. Because you must work with these gears in optical shops, knowledge concerning the basic types will be beneficial to you.

Spur Gears

Some spur gears are shown in figure 6-23 (from a Mark 74 gunsight), and they are used more than any other type of gear in optical instruments to transmit power from one shaft to another.

Teeth on spur gears vary in size (in accordance with requirements), stated in terms of QUANTITY as PITCH, or DIAMETRAL PITCH (number of teeth per inch of pitch diameter). This means that a spur gear with 16 pitch and a pitch diameter of 1 inch has 16 teeth, and so forth. The FACE OF A GEAR is its thickness, measured across the base of its teeth. A gear with a face of 3/4 inch, for example, is 3/4 inch thick at that point.

Speed ratios between shafts having spur gears is important, and ratio is defined as the RECIPROCAL OF THE RATIO OF THE QUANTITY OF TEETH OF THE TWO GEARS, or reciprocal of the ratio of their pitch diameters.

Metals generally used in small spur gears are brass and steel; but cast iron is widely used in large spur gears. Spur gears, however, are also made of non-metallic substances.

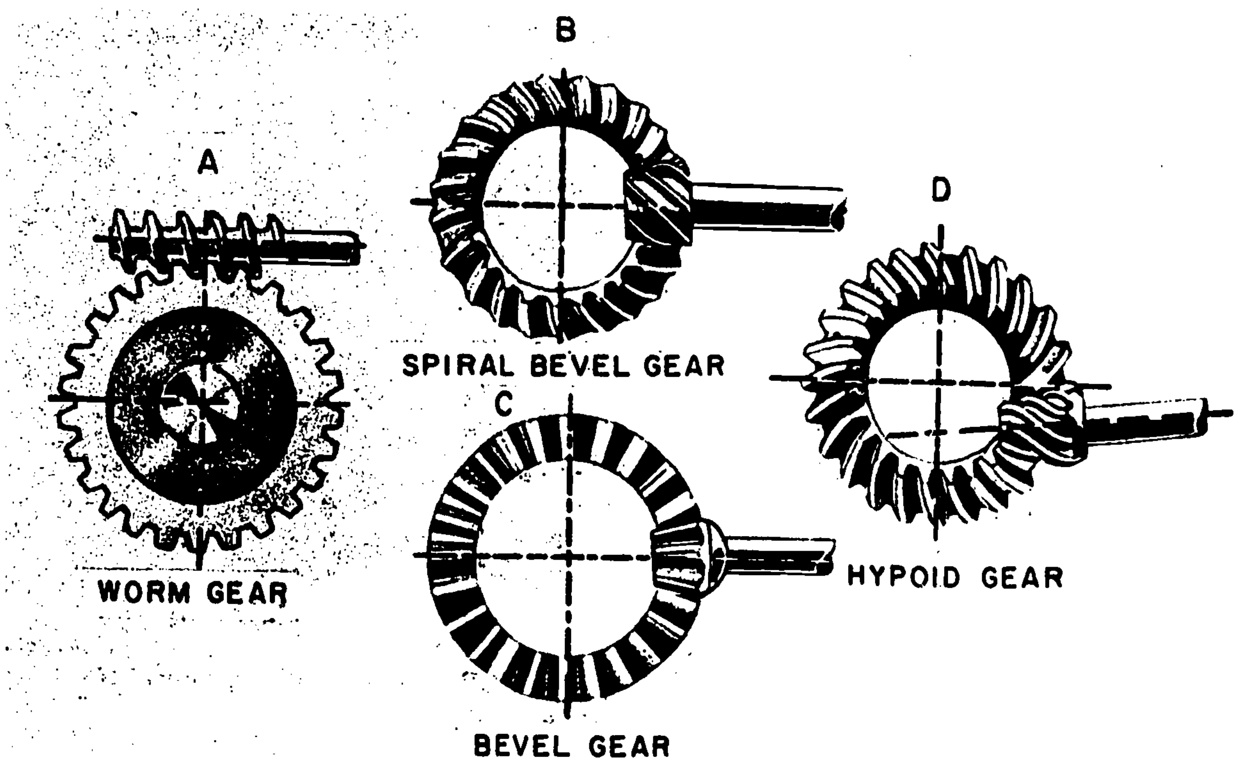
Bevel Gears

Bevel gears used in optical instruments can be put on shafts which intersect at desired angles, provided the angle of the teeth is correct in relation to the shafts.

Bevel gears are made with straight or curved teeth, but they CANNOT BE INTERCHANGED WITH SPUR GEARS. By using the proper type of bevel gear, however, you can get a different speed ratio, as desired. When these gears are used to change the direction of motion 90°, with no change in speed, THEY ARE CALLED MITER GEARS. NOTE: If lapped pairs of bevel gears are used in an optical instrument (and others), almost perfect quietness of operation is obtained.

The shape of bevel gears, especially those with spiral teeth, causes them to exert much thrust. For this reason, the end of a shaft which contains the gear is generally supported by an angular ball bearing, and the other end has a radial ball bearing.

When one component of a pair of gears which mesh together is bigger than the other (B, C, and D, fig. 6-24) THE BIGGER COMPONENT IS USUALLY CALLED THE GEAR AND THE SMALLER COMPONENT IS CALLED THE PINION.



81.195

Figure 6-24.—Types of bevel gears.

Spiral bevel gears (part B, fig. 6-24) are used in optical instruments (and others) because they are interchangeable for varying the speed ratio and can be used in different ways, as illustrated. They are cut right- and left-hand, and they are specified like spur gears with reference to face, pitch, and pitch diameter.

Spiral bevel gears which have the same cut (right or left hand) operate at right angles; those which have opposite cuts are used on parallel shafts. Because the teeth of spiral bevel gears slide over one another, bronze or hardened steel is used in their manufacture to make them more durable.

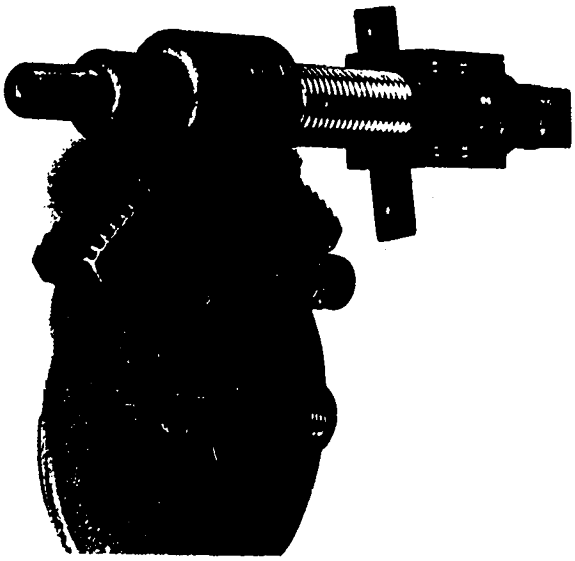
Worm Gear and Worm

Study part A of illustration 6-24, the top part of which is called a WORM, and the bottom part of which is called a WORM GEAR. Worm gears and worms are used extensively in instruments because they provide an effective means for reducing velocity and transmitting power. Study the worm and sector gear from a gunsight elevator shaft in illustration 6-25.

If a worm has ONLY ONE continuous thread, it is called a SINGLE-THREAD worm; but more than one thread may be cut on a worm. Two continuous threads on a worm constitute a DOUBLE-THREAD worm; three continuous threads on a worm are called a TRIPLE-THREAD worm.

Single-thread and double-thread are terms which indicate the TOTAL NUMBER of continuous threads, NOT number of threads per inch. Pitch of a worm means linear distance from a specific point on one thread to a corresponding point on the adjacent thread, measured parallel to the axis of the worm. The pitch can also be determined by dividing one (1) by the number of threads per inch.

Pitch is therefore the RECIPROCAL of the number of threads per inch; and LEAD is the axial distance (parallel to worm axis) moved by the worm thread upon completion of one revolution of the worm. On a worm with a single thread, lead and pitch are therefore equal; but



5.22.9
Figure 6-25.—Sector gear and worm.

the lead is TWICE the pitch on a double-thread worm and THREE TIMES the pitch on a triple-thread worm.

As is true for spur gears, worms are specified in DIAMETRAL PITCH and PITCH DIAMETER; because they must be so machined that they fit the worm gears with which they mesh. This means that such factors as thread number, threads per inch, face length, and pitch diameter must be taken into consideration.

Rack and Pinion

Some fire control equipment and optical instruments use a rack and pinion such as the one illustrated in figure 6-26. The rack gear moves in a linear motion, as indicated; and it is simply a straight bar into which the gear teeth have been cut. The pinion, of course, moves in a rotary motion.

INSTRUMENT SEALING METHODS

To maintain the cleanliness of the optics in optical instruments, the instrument bodies are sealed to keep out moisture and dirt. All optical instruments are sealed but they are not necessarily waterproofed to stand submersion in water.

Sealing is effected by closing all openings with sealing compound or gaskets. A combination of both is often used. The gaskets may be made of rubber, plastic or of a metal such as lead.

Waterproofing is accomplished by using gaskets on all outside joints or, where a gasket cannot be used because of physical limitations, sealing compound is applied as a seal. A well-designed waterproof instrument would have gaskets for all seals except for such small, non-flexing joints as a set screw going through the body.

The primary job of waterproofing or sealing must be done by the designer. The repairman's responsibility is to do his job of sealing with care and precision. The standard techniques for performing waterproofing and sealing operations are set forth in the following paragraphs.

WAX

Sealing procedures making use of compounds naturally fall into two categories: Sealing lenses in lens mounts and sealing mechanical parts. The following procedure is applicable to sealing lenses, reticles and windows. The shape is of no consequence. The common elements in all classes of this work is the joint of glass to a metal shoulder in a mechanical part.

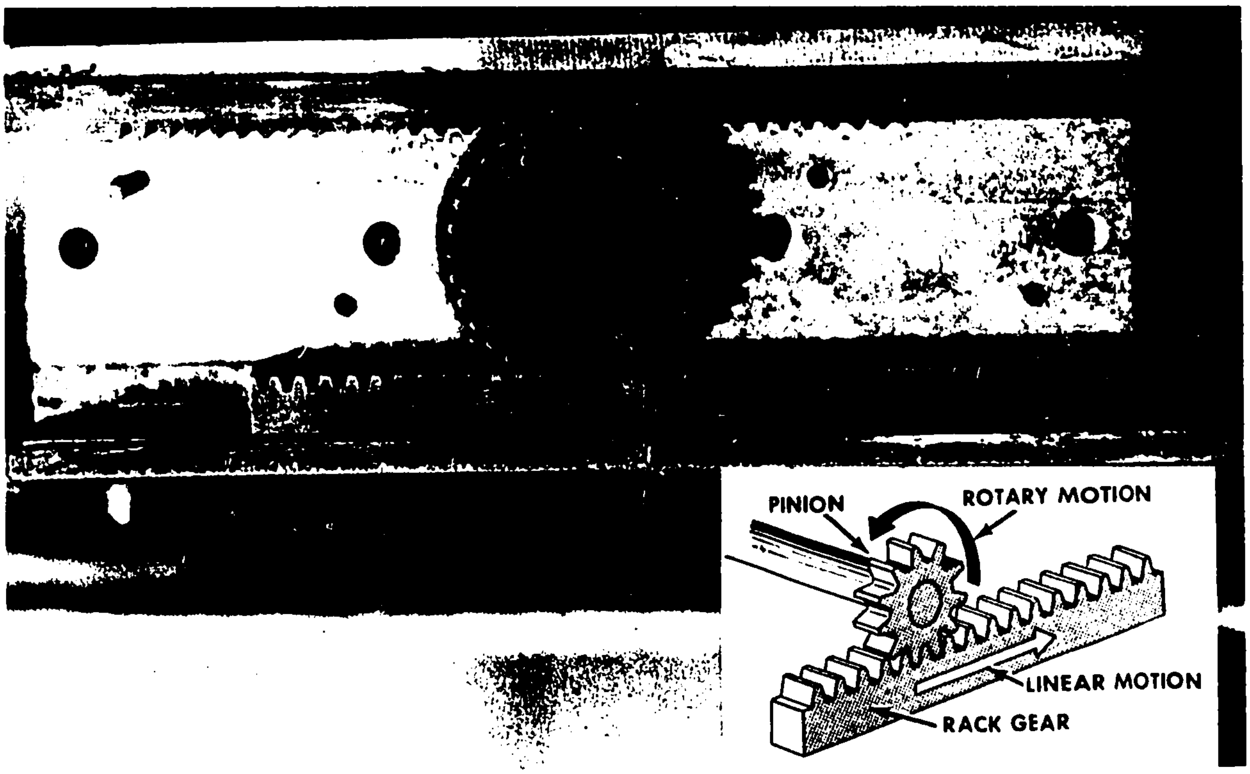
The actual seal is provided in a space between the lens and its mount. The lens seating shoulder in the mount is beveled or the wall around the shoulder is undercut. Also, the edge of the lens is beveled. Figure 6-27 shows the cross-sections of two typical mounts with the lenses in place. Note the clearance space for the sealing compound.

The procedure for sealing lenses is for the use of a sealing compound that is plastic for all atmospheric temperatures. No heat is required for its application.

NOTE

The diameter of the sealing compound string is determined by the size of the lens and the width of the shoulder. A universal size of 1/16-inch diameter is generally useful for lenses in navigational instruments.

- Place a string of sealing compound around the entire circumference of the lens shoulder of the lens mount. The string must be cut to



5.22.13

Figure 6-26.—Rack and pinion.

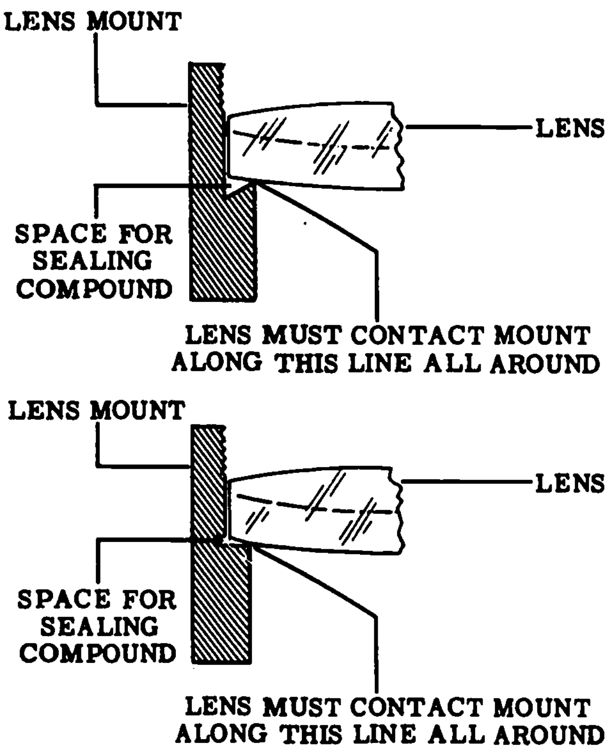
size to go around once and have its ends just meet without stretching or overlapping.

- Use a 1/8 inch diameter hard wood stick with a smooth end to pack the string into the recessed corner of the shoulder which is designed as space for the sealing compound. See figure 6-28.
- Excess sealing compound caused by uneven thickness of the string or overlapping may prevent the lens from seating down evenly against the shoulder. Too little compound at any one point will provide a poor seal. Fit the length to just go around the shoulder.
- After setting the lens in the mount, against the sealing compound press the lens down on the sealing compound to seat it evenly all the way around. Sufficient pressure should be applied to make the lens seat firmly against the mounting shoulder. See Fig. 6-27. An even bulge of wax will indicate an even seat and seal.
- Screw the lens retainer ring gently into the mount, up against the lens. Use the tool designated in the instrument manual.

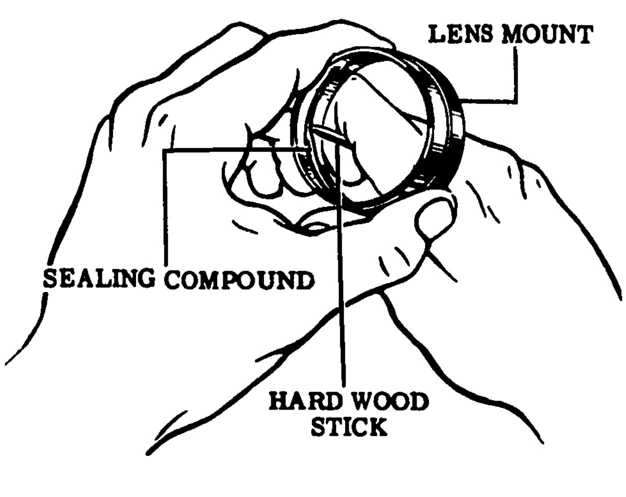
CAUTION

If the retainer ring is screwed in with too much pressure, it may crack the lens. Even if not, excess pressure will produce strain in the glass, which will cause distortion of the image. Temperature variations may cause contraction of the mount and ring, resulting in strain and possible damage to the lens. Too little pressure may leave the lens loose or the lens may not be properly positioned.

- To set the retainer ring to the correct pressure, tighten it up snug. Then back off the retainer ring slightly (1/16 of a turn). This should release any strain in the lens.
- In loosening the retainer ring to eliminate strain, be careful not to loosen it beyond what is needed to release the strain. For lenses not mounted in sealing compound, shake the mount. A loose lens will rattle. Those in sealing compound will appear tight because they are stuck



137.194
Figure 6-27.—Space for sealing compound in lens mounts.



137.195
Figure 6-28.—Pressing sealing compound into the recess of a lens mount.

in the sealing compound. However, they will come loose eventually if the ring is not snug against the lens.

The sealing of mechanical parts does not resolve itself into a series of step-by-step operations which can be used in all situations.

Closing an opening is the basic purpose of sealing. This sounds simple and obvious, yet it must be kept in mind constantly. Each sealing operation must be studied to determine where the opening is and where to apply the sealing compound.

There are two varieties of sealing compounds and their use is dependent upon the job to be done.

The first type is plastic at all atmospheric temperatures. It is used for joints between parts where it is protected from removal by casual handling. It is readily applied in its natural state. When extruded in string form, it is most convenient for application to ring-type joints.

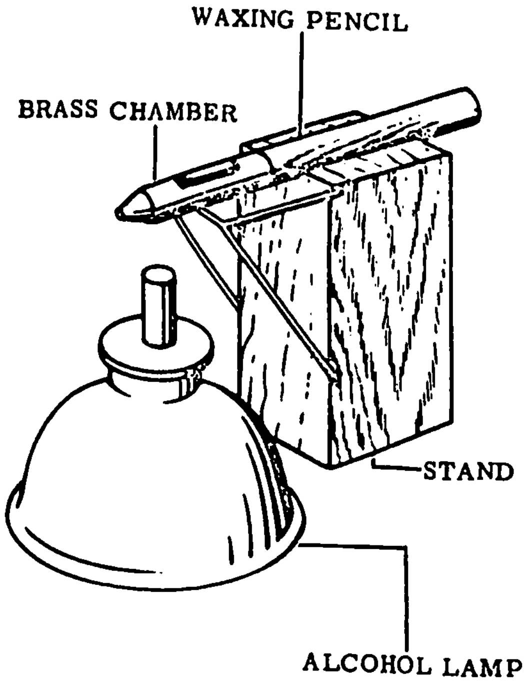
The second type of sealing compound is used for sealing openings in external fillets or grooves, and plugging openings such as space over external screws. These compounds are almost hard at normal temperatures and harden with age when exposed. Hence, heat is necessary to soften them for application. They are usually colored to match the finish of the instrument. Being hard, they resist abrasion and are quite permanent. A convenient applicator, a waxing pencil complete with stand and alcohol lamp, is illustrated in Fig. 6-29. The brass chamber on the pencil is filled with compound and held over the alcohol lamp to soften the compound sufficiently to make it flow out of the end. The pencil must be heated repeatedly but not too much, as the compound will smoke if it is overheated.

PREFORMED GASKETS

The most widely used method of sealing an optical instrument is "Preformed Gaskets." They provide the best seal and are used extensively when an instrument must be watertight or pressuretight. Two types of preformed gaskets are used on Navy instruments; flat gaskets of irregular shape as shown in figure 6-30, and round "O" rings as shown in figure 6-31.

When sealing an instrument with flat gaskets the following rules should be strictly adhered to:

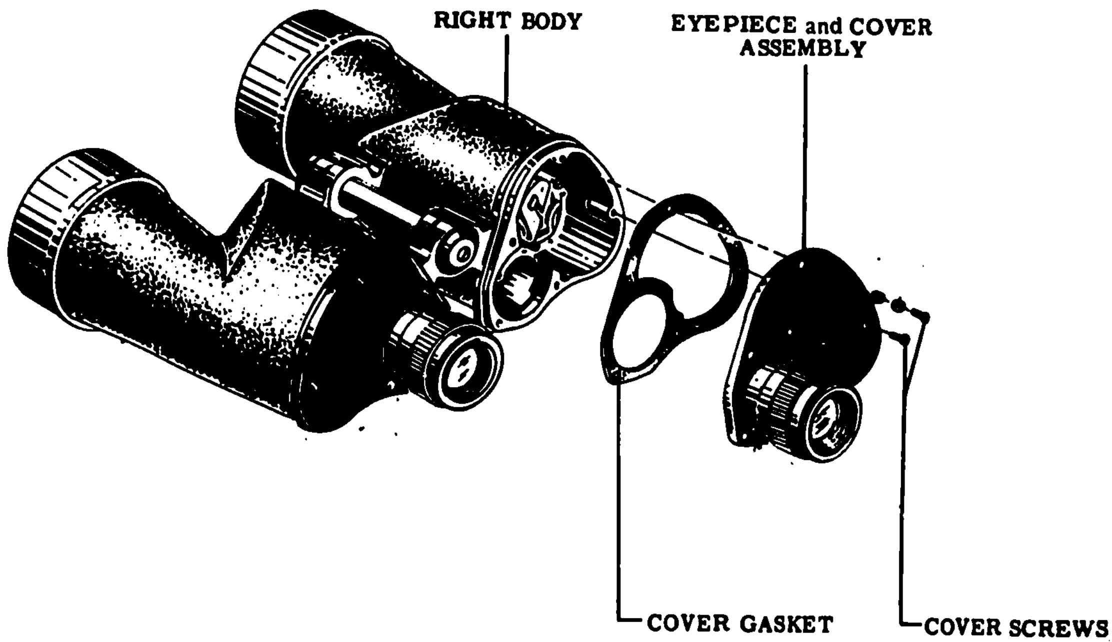
- Use the proper gasket for each joint.
- Use new gaskets. They go far to assure a watertight instrument.



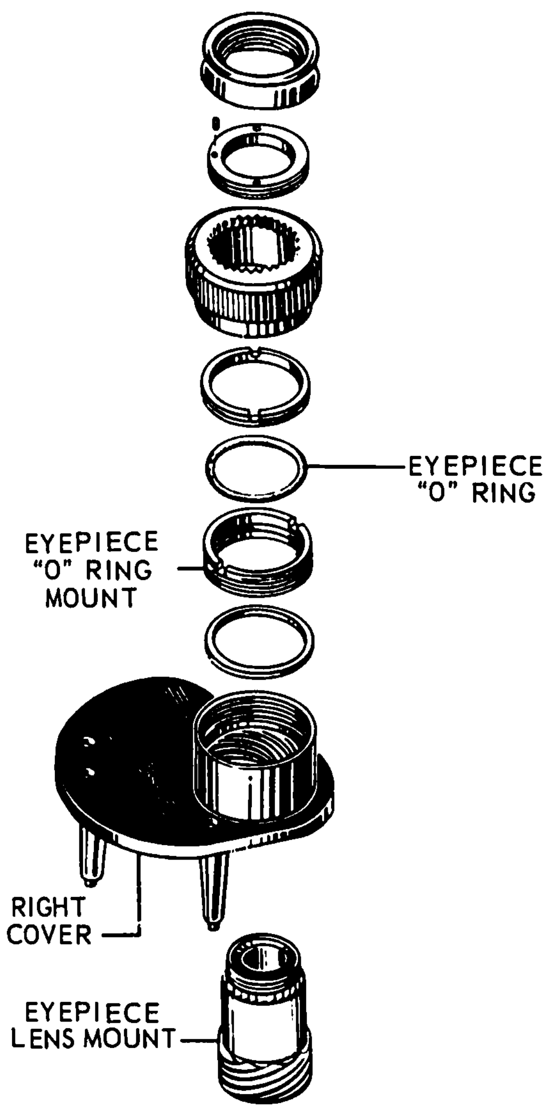
137.522
Figure 6-29.—Heating hard wax for sealing.

- The gasketed surfaces of the parts and the gasket itself must be clean. Foreign matter may cause a gap in the seal.
- Place the gasket in the correct position and make sure it will be flat between the parts it is sealing.
- The parts to be sealed must be tightened sufficiently to squeeze the gasket; however, excess pressure may cut the gasket.
- Examine a gasket joint, if possible, after it has been reassembled, to check the gasket for proper position.

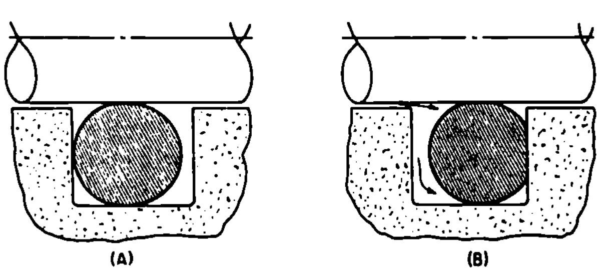
An "O" ring seal on an optical instrument is engineered to meet a set of standards that apply to all "O" ring seals. The dimensions of the "O" ring groove (seat) and the size of the "O" ring must be exact if the seal is to function properly. Unlike the flat gasket which seals as a result of the squeeze from the two parts, the "O" ring seals as a result of distortion caused by pressure. Notice figure 6-32 which shows the proper installation of an "O" ring. The clearance for the "O" ring in its seat is less than the free outer diameter and the "O" ring is slightly squeezed out of round (A of fig. 6-32). The seal is so designed that when pressure is



137.467
Figure 6-30.—Eyepiece and cover assembly gasket.



137.523
Figure 6-31.—Eyepiece "O" ring seal.



137.524
Figure 6-32.—Properly installed O-ring.

applied to the "O" ring it moves away from the pressure into the path of leakage, thus, completely sealing the passage. (B of fig. 6-32).

All O-rings are molded and trimmed to extremely close tolerances in cross-sectional area, inside diameter, and outside diameter. The O-ring is generally fitted into a rectangular groove machined in the mechanism to be sealed.

The greater the pressure applied, the tighter the seal becomes. When the pressure is decreased, the resiliency and elasticity of the seal results in the O-ring returning to its natural shape.

The first step in replacing an O-ring is to identify it both as to size and material. The size is indicated by a dash number, which always follows the part number of the O-ring. For example, in the part number MS28778-6, the -6 indicates the size.

After determining that the replacement seal is made of the correct material and is of the proper size, the seal should be inspected visually for cuts, nicks, or flaws and discarded if any defects appear.

When installing an O-ring, use extreme care to prevent scratching or cutting the seal on threads or sharp corners. Also make certain that it is not installed in a twisted condition, for it will not function correctly if twisted.

Individuals working with optical systems must be able to positively identify, inspect, and install the correct size and type O-ring for every application in order to insure the best possible service.

The task of procuring and positively identifying the correct seal can be difficult since part numbers cannot be put directly on the seals. This situation is further confused by the fact that there is a continual introduction of new types of seals and the obsolescence of others.

Because of the difficulties with color coding, O-rings are made available in individual hermetically sealed envelopes, labeled with all pertinent data. It is recommended that they be procured and stocked in these envelopes.

When selecting an O-ring for installation, information printed on the envelope should be carefully observed. If an O-ring cannot be positively identified, if should be discarded.

Almost all kinds of O-rings are similar in appearance and texture, but their characteristics may differ widely. Here again the basic part number on the package label provides the most reliable identification.

To identify O-rings, some manufacturers provide a color code. However, this is not a reliable or complete means of identification. There are several limitations to the color coding. Some coding is not permanent, while on others it may be omitted due to manufacturing difficulties or interference with operation. Furthermore, the color coding system provides no means to establish the age of the O-ring or its temperature limitations. When selecting an O-ring for installation, the basic part number on the sealed envelope provides the most reliable and complete identification.

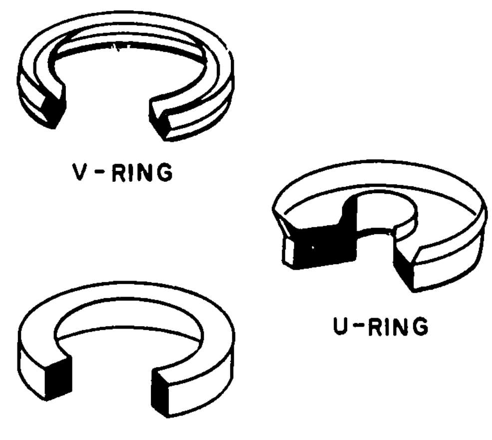
Although an O-ring may appear perfect at first glance, slight surface flaws may exist. These are often capable of preventing satisfactory O-ring performance under the variable operating pressures of fluid power systems, and O-rings should be rejected for flaws that will affect their performance.

By rolling the ring on an inspection cone or dowel, the inner diameter surface can be checked for small cracks, particles of foreign material, and other irregularities that will cause leakage or shorten the life of O-rings. The slight stretching of the ring when it is rolled inside out will help to reveal some defects not otherwise visible. A further check of each O-ring should be made by stretching it between the fingers, but care must be taken not to exceed the elastic limits of the rubber. Following these inspection practices will prove to be a maintenance economy. It is far more desirable to take care identifying and inspecting O-rings than to repeatedly overhaul components because of faulty seals.

PACKING

As used in mechanics, the term packing refers to the material used to seal an opening where the two component parts are not stationary and move in relation to each other. The type of material used depends on several factors as temperature, pressure, and type of motion. The most commonly used packing materials for optical instruments are natural rubber, plastics, flax and synthetics such as neoprene and koroseal. These packing materials come in wide ranges of density, tensile strength, and shape. Packing can be in either preformed shape as shown in figure 6-33, or in bulk sheet and spools.

Unfortunately, the length of time that a seal will function properly depends on many factors; many of them unpredictable. Therefore, it is almost impossible to say that a seal will wear out in a specified time.



5.35(137A)
Figure 6-33.—Packing rings.

Each time a component or unit is disassembled the seals should be carefully inspected. If there is any doubt as to their condition, they should be replaced. In most cases, automatic replacement of the seal is standard procedure. The manufacturers' recommendations along with the previous experience of the personnel repairing the unit or component should be the main criteria for determining when to replace a specific seal. Installation of seals should be carried out as specified in the Maintenance Instructions Manual, manufacturers' publication, NavShips Technical Manual.

It has been found with experience that packings deteriorate with age. Therefore, knowing and understanding packing shelf life will save many hours of unnecessary toil experienced in repacking a unit and having it still leak because the packing was defective due to age.

Prior to the installation of natural and synthetic rubber packings, a check must be made to determine whether these parts are acceptable for use. All natural and synthetic rubber packing containers are marked to facilitate an age control program. This information is available for all packings used, regardless of whether the packing is stocked on shipboard at stock distribution points, or furnished as an integral part of a component. Positive identification, indicating the source, "cure date," and "expiration date" must be made of packings.

The age control of all natural packings is based upon the cure date stamped on the manufacturer's unit package, intermediate package, and shipping container. Shelf life control of all packings is governed by the expiration date stamped beside the manufacturer's cure date on each package.

Expiration date is the date after which a packing CANNOT be used in service, and time of delivery means the date of acceptance by the purchaser. All packing is scrapped if not put into use by the time of the expiration date.

Cure date means the time the packing was manufactured and is designated by the quarter of the year and the year of manufacture. Packings manufactured during any given quarter are considered one-quarter old at the end of the succeeding quarter. For purposes of explaining the coding used by manufacturers to designate the cure date, each year is divided into quarters as follows:

1. First Quarter: January, February, and March.
2. Second Quarter: April, May, and June.
3. Third Quarter: July, August and September.
4. Fourth Quarter: October, November, and December.

To identify the age of natural or synthetic rubber packing, use the following procedure:

1. On the manufacturer's containers, stamp the cure date by quarter of the year and the year in accordance with Specification MIL-STD-129. The quarter of the year should be separated by the letter "Q" to indicate whether first, second, third, or fourth quarter. Containers of packings from manufacturers marked with an illegible cure date are cause for rejection of delivery.
2. An expiration date should also appear on the manufacturer's unit package to facilitate scrapping. The date should be specified by month and year, 2 years after the manufacturer's cure date, using the last month of the quarter.

EXAMPLE: 1Q66 Expiration Date: March 1968.

1Q66 means a cure date of the first quarter of the calendar year 1966. Expiration Date: March 1968 indicates the time when the usefulness of the packing expires.

Natural or synthetic rubber packing must not be removed from the manufacturer's unit package until ready for use, and should be stored in an area protected from sunlight and drafts. The storage temperatures, also applicable to components in which these packings are installed, should normally range from 60°F to 100°F, and must not exceed 125°F.

LUBRICATION

Proper lubrication, using only authorized lubricants, is an important part of optical instrument repair. It is a matter which has been regarded too lightly in the past, the theory being that any grease or oil would do. Experience proves that such an idea is detrimental to the best performance of the instrument.

A lubricant may work perfectly in temperate zones, but stiffen up to the extent of rendering the instrument useless in colder climates. Likewise, a lubricant suitable for use in temperate and cold climates may be entirely unsatisfactory for use in hot regions, where the heat could soften the lubricant to the point of flowing into locations where its presence would impair the functioning of the instrument.

The foregoing facts, while generally true, are particularly of importance in the case of optical instruments where even a very thin film of grease or oil on an optical surface would render the instrument absolutely useless. Since the Navy must use its optical instruments in climates from one extreme to the other, the lubricants used must perform properly under widely varying conditions and in no way impede the functioning of the instrument.

The use of an excessive amount of lubricant is a waste, and often is as bad as or worse than not enough. Where closely mated parts that require only a very thin film of lubricant are concerned, an excess can introduce errors in the readings of the instrument; in other cases, the functional accuracy can be impaired if too much oil or grease is employed.

Excess oil or grease on optical instruments may eventually find its way onto optical surfaces and render the instrument useless. Therefore, you must use great care in performing what seems to be relatively simple work. Apply only a thin, even coating to the surfaces and remove any excess before assembling.

The primary purpose of lubricants in optical instruments is to provide smoothness of action. Lubrication is not used to prevent wear, as is oil in an automobile engine. Thus, only a little will go a long way.

TYPES OF LUBRICANTS

The Navy has adopted the procedure of buying ready made lubricants which have been found to be satisfactory in every respect for use on optical instruments. These lubricants, trade named LUBRIPLATE and designated by number, are manufactured by the FISKE BROS. REFINING CO., New York City and may be purchased through the Navy supply system.

These recommended lubricants are manufactured in several different grades adaptable to all types of applications and temperature ranges. The repairman should be thoroughly familiar with the temperature ranges of all lubricants before using them.

INSTRUMENT SPECIFICATIONS

At all times, the optical repairman should follow the specifications of technical manuals when lubricating an optical instrument. When specific instructions are not available, the following general recommendations should be followed (see table below).

If the above lubricants are not available, an eyepiece grease can be made by slowly heating and blending 5 ounces of Japan wax and 5 ounces of white vaseline.

A good hinge grease can be made by heating and blending 4 ounces of beeswax, 2 ounces of rosin, 2 ounces of raw rubber, and 1 ounce of white vaseline.

To make a lubricant from a general formula is an art in which considerable experience is required in order to obtain a consistently uniform product. The above formulas are for EMERGENCY USE ONLY, and whenever possible the recommended products should be ordered ready made.

To apply grease to a surface, use a round hardwood stick which has a chisel point on one end. Dip the end of the stick into the container and pick up a small amount of grease on the end.

Apply the grease to the surface to be greased, smoothing it out with the stick so that the entire bearing surface is covered with a thin film of the grease.

Fit the greased parts together and run them in; or in the case of a screw, turn it in and out a few times to distribute the grease evenly over its entire working area. Then remove the excess grease that is forced out, using the stick to pick off the bulk of the unneeded lubricant.

Wipe grease from areas where none should remain, using a clean lintless cloth moistened with solvent.

Keep the oils in small individual instrument oil cans fitted with a cap for protection against dirt. Greases must be kept in clean jars or cans, and be kept covered when not in use, to prevent contamination by dust, grit and dirt. All containers should be properly labeled with the name of the lubricant and also the material specification number.

Source	Use	Lubricant	
Ordnance Pamphlet	Ball and plain bearings	Lubriplate No. 210)	
No. 463 - pg. 35*	Eyepiece draw tubes and similar assemblies	Lubriplate No. 220)	Fiske Bros. Refining Co.,
	Worms and gears	Lubriplate No. 310)	N. Y. C.
(1st Rev.)	Binocular hinge and similar assemblies	Lubriplate No. 320)	

CHAPTER 7

MAINTENANCE PROCEDURES—PART I

This chapter will provide you with information on repair and maintenance of optical instruments. It will also stress the importance of careful handling and cleanliness of, not only the instruments, but, also, the tools that you work with.

Optical instruments are expensive precision-built instruments and care in maintaining them cannot be overemphasized. If you handle an instrument roughly or drop it, the shock may result in misalignment or breakage of the optical and mechanical parts. When this happens, you have only one choice—REPAIR. This means that you must unseal the instrument, disassemble it, make repairs, reassembly and collimate. This is a lot of work caused by thoughtlessness and negligence in handling.

Optical instruments are shipped in specially constructed containers designed for adequate protection during transportation. When you receive optical instruments in the optical shop, check their containers for damage and cleanliness; then, if there is no reason why you should remove the instruments from the containers, stow them in clean storage cabinets or spaces provided for them. CAUTION: When you MUST MOVE AN INSTRUMENT from one location to another, if possible, move it in its container.

Most containers for optical instruments have catches or locks for securing the instruments in position; so when you put an instrument in its container, place it GENTLY INTO POSITION and carefully close the lid. DO NOT TRY TO FORCE AN INSTRUMENT INTO ITS CONTAINER OR SLAM THE COVER SHUT. The contour of the interior of the case was made in the best manner possible by the manufacturer to hold the instrument snugly in place to prevent damage during handling. If the instrument does not go into its case without difficulty, check for an extended drawtube or something else which is hindering smooth entrance into proper position. CAUTION: Always secure the cover to the container with the catches installed by the manufacturer.

INSPECTION AND TESTING

The duties of an opticalman will always call for him to inspect and test optical instruments. The inspection may be held aboard ship before the instrument is delivered to the shop or it may be held by the repairman just before he begins the repair work. In any case, the inspection and testing of an optical instrument is vital and the opticalman should have a thorough knowledge of the instrument and procedures.

INSPECTION OF INSTRUMENTS

There may be occasions when you will be given full responsibility for inspecting all optical instruments aboard a ship. By carefully inspecting the instruments and taking care of little troubles, you will be able to save yourself and your repair activity much work. Make notes on your inspection of each instrument and recommend appropriate remedial action, aboard your ship or at a repair facility.

CAUTION: When you inspect an optical instrument in use aboard ship and follow up with minor repairs, do NOT DISTURB the optical system unless it is required.

When you are assigned duty in a repair activity afloat or ashore, inspect every instrument sent to the optical shop for repairs. If an instrument is unfamiliar to you, get all information concerning it from Ordnance Pamphlets (OP's), NavOrd publications, NavShips Manuals, and blue prints. Never attempt to disassemble and repair an instrument until you fully understand it.

During your predisassembly inspection of an instrument, try to locate difficulties. Inspect the physical and mechanical condition of the instrument and also its optical system. Use a casualty analysis inspection sheet and record all your findings on it.

The defects to look for when inspecting an optical instrument are: dents; cracks; and breaks in the housing, mount, and bearing surfaces. Unless they are on a bearing surface, small breaks are generally not serious, but they still require immediate attention. A crack in the housing (or a loose or broken seal), for example, soon causes condensation of moisture within the instrument.

Inspect assembly screws for tightness. If retaining rings are exposed at the end of the tube of an instrument, check them also for tightness, by applying light pressure with your fingers.

CAUTION: Do NOT TOUCH the lens with your fingers, and do NOT USE a retainer ring wrench to test the rings for tightness. The setscrew of the ring (or the ring itself) may be sealed with shellac; and if you attempt to turn the ring with a wrench, you may break the seal.

Take a close look at the condition of the paint on exposed metal parts. To prevent corrosion, cover worn or cracked and chipped paint with a thin film of approved oil. As soon as possible, send the instrument to the shop for repainting.

Mechanical Condition

Carefully examine mechanical adjusting screws, and check knob and gear mechanisms for slack or excessive tightness. If the instrument moves on bearings, test them for binding or looseness.

Try the focusing action of the eyepiece to find out if you can focus it (in and out) without binding or dragging. If binding or dragging exists, the eyepiece adapter or the drawtube is eccentric, which condition is generally caused by dropping or jarring.

Backlash in the focusing action of an eyepiece is usually caused by a loose stop or a retainer ring; but it may be caused by a loose key and its screws in the spiral keyway assembly.

Check the mechanical, 0 diopter setting of the eyepiece to determine whether the index mark points to 0 diopters when the eyepiece drawtube is at mid-throw (halfway in and halfway out). The focusing action should be such that the index mark clears all diopter graduations (plus and minus) during full travel of the drawtube.

If the instrument has turning shafts (ray filter or input), check them by turning the shafts. If rotational action of the ray filter shafts does not turn the color filters in or out of the line of sight, the cause is most likely improper meshing of gears, or detachment of the gear itself from the shaft. If the shaft does not rotate, it is corroded or bent.

All mechanisms must move freely, without binding, slack, backlash, or lost motion. Moving parts should be just tight enough to keep them in proper position.

Check for missing or broken parts—retainer rings, set screws, and so forth. You can locate loose or broken internal parts by shaking the instrument.

If the instrument is gas sealed, CHECK ITS GAS PRESSURE by attaching a pressure gage to the gas inlet fitting. Then crack the valve screw and read the pressure on the gage to find out if it is correct. Correct pressure in most nitrogen-charged optical instruments is approximately two pounds per square inch, or as indicated in the manufacturer's technical manual for a particular instrument. If the gage indicates NO PRESSURE in the instrument, there is a bad gasket, a loose fitting, or a loose screw. Check for all of these defects when you disassemble a gas-filled optical instrument.

Optical System

Because optical elements constitute the HEART of an optical instrument, inspection of the optical system is very important and you should learn to do this phase of your work well. When you first examine an optical system, you may have difficulty in distinguishing one element from another. Through adequate experience, however, you will be able to make this distinction; and you will know where each element belongs in the system and when it is defective.

The best method to follow in inspecting the optical system of an instrument is to point it toward an illuminated area and look for the following:

1. DIRT AND DUST. Dirt and dust show up as dark spots (specks) on the surface of an optical element.

2. CHIPS, SCRATCHES, BREAKS. These defects in an optical element show up as bright, star-like specks, scratches, or areas, when light is reflected from them.

3. GREASE OR OIL. Grease or oil on an optical element in a system is indicated by streaked, clouded, or nebulous areas, with an occasional bright, translucent spot. You may even be able to detect the color by knowing the color of the grease used on the instrument.

4. MOISTURE. Moisture shows up as a sharply defined nebulous area, with brilliant reflection or a diffused, clouded appearance when the area is not illuminated.

5. FUNGUS OR WATER MARKS. Brown or green patches, or stains, indicate the presence of fungus or water marks. Deposits of salt may cause a grainy, milky color similar to that of frosted glass.

6. DETERIORATED BALSAM. Deterioration of Canada balsam used to cement lenses together is indicated by cracking, or a dark or yellow color; and areas between the elements appear milky, colored or opaque, splotched, or net- or thread-like. When the cement just begins to separate, bubbles and areas of splotches shaped like oak leaves appear between the elements. If there are brightly colored bands or rings (Newton's Rings) between the elements, the lenses are under strain in their mounts, or a sudden, sharp blow on the instrument caused the cement to break down.

7. HAZY OR CLOUDED IMAGE. Foreign matter on the objective lens the erectors, or the prisms of an optical system cause a hazy or clouded image.

You can examine color filters in an optical system, provided they are within the focal length of the eyepiece, by holding one eye a few inches from the eyepiece and turning the ray filter shaft. Defects on a filter show up when it rotates in and out of the line of sight.

If the field of view (true field) is not perfectly round, there is a loose diaphragm within the instrument or the color filter plate is not properly engaged with the detent ball or roller.

Check the anti-reflection (magnesium fluoride) coating on coated optics by holding the instrument under a daylight fluorescent lamp (white light). If the coating is of proper thickness on the optic, its color is light-reddish purple. If the coating shows signs of wear (too thin), it is pale-yellow, straw, copper, or reddish-brown in color.

If the coating on a lens is too thin, the best thing to do is replace the lens. The coating must be of adequate thickness in order for the lens (coating) to reduce reflection properly. If the coating is of satisfactory thickness and color, but has scratches, the lens is still usable; for a few scratches do not cause noticeable loss of light.

Optical elements (reticles and collective lenses) placed in or hear image planes of an instrument are not coated, because scratches on them, or deterioration of the coating, appear to be superimposed on the image in the field of view. Optical surfaces cemented to other optical surfaces are not coated, as is true for the concave and convex surfaces of a cemented doublet. Cement will NOT adhere to coated surfaces.

Reflecting surfaces of prisms which use the principle of the critical angle and total reflection are NOT coated, for the coating causes too much loss of light.

Inspect prisms and mirrors for signs of wear, peeling, or darkening of the silvered or aluminum surfaces. All of these defects show up as blisters and cracking of the coating or a yellowish color.

Some optical defects are illustrated in parts A through K of illustration 7-1. If available, get some lenses with the defects shown and study them as you read the following discussion of various lens defects.

CHIP. A chip (part A, fig. 7-1) is a break at the edge of a lens or prism caused by uneven pressures or burrs on the lens seats of the lens mounts.

NOTCH. A notch (part B, fig. 7-1) is a ground off surface of a chip on a lens or prism outside the free aperture. A notch, however, cannot be considered a defect in the true sense of the word, because an optical repairman (Opticalman) must place it in the position indicated in order to prevent internal reflections.

SCRATCH AND STRIPE. A scratch (part C, fig. 7-1) remains visible as you rotate a lens or prism through 360 degrees; a stripe, on the other hand, vanishes at some position as you rotate the optical element. You can most easily see scratches and stripes in optical elements when you place the elements against a dark background.

RING. A ring (part D, fig. 7-1), is a circular scratch or stripe around the external edges of a lens, and it is caused by pressure against the lens by the mount seats and the retainer ring. An INTERNAL RING between the elements of the lens may appear at the edges of the lens when lens cleaning fluid dissolves the Canada Balsam.

CRACK. A crack (part E, fig. 7-1) is generally caused by a sudden change of temperature, resulting in sudden contraction or expansion of the outer surface of the glass and fracture of the lens or prism because the center of the optical element does not expand or contract as rapidly as its edge section, which is thicker in convex lenses and some prisms.

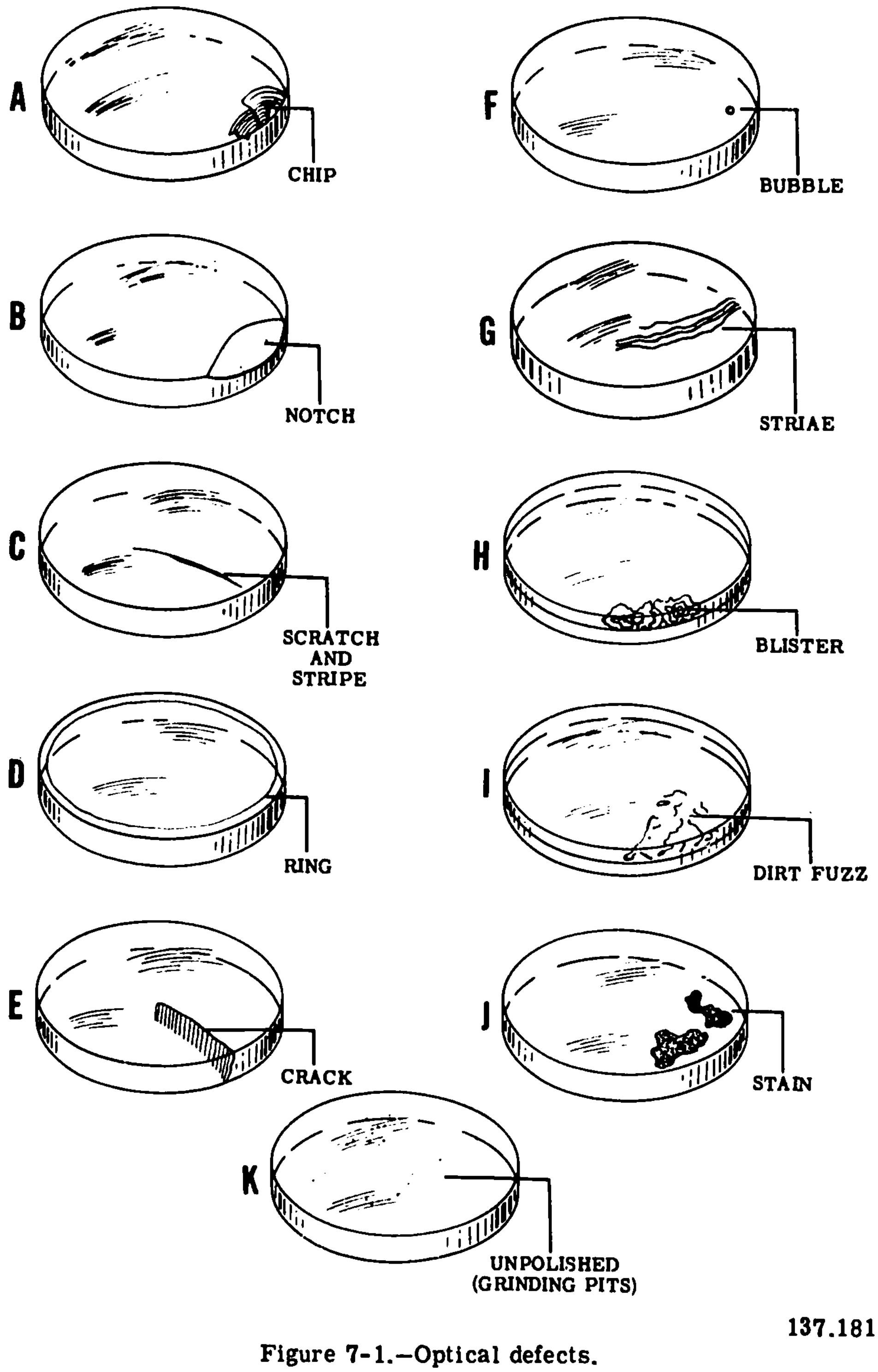


Figure 7-1.—Optical defects.

BUBBLE. A bubble (part F, fig. 7-1) may result from gases left in the glass during manufacture, or from air which did not escape from the cement when the elements were joined with it.

STRIAE. Striae (part G, fig. 7-1) look like veins or cords running through the glass, and you can see them by looking through the glass at a contrasting light and dark background. This is a manufacturing defect in the optical element.

BLISTER. A blister (part H, fig. 7-1) is an air bubble trapped in the layer of cement between two lenses. If it extends toward the center of the lens, it is called a RUN-IN, generally produced by the dissolving action of a cleaning fluid. A blister, however, may result from uneven mounting during assembly in the instrument, or by dirt between cemented lenses. Blisters can be seen best by reflected light, and they usually increase in size over a period of time.

DIRT FUZZ. Lint, dust, or dirt (part I, fig. 7-1) in the layer of cement between lenses may eventually cause a blister. You can see this type of foreign matter in a lens most easily by transmitted light against a dark background. Dirt fuzz is a manufacturing defect in a lens.

STAIN. A stain (part J, fig. 7-1) is usually brown or green in color and is produced by the evaporation of water or moisture which gets on lenses or prisms and dissolves some of the anti-reflecting coating, thereby causing a very faint deposit (sometimes bacterial in growth).

UNPOLISHED CONDITION. An unpolished state or condition of a glass optic (part K, fig. 7-1) results from the manufacturer's failure to remove grinding pits from it. In some instances, however, this condition is produced on optical surfaces exposed to gases, grit, and particles of all sorts in the atmosphere.

The last step in checking the optical system of an instrument is TESTING FOR PARALLAX, or COLLIMATION of the instrument. Always check the collimation of an instrument before you disassemble it, for the information you thus procure will help you during the making of your casualty analysis.

You can check the collimation of an optical instrument in two ways: (1) by looking through the instrument at an infinity target, or (2) by checking it more accurately with an auxiliary telescope. The first method, however, is generally used when quick results are necessary.

Focus the instrument on a distant target and check for parallax by moving the eye from side to side and up and down. If parallax is present, the reticle (crossline) appears slightly out of focus and seems to move back and forth, up and down, over the target. If parallax is not present, the reticle is in sharp focus with the target and remains superimposed in one spot on the target, regardless of the direction in which you move your eye behind the eyepiece.

Hold the instrument up to your eye in the position in which it is normally used and look at the horizontal wire of the reticle to determine whether it is parallel with the horizon, or square in appearance. The only manner in which you can make an accurate check of the SQUARENESS of the crossline, however, is with a collimator and an auxiliary telescope.

To check the eyepiece diopter setting, focus the instrument on an infinity target and observe the position of the index mark on the diopter scale. If the index mark is not pointing to your personal diopter setting, the 0 diopter is incorrect. At this point, you can determine the number of diopters from the 0 setting your PERSONAL DIOPTER SETTING is off.

If the index mark points to three graduations past your personal setting, for example, the eyepiece diopter setting is off three diopters from 0 diopter to the minus side, provided you focused from plus to minus on the scale. If the index mark points to your personal diopter setting on the diopter scale, the instrument is optically set to 0 diopters, even though the index mark is NOT pointing to 0 diopters.

If the instrument has a porro prism erecting system, check the optical system for LEAN by looking through the instrument with one eye at a vertical target (flag pole or side of building) and by looking directly at the target with the other eye. If the two images are not PERFECTLY parallel, there is leaning (termed LEAN) in the optical system; that is, the image through the instrument appears to LEAN away from the image observed with the naked eye. The reason for this LEAN is that the frosted sides of one porro prism are not at a 90° angle with the frosted sides of the other porro prism.

TESTING OF INSTRUMENTS

Image fidelity is the FAITHFULNESS AND SHARPNESS OF AN IMAGE VIEWED WITH AN OPTICAL INSTRUMENT. As you know, good performance of an optical instrument is obtained only when the images it creates are free of aberrations and distortions.

You can make a rough test of image fidelity in a telescope, or a similar instrument, by doing the following:

1. Find and measure the greatest distance at which you can read clearly a newspaper headline, or any print of comparable size.
2. Multiply the distance measured by the magnification of the instrument you are testing.
3. Mount the print at the distance you calculated in item 2 and observe it through the telescope. If it is now just as clear and readable as it was with your naked eyes at the closer distance, THE IMAGE IS SHARP (IMAGE FIDELITY IS GOOD); if the image is fuzzy, IMAGE FIDELITY OF THE INSTRUMENT IS POOR.

You can make a more accurate test for image fidelity by placing a small, glass globe where you can see the reflection of the sun in its surface and focusing your telescope on that reflection. Adjust the eyepiece as necessary to create a small, sharp image of the sun and move the eyepiece in or out from the setting. When you do this, you can see a number of rings around the sun's image. If these rings are circular and concentric, IMAGE FIDELITY (SHARPNESS) OF THE INSTRUMENT IS PERFECT. Any distortion of the rings indicates A LACK OF IMAGE FIDELITY—the greater the distortion of the rings, the poorer the quality of image fidelity.

When you check the image fidelity of an optical instrument, check for two things: (1) CENTRAL ASTIGMATISM, and (2) CENTRAL RESOLUTION. Optical performance is basically a function of design of the instrument and cannot be varied unless the characteristics of the optical elements are changed. There are several possible service defects, however, WHICH CAN CHANGE THE OPTICAL QUALITIES OF ONE OR MORE ELEMENTS. An optical element under strain by mechanical parts, for example, or tilted and improperly positioned elements (faulty mounting), badly matched recemented optics, and even wrong optical parts all cause poor image fidelity.

Tests for central astigmatism and central resolution provide an overall check of both basic optical performance and service defects.

A test for central astigmatism is made ON THE AXIS of the optical system with the test figures in the center of the field of view, which is zero (0) on the axis of an optical system; and it is called CENTRAL OR AXIAL ASTIGMATISM to distinguish it from aberration astigmatism (OFF-AXIAL ASTIGMATISM).

Resolution (resolving power) is the ability of an optical system to distinguish details in an object; so it is therefore a very important characteristic of an instrument, usually stated in terms of the ANGLE SUBTENDED BY THE CLOSEST POINTS ON AN OBJECT THAT THE SYSTEM CAN REVEAL SEPARATED. A strict test of the resolving power on the optical axis—central resolution—is a good check on the overall image fidelity.

Image Fidelity

Take a close look now at illustration 7-2, which shows a standard test chart for testing image fidelity in optical instruments. This is a standard test chart available through naval supply channels.

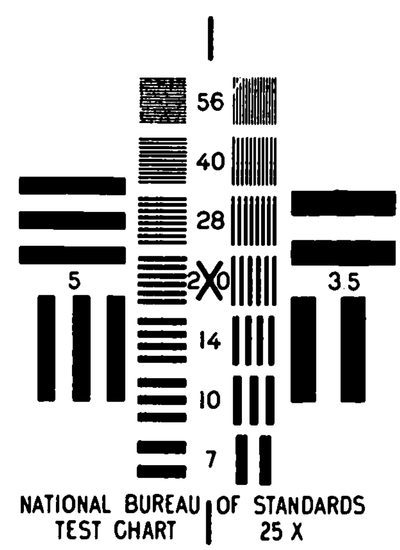


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Figure 7-2.—Image fidelity test chart.

The 56-line-per-inch group at the top of the image fidelity test chart is used for testing central resolution of 7 x 50 binoculars and Mark 1, Mod 0, ship's telescopes. The 28-line-per-inch group is used for testing central astigmatism in these instruments. You can make up a separate chart for each required line spacing by cutting out the groups of lines from two standard charts (fig. 7-2) and pasting them on a white background.

The resolution test requires a test pattern which represents objects at critical distances and spacing. The following paragraphs describe the selection of resolution test patterns. The astigmatism test does not require critical line spacing or distance, but it is convenient to use the same chart and setup for both tests. The group of lines around number 28 is an easily viewed pattern for testing astigmatism in 7 x 50 binoculars and the Mark 1, Mod 0, ship's telescopes.

The width of the black lines on the test chart IS EQUAL TO THE WHITE SPACES BETWEEN THE LINES. Image fidelity test chart values (fig. 7-3) give the reciprocal of the space between the centers of adjacent lines as line per inch, the distance from which you should view the chart and the resolution requirements in terms of ANGLE IN THE FIELD FOR EACH CLASS OF INSTRUMENT. The corresponding patterns for the astigmatism test are also given in terms of the number of lines per inch. These are selected for convenient viewing at the same distance prescribed for the resolution test.

It can be proved that the angular limit of resolution is related inversely to the diameter of the lens. According to Dawes' rule (an approximation): A (in minutes of arc) = $\frac{1}{D_0}$ in fifths of an inch, which means that it advisable TO HAVE LARGE OBJECTIVES FOR SHARP DEFINITION. A target shooter uses a scope with a 1 1/4" objective (diameter), or even large. A pair of 7 x 50 binoculars provides good resolution because of the large size of the objective (50 mm in diameter), and for this reason, it is better than a pair of 7 x 35 binoculars, with a 35 mm objective.

For best resolution, the power of the eyepiece in an optical system should be ascertained by the following formula:

$$\text{Focal Length of Eyepiece} = \frac{\text{Diameter of Eye}}{\text{Pupil}} \times \frac{\text{Focal Length of Objective}}{\text{Diameter of Objective}}$$

NOTE: All values in this formula are in millimeters. Although the resolving power of the human eye is equal to 1 minute of arc, after long, continuous observation, this is reduced to 2 or 3 minutes of arc by resultant eye fatigue. For continuous operation, therefore, an instrument of greater power is needed to provide the same definition obtainable with a lower-power telescope used for short intervals. Transparent foreign material (grease or fingerprints, for example) on a lens impairs definition (resolving power). Opaque, foreign material on the eyepiece may either impair definition or blot out small portions of the field.

When you test the optical system of an instrument, check for all defects, including aberration

Instrument	Θ Resolution Min. Limit in Seconds of Arc	Resolution $\frac{1}{S}$ Lines per inch	D in feet	Astigmatism $\frac{1}{S}$ Lines per inch
7 x 50 Binocular	4	56	77	28
Telescopic Alidade	11	40	39	20
Ship Telescope	4	56	77	28
Azimuth Telescope	8	40	54	20
Sextant Telescope	18	40	24	20

137.183

Figure 7-3.—Image fidelity test chart values.

(all types), coma, astigmatism, flatness of field, and distortion. All of these defects, singly or in combination, can affect the quality of image formed by an optical instrument; or even render the instrument useless.

The procedure for testing an optical instrument for astigmatism follows.

1. Use the proper test chart and set it at the distance given in the listing of values. Sight the test pattern for astigmatism on the chart with the instrument to be tested, and line up the center of the astigmatism pattern in the center of the field of view.

2. Place an auxiliary telescope to the eyepiece of the instrument undergoing the test and adjust it to bring the horizontal set of lines into sharp focus. Note the diopter reading on the auxiliary telescope. CAUTION: The focusing adjustment of the primary instrument (one undergoing the test) must NOT BE CHANGED after you perform the preceding operation.

3. Check the vertical set of lines for focus. If it is not sharp, ASTIGMATISM IS PRESENT. To put the vertical set of lines in sharp focus, adjust the auxiliary telescope diopter ring. OBSERVE THE DIOPTER READING.

4. The maximum allowable difference in diopters between the horizontal and vertical lines is 0.15 diopters for the primary instrument being tested. Divide the diopter difference found in the auxiliary telescope, steps 2 and 3, by the square of its power to arrive at the corresponding change that would be found in the primary instrument without the auxiliary telescope. For example, the diopter change in the primary instrument equals:

$$\frac{\text{Diopter Change in Auxiliary Telescope (DCA)}}{(\text{Power of Auxiliary Telescope})^2}$$

As you can see, the auxiliary telescope increases the sensitivity of the test BY THE SQUARE OF ITS POWER. The maximum allowable diopter difference for typical auxiliary telescopes is as follows:

Power of Auxiliary Telescope	Maximum Allowable Diopter Difference
3	1.35
4	2.40
5	3.75
6	5.40

5. If the horizontal and vertical lines are in focus within the allowable tolerance, repeat steps 2 and 3 for the diagonal sets of lines. The same tolerance prevails.

NOTE: Excessive astigmatism may be caused by a defective or poorly mounted lens. Check the objective lens first, and then the reflecting surfaces of the prisms (objective prism first). These surfaces must be optically flat to close tolerances.

If the instrument you are testing passes the astigmatism test, keep the test setup intact and use the following procedure to test for central resolution:

1. Sight the proper chart at the correct distance with the instrument you are testing with an auxiliary telescope and adjust the instrument in order TO BRING THE CENTER OF THE RESOLUTION PATTERN INTO THE CENTER OF THE FIELD OF VIEW.

CAUTION: Be sure you have the pattern centered. The resolving power falls off away from the optical axis. Focus on one set of lines.

Because the minimum resolving power of a well-designed instrument is finer than the eye can observe, always use an auxiliary telescope to mkae a test for central resolution. The instrument is better than the eye, and the auxiliary power reveals details to the eye.

2. When the black horizontal and vertical lines on the test chart (and the other diagonal sets of lines) APPEAR SHARP AND CLEARLY SEPARATED, resolution in the instrument is satisfactory.

Poor resolution is caused by defective objective lenses and prisms. Always replace the objective lens first. Misplaced, unmatched, and shifted prisms cause trouble because they displace the line of sight. A bad reflecting face on a prism also causes poor resolution.

To check an optical instrument for flares and ghosts, point it toward a small, bright object against a dark background and focus sharply. If you observe rings or streaks of light, or one or more faint GHOST IMAGES, the image HAS EXCESSIVE INTERNAL REFLECTION. Flares and ghosts in an instrument INDICATE A PROBABLE NEED FOR RECOATING OF LENSES.

ILLUMINATION AND CONTRAST

Illumination of an image depends upon the amount of light received by the objective and the specific intensity (bright daylight or twilight) of these light rays. As you know, the amount of light received is determined by the diameter of the entrance pupil of the objective; and the amount of light which enters the eye is limited by either the exit pupil of the instrument or the pupil of the eye, whichever is smaller.

For maximum illumination at any given light intensity, the exit pupil of an optical instrument must equal the entrance pupil of the eye under the same conditions. With any instrument, furthermore, retinal illumination is never greater than illumination by the unaided eye. Opaque foreign substances—dust or lint, for example—on any optical surface (except one in a real image plane) reduces the amount of illumination in the system.

To test for illumination and contrast in an optical instrument, focus the instrument on a distant object and check the image for brightness. The IMAGE SHOULD BE NEARLY AS BRIGHT AS THE OBJECT APPEARS TO THE NAKED EYE. If the image is dim, the exit pupil may be too large; if the size of the exit pupil is correct (about 0.1" for bright light, to 0.3" for very dim light), look for dirty, stained, or uncoated optical surfaces and darkened mirrors or cement.

Contrast of the image produced by the instrument should be just as good as the contrast of the object seenby the naked eye. If the image is dull and cloudy, look for dirty, oily, or damp optical surfaces.

Aberrations

When you test an optical instrument, check closely for all defects, including aberrations, coma, astigmatism, flatness of field and distortion.

To test an optical instrument for spherical aberration, cover the outer half of the objective with a ring of black paper, focus sharply on a distant object, and read the diopter scale. Then remove the ring of paper and cover the inner half of the objective with a black disk. Refocus the instrument and read the diopter scale again. If the amount of movement of the eyepiece for focusing is very small, the instrument is well corrected for spherical aberration.

Chromatic Aberration

You can test an optical instrument for chromatic (color) aberration by doing the following:

1. Set up a white disk against a black background, far enough away to enable you to focus the instrument sharply. When the image is in focus, IT SHOULD HAVE NO COLOR FRINGES.
2. Push the drawtube in a short distance and look for a light-yellow fringe which should be around the image of the disk.
3. Refocus and pull the drawtube out a short distance, AT WHICH POINT THE IMAGE SHOULD BE FRINGED WITH PALE PURPLE.

The two colors (light-yellow and pale-purple) you got by focusing the instrument constitute the SECONDARY SPECTRUM OF THE OPTICAL SYSTEM, and they show that THE SYSTEM IS WELL CORRECTED FOR PRIMARY CHROMATIC ABERRATION (RED AND BLUE).

Coma and Astigmatism

Focus the instrument sharply on a small, round, white object near the edge of the field and study the image produced. If the image is circular and flareless, the INSTRUMENT IS FREE OF COMA.

NOTE: Test for coma at FIVE OR SIX DIFFERENT POINTS around the outer edge of the field.

An optical instrument has excessive astigmatism if one of the cross lines of the reticle shows parallax after you have eliminated parallax for the other cross line.

Point the instrument being tested toward the horizon and focus sharply on AN OBJECT IN THE CENTER OF THE FIELD. If the edges of the field are IN SHARP FOCUS, THE FIELD IS FLAT; if the edges are not IN FOCUS, REFOCUS THE INSTRUMENT AS NECESSARY in order to create a sharp image of objects at the exterme edge of the field. The change you made in the diopter setting of the eyepiece shows the amount and direction of curvature.

NOTE: If refocusing of the instrument does not sharpen the image of objects at the edge of the field, ASTIGMATISM OR COMA IS RESPONSIBLE.

Distortion

You can test an optical instrument for distortion in the following manner:

1. Rule a pattern of vertical and horizontal lines on a large sheet of cardboard and put it where the pattern nearly fills the field of view of the instrument.

2. Focus the instrument sharply and check the image, which should be composed entirely of straight lines. IF ANY OF THE LINES APPEAR CURVED, THE IMAGE IS DISTORTED.

OVERHAUL AND REPAIR

As an Opticalman, you have a complicated job. To repair and overhaul optical instruments, you'll use a wide variety of tools. You'll need special skills, and a lot of information on many subjects. Only by careful practice can you develop skill in using your hands. You'll never do it just by reading a book. The best we can do in this chapter is to try to get you started right.

We'll give you a brief introduction to subjects like these: the use of hand tools; soldering; the use of drills and power tools; thread cutting; handling chemicals; the use of blueprints; and the units of measurement you'll use in your work. We'll introduce you to your tools, and tell you what they're for. We'll give you a few tips that will save you time and trouble. The rest is up to you: stay alert, look around you, ask questions. Learn all you can about each job. Then, when you understand it, try it for yourself.

Keep your working space, your clothes, your tools, and your hands strictly clean. It's a good idea to cover the top of your workbench with a large sheet of clean, light-colored paper before you begin to work. You can keep your hands from sweating by washing them frequently in cold water. (Be sure to dry them thoroughly before you go back to work.)

The old saying "a place for everything and everything in its place" is especially true in the optical shop. You can't do an efficient, fast repair job if you have to stop and look around for every tool you need. Keep each tool in its place. When you've finished with it, don't put it back until you've checked it for dirt and rust. You'll do better work, with less effort, if you keep your tools in good shape and use them only for the jobs they're intended to do.

COMMON TOOLS

Many of the tools used in optical repair work are common hand tools and are thoroughly covered in Basic Handtools, NavPers 10085-A. However, the quality of the tools and their condition are vital to the work done on precision optical instruments. When you select a tool to be used in the optical shop, be certain that it is of the highest quality tool that is available and in good condition. Your skill in selecting, caring, and handling of tools is a measure of your expertise in the OM rating.

SPECIAL TOOLS

Of all the various tools used by an Opticalman, those most valuable will be the special tools that are manufactured specifically for optical work. These special tools may be manufactured by the repairman himself, or on rare occasions, purchased through normal supply channels. When you must manufacture a special tool, the same quality standards that apply to all optical instruments must be used to ensure that the tool is properly made.

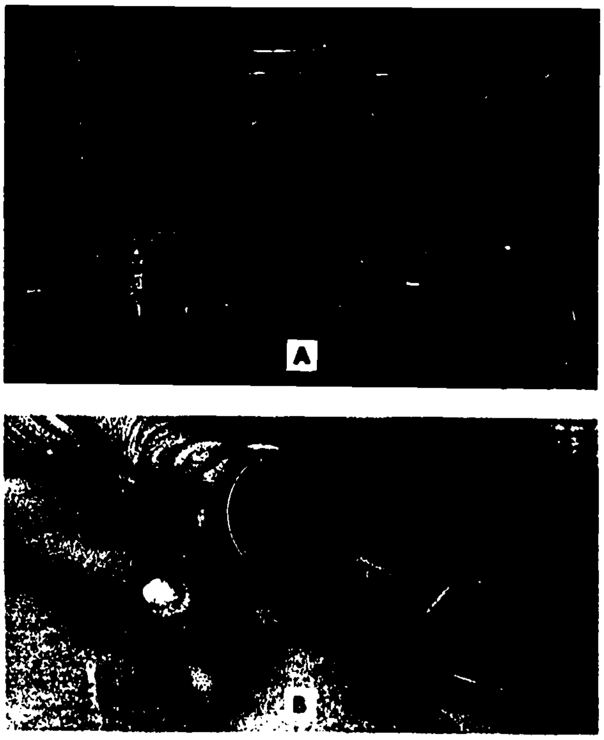
The first step in manufacturing a tool is to make a sketch that shows exact dimensions and the type of material that is to be used. If you are in doubt about the procedure to follow or what machinery to use in making the tool go to the shop supervisor for guidance. Remember: Never operate any machinery until you are thoroughly familiar with its operating instructions and safety precautions.

Some of the special tools used constantly in optical repair work are discussed in the following paragraphs.

Pin Wrenches

Study the different types of retainer ring wrenches shown in part A of figure 7-4. These wrenches are also known as SLOT or PIN wrenches. Part B of illustration 7-4 shows an Opticalman using the blade portion of a retainer ring wrench to rotate a slotted retainer ring in a lens mount. A retainer ring may be equipped with two small holes (instead of slots) spaced 180° apart, in which case the pointed tips of the retainer ring wrench are used to turn the retainer ring. This special tool is adjustable, and it can be used to remove or tighten a retainer ring of various sizes.

CAUTION: Slippage of a retainer ring wrench during use can cause much damage to unprotected optical surfaces, as well as the retainer ring and mount. To prevent such damage, be very careful when you use the wrench; be sure it fits properly in the slots or holes of the retainer ring. Protect optical surfaces with disks—rubber, blotting paper, or clean cardboard.



137.185
Figure 7-4.—Retaining ring wrenches.

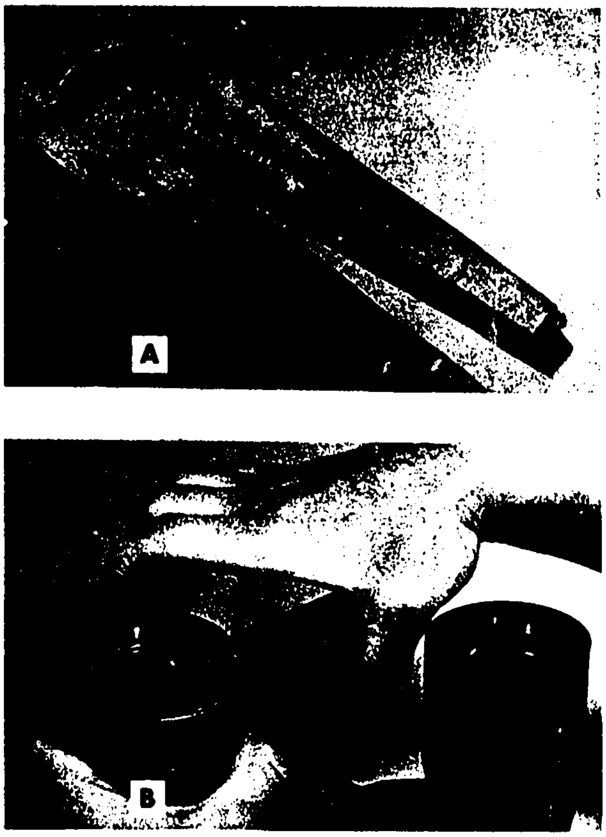


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Figure 7-5.—Grip wrench and usage procedure.

Grip Wrenches

Illustration 7-5 shows a grip wrench (part A) and the procedure for using it (part B). A grip wrench is made of fiber in sizes at intervals of 1/16 inch until a size of about one inch is reached; and then at 1/8 inch intervals up to sizes of about 3 1/4 to 4 inches.

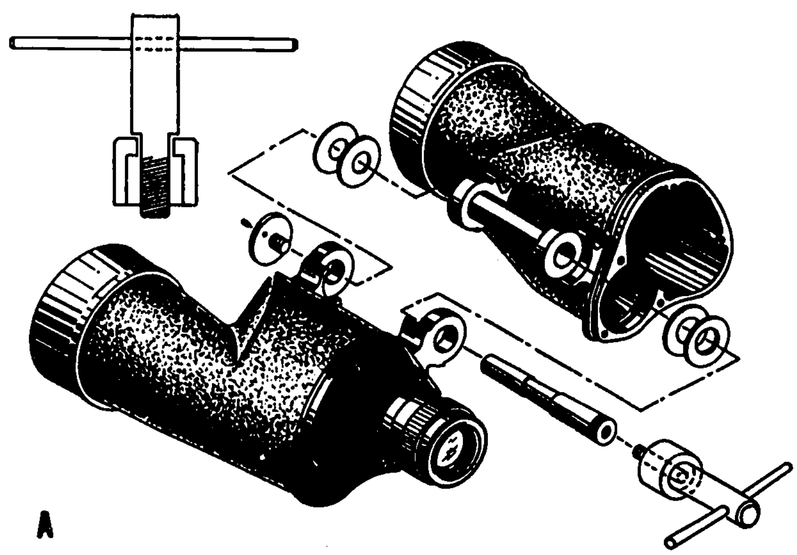
When you use a grip wrench, select the smallest size which meets a specific need, without forcing it onto the part you must turn. CAUTION: Grip wrenches have much leverage and you can exert tremendous pressure with them. Most optical parts are by necessity thin and light; so to prevent crushing of parts, try to use the grip wrench over that portion of a tube externally reinforced with a retainer ring or lens mount.

Hinge Pin Puller

Some special wrenches are useful for only one or two purposes and are used on optical instruments with similar design features. A binocular hinge pin puller is an example of such a tool, almost indispensable for repairing binoculars. Part A of illustration 7-6 shows a cross section of a hinge pin puller, with which you can pull and install a tapered binocular hinge pin without damaging other components of the hinge. Part B of figure 7-6 shows a special telescope wrench used for binocular eyelens retainer rings.

Special Retainer Wrenches

Take a look now at part A of illustration 7-7 which shows a special wrench used to remove or tighten a retainer ring. Part B of this illustration shows another type of retainer ring wrench which is used frequently. This type of wrench is especially useful for adjusting retainer rings inaccessible to an adjustable retainer ring wrench.



A. Binocular hinge pin puller
B. Special telescope wrench

137.187

Figure 7-6.—Special wrenches for optical instruments.

Bench Block

Illustrated in figure 7-8 is a bench block. It is used extensively to support mechanical parts when center punching and driving out taper pins or similar retainers.

GENEVA LENS MEASURE

A Geneva lens measure (fig. 7-9) is an instrument designed to measure the dioptric strength of thin lenses, by measuring the amount of curvature of their surfaces.

The dial of a Geneva lens measure is graduated in diopters. The outside red scale is graduated to read clockwise in quarters of a diopter from 0 to -17 diopters; the inner black scale is graduated to read counterclockwise in quarters of a diopter from 0 to +17 diopters.

The index of refraction of the glass for which a Geneva lens measure is designed for measuring dioptric strength is printed on the dial (1.53), and this number is the index of refraction of crown glass. A formula which is provided, however, permits use of the gage to measure types of glass with different indices of refraction.

To use a Geneva lens measure, place the contact points directly on the polished surface of the lens you desire to check for dioptric strength. The outer points (2) of the gage are STATIONARY, and the CENTER POINT must be activated until the outer points contact the lens surface. To ensure accurate readings and/or measurements, hold the gage perpendicular to the surface of the lens.

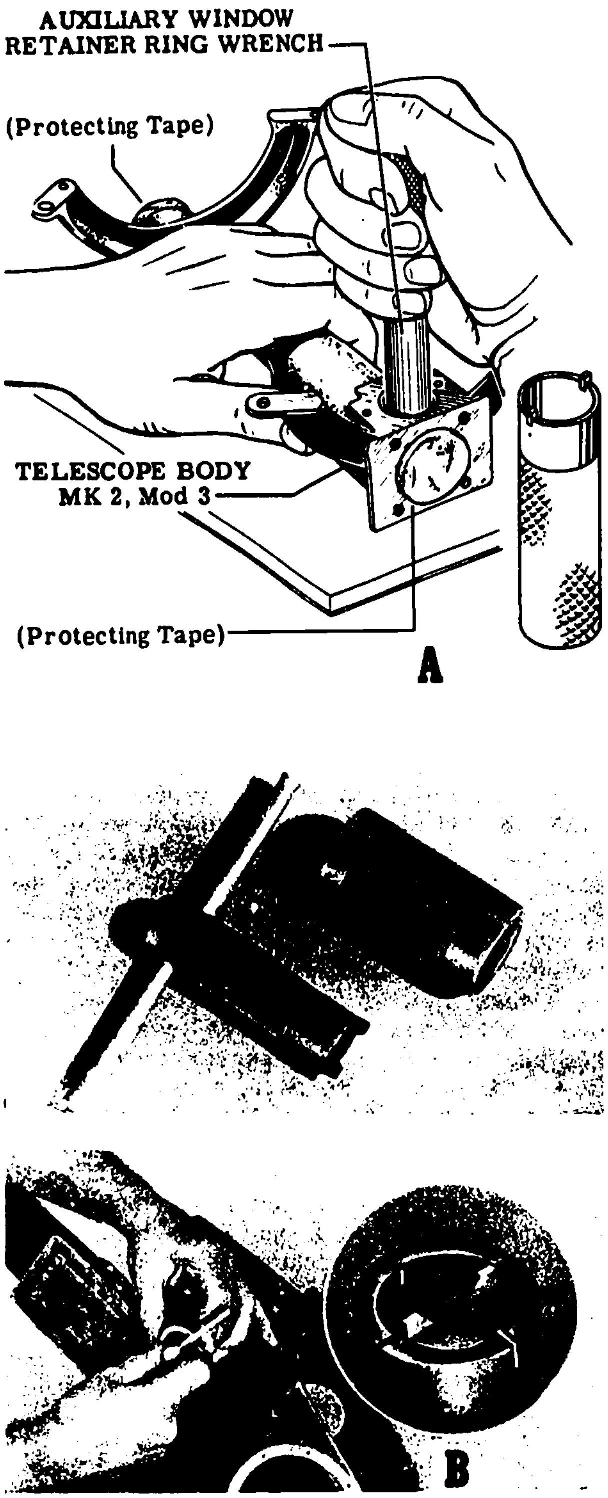
If the dial hand of the lens measure reads 0, the surface of the lens if PLANO or flat. Readings for convex surfaces must be PLUS; readings for concave surfaces must be MINUS. Take the reading in diopters of one lens surface and then measure the other surface. If you ADD THE DIOPTRIC STRENGTH of each lens surface, you get the TOTAL dioptric strength of the lens, provided its index of refraction is 1.53.

When you wish to take a reading of a lens with an index of refraction other than 1.53, use the following formula:

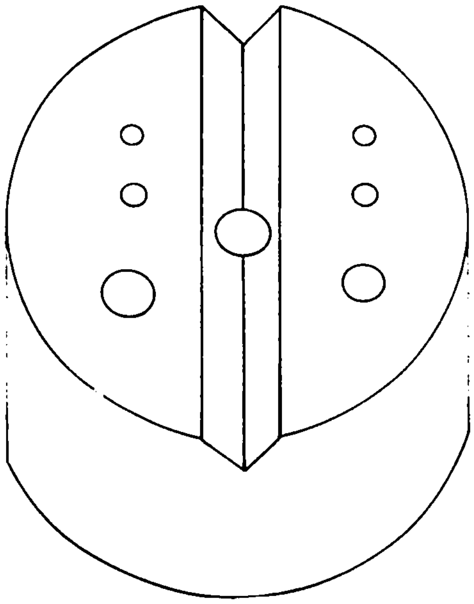
$$\text{True DP of Lens Surface} = \frac{n - 1}{0.53} \times \text{DP reading of lens surface with the gage}$$

(n = index of refraction of lens)

To use this formula, take a reading of the first lens surface and transpose its dioptric strength into the formula and obtain a true dioptric strength of the first surface. Then take



137.187
Figure 7-7.—Special retainer ring wrenches.



137.525
Figure 7-8.—Bench block.

137.186
Figure 7-9.—Geneva lens measure.

a reading of the second lens surface, put your results in the formula, and solve it for the true dioptric strength of the second surface. The sum of the two answers you got by solving the formula is the TOTAL dioptric strength of the lens.

Because a compound lens is constructed of a positive and a negative lens of different indices, you cannot use a Geneva lens measure to obtain its dioptric strength; but if the two elements of the lens are separated, you can obtain the dioptric strength of the individual elements and add both results to get the dioptric strength of the combination. NOTE: The lenses must be in contact and used as a unit in order to use the correct dioptric strength of the combination.

Remember that the dioptric strengths of the two lenses have opposite signs; that is, the positive lens has a positive dioptric value and the negative lens has a negative dioptric value. You must remember this when you add the two values.

Another thing to keep in mind concerning a Geneva lens measure is that it is designed to measure only the curvature of a lens' surfaces; so the thicker the lens, the less accurate the results derived through its use. When you are cementing lenses together, use a Geneva lens measure to make certain that the positive lens surface matches the negative lens surface.

DISASSEMBLY

Before you do any repair work on optical instruments, clean your work space and get everything ready and in position. Your working space, your clothes, your tools, your hands, and everything should be almost immaculate before you begin work on an optical instrument, especially on optical elements. Cover your workbench with a sheet of clean, dry paper of light color.

Clean outside metal and painted surfaces with a clean, soft cloth (used for this purpose only). If a solvent is required to remove grease or foreign matter, use benzene or an approved dry cleaning solvent. Clean the outside surfaces of objectives and eyepieces in their mounts. Some particles of dust on an objective do not have a particularly harmful effect on an image produced by the objective, though they do prevent passage of light through the area they cover; but a film of dust on the objective may affect the quality of the image and you must therefore remove it.

If your casualty analysis indicates that the instrument must be partially or completely disassembled in order to effect necessary repairs, follow the procedure discussed next.

Procedure

When you disassemble an optical instrument, do not mix non-interchangeable parts of one instrument with non-interchangeable parts of another instrument. In the interest of production and/or competence of performance, experienced optical repairmen work on more than one instrument at a time; and this same statement is true for many Opticalmen, especially when all the instruments require a major overhaul.

If you must work on more than one instrument at a particular time, keep the parts of each instrument in separate containers; and label the parts for double safety and easy identification. One of the surest and best ways to label parts is to scribe each metal part with an identifying mark. When you are giving four pairs of binoculars a general overhaul, for example, you can label the parts of the first binocular #1, the parts of the second binocular #2, and so on, In order to identify satisfactorily the parts for right and left barrels, add an R (right) or an L (left), as appropriate. Your markings on the parts for the right and left barrels would thenbe #1R, or #3L, and so forth. Be careful to scribe these marks where they will not be covered with paint later, and where they will not affect the performance of the instrument.

Other markings which you may be required to make or check during disassembly are ASSEMBLY MARKS. When a manufacturer makes an optical instrument, he fits certain parts by hand; and if there is danger of incorrect assembly of these parts during a later overhaul, he marks them with a small punch mark or a scribe line (on each part of an assembly). When you disassemble an optical instrument, therefore, look for these assembly marks; and if they are missing, make appropriate marks of your own. See figure 7-10, which shows the procedure for marking a part.

Optical elements (glass) require another marking technique, which must meet two requirements: (1) the direction the optic must face when reassembled, and (2) the function the optic serves in the optical system.

You can identify the function of the optic by writing on the frosted portion the following: Obj. (objective lens), #1 Er. (first erector), #2 Er. (second erector), and so on until you mark the last element in the system. The first erector receives the light from the objective and should therefore be numbered first. Use a soft-lead pencil or an instant-drying marking pen.

The accepted method for determining the direction an optical element must face in a

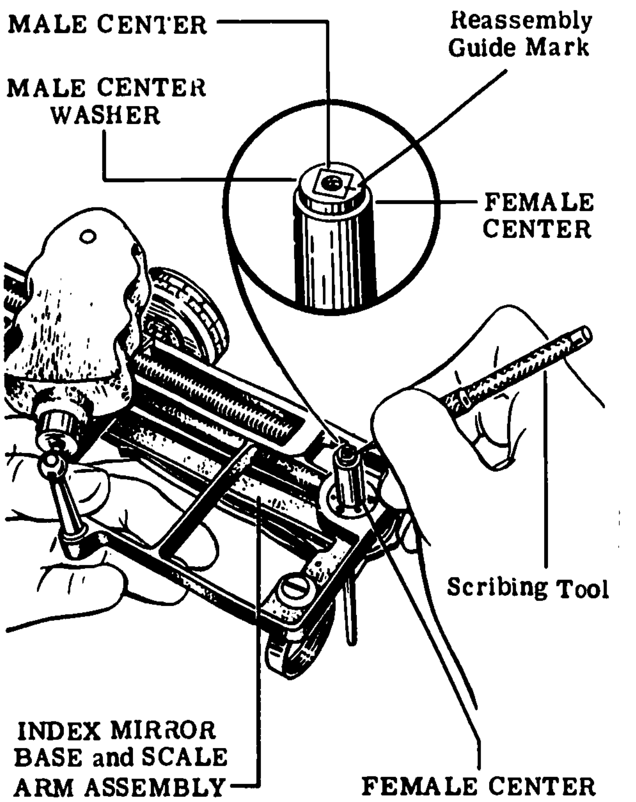


Figure 7-10.—Scribing an assembly mark.

system is to mark an arrow on the frosted edge of a lens or prism, the tip of which indicates the direction of light through the instrument.

If you presume a lens in a system is facing the wrong direction, study the diagram for that particular instrument (MARK and MOD) as you remove the lens. You can also use a Geneva lens measure to check the readings of the lens against those listed on the optical diagram.

If you do not fully understand an instrument you must overhaul, obtain and follow a disassembly sheet, or follow the disassembly procedure in the applicable naval publication (NavShips manual; Ordnance Pamphlet, OP).

These authentic sources provide information on troublesome areas pertaining to disassembly, and they also list the precautions you should take.

CAUTION: Before you disassemble any optical instrument, determine whether it is a pressure-tight type. If it is gas filled, release the gas pressure slowly by opening the gas outlet valve. Never remove anything from the instrument until the pressure is fully released.

Start your disassembly of an optical instrument by removing exterior parts which hinder further disassembly, or by removing an exterior retainer ring, cover cap, or access plate (secured by screws). These exterior parts may occasionally be frozen, because they have been exposed to the weather; that is, metal parts in close contact become secured together as a result of corrosion, electrolytic action, or natural affinity for each other. Aluminum-to-aluminum joints have the greatest tendency to freeze (also called seize). Salt-laden atmosphere enhances the tendency of metal parts of navigational instruments to seize together; and if the moisture seal of the instrument was unsatisfactory, salt-laden moisture will most likely be present inside the instrument.

If this moisture is present inside the instrument, some of the interior parts may also be frozen.

Frozen Parts

The procedure for removing frozen parts follows:

1. To prevent damage to parts which come off easily (especially optics), remove them first.
2. Use proper tools, and do not crush parts with wrenches.
3. If you could not remove a lens, cover it with a pad of blotting paper, or a rubber disk of the same size.
4. When time permits, soak frozen joints in penetrating oil.
5. Use shaped wooden blocks to hold a part in a vise. Powdered rosin on the blocks helps to hold a part and prevent it from slipping out of position.
6. If a joint is still frozen after you have soaked it a reasonable time in penetrating oil, proceed as follows:

    a. Wipe off excess penetrating oil and apply heat to the exterior part as you turn it slowly.

    b. If the part breaks free, remove the heat, apply penetrating oil, and carefully separate the parts.

    c. To separate badly frozen parts which can be held solidly, apply penetrating oil and heat. Then apply pressure to the part in the form of an impact, not a steady pressure; for example, put a wrench on a nut or part and strike the wrench (just back of the head over the part) with a fiber mallet. This impact loosens the nut or part, as a general rule.

d. If the parts are light and springy (body tubes and retainer rings, for example), use a light fiber mallet to tap lightly around the joint as you apply penetrating oil and heat, to help work the penetrating oil into the joint and work the corrosion out.

CAUTION: Use extreme care and patience when you apply heat and pressure to frozen joints, lest you cause distortion (twisting and bending) of metal parts, and breakage of optical elements you could not remove at the outset.

7. If frozen parts do not yield to the procedures just outlined, salvage the most expensive part or parts by carefully cutting, breaking, or machining away the other frozen parts or parts. When a retainer ring is frozen, for example, drill a hole down through it towards the lens; but use care, lest you drill too deeply and ruin the lens with the drill. The diameter of your drill should be slightly less than the thickness of the ring.

After you weaken the ring by drilling the hole, carefully bend the ring out at that point and remove the free ring and lens. Some retainer rings are kept in place (made vibration proof) by an application of shellac or a similar substance on the threads of the mount and to the edge of the ring. You can soften this compound by repeated applications, as necessary, of acetone or alcohol.

8. To remove screws and set screws with stripped slots or heads twisted off, usually troublesome during disassembly, proceed as follows:

a. If a screw is frozen in a hole as a result of corrosion, loosen it with penetrating oil and heat. NOTE: Do this before you try to remove the screw.

b. If the body of a screw protrudes above the surface of a part, file in a new screwdriver slot with a small swiss slotting file and remove the screw with a screwdriver of proper size. You can generally remove some protruding screws with parallel motion pliers.

c. If a screw is deep in a tapped hole, use a sharp scribe tip and, if possible, make a new slot in the screw. This process is slow and requires patience and care.

d. If the procedures just described do not work, use one of the following procedures to drill the screw out:

(1) For very small screws, use a drill slightly smaller in diameter than the minor diameter of the screw and drill through the screw. The outer shell and threads of the screw still remain, and you can run a tap of correct size through the hole to finish the job.

(2) On screws of larger size, drill a hole of proper size in the screw and remove it with a screw extractor. (Each extractor has a drill of recommended size to use with it.)

Remember that patience and careful, intelligent workmanship are required in order to remove frozen parts from an optical instrument; but do not spend more time on an instrument than it is worth. Consult your shop supervisor whenever you are in doubt.

After you remove all frozen parts, continue with the disassembly. Remember to mark all optical and mechanical parts. Before you turn off a retainer ring or try to unscrew or slide a lens mount, remove the setscrews which secure them. Some of these screws may be hidden under sealing wax, so check for them carefully. Failure to remove these setscrews may cause a part to become seized.

Exercise extreme care when you remove optical elements and geared assemblies through openings in the optical chamber. These parts can be easily damaged by striking other parts and the chamber housing. When you remove a part which exposes the interior of the optical chamber of an instrument, make sure you tape or close it off in some manner in order to exclude foreign matter.

As you remove parts and assemblies from the interior of an instrument, check them for damage not previously noted and write your findings on your casualty analysis sheet for future reference.

Thus far, with few exceptions, our discussion of disassembly of an optical instrument has covered mostly mechanical parts, because this is the proper sequence for disassembling the instrument. As you disassemble an instrument, remove each lens mount and cell and set it aside for disassembly after you complete the disassembly of mechanical components.

Lenses from Mounts

The techniques discussed at this point for removing lenses from mounts are primarily for lenses mounted with a sealing compound, but they are also applicable for the removal of optics difficult to disassemble. The techniques to follow (and precautions to use) when you disassemble optical elements from their mounts cannot be formulated as step-by-step instructions. The information and/or things which you should keep in mind, however, when doing this work may be classified as follows:

1. Although optical glass is easily chipped or cracked, and easily damaged by shock, steady pressure within limits does not ordinarily crack a lens if the thickness of the glass is sufficient.

NOTE: Removal of the eyepiece and the objective is usually more difficult than removal of other optics, because these two lenses are usually sealed in their mounts with a sealing gasket or compound. Also, these lenses are doublets, which means that excessive or uneven pressure on the lenses can cause damage to the cement used to put them together, or cause the thin planoconcave flint element of the eyepiece to break.

2. Shearing action caused by uneven pressure is the greatest enemy of cement between optical elements; therefore, to force the compound lens out of its mount, press down squarely and evenly over a large part of its area. A device similar to that illustrated in figure 7-11 may be used to support the lens. Note the name of this device, LENS CHUCK AND CLEANING HOLDER, which is a cylindrical brass tube with the edges at one end beveled to match the curvature of the lens. By exerting even pressure on the lens mount, you can break the seal. Observe that the word PRESS in the illustration indicates the point where you should apply pressure.

3. An application of heat to a lens mount helps to loosen it from the lens in two ways:

a. The metal expands more than the lens.

b. Most sealing compounds are softened by moderate temperature.

CAUTION: A temperature of 125°F to 140°F softens Canada balsam used to cement the elements of compound lenses together. If a compound lens does not therefore yield to pressure and an application of heat at low temperature, the Canada balsam probably melted previously and ran out between the elements of the lens and the mount and hardened a second time. When this happens, a high temperature is required to soften the cement.

4. When you remove a lens from its mount, protect its surfaces with a clean cloth or tissue paper. DO NOT TOUCH POLISHED GLASS OPTICAL SURFACES WITH YOUR FINGERS. Be sure to mark the path of light through the lens, to make certain that you reassemble it correctly. Then wrap the lens in lens tissue (several thicknesses) and place it where the mechanical metal parts cannot damage it.

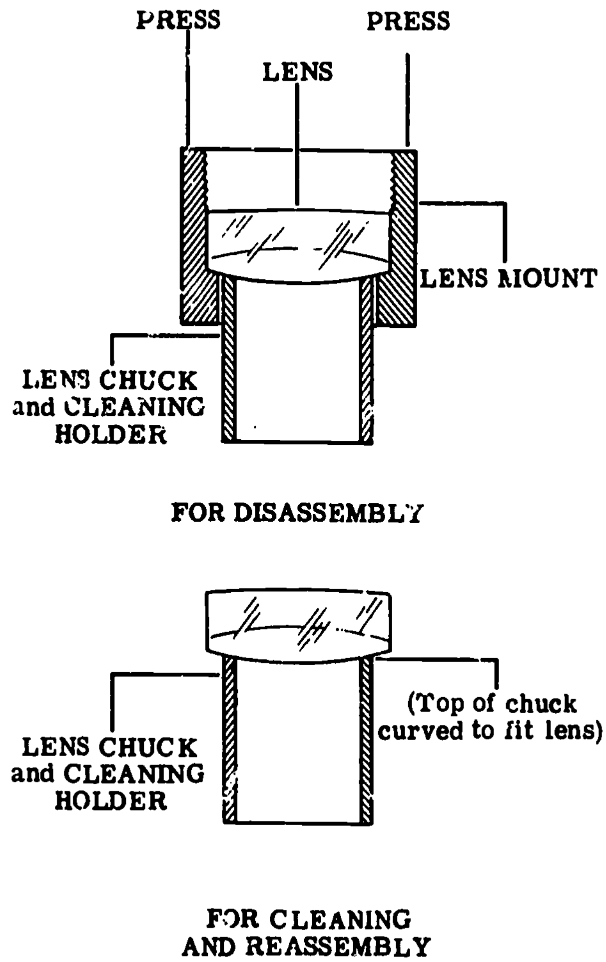


Figure 7-11.—Lens chuck and cleaning holder.

5. When you cannot push a lens out from the back, as is sometimes the case, use a small suction cup or piece of masking tape to grip the lens and then ease it out of the mount.

CAUTION: Large thin lenses have a tendency to twist diagonally (COCK) as you try to remove them; so use care in order to prevent sticking. To loosen a COCKED lens, tap LIGHTLY ON THE EDGE OF THE MOUNT, on the side where the lens is stuck. As you tap the mount, so hold it that the lens will eventually drop out into your hand. If you accidentally touch the lens with your fingers, clean it thoroughly at once, to remove salts and acids deposited by your fingers.

REPAIR PROCEDURE

When you start to overhaul and repair an optical instrument, refer to the notations you made on the casualty analysis sheet for it prior to and during disassembly; and use this information as you proceed with the repair process.

Cleaning and Inspecting Parts

The first phase of overhaul of the instrument is cleaning of mechanical parts. Always use approved cleaning solvents, which may be slightly toxic and irritating to your skin and necessitate cleaning in well ventilated spaces only. Avoid prolonged contact of the hands with the solvent. The best policy (safest) is to use solvents only in a space specified for their use.

A cleaning machine of the type shown in figure 7-12 is excellent for cleaning some mechanical parts of optical instruments. An electric motor in the machine revolves a basket of parts a sufficient amount of time in an approved cleaning solvent and thus thoroughly cleans the parts. The second step in this process is to put the clean parts into another basket and rinse them in a container of approved rinsing solution. The final step (usually) in this cleaning process is to wash off the rinsing solution and dry the parts in the machine.

Another type of instrument cleaning machine (not illustrated) agitates solvent around the

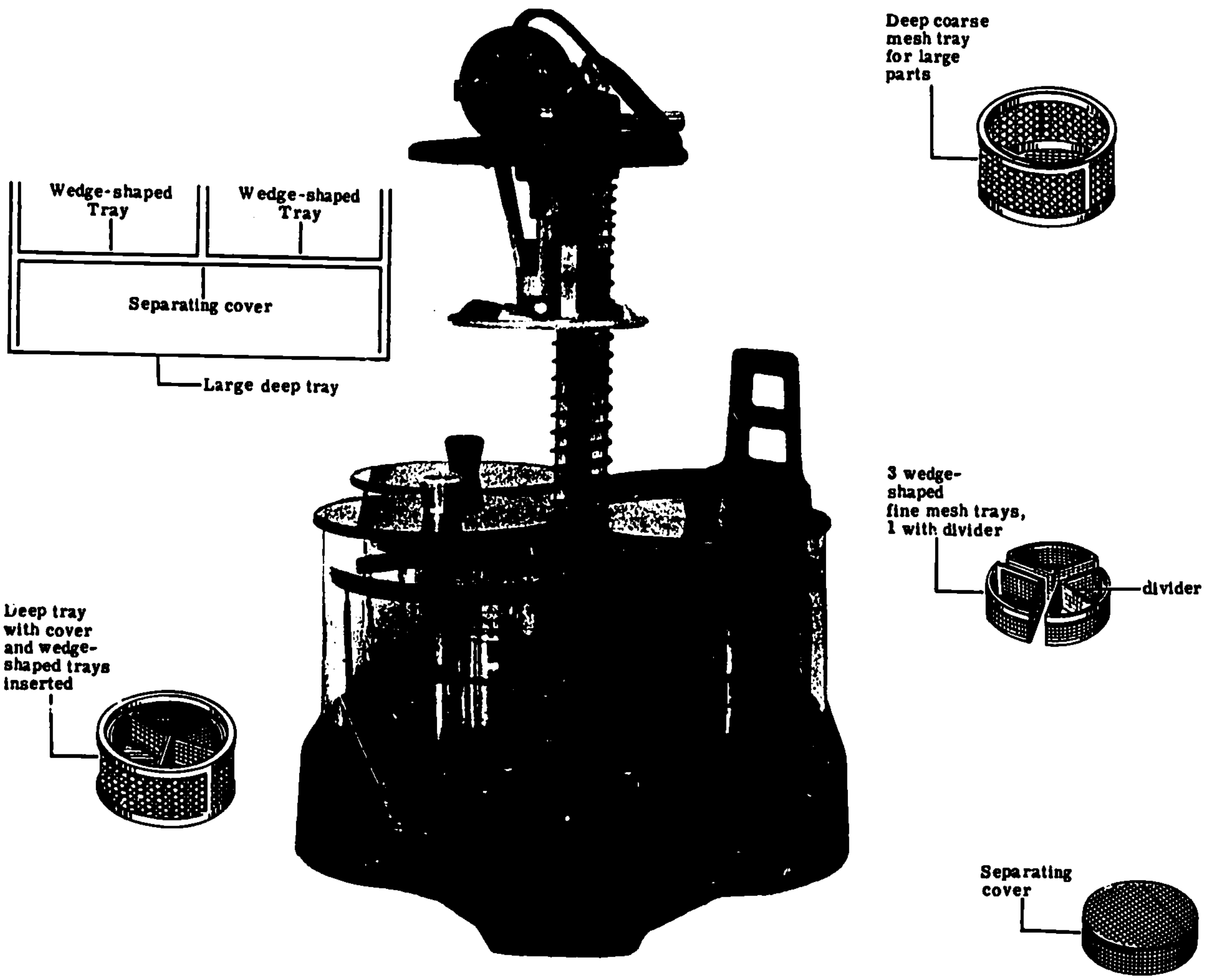


Figure 7-12.—Instrument cleaning machine.

parts by vibration. The newest types of cleaning machines employ an ultrasonic oscillator to act on an approved liquid cleaning agent and thereby clean the parts.

NOTE: When you use a cleaning machine, follow the instructions listed in the manufacturer's technical manual. If you do not have this manual, consult your shop supervisor.

If your shop does not have a cleaning machine, use a stiff-bristle brush to clean instrument parts in a tank of cleaning solvent. This is one of the best and simplest methods for cleaning some (if not all) instrument parts. Some solvents leave an oily residue on clean parts, and you must remove it by rinsing the parts in an approved degreasing agent. Traces of oil on the interior of an optical instrument may later get on the lenses and affect image formation, or render the instrument useless.

After you clean instrument parts, inspect them for traces of lubricants, grease, sealing compound, or dirt. Scrape off dirt and grease not removed during the cleaning process.

CAUTION: Do NOT scrape bearing surfaces. As you examine each cleaned part, look for defects previously hidden by dirt, wax, or grease; and also check them for corrosion. Replace badly corroded parts.

Place the cleaned parts you intend to use in a suitable, clean container and cover the container to protect the parts from dust and dirt.

Repair Categories

Now that you have cleaned and inspected the parts of the instrument undergoing repair, proceed IMMEDIATELY with the repairs. The repair process generally consists of three phases or categories: (1) repair and refitting of old parts, (2) using a new part (replacement) from stock, and (3) manufacturing and refitting a new part. Each of these categories is discussed in some detail in the following pages.

REPAIRING OLD PARTS.—Repair reusable old parts, as necessary, and refit them into the instruments from which you removed them. The repairs which you may have to make on a part are discussed next.

If a part must be straightened or reformed to its original shape, strike it carefully at the proper place with a soft-faced hammer. CAUTION: Give the part necessary support before you strike it, lest you inflect further damage upon it.

When a part has stripped or damaged thread in a tapped hole, whenever possible, drill the hole out and retap it for a screw of larger size; but do not go over one or two screw sizes larger than the original size stated on the blueprint. If the screw size must be exactly as stated on the blueprint, proceed as follows:

1. On steel, bronze, and brass parts, drill and tap the hole two or three screw sizes larger than originally and fill the hole with the same material of which the part is made. Use silver solder to secure the plug. NOTE: A screw which fits the larger size makes a good plug. Then file the plug flush with the surface of the part and drill and retap a hole of correct size.

2. If a larger size screw can be used, repair aluminum parts with stripped threads in the same manner as you repair parts made of other metals. It is difficult to solder aluminum parts, however, and it is best to ask the shop supervisor to have the soldering accomplished in another facility, if possible. When the soldered part is returned to you, dress the soldered area, and redrill and tap the hole to the size specified on the blueprint.

3. Dress up scratched, burred, and dented parts, in accordance with prescribed shop procedures.

Use much care when you repair parts, to prevent damage to precision bearing surfaces machined on them. Use a stone or a bearing scraper to remove burrs from a bearing surface, and be careful to remove only as much metal as is essential to do a good job. Do NOT file a bearing surface, for filing may completely ruin it.

When you complete repairs on an instrument part, refit the part on the instrument and check its action and/or operation for accuracy. If necessary, scrape off a slight amount of a surface in order to make a part fit properly; and redrill undersized holes and make other necessary changes of your repair job in order to have the part fit correctly. After you fit a part, DO NOT FORGET to make an assembly mark on it to indicate direction of installation.

CAUTION: Reassembly of an instrument containing improperly fitted parts may necessitate unnecessary subsequent disassembly on part or all of the instrument.

The THREAD CHASER is a handy tool for removing dirt, corrosion, and burrs from threaded parts. As you can see in figure 7-13, there are two basic types—one for inside threads and one for outside threads. Be sure to use the

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Figure 7-13.—(a) Types of thread chasers.
(b) Reshaping inside threads.
(c) Reshaping outside threads.

right type, and carefully check the thread size before you use it.

REPLACEMENT PARTS.—Sometimes a part is damaged to such an extent that it must be replaced with a new part. One source of replenishment is from stock, for some purposes only.

When you receive a replacement part from stock, try it for proper fit in the instrument or assembly. If it does not fit, take necessary action, including machining. A manufacturer, for example, does not drill dowel pin and screw holes; so you must drill them of correct size wherever required. A manufacturer also makes bearing parts slightly oversized, so that you can fit them properly by hand. Do not forget to make assembly marks on the new parts after you fit them, to ensure correct fitting of them into the instrument later.

MANUFACTURED PARTS.—Occasionally, your shop supervisor can have parts made by submitting an intershop job order; but there will also be times when you will be compelled to manufacture parts. The procedure for doing this is as follows:

1. Use information on the old part, or its name, to locate the blueprint. Use its dimensions to make or procure a new part when the blueprint is unavailable.
2. If the foundry can cast the part, give the old part and the blueprint which covers it to the pattern shop so that it can make an accurate pattern of the part for the foundry.
3. After you receive the manufactured part, machine it as necessary and then fit it by hand to the instrument.

Miscellaneous Repairs

When you gave the instrument on which you are working a pre-disassembly inspection, you perhaps noted undamaged moving parts in the instrument which were dry, tight, grinding, or rough in action. You also perhaps found in some instances a combination of these malfunctions, and even others not mentioned here.

When you effect miscellaneous repairs on an instrument, look for all types of trouble and remedy it, including lack of or dirty lubrication, excessive or insufficient clearances, incorrect alignment, and improper assembly. If the cause of malfunctioning is not readily apparent, proceed as follows:

1. Clean all parts of the bearing assembly.
2. Make a trial assembly, but do not force parts.
3. Check parts for proper clearance in order to determine the cause of binding or excessive lost motion.

When cleaning, lubrication, and proper aligning of parts fail to correct casualties and/or malfunctioning, take the action discussed in the following paragraphs:

INSUFFICIENT CLEARANCE.—If there is an insufficient amount of clearance on such parts as eyepiece drawtubes, tapered sleeve bearings, ball and socket bearings, and multiple-lead thread eyepieces, do this:

1. Make a thin solution of pumice and clock oil (small amount of pumice at first) and put a little portion of the solution on the parts as you reassemble the bearing.
2. Work the parts of the bearing back and forth, or rotate them until their movement is of desired freedom.
3. Disassemble the bearing and wash out all traces of pumice and oil.
4. Reassemble the bearing, lubricate with the proper type of lubricant, and check the motion.

Follow the procedure just described until you obtain the desired fit.

When there is insufficient clearance on a flat, sliding-surface bearing, do the following:

1. Put a thin coat of Prussian blue machinist's dye on a surface plate and rub the oversized portion of the bearing assembly over the Prussian blue.
2. Carefully scrape away the high spots on the bearing indicated by the Prussian blue.

CAUTION: Remove only a small amount of metal at a time, and make a trial assembly after you remove each amount. The important thing here is prevention of the removal of too much metal from the bearing.

Another method for removing excess metal from a sliding-surface bearing is to spread a small portion of a thin mixture of pumice and clock oil over the surface of a flat lap and rub the high part of the bearing over the surface of the coated flat lap. Use a sweeping figure-of-eight motion to ensure uniform removal of the metal. Do NOT remove too much metal.

EXCESSIVE CLEARANCE.—If there is no way of adjusting a bearing by removing excessive clearance with shims, or the bearing does not have some means by which it can be adjusted, replace it with a new one. If there is some way to adjust the bearing, however, adjust it as necessary in order to get a tight fit and then remove high spots in the manner described for obtaining sufficient clearance.

NOTE: Always mark bearing parts to ensure proper assembly after you hand fit them in the manner just described.

CLEANING AND PAINTING

Having completed all repairs to your instrument, you are now ready to accomplish essential cleaning prior to painting. Reclean all parts on which you made repairs, to remove traces of moisture, dirt, metal chips, and grease from its surfaces. If a part does not require painting, put it in the container with other cleaned parts of the instrument.

Before you can successfully paint any metal object, you'll have to get it thoroughly clean. If the surface is covered with rust, or dirt, or grease, the paint can't reach the metal. It forms a loose coat that chips off or peels off. If you paint over grease or oil it will probably mix with your paint. And the mixture will dry very slowly, or not at all.

Corrosion Removal

When a part is corroded, thoroughly clean it in order for the paint to adhere and give a good finish. This may be accomplished by using approved commercial compounds. Always follow the manufacturer's instructions when you use any product, and protect yourself by following safety precautions.

Corrosion generally eats into a part, and the best way to remove it is to soak the part for a sufficient amount of time in a tank (stainless steel) of the compound.

If you do not have an approved corrosion removal compound, you may make some (for different metals) by using the following formulas:

1. To make a corrosion removal compound for CAST IRON AND STEEL, use a 50 percent solution of sulfuric acid and distilled water (about 150°F). Then dip the corroded metal parts in the warm acid for about 5 seconds and wash them immediately in several changes of hot water.

CAUTION: Do not handle chemicals until you understand the safety precautions which pertain to them. NEVER USE ACID ON BEARINGS, or GEAR TEETH.

2. You can make a corrosion removal compound for brass by using the following formula:

Water (pure, distilled	491 cc
Sulfuric acid (concentrated)	435 cc
Nitric acid (concentrated)	72 cc
Hydrochloric acid (concentrated).	2 cc

If a brass surface is bright in spots, there is probably some clear lacquer on it. Submerge the part in paint remover and then rinse it with hot water. Continue by dipping the part in the correct amount of the corrosion removal solution for 4 or 5 seconds, rinsing it in water, drying thoroughly with an air hose, and applying at least one coat of clear lacquer before the surface oxidizes. NOTE: Do not use lacquer if the part requires paint.

CAUTION: Do not use a brass dip on bearing surfaces.

3. To clean corrosion from aluminum, dip it for 5 to 10 seconds in a 10 percent solution of sodium hydroxide (lye) at a temperature of about 150°F and wash the lye off immediately with hot water.

You can also use some non-chemical methods for removing corrosion and giving a bright, clean finish to metal parts. These methods involve types of abrasives, wire brushes, buffing wheels, and abrasive cloth, listed in the order of discussion.

1. REMOVING CORROSION WITH A WIRE BRUSH. There are two types of wire brushes which you may use to remove corrosion from metal, rotary-power and hand.

CAUTION: To prevent damage to your eyes, wear your goggles to protect them from flying wire. Do not use a wire brush on a bearing surface or an engraved part.

To use a rotary-power wire brush, hold a part against the wheel with enough pressure to force the moving wire bristles into the corrosion and keep the part moving slowly and evenly against the wheel. Run the wheel from the center of the part toward the edges, to ensure thorough cleaning of the edges. Use a hand wire brush, emery paper, or a scraper to remove corrosion from the inside corners of the part.

2. REMOVING CORROSION WITH A BUFFING WHEEL. A buffing wheel gives a part a brighter, polished finish than a wire brush (wheel), but it will not remove heavy corrosion. For this reason, do not use these wheels on large areas, but use them to polish metal parts which must remain bright.

Use a polishing compound with a buffing wheel, and polish a part until you have the desired brightness and polish. Then remove the remains of the polishing compound with a solvent, dry the part thoroughly, and apply at least one coat of clear lacquer.

NOTE: To speed up the buffing process, clean the parts first in a corrosion remover.

3. REMOVING CORROSION WITH ABRASIVE CLOTH. You can remove corrosion from metal with an abrasive cloth in the following manner:

a. Polish flat pieces by hand on crocus cloth (embedded with an oxide of metal) laid on a flat surface.

b. Polish irregular pieces which you cannot buff on a wheel by hand. Use wood or metal in the jaws of a vise to protect these pieces and secure them ONLY as tightly as essential. To polish a piece in the vise, use a strip of fine emery cloth and complete the job with a piece of crocus cloth, to remove grains produced by the emergy cloth.

c. Put small, round parts of an instrument in the collet of a lathe and (with the lathe running at high speed) touch the parts lightly with emery cloth or crocus cloth to the extent necessary to obtain the polish desired.

CAUTION: Do not use abrasive cloth on bearing surfaces. When a bearing surface has deep pits caused by corrosion, it is worthless; the bearing is ruined. Use a non-abrasive cleaner to remove light corrosion from the surface of a bearing. Unless there are provisions provided in the construction of a bearing for refitting it, and you can do this in your shop, never remove metal from a bearing surface. When you remove corrosion from a bearing surface, rub it off carefully with crocus cloth or a fine paste of clock oil and pumice, or by scraping.

You have perhaps learned a great deal about safety precautions in basic naval training courses you studied previously; and they need little or no repetition here UNLESS THEY ARE ESPECIALLY APPLICABLE TO OPTICALMEN. The safety precautions listed and discussed in the next section belong in the category of those important in a particular way to Opticalmen.

Study the following rules applicable when you work with all kinds of chemicals. If you know them well, you may on occasions be able to prevent extensive harm and/or damage to your body as a result of their contact with it; you may, in fact, even be able to save your life by the knowledge you have about chemicals.

1. DIRECTIONS FOR USE.—Study the directions on the container for using a specific chemical. If you mix chemicals improperly, or in incorrect proportions, they WILL NOT WORK and they MAY BE DANGEROUS. Such mixtures sometimes explode and cause much harm and damage.

CAUTION: NEVER MIX CHEMICALS AT RANDOM, OR PLAYFULLY, JUST TO FIND OUT WHAT HAPPENS. IF YOU DO THIS, YOU MAY NEVER LIVE LONG ENOUGH TO FIND THE ANSWER TO YOUR CURIOSITY.

2. LABELS.—Keep labels on containers and bottles of chemical intact. If you notice that a

label is coming loose, glue it back in place. Then coat the label WITH PARAFFIN WAX TO PROTECT IT.

CAUTION: NEVER USE A CHEMICAL FROM AN UNLABELED CONTAINER—GET RID OF IT IN THE PROPER MANNER.

3. WATER AND ACID.—If you must mix water and acid, POUR THE ACID VERY SLOWLY INTO THE WATER.

CAUTION: If you pour water into acid, the MIXTURE WILL BOIL OVER QUICKLY AND BURN YOUR HANDS AND EVERYTHING IT TOUCHES.

4. ACID AND CYANIDE.—The chemical reaction of acid and cyanide generates a deadly poison.

5. CLEANLINESS.—Keep chemicals and their containers clean, as well as all equipment, supplies, and spaces you use when handling chemicals. Even a small amount of dirt or grease, for example, may ruin your work.

6. CHEMICAL POISONING.—Most chemicals are poisonous, and many of them can burn your clothes and hands. CAUTION: WEAR RUBBER GLOVES, A RUBBER APRON, AND GOGGLES WHEN YOU MIX CHEMICALS OR WORK WITH THEM.

Learn by heart the antidotes for poisoning and burning by chemicals. This knowledge may save your life.

Treat acid burns AS QUICKLY AS POSSIBLE. Wash the acid off with an abundance of water and then wash your hands under a spigot, if they were involved. Continue by neutralizing all acid which remains with lime water, a mixture of equal parts of lime water and raw linseed oil, or a paste of baking soda and water. REMEMBER THIS: Baking soda is a base and it neutralizes acids. If acid gets in your eyes, wash it out with cold water and then WASH YOUR EYES WITH WEAK LIME WATER.

WASH ALKALI BURNS WITH PLENTY OF COLD WATER; then neutralize remaining portions of the alkali WITH VINEGAR OR LEMON JUICE. REMEMBER THIS: Acids such as VINEGAR OR LEMON JUICE neutralize bases (alkalies) such as lye.

Some good antidotes for poisons are listed next. Study them carefully; better still, memorize as many as possible.

ACETIC ACID.—Use an emetic to cause vomiting. Magnesia, chalk, whiting in water, soap, oil, mustard, and salt are emetics. A quick method for making a GOOD EMETIC is to stir a TABLESPOONFUL OF SALT OR MUSTARD into a glass of warm water.

HYDROCHLORIC, NITRIC, AND PHOSPHORIC ACID.—Use milk of magnesia, raw egg white, cracked ice, or a MIXTURE OF BAKING SODA AND WATER as an antidote for poisoning by these acids.

CARBOLIC ACID.—Some good antidotes for carbolic acid are: egg white, lime water, olive or castor oil with magnesia suspended in it, zinc sulfate in water, cracked ice, pure alcohol, or about 4 ounces of camphorated oil. Remember particularly: Egg white, lime water, and cracked ice, for they will most likely be readily available.

ALKALIES (sodium or potassium hydroxide).—Good antidotes for poisoning by sodium or potassium hydroxides are: vinegar, lemon juice, orange juice, oil, or milk. You can easily remember these antidotes.

ARSENIC (including rat poison and Paris green).—Use milk, raw eggs, sweet oil, lime water, or flour and water as an ANTIDOTE FOR ARSENIC POISONING.

CYANIDE.—Cyanide poisoning works so rapidly that you can do little to prevent death, which this poison causes in less than a minute. If possible, GIVE HYDROGEN PEROXIDE TO A VICTIM. If breathing stops, apply artificial respiration and let the patient breathe ammonia or chlorine produced by chlorinated water. If the victim is conscious, give him ferrous sulfate in water; then give him emetics and keep him warm.

DENATURED ALCOHOL.—Antidoes for poisoning by denatured alcohol are: emetics, milk, egg white, and flour and water. If breathing stops, give artificial respiration.

IODINE.—Give emetics, or plenty of starch or flour in water (stirred) as an antidote for iodine poisoning.

LEAD ACETATE (sugar of lead).—Use emetics; sodium sulfate, potassium sulfate, or magnesium sulfate in water; milk; or egg whites as antidotes for lead acetate poisoning.

MERCURIC CHLORIDE (corrosive sublimate).—Some good antidotes for mercuric chloride poisoning are: emetics, egg white, milk, table salt, castor oil, and zinc sulfate.

SILVER NITRATE.—For poisoning by silver nitrate, give a solution of table salt and water.

The first thing to do for all types of gas poisoning is this: GET THE VICTIM IN FRESH AIR IMMEDIATELY. IF HE STOPS BREATHING, GIVE HIM ARTIFICIAL RESPIRATION.

Breathe ammonia or amyl nitrite for poisoning by carbon monoxide, illuminating gas, ethylene, or acetylene.

The antidote for poisoning by chloroform and ether is COLD WATER ON THE HEAD AND CHEST.

Paint Removal

When you're going to repaint a surface that's already painted, of course you'll have to remove the old paint first. Apply a commercial paint remover by brushing it onto the painted surface. (After you've used a brush for paint remover, don't use it again for any other purpose.)

Brush-on paint remover dissolves synthetic-bristle brushes, so use a natural-bristle brush and brush it on the painted surface of an instrument part. Leave the paint remover on the part as long as necessary for it to dissolve the paint and then wipe it off. Finish the job by rinsing the part in lacquer thinner or benzene to remove wax used in the remover as one of the ingredients.

Because it is difficult to wipe brush-on paint out of holes and corners, you will experience some difficulty in using it.

Paint and carbon removers are available through Navy supply channels and also commercially. They are designated as SUPER cleaners. Besides removing paint, they remove heavy carbon, grease, varnish, and sticky gums.

You will obtain the best results with a paint and carbon remover by putting at least 10 gallons in a stainless steel tank and soaking the parts as long as necessary in it. Then wash each part with hot water, remove the water with a compressed air hose, and bake it briefly in an oven. It is then ready for painting.

Types of Paint

Some paint manufacturers make lacquers and enamels which put a fine finish on instruments. Many optical parts have a very smooth, hard finish which appears to be part of the metal itself. This finish is called ANODIZE, applied to the metal by an electrochemical process.

A baking enamel of high quality gives a hard, durable finish, but air-dried enamel is good for touching up or painting an instrument which cannot be subjected to heat in a baking oven. Lacquers have one outstanding characteristic, quick-drying, but they cannot resist chemicals and are therefore not as durable as enamels.

Acrylic enamels sprayed from small aerosol cans are widely used in optical shops. Results are not as good as baking enamels or enamels sprayed from a gun, but such enamels are satisfactory for most instrument finishes.

CAUTION: Never cover enamel with lacquer, because the lacquer loosens the enamel from its base and causes it to blister.

Lacquers and enamels which give a dull-flat, black finish are used to cut down surface reflections, and they are also used to kill internal reflections on the inside of optical instruments. You will generally use a dull-black finish paint on most optical instruments.

Paints which give a semigloss, black appearance and a hard, durable finish are used on parts which receive considerable handling, and on such small articles as eyepiece focusing rings, knobs, handles, and pointers.

Always use clear lacquer on parts subject to corrosion but which are not painted, to protect their high polish.

Preparing Paint

Prepare both the primer coat and the finish coat in the same manner for use in a spray gun, as follows:

1. Stir the paint thoroughly in order to mix the pigment back into the liquid vehicles used to suspend it. Unless you do this, the paint will not cover surfaces with uniform thickness and will not have luster and the same color all over.

2. Thin thick paint before you put it into a spray gun; otherwise, it will clog the gun and not go through it. Follow the manufacturer's instructions when you thin the paint. Dip a pencil vertically into the lacquer or enamel and then withdraw it. If the consistency is correct for spraying, the lacquer or enamel will run off the pencil in a smooth, thin stream. When thinning paint, however, do not add much over 20 percent of thinner to the paint, lest you get it so thin that it will not cover material properly. (Total volume of paint and thinner should be

about 20% thinner.) After you add thinner, stir the paint thoroughly.

3. When you have the paint at the right consistency for spraying, strain it through several thicknesses of cheesecloth or medical gauze to eliminate lumps of undissolved pigment, dirt, and any other particles which could clog the spray gun and give a poor finish on your work.

Instrument Painting

After you remove corrosion from instrument parts, you are then ready to paint those which require paint. There are three reasons for painting metal parts of optical instruments, as follows (in order of importance):

1. To protect the metal from rust and corrosion. This is most important for instruments used aboard ship, where salt spray and damp, salty air quickly corrode unprotected metals.

2. To kill reflections. The glare of bare metal in the sunlight is very annoying to the user of an optical instrument; and under some conditions, a brilliant reflection from a metal surface may reveal the observer's presence to an enemy.

3. To improve appearance. A good-looking, pleasing appearance of an optical instrument creates a good impression on all who see and use the instrument. Inspection of painted surfaces of instruments is part of your mandatory inspection procedure.

Most paints and their thinners are flammable, and some are explosive; so use a spray booth with an explosion-proof exhaust fan. To prevent spontaneous combustion, put rags used for wiping up paints, oils, thinners, etc., in a container with a self-closing cover and dispose of them completely as soon as practicable. Stow paint materials in a locker which will not tip over, and at a temperature less than 95°F, preferably—never over 95°F.

CAUTION: Permit no smoking in the spray room, and have a CO_2 fire extinguisher available in the room's equipment. Do NOT play with the air hose, or point it toward your own person or any one else.

When you paint with a spray gun (usually the case), mask bearing surfaces, threads, and holes to the interior of the instrument, from which you desire to exclude the paint. Tear off strips of the tape and put them over the surfaces of the bearings, with the edges of each successive strip (one side) slightly overlapping the last strip applied. Then trim off excess tape with a sharp knife or razor blade. Mask off also all points on the instrument you do not wish to paint.

Punch holes in a small box top or piece of cardboard and stick the bodies of screws whose heads you desire to paint into the holes, to keep paint off the bodies of the screws. You can also place on the cardboard top small parts which you intend to paint on one side only. String parts which you desire to paint all over on small pieces of brass wire.

Before you use a spray gun for the first time, seek good information concerning its operation, or closely follow the manufacturer's instructions for its use. Check the spray gun for cleanliness. If it is dirty or has old paint on the inside, disassemble it completely and soak the metal parts in a paint remover. Clean the gaskets in lacquer thinner. CAUTION: Paint remover will ruin the gaskets. When you reassemble the spray gun, lubricate all moving parts.

Fill the canister of the spray gun with your prepared paint and turn on the air pressure, about 10 to 25 pounds per square inch, or as recommended in the manufacturer's technical manual for the gun. Then so adjust the gun that it delivers a fine spray with enough density to cover surfaces rapidly with a uniform, wet appearance. Then begin your spraying.

Hold the spray gun about 10 inches from your work and keep it moving horizontally, back and forth. Be sure to carry each swing of the gun out past the end of the work before you start back, to prevent piling up of the paint near the edges of the work and subsequent sagging. Start at the top of a surface and work down, back and forth in horizontal motion, and cover the last old lap with about half of your new lap. If you follow this procedure, your paint will be uniformly thick over the entire surface.

After you finish a paint job with a spray gun, spray lacquer thinner over the gun to remove lacquer and enamel from the small openings. At the end of the day, if you use the gun last, completely disassemble the gun and wash all parts in lacquer thinner. Then dry, lubricate, and reassemble it so that there will be no delay of work the next day. The best time to clean a spray gun is while the paint on its surfaces is still wet.

NOTE: Your spray gun should have an air pressure and reducing valve with a water and oil trap (and filter) which should work correctly all the time. Drain this trap regularly. If water and oil get into your spray gun and paint, it will ruin the appearance of your work; and the lacquer or enamel will not dry.

Finish Defects

Following is a list of difficulties sometimes experienced with a spray gun, with the reason for each difficulty given.

- FINISH REFUSES TO DRY. You forgot to remove the oil and grease from the metal surfaces of your work, or from your air supply.
- FINISH COVERED WITH TINY ROUGH SPOTS. There was too much dust or moisture in the air, or in the paint or spray gun.
- FINISH HAS SMALL CIRCULAR MARKINGS. There was water in the air hose, or water dripped or condensed on the work before it was completely dry.
- FINISH SHOWS HORIZONTAL STREAKS. Your spray was too fine and the last lap had started to dry before you applied the next one, or you forgot to cover half of each old lap with the following lap.
- FINISH IS UNIFORMLY ROUGH. The spray was too fine, or you held the gun too far from the work, and the droplets began to dry before they hit the work.
- THE FINISH HAS LUMPS OR BLOBS. The spray gun or hose line was dirty, or you forgot to strain the paint.
- THE FINISH RUNS. The consistency of the paint was too thin.
- THE FINISH SAGS. You moved the gun too slowly or held it too close to the work.
- THE FINISH SHOWS ORANGE-PEEL EFFECT. The consistency of the paint was too thick, your spray was too fine, or you held the gun too far from the work.

Baking Procedure

When you intend to paint and bake instrument parts, remove all masking tape before you put the parts in the oven. If you cannot remove the tape before you bake the parts, remove it immediately upon taking the parts out of the oven. This is also a good time to apply engraver filler, commonly called MONOFILL, a soft, wax-base compound (generally in crayon form) used to fill in and accentuate engraved index lines and numbers. While the part is hot, the filler flows easily into an engraving. When the part cools, wipe off the excess filler with a soft cloth. Always follow the paint manufacturer's instructions on baking and drying the paint that you use. When you do not have specific instructions, a good rule of thumb to follow is bake for 2 1/2 hours at 250 degrees fahrenheit. For air dry enamel, allow 12 to 16 hours at room temperature.

LEN CLEANING AND CEMENTING

Clean the lenses and prisms of an instrument you repair while paint on the finished work is drying, and also accomplish necessary lens cementing.

The Navy standard for cleaning glass optical elements is this: OPTICS MUST BE CLEANED TO ABSOLUTE PERFECTION.

Bear in mind that an optical instrument with components of the highest quality arranged in the best design possible is of little or no value if vision through it is obscured by dirty optics. This statement does not mean grime or mud; IT MEANS THE SMALLEST VISIBLE SPECK OF DUST. EVEN A SPECK on a reticle may obscure much detail of an image, and a fingerprint or film of oil will most likely blur the overall image.

For the reasons just given, you must learn the proper technique for cleaning glass optics, and you must then APPLY THEM WITH PATIENCE, CARE, AND THOROUGHNESS. Knowledge of procedure, plus appreciation for quality work, will enable you to attain the absolute-perfection standard required.

CLEANING EQUIPMENT

The equipment you need for cleaning optical elements includes a rubber or metal bulb syringe, several camel's-hair brushes (small), alcohol, medically pure acetone, lens tissue (soft, lintless paper), absorbent cotton or silk floss, wooden swab sticks, stoppered containers for alcohol and acetone, and a container to keep the cotton or silk floss absolutely clean. To this list you may also wish to add a special lintless cloth for cleaning optics, the best type of which is SELVYT CLOTH.

You can make a lens cleaning swab of cotton, silk floss, or lens tissue. To make a cotton or silk floss swab, use the end of a wooden swab stick to pick up the top fibers of the material. Thrust the tip of the stick into the material and rotate the stick until some fibers catch on it; then pull the captured fibers loose from the mother material. Repeat this process as often as necessary until you have the swab of desired size. Shape the swab by rotating its tip against a clean cloth or lens tissue.

CAUTION: Do NOT touch the tip of the swab with your fingers or lay it down on the bench top where it will pick up dirt.

Figure 7-14 shows the procedure for making a swab out of lens tissue, step by step. Swabs made in this manner are useful for picking up individual specks of dirt from a lens or reticle, using acetone as a cleaner. Make a supply of lens tissue strips for fabricating swags by cutting a packet of 4" x 6" lens tissue down the center, lengthwise, so that you can remove the strips one at a time.

The fourth step for making a swab (4, fig. 7-14) shows how to press the tip of the round swab between the cover and the top tissue in order to obtain a flat, chisel-like cleaning tip, as shown in step five (5) of illustration 7-14.

You can make a large, useful lens cleaning pad by folding two thickness of 8" x 11" lens cleaning tissue along its length and bringing the two ends together. When you dampen this pad with acetone, you can clean a large area of glass quickly and effectively.

CLEANING PROCEDURE

The recommended procedure for cleaning glass optics is presented by steps in the following paragraphs:

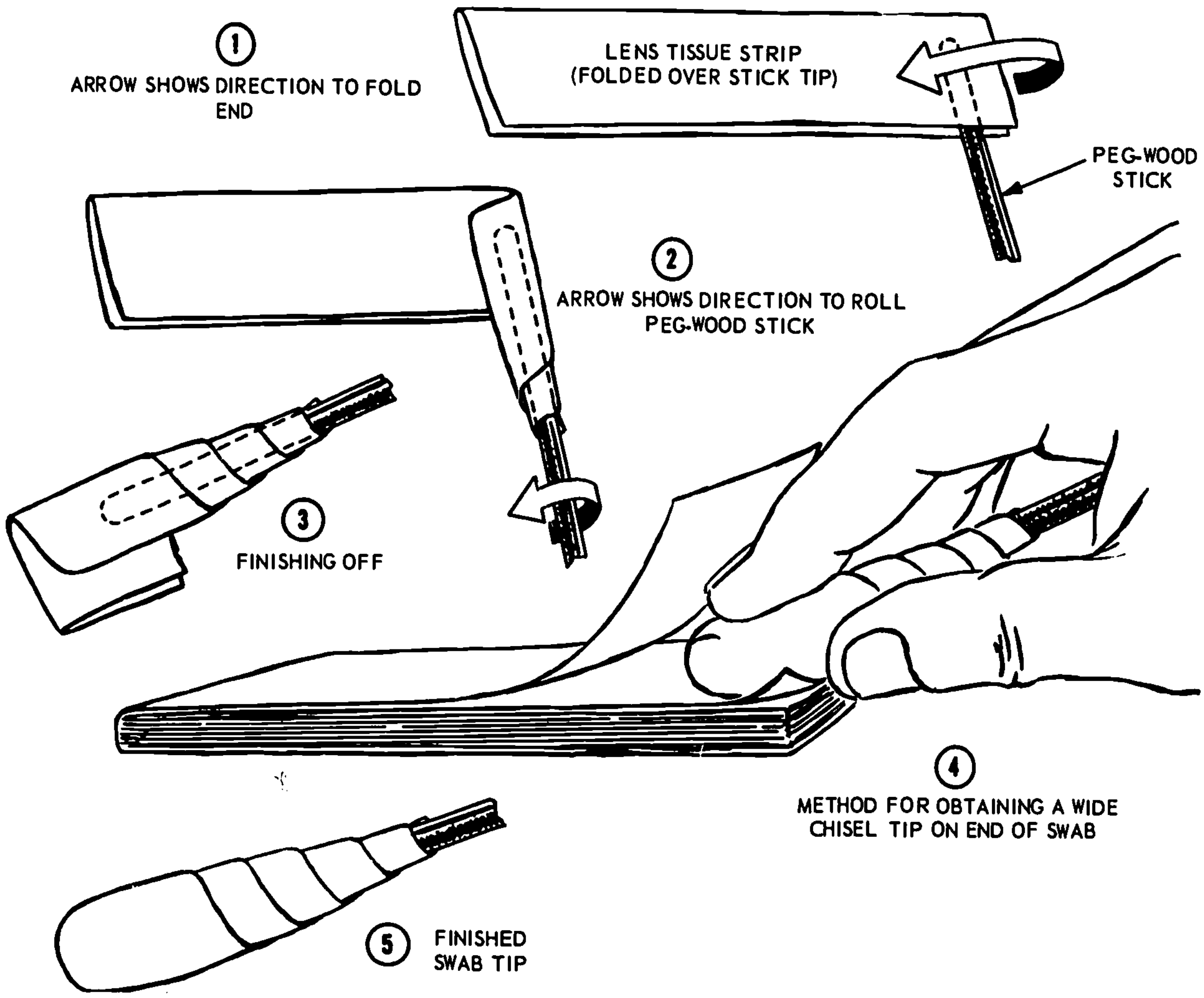

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Figure 7-14.—Procedure for making a lens-tissue swab.

1. Blow all coarse and loose dust from the surface of the lens with a bulb syringe. Then brush the surface of the lens with a camel's-hair brush, using quick, light strokes. Flick the brush after each stroke to dislodge the dust it picked up, and blow off newly loosened particles of dust on the lens (optic) with the bulb syringe.

2. If the lens is large, use several pads of lens tissue dampened with alcohol to remove remaining dirt and/or grease. Change cleaning pads or swabs frequently enough to prevent damage to the optic by the dirt or grit. Use a cotton, silk, or floss swab, or lens tissue on small lenses.

3. Finish the cleaning of the optic by using a pad or swab dampened with a few drops of acetone, to remove traces of film of the alcohol used during precleaning.

CAUTION: If you use a swab or pad moistened with acetone for more than 20 seconds on an optic, it leaves a film or water marks on the lens. Acetone evaporates quickly and moisture in the surrounding air condenses in the swab or pad. Medically pure acetone (triple-distilled) leaves an optical surface perfectly clean and free of film when used as described. ACETONE IS HIGHLY FLAMMABLE; KEEP IT AWAY FROM FIRE AND HEAT.

4. As you clean an optic, swab lightly with a rotary motion, working from the center to the edges. Avoid excessive rubbing to prevent damage to the coating of an optic and charging with static electricity. Study figure 7-15 for the correct procedure to follow when you clean a lens with a swab.

5. Under a strong light, examine the lens for dirt, fingerprints, and film which you may have missed. If these are difficult to remove, do the following:

a. Swab the surface with concentrated nitric acid solution and rinse with distilled water. Then reclean with alcohol and acetone.

b. If this procedure does not clean the optic, rub the surface with a damp piece of lens cloth dipped in precipitated chalk. Then clean with alcohol and acetone.

CAUTION: Rub just enough to remove dirt and/or stains, some of which may be in the reflection-reducing magnesium fluoride coating and cannot be removed by rubbing with chalk, for this would ruin the film.

6. If you are satisfied with your cleaning job, wrap the lens in clean lens tissue and put it back in a safe place where it will not become damaged.

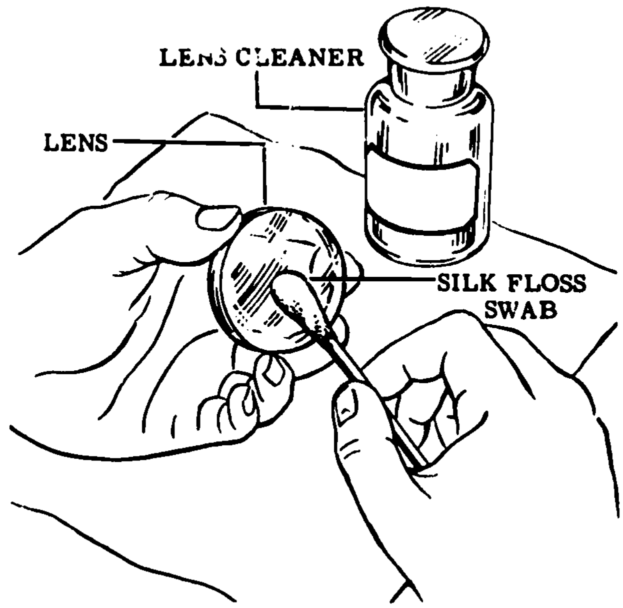

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Figure 7-15.—Cleaning a lens with a silk-floss swab.

CEMENTING EQUIPMENT AND MATERIALS

When a lens requires recementing, set up all the equipment that you need in a clean, convenient area. In addition to the material for cleaning the lens, you will need a lens centering machine or 2 matched V blocks, an electric hot plate with controlled heat, sheet asbestos to cover the hot plate, black paper, rubber topped tool, tongs or brass tweezers for handling warm optics, a small glass bell jar or similar cover for the optical elements and Canadian balsam or other approved lens cement.

After you have the equipment ready, separate the elements to be cemented; thoroughly clean them; and then recement.

TYPES OF CEMENT

Canada balsam is usually available in prepared form in metal tubes, through Navy supply channels. Use this lens cement on all lenses except very small or very large ones, which can be cemented together better with cements made by specific formulas, as explained next.

1. CEMENT FOR LARGE LENSES. Put three parts of rosin and one part of Canada

balsam in a clean cup or bowl in a water bath at a temperature of 130°F. CAUTION: Keep the temperature of the water constant, as determined by a thermometer. Do not get any water in the cement. Stir the cement every 10 or 15 minutes, over a 2 1/2 hour period and then strain it through a piece of clean silk, after which you may use it.

2. CEMENT FOR VERY SMALL LENSES. Mix 4 parts of rosin with 1 part of refined camphor and follow the procedure just described for large lenses to make the cement.

Most lenses with a diameter over 2 1/2 inches are not cemented together; they are air-spaced. The elements of the lenses are made of constituents with different coefficients of expansion which causes breakage of the cement during expansion and contraction. Some large lenses are also ground with different curvatures on their mating surfaces which make joining by cement impossible.

The reasons for joining the elements of a lens by cement are as follows:

1. Cementing keeps the elements optically aligned.

2. Cementing reduces the number of glass surfaces exposed to the air, which serves the same purpose as a film on optics, to make the image brighter and clearer. Since the index of refraction of Canada balsam is about the same as that of crown glass, there is practically no reflection when two crown glass surfaces are cemented together, and very little reflection when a crown glass surface is cemented to a flint glass surface.

3. Because a soft glass (hydroscopic) has special optical properties, a lens designer may sometimes desire to use it. This type of glass, however, is unstable and quickly deteriorates when used alone; but it can be used satisfactorily when cemented in place between two stable elements.

4. Groups of cemented lenses reduce the number of parts used in an optical instrument.

You will occasionally find a lens doublet (generally from a gunsight, where it is used because it withstands the shock of gun fire) that will not separate when heated. If the elements of a compound lens do not separate at a temperature of 300°F, they were probably cemented together with a thermo-setting plastic, which a manufacturer sometimes uses for two reasons:

1. It resists temperature changes better than balsam.

2. It speeds up lens production.

When you have reason to believe that lens elements have been secured together with a thermo-setting plastic, check the lens with ultraviolet light for FLUORESCENCE. If the cement between the elements is a thermo-setting type, there will be little or no fluorescence; if the cement is balsam, you will see a definite, hazy-white fluorescence. When in doubt about the cement used in lenses, consult your supervisor.

SEPARATING CEMENTED ELEMENTS

Turn your electric stove on LOW and place a piece of 3/8" asbestos on top, over which you now need a piece of the black paper. Put the lens on the paper and cover it with the bell jar or cardboard box. Then watch the black paper for signs of scorching, which shows that the stove is too hot and more asbestos is required over the hotplate.

When the lens is hot enough (between 275°F and 300°F), gently pry the elements of the lens apart with your rubber-tipped tool and allow them to cool slowly. When the temperature of the separated elements is approximately equal to that of the room, remove old balsam from them with alcohol, and then clean them thoroughly with acetone.

RECEMENTING

Put the clean lenses on the hotplate, with the surfaces to be cemented together facing upward. Inspect them for dust or dirt which may have fallen on them since they were cleaned, cover with the bell jar, and apply just enough heat to melt balsam.

When the elements are hot enough, put a little balsam on the surfaces to be joined together, pick up the positive element with your tweezers, and join the two cemented surfaces. Then use your rubber-tipped tool to work the top element over the lower one as much as necessary to squeeze OUT all air bubbles. The black paper on the heater makes air bubbles in the elements appear bright.

Use the lens-centering instrument (fig. 7-16) to center (align their optical axes) the elements. This instrument consists of an astronomical telescope with a crossline and a collimator telescope mounted on a tripod, with the objective lens of one instrument facing the objective lens of the other instrument. The crossline mount of the collimator telescope moves in a

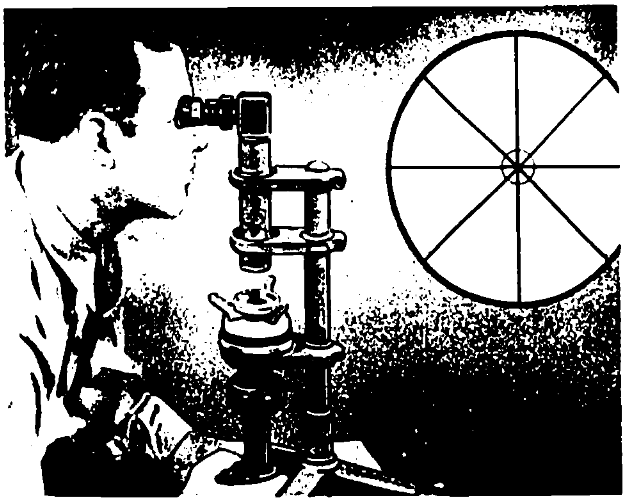

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Figure 7-16.—Lens-centering instrument.

drawtube, which enables you to bring the image of its crossline into focus with the image of the astronomical telescope. A lens chuck mounted between the two telescopes can be rotated 360°, or more.

Heat the chuck jaws with a small torch or a hot piece of metal and then transfer the hot lens to the chuck. NOTE: Cold chuck jaws may crack one or both elements of the lens. Mount the hot, freshly cemented lens in the warm chuck, which grips ONLY the negative elements of the lens.

Sight through the eyepiece while you rotate the chuck and observe the eccentric movement of the lower crossline. The move the upper element of the cemented lens over the lower one as necessary to have the crossline intersections coincide.

Allow the lens to cool for a few minutes in the machine and recheck the alignment, remove the asbestos sheet from the hotplate, and place the lens on the asbestos sheet. Then cover the lens with the bell jar (or box) and allow the lens adequate time for cooling. Remove the bell jar and scrape excess balsam from the edge of the lens with a razor blade, after which the lens is ready for final cleaning and inspection.

NOTE: If you do not have a lens-centering machine, use V-BLOCKS in the following manner to align the optical axes of a compound lens: Heat the V-BLOCKS on the hotplate while you are cementing the lens elements; and when you have the elements joined, slide the V-BLOCKS against the edges of the lens from opposite directions. Then turn off the hotplate, cover the lens and V-BLOCKS, and allow the combination to cool simultaneously. NOTE: Lenses whose edges are not concentric when aligned cannot be cemented in this manner.

CHAPTER 8

MAINTENANCE PROCEDURES—PART II

REASSEMBLY AND COLLIMATION

Now that you have effected essential repairs to instrument parts, performed necessary refinishing, accomplished required cementing of optical elements, and cleaned everything perfectly clean, you are ready to begin the reassembly process.

If you have accomplished your repair and overhaul well, reassembly will be smooth and easy. Unless you know the instrument on which you are working very well, follow a reassembly sheet. Because reassembly is different for each instrument, no set procedure for accomplishing it can be given in this manual. The reassembly tips presented in the next few pages, however, will be helpful.

REPLACING LENSES

Before lenses are mounted in their cells or mounts you must be sure that all dirt and foreign matter have been cleaned from the cell. If the interior of the cell is particularly long or hard to clean, most particles can be removed by first covering the open ends of the cell with masking tape. Then with the cell held in an upright position, tap on the exterior with a small 2 or 3 ounce fiber mallet. This action jars the dirt loose from the cell and causes it to drop and stick to the tape on the end of the cell. This procedure may also be used on large body tubes and castings.

Carefully unwrap the clean optic and use the correct tool to reassemble it in the instrument. A lens chuck and cleaning holder (fig. 8-1) is a good tool at this time for cleaning. After you have the lens thoroughly cleaned, install it in its mount.

Tighten the retainer ring to seat the lens properly and clean off fingerprints (if any) and dirt. Use a silk floss or lens tissue swab dampened with acetone for cleaning a lens in its mount or cell. See illustration 8-2

Some lenses must be sealed in their mounts, and the actual seal is provided by a string of wax about 1/16" in diameter in the form of

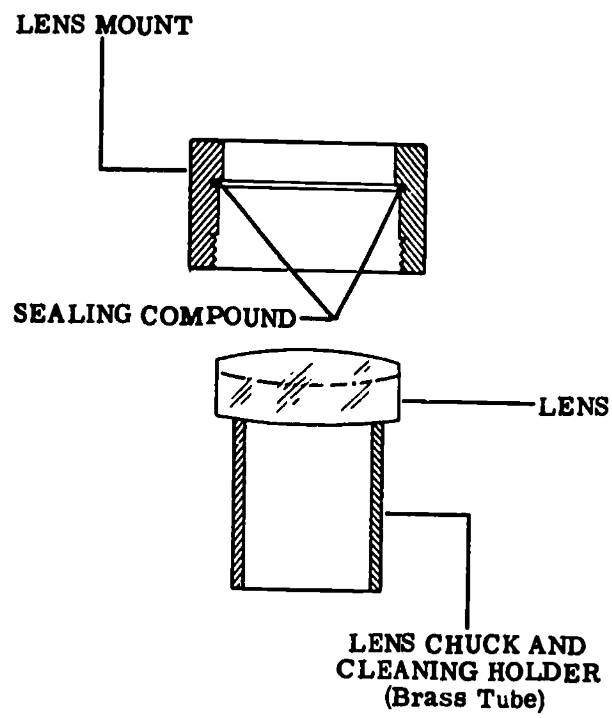

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Figure 8-1.—Placing a lens in its mount.

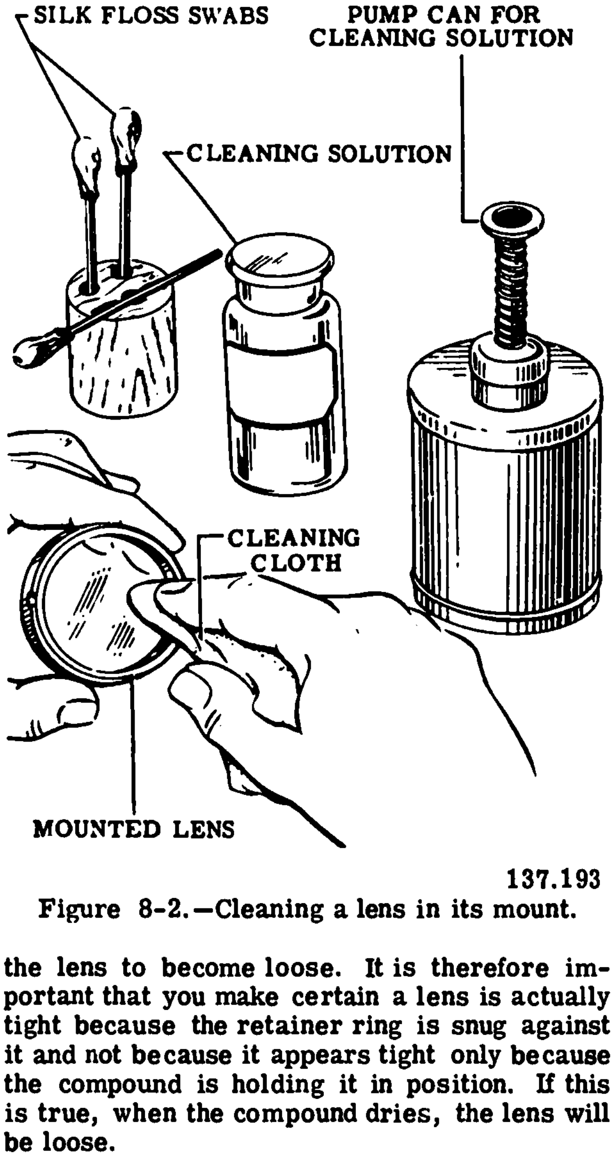
sealing compound in a space between the lens and its mount, as illustrated in figure 8-1.

After you seat a lens in wax, remove the excess wax with a chisel-tipped hardwood stick.

Thin gaskets are used to seal lenses in some instruments, in which case you must use the same procedures and observe the same precautions required for sealing lenses in mounts with a compound.

Follow the method illustrated in figure 8-1 to place the lens in its mount and screw the retainer ring snugly against it. A small amount of heat applied carefully to the mount with a torch at this time helps to seat the lens properly. After you apply the heat, screw the retainer ring a bit tighter.

CAUTION: If you make the retainer ring too tight, you may crack the lens, or cause strain which will distort the image. Insufficient pressure, on the other hand, will eventually allow



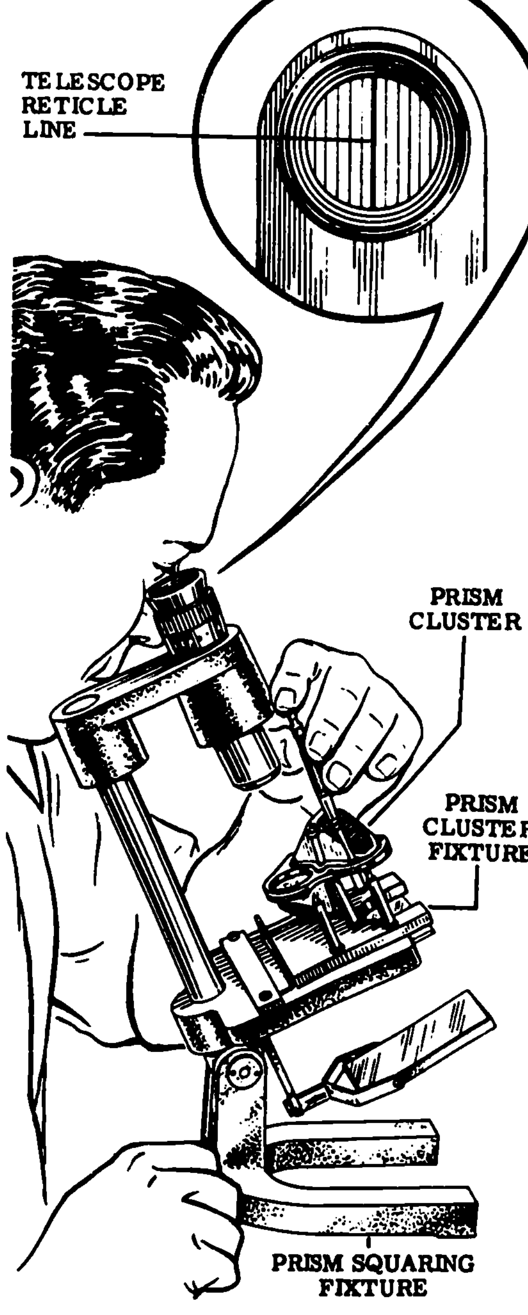
137.193
Figure 8-2.—Cleaning a lens in its mount.

the lens to become loose. It is therefore important that you make certain a lens is actually tight because the retainer ring is snug against it and not because it appears tight only because the compound is holding it in position. If this is true, when the compound dries, the lens will be loose.

ASSEMBLING PRISMS

After you assemble all lenses in their cells and mounts, assemble the prism clusters, or prism mounts (if any). Secure the prisms in their mounts by straps and/or collars, which must fit snugly enough to hold the prisms but not so tight that they may cause strain. A collar should fit over a prism with a slight press. If the fit is too tight, strain and breakage usually result; if the fit is too loose, the prism may shift its position and throw the instrument out of adjustment.

When you assemble a prism cluster used as an erector assembly, check the assembly for



137.199
Figure 8-3.—Prism squaring fixture.

LEAN before you put it into the instrument. In a prism erecting system, LEAN results when the prisms are not oriented exactly 90° to each other. Illustration 8-3 shows how to correct lean with a prism-squaring fixture. Note that the repairman is adjusting the prism by loosening the prism collar and shifting it slightly. He can also detect LEAN and remove it by using the grids on a sheet of graft paper.

To remove lean from a prism cluster with a prism-squaring fixture, look at the grid through the prism cluster with one eye and at the same time look directly at the grid with the other eye. If there is lean in the prism cluster, the grids will not look parallel. This procedure for detecting LEAN in the cluster is not as easy as it sounds and takes practice in order to attain perfection.

If you assemble a pair of binoculars with LEAN in one or both barrels, the instrument will probably hurt the operators' eyes and will require disassembly and correction of the clusters for LEAN. So check for LEAN in prisms WITHOUT FAILURE before you assemble them in binoculars; and do not forget to check the prism clusters for strain after you assemble them and also prior to installation in the instrument.

ASSEMBLING MECHANICAL PARTS

As you assemble parts in an instrument, be sure to match all assembly marks; otherwise, you will be compelled to disassemble the instrument, make corrections, and reassemble it.

Check each part as you reassemble it for fragments of foreign matter clinging to it. Each part MUST BE IMMACULATELY CLEAN before you assemble it in the instrument. Keep openings to the interior of the instrument closed with masking tape and remove it only when you must make additional installations. Follow this procedure as you reassemble each part, until you make the final closure.

As you replace components and parts in an instrument, try to work from the top down, to prevent unnecessary work over an optical element, and perhaps damage to it.

Do not force a part into place in an optical instrument; use a light press with the fingers; unless the part must be fitted in position by force in accordance with specifications. If there is a bind, determine the cause.

You can make some adjustment on parts as you assemble them in an instrument. Whenever possible, these adjustments should be made during collimation; but in some instances an adjustment is impossible after reassembly because of inaccessibility of parts. The removal of LEAN in an erector prism cluster is a good example of an adjustment which must be made during assembly.

Threads on retaining rings, lens mounts, caps, screws, and setscrews are extremely fine and can be cross threaded easily. When you therefore insert them, turn in a counterclockwise direction until the threads snap into place, and then turn clockwise. NOTE: Always place a small amount of grease or anti-seize compound on threads before you turn them into place.

Seal the final cover to the interior of an optical instrument with sealing wax, gaskets, or packing. The function the instrument must serve determines the method for sealing it, and this is included in design specifications.

Seals used on optical instruments can be placed in one of the following types:

1. Moisture seal.
2. Gas-tight seal.
3. Pressure seal

After you finish the reassembly process, seal all openings except those you must use when you collimate the instrument. Upon completion of the collimation process, final sealing, drying, and charging of the instrument must be accomplished, as you will learn next.

COLLIMATION

One of the final steps in overhaul and repair of an optical instrument is collimation, which is the ALIGNMENT OF THE OPTICAL AXIS OF THE INSTRUMENT to its mechanical axis. In simpler terms, orientation of all the axes of lenses in an optical system in such manner that they coincide with each other in a straight line and parallel to the mechanical axes of the bearing surfaces (telescope's mounting pads, for example) of the instrument is known as collimation.

Suppose you have an instrument constructed only of a straight tubular housing mounted in two ball bearings like a shaft. It contains no optics: it is only a straight, hollow tube. If you now peer through this tube and rotate it on its bearings like a rotating shaft, you will find that the least amount of rotation is in the center of the tube. THIS CENTER OF LEAST ROTATION IS THE MECHANICAL AXIS OF THE TUBE.

If you point the tube toward an infinity target, you can superimpose this mechanical axis on the object. Regardless of the direction in which you rotate the tube, its mechanical axis

REMAINS SUPERIMPOSED on the same spot of the object.

Suppose that you now place in the tube the optical elements required to construct a telescope which will magnify the infinity target and then rotate the tube (telescope) again. If the target (now magnified) appears to revolve around in a circle in the same direction, the optical axes of the lenses are NOT ALIGNED with the mechanical axis of the tube; but you can so position the optical elements of the system (usually laterally) that the target will remain stationary when you rotate the tube. When this is true, you have the optical axes of the lenses aligned with the mechanical axis of the tube. The process you just completed, therefore, is collimation.

Collimation varies for different optical instruments; that is, the procedure for collimating one instrument may be exactly opposite that for collimating another instrument. Some instruments are also collimated on targets at a distance less than infinity (2,000 yards, or more); but most of them are collimated at infinity, because they are used to observe targets at infinity.

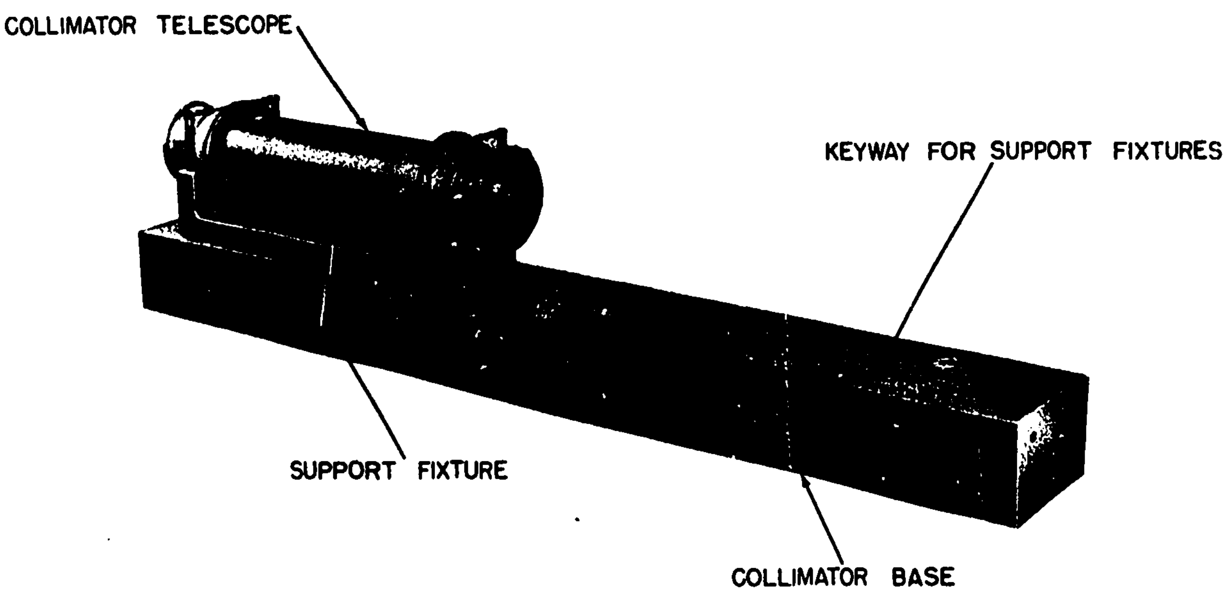
If you must collimate an optical instrument on an infinity target, you must have access to such a target every hour of the day and every day of the year, regardless of weather conditions. Because it is difficult or impossible to obtain and maintain an infinity target for long periods of time under ideal weather conditions, you must be able to produce and/or use a suitable artificial target at infinity. Such an infinity target can be produced by an instrument known as a collimator, which is discussed next.

Collimators

Collimators are precision instruments (with both optical and mechanical elements) which provide an infinity target suitable for use in aligning and adjusting the optical and mechanical components of optical instruments, so that they will perform accurately.

Although collimators may vary in design and/or construction, the optical principle employed in them is the same. Illustration 8-4 shows one type of collimator, but there are many different designs. Observe the nomenclature. This is Mk 4, Mod 0 telescope collimator used to collimate small telescopes, gunsights, and navigational instruments. It has a steel base several feet long with a precision, flat bearing surface machined on its entire top. A keyway is cut down the center of the bearing surface, as shown, for supporting fixtures.

This collimator telescope is secured to the bearing surface with a V-block support, with a



137.200

Figure 8-4.—Telescope collimator.

highly precisioned bearing surface which slides (rides) on the bearing surface of the base. Other types of V-block supports may be part of the collimator base, and other designs may have keyways cut along the bottoms of their bearing surfaces. A key is then inserted half its thickness into the keyway of the V-block support, with the other half of its thickness in the keyway of the collimator base, to keep the V-block support and collimator telescope aligned parallel with the keyway in the collimator base.

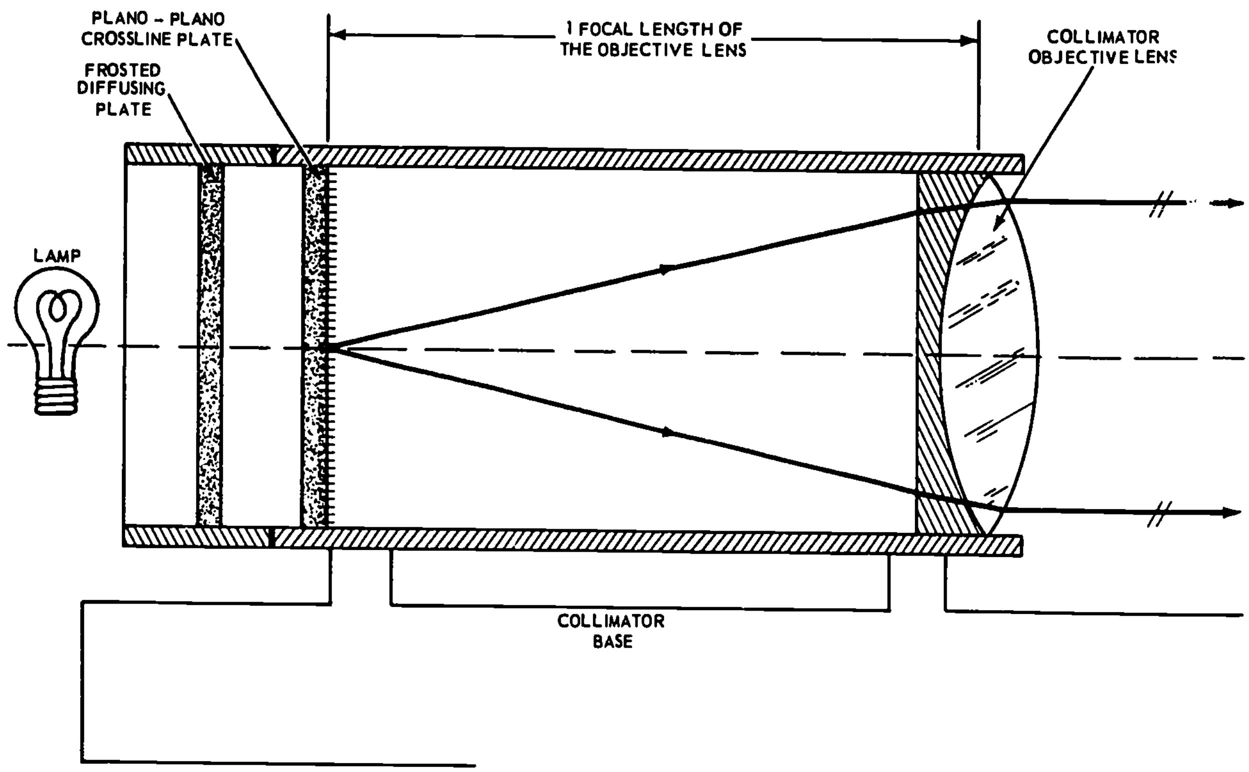
The telescope of the collimator (with its bearing rings) can be secured or rotated on the bearing surfaces of the V's of the V-block support for making adjustments. This telescope consists of a tube with an achromatic doublet objective lens and a crossline reticle mounted internally in the principal focal plane of the lens. Located a short distance behind the reticle is a frosted-glass diffusing plate, and located behind the diffusing plate is either a plain reflecting mirror or a lamp, as illustrated in figure 8-5, which shows the optical principle of the collimator telescope.

When light from the lamp, or reflected light from the mirror, strikes the diffusing plate, the plate diffuses the light evenly over the entire crossline reticle. The reticle then becomes a new light source and emits diverging rays which are received and refracted parallel by the objective lens, as illustrated. If you were to look through the objective lens, the crossline would appear to be at infinity.

Auxiliary Equipment

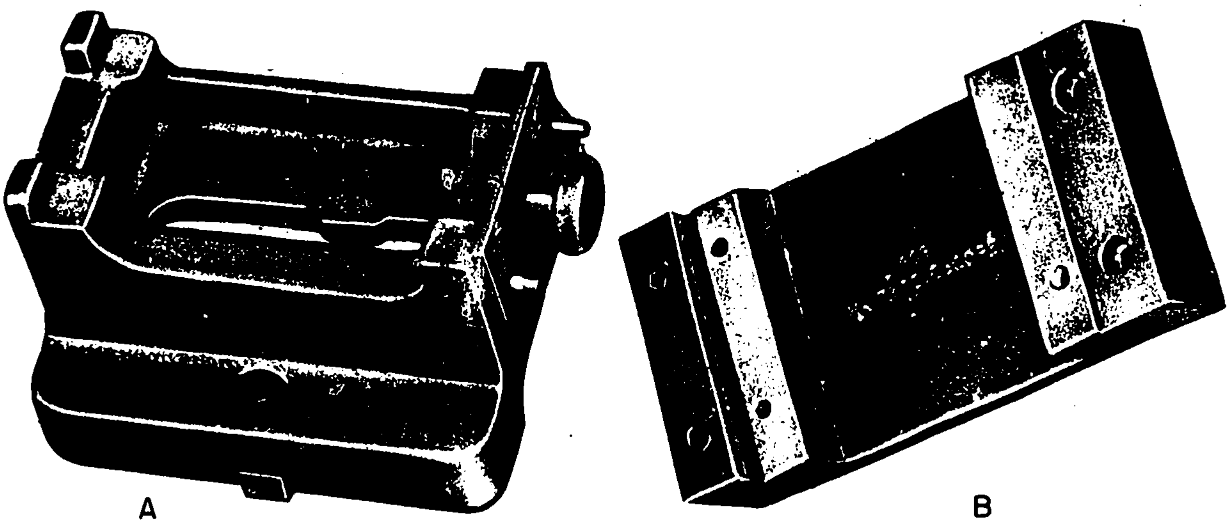
Auxiliary fixtures and equipment consist of special attachments, stands, supports, riggings, fixtures, and other optical instruments you must use with a collimator when you collimate various optical instruments.

An auxiliary fixture may be any piece of equipment which can be attached to a collimator or its base, or a piece of mechanical or optical equipment, and used during the repair and collimation of an optical instrument. Auxiliary fixtures most generally used are: dynameters, collimator telescopes, checking telescopes,



137.201

Figure 8-5.—Principle of operation of a simple collimator telescope.



137.202

Figure 8-6.—Auxiliary support fixtures.

auxiliary telescopes, special support fixtures, and various other fixtures.

Some auxiliary support fixtures, or mounts, are illustrated in figure 8-6. These fixtures securely hold an optical instrument on the base of a collimator during collimation.

Auxiliary support fixtures differ from special support fixtures in that they are used in the collimation of a large number of optical instruments. Special support fixtures are used during the collimation of a limited number of instruments. In some instances, a special support fixture may be used to collimate only one specific instrument.

Checking Telescopes

A checking telescope (fig. 8-7), or a dummy telescope, is a relatively small standard or master instrument used to align collimator components and instrument support fixtures. Design of the telescope varies in accordance with its use, but a checking telescope generally consists of an astronomical telescope with a crossline reticle. Study the nomenclature of the telescope shown in figure 8-7 carefully, noting particularly the position of the optical elements.

Checking telescopes are generally used to collimate collimators employed on many different optical instruments, but one may be designed to collimate a collimator used only on one instrument.

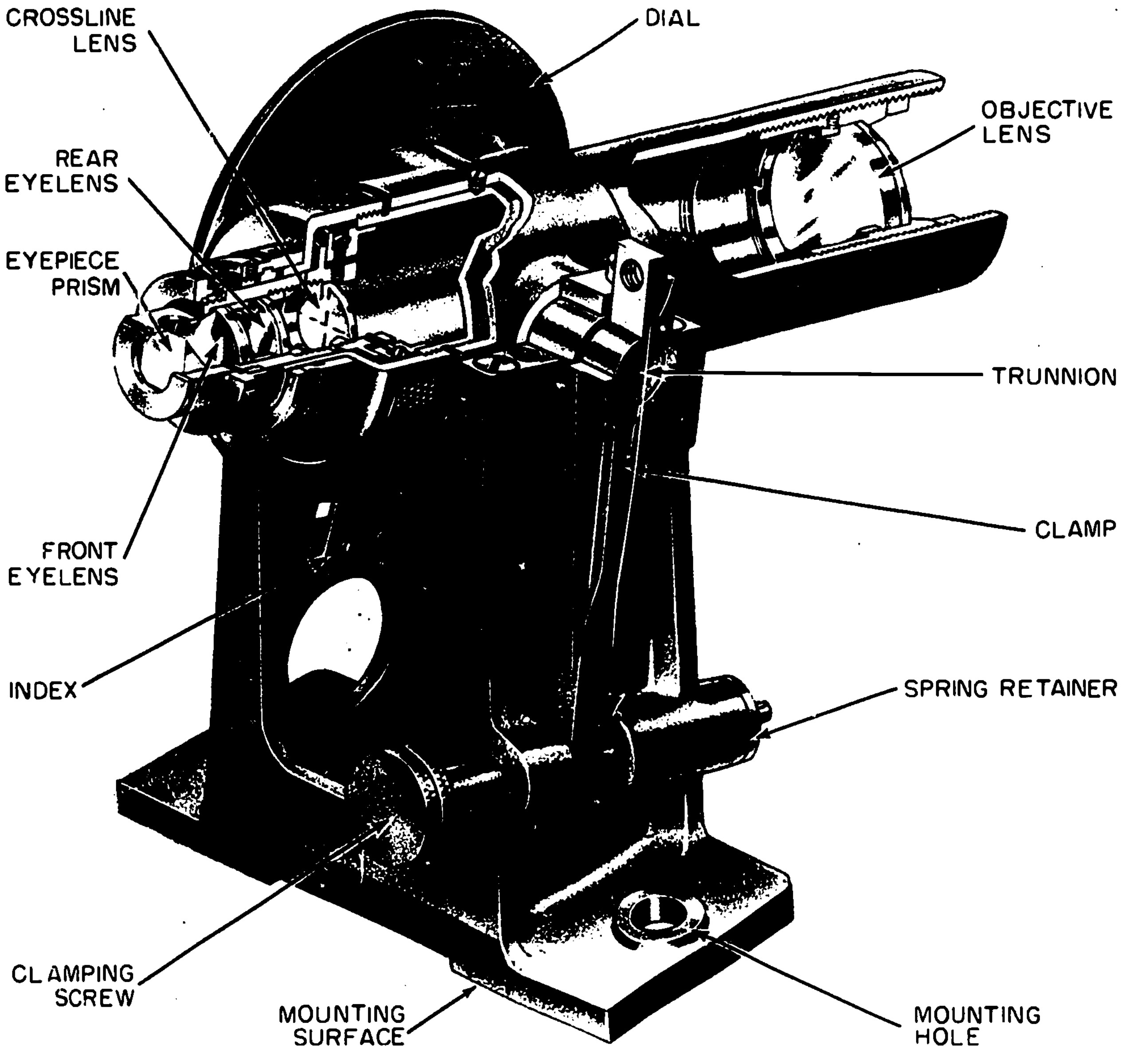
A checking telescope is a master instrument whose delicate components must receive the best care. NOTE: Never attempt to repair a checking telescope. Only its manufacturer has the equipment required to repair it satisfactorily.

Auxiliary Telescopes

An auxiliary telescope is probably used more than any other auxiliary fixture in instrument collimation. It is an astronomical telescope with a Kellner eyepiece, and its main purpose is to compensate for inherent eye errors of a person who is collimating an instrument. Study part A of figure 8-8. Observe the position of all components and their nomenclature.

If individuals who work on collimation of optical instruments have normal vision, no near- or farsightedness, an auxiliary telescope may not be required for doing some phases of collimation. Because most persons have some sort of eye defects, however, an auxiliary telescope must be used to determine what dioptric errors they have in their eyes before they collimate an instrument.

You can determine what the dioptric settings of your eyes are by focusing (from plus to minus on the diopter scale) the auxiliary telescope on an infinity target, or on a collimator



137.203

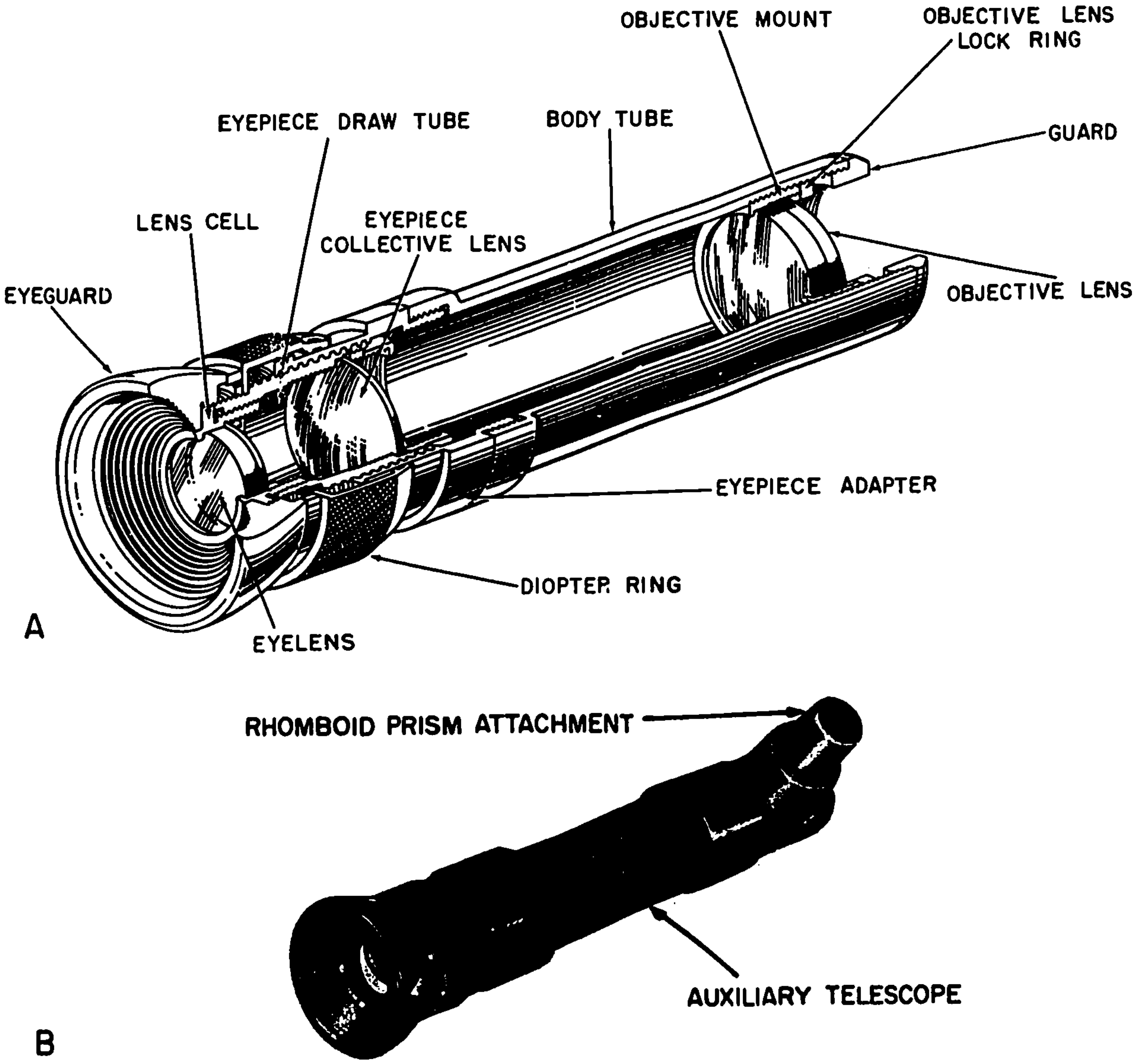
Figure 8-7.—Checking telescope.

telescope crossline until the image is sharply defined. For best results, take five readings and use the reading which appears most during the readings. This is the MODE.

After you get this dioptric setting, do NOT change the focus until you decide to check your setting again for eye fatigue or strain.

You can also use an auxiliary telescope for the following collimating operations:

1. Setting focusing eyepieces to the NORMAL or ZERO diopter setting.
2. Setting fixed-type eyepieces to their required diopter setting.
3. Checking for and aiding in the removal of parallax in an instrument.
4. Increasing magnification of another instrument, by placing the auxiliary telescope to the eyepiece of the instrument. Increase in magnification of the instrument is equal to the



137.205

Figure 8-8.—Auxiliary telescopes.

combination of the powers of the two telescopes, obtained by multiplying the power of the auxiliary telescope by the power of the instrument (3X x 10X = 30, for example).

5. Collimating hand-held binoculars by means of an auxiliary telescope rhomboid prism attachment, as shown in part B of figure 8-8.

Procedure

Before you collimate an optical instrument, you must first collimate the collimator; that is, you must adjust and align the optical and mechanical components of the collimator as necessary to have it conform with the specifications of the optical system of the instrument to be collimated.

Collimation of a collimator telescope generally consists of adjusting:

1. The collimator telescope mechanically, so that its optical axis is parallel to the bearing surfaces of the collimator's base and the instrument's auxiliary support fixture bearings.

2. The collimator telescope's crossline, so that its vertical wire is perpendicular to the bearing surface of the collimator base. This is called squaring the collimator crossline.

Collimation of collimators varies in accordance with the design of each collimator and for each instrument to be collimated, and no attempt is made here to establish specific standards or procedures for collimating a collimator. The most common practice is to use the following fixtures (fig. 8-9): auxiliary eyepiece, machinist's square, checking telescope, auxiliary objective lens, and the master instrument.

Auxiliary pieces are most commonly used on collimators when the collimating telescope is not designed for horizontal and vertical adjustment. The collimating telescope is permanently aligned on the V-block support in such manner that its optical axis is parallel to the bearing surface of the collimator's base.

The procedure for collimating a collimator with auxiliary pieces is as follows:

1. Level the collimator base with its adjusting screws on the legs.

2. Place the auxiliary objective lens and the eyepiece lens in the V-blocks on top of the collimator bearing surface. NOTE: Any two lenses may be used, but the objective must have a longer focal length than the eyepiece lens. You may place the auxiliary objective lens in front of the collimator objective at a reasonable distance, as desired. Place the eyepiece lens behind the auxiliary objective lens at a distance equal to the sum of their focal lengths in order to construct an astronomical telescope. If you now look through the astronomical telescope you see a magnified image of the collimator's telescope crossline.

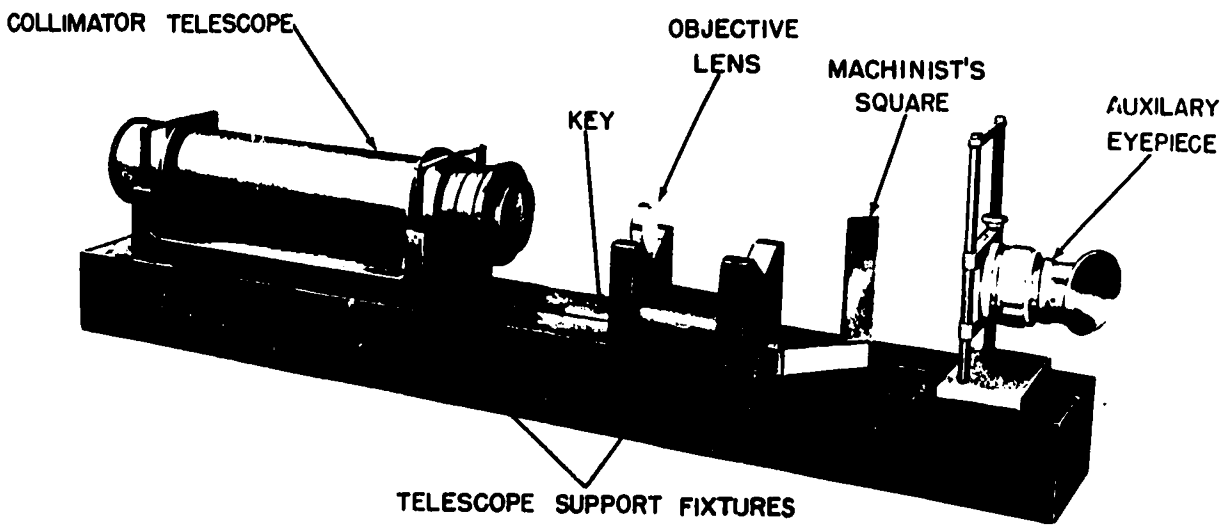
3. Place the machinist's square on the bearing surface of the collimator base, with its straight edge perpendicular and in the focal plane of the auxiliary objective lens. If you now look through the astronomical telescope you see sharply defined both the crossline and the machinist's square's straight edge.

4. To square the collimator in such manner that the vertical wire of the collimating telescope is perpendicular to the bearing surface of the collimator's base, rotate the collimating telescope until the vertical wire is parallel to the straight edge of the machinist's square. This step should complete the collimating process for the collimator.

For collimators with adjustable collimating telescopes (horizontal and vertical adjustments), use the procedure just described only for squaring the collimating telescope. If the collimator, however, is to be aligned parallel to the collimator's base or the bearing surfaces on an instrument's auxiliary support fixture, use a checking telescope.

The procedure for collimating a collimator with a checking telescope follows:

1. Level the collimator's base by adjusting the legs, and place on the collimator's base the



137.206

Figure 8-9.—Squaring collimator and auxiliary pieces.

auxiliary support fixture you desire to use for holding the instrument during collimation.

2. Place the checking telescope in the auxiliary support fixture and secure it. NOTE: Both the support fixture and the checking telescope must be placed flat and square in their positions, to ensure proper alignment of the collimator.

3. Peer through the checking telescope and focus it on the collimating telescope's crossline. If this crossline is not square with the crossline of the checking telescope, rotate the collimating telescope until its crossline vertical wire is parallel to the vertical wire in the checking telescope.

4. Superimpose the crossline of the collimating telescope on the crossline of the checking telescope by adjusting the screws under the objective lens of the collimating telescope, to move the collimating telescope horizontally or vertically, as desired. Both crosslines should now appear as one when you look at them through the checking telescope; and if they do, collimation is completed.

You can also use a master instrument, previously collimated, to collimate a collimator for small navigational instruments. This master instrument is used only for collimating collimators. Adjustment on the collimator must be the same as that on the master instrument.

After you collimate a collimator, securely lock all of its mechanical components in position. The collimator should be securely aligned and locked in position while you are collimating an instrument, but changes in temperature throughout the day may affect the accuracy of collimation of the collimator, because its mechanical parts expand and contract in accordance with changes in temperature. For this reason, NEVER assume that a collimator is collimated; check its alignment frequently to make certain that it is collimated.

The procedure for collimating optical instruments varies with different instruments; and for this reason, collimation procedures for a specific type of optical instrument are not listed in this manual. The collimation procedures considered here are general in nature and applicable to all optical instruments. For information relative to collimating procedures for a specific instrument, refer to applicable publications and/or blueprints.

The general steps in collimation of an optical instrument are:

1. Collimate the collimator on the proper telescope support fixture.

2. Put the telescope to be collimated on its support fixture and adjust the auxiliary telescope to your eye correction.

You are now ready to remove parallax, square and superimpose the instrument's crossline, and set the eyepiece diopter setting. The things you generally do to collimate an instrument are explained next.

NOTE: When you use an auxiliary telescope during collimation, do not change the eye correction after you set it properly. When you focus the eyepiece of an instrument, focus from PLUS to MINUS on the diopter scale.

Removal of Parallax

As defined earlier in previous chapters of this manual, parallax is a condition brought about when the reticle of an instrument does not lie in the same plane as one of the image planes, usually the image plane of the objective lens.

To check for parallax in an instrument, place an auxiliary telescope to the eyepiece of the instrument, sight through both, and focus the eyepiece of the instrument until the image of the collimator crossline or the crossline of the instrument (whichever comes into view first) is sharply defined. If parallax is present, one of the two crosslines will come into focus first; if there is no parallax, both crosslines will come into focus at the same time.

The amount of parallax between the two crosslines can be measured in diopters on the diopter scale of the instrument's eyepiece. You can determine the amount of parallax by focusing the eyepiece of the instrument in until the first crossline is sharply defined and by observing the diopter reading to which the index marker points. Then continue to focus until the other crossline is sharply defined and observe where the index mark is pointing on the diopter scale, and also note the number of diopters between the position of clarity of the first crossline and the point of clarity of the second crossline. If the instrument's crossline, for example, came into focus at plus two diopters on the diopter scale and the collimator's crossline came into focus at minus 3 diopters on the diopter scale, the total amount of parallax is 5 diopters.

By knowing which crossline came into focus first, we know the location of the instrument's crossline in relation to the focal plane (image plane) of the objective lens. If the instrument's crossline comes into focus first before the collimator's crossline, the instrument's crossline is farther from the objective lens than its focal plane (image plane). If the collimator's crossline comes into focus before the instrument's crossline, the instrument's crossline is closer to the objective lens than its focal plane.

The problem in collimation now is to place the instrument's crossline in the focal plane of the objective lens, in one of two ways:

1. Move the instrument's crossline forward or aft axially until it is in the focal plane of the objective lens.

2. Move the objective lens until its focal plane is in the same plane as the instrument's crossline. This method is preferred for placing the crossline of an instrument in the focal plane of its objective lens. The objective lens is mounted in an externally threaded mount which can be moved axially along the interior of the instrument. When the objective lens mount is moved any amount, the focal plane and image of the collimator's crossline in the focal plane move in the same direction and the same amount as the objective lens.

In some instruments, spacers or separators are placed in front and at the rear of the objective lens mount (not threaded externally) to allow for axial positioning of the mounts in order to remove parallax.

Removal of parallax by axial adjustment of the instrument's crossline is not preferred over axial adjustment of the objective lens, because a portion of the telescope's body must usually be disassembled in order to reach the crossline. Instruments which provide for adjustment of the crossline have it mounted in an externally threaded mount which can be adjusted by screwing forward or backward. Some optical instruments also provide for adjusting both the objective lens and the crossline.

After you completely remove parallax from an instrument, both crosslines must come into focus at the same time on the same diopter reading on the diopter scale of the instrument.

NOTE: There is NO tolerance for parallax in any optical instrument.

Squaring and Superimposing the Crossline

You can square and superimpose the crossline in the following manner:

1. Square the crosslines of the instruments; that is, have the vertical line of one parallel with the vertical line of the other. You can do this by rotating the crossline of the instrument in its mount with a cotton swab or a soft, rubber-tipped eraser—NOT THE FINGERS. You must do this carefully in order to prevent scratches on the glass surface of the crossline, for these defects appear greatly magnified when superimposed on the target.

2. When you have the crossline positioned correctly, tighten its retainer ring. If you find that the crossline rotates with the retainer ring when you tighten it, so position the crossline that it will rotate into correct position (squared) when you tighten its retainer ring.

3. Superimpose the instrument's crossline with the crossline of the collimator, so that both crosslines appear as one when you look at them through the instrument. You can do this in several ways, but the method generally used is to rotate the objective lens' eccentric mount and ring (if provided). When you rotate the mount and ring, or each singly, the optical axis of the objective lens moves laterally and causes the image of the collimator's crossline to move in the same direction and in a circle. So manipulate the eccentric mount and ring that you superimpose the collimator's crossline image on the crossline of the instrument.

In some objective lenses, the optical centers are slightly different from the geometrical centers, which means that you can rotate the objective lens in its mount and give the same effect you get by using an eccentric mount and ring.

Another method for superimposing the crossline is to adjust the crossline and its mount laterally with a screw adjustment mount (described in chapter 6). Adjust the screws as necessary to push the crossline of the instrument horizontally and vertically and superimpose it over the image of the collimator's crossline.

You can superimpose the crossline of instruments containing a prism erecting system by adjusting the erecting prism. An excellent example of this is an Amici prism in a gunsight telescope. The prism is positioned at a definite point between the objective lens and its focal plane; and movement of the prism causes the optical axis and focal plane to move in the desired direction until the image of the collimator's crossline is superimposed with the crossline of the instrument.

The diopter setting of eyepieces varies in accordance with type, focusing or fixed-type, each of which is set to different optical values.

A focusing-type eyepiece is set to a value called 0 DIOPTERS, which can be accomplished when an infinity target (collimator crossline) image is defined sharply, with parallel rays of light emerging from the rear eyelens, and with the index mark pointing to 0 diopters on the diopter scale of the instrument's eyepiece. NOTE: Parallel rays of light have 0 dioptric value.

You will recall that when you removed parallax from an instrument the images of the crosslines of the instrument and the collimator came into focus with the same reading on the diopter scale, regardless of the reading (plus or minus). If one image, for example, comes into focus at -4 diopters on the diopter scale, the other image must do likewise. This means that the eyepiece focusing mechanism must be focused in from its mid-throw (mechanical 0 diopters) position to allow the images to coincide with the principal focal plane of the eyepiece. (When images or objects are in the principal focal plane of any lens, the rays which leave the images diverge, enter the lens, are refracted, and emerge parallel.) The problem, then, is to move the images OUT toward the observer to the mid-throw position, so that you do not need to focus the draw tube of the eyepiece IN past its mid-throw position.

A condition exactly opposite to that just described may also exist; that is, if both images come into focus on the plus side of 0 diopters, your problem is to move the images IN to the mid-throw position so that you need not move the draw tube OUT in order to have the principal focal plane coincide with the images.

The procedure for moving these images together simultaneously depends upon the type of erecting system in the instrument; that is, a single erector or a two erector (lens) system. The rule to follow for moving a single erector lens is as follows: If the images come into focus on the MINUS side of the 0 diopter graduation on the diopter scale, move the erector lens AWAY from the eyepiece; if the images come into focus on the PLUS side of the 0 diopter graduation, move the erector lens TOWARD the eyepiece. Review the discussion on construction of telescopes in chapter 7 of this manual.

It may appear that the opposite effect occurs to the movement of the image when you move the erector lens; but if you remember the optical theory involved here, you know that the images move in the opposite direction to the movement of the single erector lens. Move the erector lens in the desired direction until the images are in focus, with the index mark pointing to 0 diopters on the eyepiece diopter scale. NOTE: You need an auxiliary telescope for setting the 0 diopter on any telescope eyepiece.

Give the diopter setting a final check by placing the auxiliary telescope to the eyepiece of the instrument and then by focusing from a PLUS to a MINUS position until you have the images sharply defined. The index mark must point to 0 diopters on the diopter scale within a quarter of a diopter tolerance.

To set a two-erector lens erecting system to 0 diopters, move the second lens in the system in the direction in which the images must be moved. The theory involved here is this: The light rays which enter the second erector lens are parallel and the images formed by the lens are in the focal plane of the second erector lens. The images in the focal plane therefore always move in the same direction as the lens. When you have the second erector lens properly positioned, when focused on the images, the eyepiece comes into focus with the index mark pointing to 0 diopters on the diopter scale.

The required diopter setting for a fixed-type eyepiece must be explained only for collimation of a fixed-prism gunsight (Mk 77 and Mk 79, for example), because the mechanical construction of this telescope must be known before you set the diopter setting.

SEALING, DRYING, AND CHARGING

After you collimate an optical instrument, the last step in the repair process involves sealing, drying, and charging, which is discussed next.

Methods used for sealing, drying, and charging differ for the various types, designated for this purpose as: (1) moisture-tight, (2) gastight, and (3) pressure-tight.

Optical instruments which are held by hand, or not permanently mounted on a ship's weather decks, must be moisture-tight. These instruments always have focusing-type eyepieces and are sealed:

1. Against the entrance of moisture, and humidity.

2. With black or green wax, or gaskets.
3. From the objective lens to the sealing windows (if provided), or to the rear eyelenses.
4. At atmospheric pressure, with or without gas.

A gas-tight optical instrument is generally mounted on a weather deck and is constantly subjected to the weather. It contains either a focusing or a fixed-type eyepiece, and it is used ONLY on surface ships.

A gas-tight optical instrument should be sealed:

1. Against the entrance of moisture and water
2. With gaskets and packing only.
3. Between the objective lens (or window) and the sealing plate or crossline (which acts as a sealing window in some instruments) of an instrument with a focusing-type eyepiece.
4. From the objective lens or window to the rear eyelens of an instrument with fixed-type eyepiece.

A pressure-tight optical instrument is mounted on sub-surface craft and must be able to withstand the force of external water pressure and it must be sealed:

1. Against the entrance of high (hydrostatic) water pressure.
2. With gaskets and packing only.
3. From the objective window to the rear eyelens.

The primary purpose of sealing, drying, and charging an optical instrument with gas is to prevent moisture from getting into the instrument and condensing on parts, thereby inflicting damage to them.

A gas-tight instrument may be charged with dry, water pumped, oil-free nitrogen, or dry helium. A pressure-tight instrument should be charged with dry nitrogen ONLY. Dry nitrogen and dry helium are used to charge instruments because they contain no moisture or oxygen; whereas, dry air contains about 20% oxygen and must NEVER be used as a final charging agent for an optical instrument.

Gas used to charge optical instruments is normally not completely free of moisture and foreign matter and must therefore be cleaned before you use it. This you can do by forcing the gas through an optical instrument dryer, which is actually a gas dryer containing a quantity of silica gel to absorb moisture from the gas as it passes through. See illustration 8-10. The silica gel used on instruments must be impregnated with cobalt chloride, which serves as a moisture indicator. When the silica gel is completely dry, it is deep blue in color. When the silica gel is saturated with 30% of

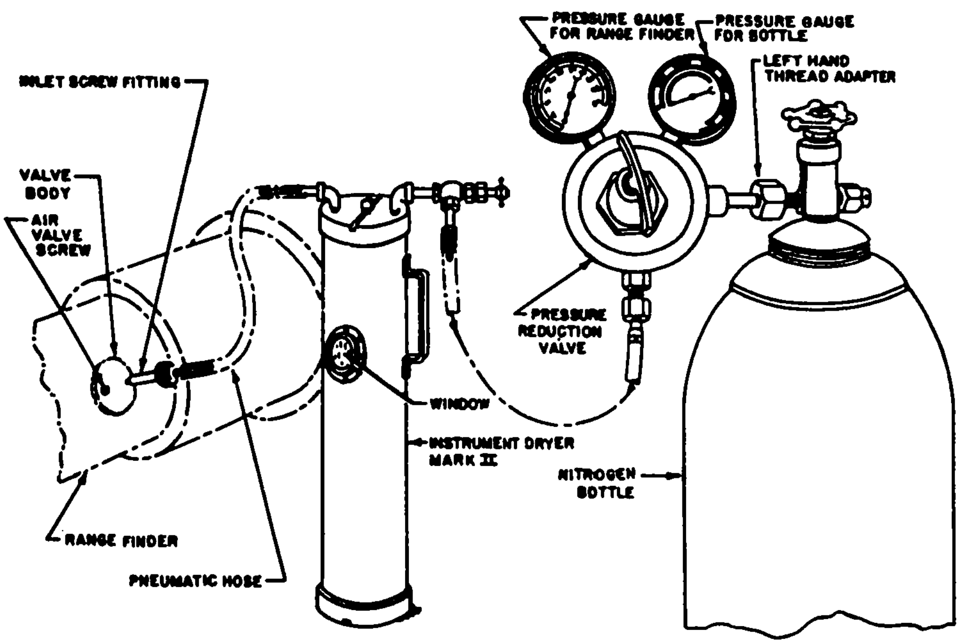


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Figure 8-10.—Setup for charging.

water, its color is lavender; and when it contains 50% of moisture, its color is pale pink At a saturation of almost 100% with moisture, silica gel is decidedly pink in color.

A window on the side of the cylinder enables you to observe the color of the silica gel; and when it changes to pink, remove it from the cylinder, place it in a container, and bake it in an oven at a temperature of 300°F to 350°F for a minimum of 4 hours, after which its color should be a deep blue.

All optical instruments except moisture-tight types are equipped with gas inlet and outlet valves, also called plugs; and on most instruments they are located on opposite ends of the instruments. As the gas enters through the inlet valve and circulates throughout the instrument, it becomes saturated with moisture in the instrument and carries it out through the outlet valve.

After you overhaul a gas-tight instrument, check its gaskets, fittings, and so forth, for air tightness.

When pressure testing an instrument follow the requirements of the technical manual that applies to the instrument. The manual will give you the type of gas to be used and at what pressure. Most navigational instruments and periscopes use dry nitrogen as a gas, so the following discussion on safe handling and pressure testing will be applied to the use of nitrogen. The same safety rules and charging procedures will apply to any compressed gas.

The use of nitrogen gas for pressure-testing navigational instruments, as prescribed in the various instrument manuals, requires that the user be familiar with safe-handling practice of pressure gases and the storage cylinders. It is also advisable that the tester have generally applicable information on the question of cleanliness which is useful for these tests.

The nitrogen will be supplied to you in the standard type of gas cylinder. Fortunately, nitrogen is an inert gas, chemically speaking, which eliminates the fire and explosion hazards associated with other gases such as oxygen, acetylene, etc. But the nitrogen is under great pressure in the storage cylinder and damage to the cylinder can result in its bursting. Also, the economic loss of damaged cylinder is to be avoided. The following rules for storage, handling and use of cylinders shall be strictly observed.

- Avoid abusing cylinders. They are carefully checked at the charging plant for safe condition. Abuse may easily render them unsafe.
- BE SURE THE CYLINDER CONTAINS NITROGEN and do not tamper with the identifying code numbers and markings on the cylinders.
- Store cylinders in an approved safe place.
    - A. Store cylinders in a definitely assigned place where they will not be knocked over or damaged by passing or falling objects. If a full cylinder falls over, it may crack and explode. If the cylinder valve is broken, the cylinder will take off like a jet-propelled rocket.
    - B. Cylinders should be kept away from stoves, radiators, furnaces and other hot places.
- While moving cylinders, keep them from becoming knocked over or from falling. A suitable hand cart should be available. The cart should have retaining devices such as chains and fitting recesses to hold the cylinders.
- Keep cylinders from being knocked over while in use; a rack should be provided.
- Full cylinders should be used in the order received from the charging plant.
- Never allow cylinders to come in contact with live wires and ground wires of electrical equipment.
- Always close cylinder valve when work is finished and always close valves of empty cylinders while in storage before returning to charging plant.
- Return empty cylinders promptly.

The pressure tests in the instrument manuals specify a source of clean, dry nitrogen at pressures of two to five pounds per square inch. The equipment setup for such a source of nitrogen is illustrated in Fig. 8-10

The pressure-reducing regulator gives an output of nitrogen at a constant pressure as determined by the setting of its pressure-adjusting control screw. Two gauges, which are part of the regulator, indicate the high cylinder pressure and the regulated output pressure.

The instrument dryer contains a replaceable dirt filter and a replaceable cartridge of desiccant to filter out foreign particles and moisture. A viewing window is provided to permit a constant check of the desiccant for the tell-tale change from blue to pink which indicates that the desiccant is saturated and needs replacement. This is to be done at the first sign of pinkness in the desiccant. The dirt filter should be checked when the desiccator is replaced. Use a new filter at the first sign of dirt.

Desiccators and filters are much cheaper than the spoilage of one newly overhauled instrument.

Plastic hose must be used from the pressure gas filter. Rubber hoses are not clean. They tend to "shed" foreign matter. It is also advisable to use a plastic hose from the regulator to the filter, but rubber will do if plastic is not available.

The following procedure shall be followed. It is prescribed to protect you and the equipment.

- Set a cylinder of nitrogen in a rack. Observe the rules for "Safe-handling Practice for Cylinders." Make sure the cylinder contains nitrogen.
- With the cylinder firmly in the rack, unscrew the valve protection cap from the top of the cylinder.
- "Crack" the cylinder valve by opening it one-quarter of a turn and then closing it immediately. DO NOT stand in front of the outlet pipe; stay in back of it. This "cracking" is intended to clear the valve and outlet pipe of dust and dirt that may have been accumulated during storage and shipment. Otherwise, such dirt might be blown into the regulator and damage it.

CAUTION

Do not use a wrench on the cylinder valve. It should open to hand pressure. If it will not yield by hand, replace the valve protection cap and return the cylinder to the charging plant with an explanation attached.

- Assemble the pressure-reducing regulator to the outlet of the cylinder. Tighten the union-joint nut securely.
- Turn the pressure-adjusting control screw of the regulator counterclockwise (to the left) until it is loose. This protects the regulator and its gauges from possible damage when the cylinder is opened.
- Stand away to one side of the front of the regulator and open the cylinder valve slightly. If the cylinder was opened wide, the sudden rush of gas might damage the regulator. Only open the valve enough to make the cylinder pressure gauge indicate a slow rise in pressure. When the needle of the gauge stops, open the cylinder valve all the way.

CAUTION

If there is a leak between the cylinder and the regulator, close the cylinder valve before tightening the coupling or doing anything else.

- Connect the hoses and the pressure gas filter together as in figure 8-10.
- Turn the pressure-adjusting control screw of the regulator clockwise until the regulated pressure gauge reads five pounds. This will blow out the filter and the lines.
- Reduce the pressure again. The system is now ready for use.

When an instrument is to be tested for leaks the general procedure is:

- Connect the hose from the outlet valve of the dryer to the inlet valve screw fitting (the small screw by the male-threaded end) on the optical instrument (A of fig. 8-11).

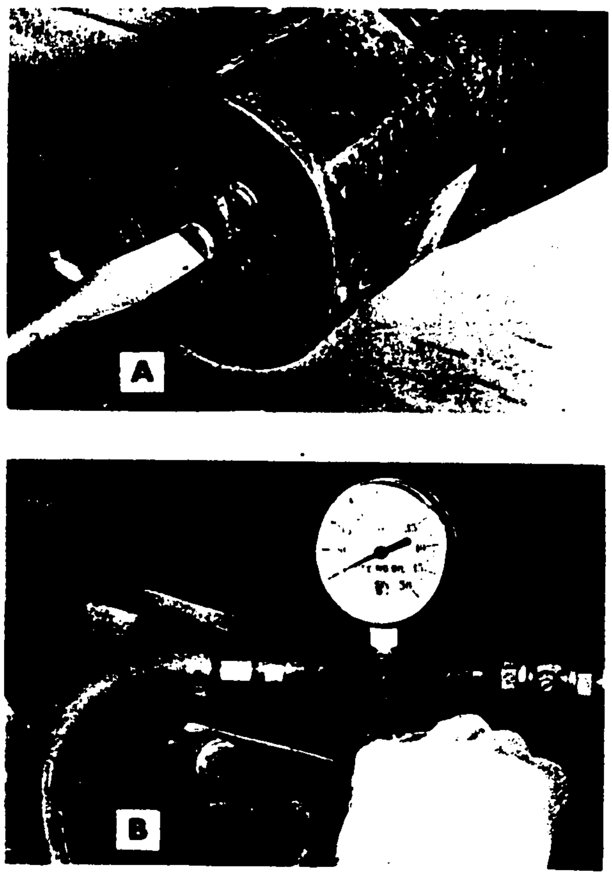

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Figure 8-11.—Optical instrument dryer.

• Open the gas inlet screw (large screw) on the inlet valve.

• Tighten the gas outlet valve screw on the opposite end of the optical instrument.

• Turn on the air supply until the pressure gage on the instrument dryer reads approximately five (5) pounds per square inch (B, fig. 8-11).

• While you maintain this pressure, use a liquid soap solution to test for leaks around all fittings, gaskets, screws, the objective window, and the rear eyelens.

• If you find leaks, mark them with a soft lead pencil, white crayon, or chalk, turn off the air supply, disconnect the hose from the instrument, and then repair the leak(s).

• After you repair leaks, connect the hose to the instrument and apply the same pressure test and check again for leaks with soapsuds.

• After the instrument passes the soapsuds test, maintain the 5 pounds of pressure and close the gas valve screw on the inlet valve.

If the instrument you are working on has a fixed-type or an internal-focusing eyepiece, continue with the following tank test. (NOTE: You can also submerge an instrument with an external-focusing eyepiece, but ONLY up to the eyepiece.)

• Submerge the instrument in a tank of water.

• Check for slow rising bubbles which may appear anywhere on the instrument. A few hours may elapse before any bubbles are visible.

• Mark the leak(s) as soon as you remove the instrument from the tank, and then repair them. Follow up by submerging the instrument in the tank again and make a double check for leaks.

When you are certain there are no leaks in the instrument, remove it from the tank and dry its exterior with a clean, soft cloth. Then recharge it to exactly 5 pounds. Twenty-four hours later, attach a pressure gage to the gas inlet valve of the instrument and check its pressure. If it has dropped, repeat either the soapsuds test or the tank test as often as necessary until you find the leak(s). Then make necessary repairs and dry the instrument.

You now have the instrument ready for charging with nitrogen, which you can do in the following manner:

• Reconnect the outlet hose from the dryer to the inlet valve on the instrument.

• Open the outlet valve of the instrument.

• Turn on the nitrogen gas and let it cycle through the entire instrument.

• Purge the instrument by holding a finger over its outlet valve. When the gage on the dryer shows a pressure up to but not exceeding five pounds, remove your finger from the outlet valve and allow the gas to escape from the instrument. At about five minute intervals during a period of approximately one-half hour, repeat the purging operation.

• When you have the instrument purged (completely free of moisture), replace the outlet valve screw and let the pressure on the dryer build up to approximately two pounds, or as indicated in the overhaul manual for the instrument.

• When the pressure reaches the specific amount, close and secure the gas valve screw (large one) on the gas inlet valve and disconnect the hose from the optical instrument. Then turn off the nitrogen bottle and replace the small, inlet valve screw.

Some moisture-tight instruments have inlet and outlet screws (not valves) which can be used for drying the instrument only. When you seal a moisture-tight instrument, test it for leaks and dry it; then replace the inlet and outlet screws.

Pressure-tight instruments must withstand a special testing procedure, so check with your instructor or shop supervisor for the instructions and specifications applicable to a particular pressure-tight instrument.

A special procedure must be followed for disassembling the equipment, as well. The following procedure is intended to protect you and the equipment.

• Close the cylinder valve. The pressure readings on both gauges should drop to zero if the hose line is open.

• Turn the pressure-adjusting control screw counterclockwise until it is loose.

• Disconnect the hoses and the pressure gas filter from the regulator.

• Disconnect the cylinder from the regulator by unscrewing the union-joint nut on the coupling.

• If a regulator is to be out of service for several weeks or longer, screw in the pressure-adjusting control screw to just relieve the spring pressure on the valve seat. At this point the control screw will no longer be loose. This aids in lengthening the life of the valve seat. Before the regulator is used again, the control screw must be loosened as prescribed in the setting up procedure.

In all cases of handling pressure gas, follow the rules outlined herein and exercise caution always.

Charge all gas- and pressure-tight instruments with gases and pressures specified for them, at the times stated next:

1. Prior to the conclusion of each ship's overhaul.
2. When inspection indicates condensation on internal optical surfaces.
3. Immediately after completion of an overhaul of an optical instrument.
4. At the completion of twelve months of service.

Some general rules to follow when you recharge an optical instrument are:

1. NEVER recharge an optical instrument when the temperature is below 32°F.
2. NEVER charge an instrument with nitrogen, or helium after the pressure in the bottle or tank falls below 400 pounds per square inch.

NOTE: If there is a trace of moisture, oil or grease in the bottle, it starts to come out when the pressure falls below 400 pounds.

3. Recharge each instrument with only the type of gas and pressure specified for that particular instrument. If in doubt, use nitrogen, and pressurize the instrument to two (2) pounds.
4. When the inlet valve or the area near it is painted ORANGE or YELLOW, always charge the instrument with HELIUM. CAUTION: NEVER use nitrogen. Follow recommended and/or Navy approved instructions for charging an instrument with helium.

HEAT TREATING AND TEMPERING

The Opticalman will work with metals at various times while working on optical instruments. Thus he should be familiar with types of metals, the properties of metals, and the heat treating processes for the most common metals.

There is no simple definition of metal. All chemical elements that possess metallic properties are classed as metals. The metallic properties might be defined as luster, good thermal and electrical conductivity, and the capability of being permanently shaped, or to some extent deformed, at room temperature. Other chemical elements, lacking these properties, are classed as nonmetals. Some elements—carbon, phosphorus, silicon, and sulfur, for example—behave sometimes like metals, sometimes like nonmetals, and are known as metalloids. An alloy is defined as a substance having metallic properties, that is composed of two or more elements.

Metals and alloys vary widely in their characteristics or properties. Chemical properties involve the behavior of the metal in contact with the atmosphere, salt water, or other environments. Physical properties relate to color, density and weight, magnetic qualities, electrical conductivity or resistance, and heat conductivity. Mechanical properties relate to load carrying ability, wear resistance, and elasticity.

The various properties of metals and alloys have been determined in the laboratories of manufacturers and are tabulated and indexed by various engineering societies interested in metallurgical development. Charts which give properties pertaining to a particular metal or alloy are published in such reference books as the Metals Handbook. The charts provide information on the physical and mechanical properties which have been determined.

What are the properties which an Opticalman needs to understand about the metals most commonly used? They include the mechanical properties of hardness, toughness, tensile strength, ductility, and malleability. Following is an explanation of the meaning of these terms.

The HARDNESS of a metal is that property which enables it to resist scratching, denting, cutting, or erosion. It may also be defined as the ability of the metal to resist penetration. A piece of lead, for example, can easily be scratched with a knife. But it would be difficult to mark a piece of steel in this manner. The reason is that steel possesses the property of hardness, and thus provides resistance to scratching and cutting.

TOUGHNESS is that property of a metal which enables it to withstand shock loading without breaking.

It is thus related to strength and to ductility. Usually, the hardness of a metal increases as the toughness decreases.

TENSILE STRENGTH is that property of a metal which resists forces that would tend to pull the metal apart. It is measured in terms of pounds per square inch which represents the load that must be exerted on a cross-sectional area in order to break the metal.

DUCTILITY is that property that renders a metal capable of being drawn into wire form, stamped, or hammered into sheets. In other words, when the metal is placed under a severe load, it deforms rather than fractures.

MALLEABILITY is the property of metal that permits it to be rolled, forged, hammered, or drawn, without cracking or breaking.

CORROSION RESISTANCE though not a mechanical property is also of primary importance. Corrosion resistance is the property that enables a metal to withstand chemical or electrochemical attack by air, moisture, soil, or other agents.

The various mechanical properties described may at times be desirable, and at other times be undesirable, depending on the purpose for which the metal is to be used. But resistance to corrosion is always a highly desirable characteristic.

TYPES OF METALS

The metals with which you work can be divided into two general classifications, ferrous and nonferrous. FERROUS metals are those that are composed primarily of iron. NONFERROUS metals are those that are composed primarily of some element or elements other than iron. Nonferrous metals or alloys sometimes contain a small amount of iron as an alloying element or as an impurity.

Ferrous Metals

A few examples of ferrous metals include pig iron, cast iron, ingot iron, and wrought iron. Carbon steel and the various alloy steels—structural as well as tool steel—are also considered as ferrous metals since they are composed of iron to which relatively small percentages of carbon and other elements have been added as alloys.

Pig iron is composed of about 93 percent iron, from 3 to 5 percent carbon, and varying amounts of other elements. It is comparatively weak and brittle, and has a limited use.

The term cast iron may be applied to any iron in which the carbon alloy is more than 1.7 percent. Cast iron has high compressive strength and good wear resistance, but it lacks ductility, malleability, and impact strength.

Wrought iron is made from pig iron by a process of puddling, squeezing, and rolling. This process removes many of the impurities, and gives the wrought iron a type of fibrous internal structure which promotes workability.

Ingot iron is a commercially pure iron (99.85 percent), easily formed and possessing good ductility.

Of all the different metals and materials which you will use while in the Navy, by far the most important is steel. Steel is manufactured from pig iron by decreasing the amount of carbon and other impurities present. About 15 pounds of manganese, an indispensable addition in the production of steel, is added to each ton of pig iron.

Most of the steel you use will be in the form of structural shapes, such as sheet, plate, and bar. The types of structural steel are: mild steel, medium steel, high tensile steel, special treated steel, and stainless steel.

Mild steel is used when structural strength is of no great importance, and when a great deal of flanging, shaping, and other shop operations are involved.

Medium steel is similar to mild steel in its workability. But, it is harder and stronger than mild steel and is used when structural strength is required.

High tensile steel, usually referred to as RTS, contains small additions of various alloys that give the steel extra hardness and toughness.

Special treated steel, known as STS, contains a small percentage of chromium-nickel; and the product has been specially treated to obtain hardness and toughness.

Stainless steel, referred to as SST, is generally designated by the percent of chromium and nickel; for example, an 18-8 stainless is an alloy containing 18 percent chromium and 8 percent nickel.

Nonferrous Metals

As an Opticalman you may work with various types of nonferrous metals. Some of the major types and their uses are discussed in this section.

Copper and copper alloys rank high among commercial metals with respect to desirable properties. Copper is ductile, malleable, hard, tough, strong, wear resistant, machinable, and weldable. Also it has high tensile strength, fatigue strength, and thermal and electrical conductivity. Copper is easy to work, and although it becomes hard when worked, it can easily be softened (annealed) by heating it to a cherry red and then letting it cool. Annealing is the only heat treating procedure that is applied to copper.

Lead is a heavy metal, weighing about 710 pounds per cubic foot. Yet lead is soft and malleable. It is available in pig and sheet form; sheet lead is rolled up on a rod so that the user can unroll and cut off the amount required. The surface of lead is grayish in color, but scraping the surface will show that the color of the metal is actually white. Because of its softness, lead can be used in various jobs. Sheet lead is used for bench tops where a great deal of acid is used. Lead lined pipe is used for systems that must carry chemicals. Alloyed with tin, in various proportions, it produces a soft solder. Lead is often added to metal alloys to improve machinability. In working with lead, remember that its dust, fumes, or vapor can be highly poisonous.

Zinc is used often as a protective coating, known as galvanizing, on steel and iron. Zinc is also used in soldering fluxes, in die castings, and as an alloying element in making brass and some bronze.

Tin has many important uses as an alloying element. Remember that it can be alloyed with lead to produce soft solders; and alloyed with copper, it produces bronze. Tin base alloys have a high resistance to corrosion; they also have a low fatigue strength, and a compressive strength which will accommodate light or medium, but not heavy, loads.

Tin, like lead, possesses a good resistance to corrosion; it has the added advantage of being nonpoisonous. But when subjected to extremely low temperatures, it has a tendency to decompose. Aluminum is easy to work and has a good appearance. Although light in weight, it has a high strength per unit weight, but its tensile strength is only 1/3 that of iron, and 1/5 that of annealed mild steel. In its pure state, aluminum is soft, and has a strong affinity for gases. The use of alloying elements overcomes these disadvantages.

True brass is an alloy of copper and zinc. Additional elements—aluminum, lead, tin, iron, manganese, or phosphorus—may be added to give the alloy specific properties.

Bronze made of 84 percent copper and 16 percent tin was the best metal available before steelmaking techniques were developed. Many complex bronze alloys, containing additional elements such as zinc, lead, iron, aluminum, silicon, and phosphorus, are now available.

Monel is an alloy in which nickel is the predominate element. It contains from 64 to 68 percent nickel, about 30 percent copper, and small percentages of iron, manganese, and cobalt. It is harder and stronger than either nickel or copper, and has high ductility. It has many of the qualities of stainless steel, which it resembles in appearance, and its strength and high resistance to atmospheric corrosion make it an acceptable substitute for steel in a system or service where atmospheric corrosion resistance is of primary importance.

HEAT TREATING PROCESSES

Metals in a solid state can be heated and cooled to change or improve a physical or mechanical property or a combination of properties. A metal part is heat treated in order to make it softer, more ductile, stronger, harder, or more resistant to wear. These properties are developed as needed to improve the usefulness and safety of a part for a definite purpose. No one heat treating operation can produce all these characteristics, and the improvement of some properties must be accomplished at the expense of other properties.

There are different forms of heat treating. Common forms used by the Navy include: annealing, normalizing, hardening, tempering, and stress relieving. The particular process used is determined not only by the physical properties to be developed or modified, but also by the composition of the metal. Ferrous metals may be hardened, tempered, annealed, and normalized. Most nonferrous metals can be annealed, and many can be hardened, but they are never tempered or normalized. (For nonferrous metals, the hardening process is usually referred to simply as heat treatment.)

While all heat treating processes are similar in that they involve heating and cooling, they differ in the temperatures to which the metals are heated, the rate of cooling, and the cooling medium. In addition, some of these processes not only effect changes in physical properties, but also alter the surface composition of the metal.

For all metals, time and temperature are the important factors in the heat treating operation. Usually, the atmosphere surrounding the metal during heating, or during heating and cooling, is also critical.

Annealing

Two main purposes of annealing are (1) to relieve internal strains, and (2) to make a metal soft enough for machining. Practically all metals, ferrous and nonferrous, may be annealed, and no elaborate equipment is essential. It is possible to produce good anneals by using a heating torch or a furnace. The basic process consists of heating the metal to a specified temperature, holding it at that temperature for a specified length of time, and then cooling it slowly to room temperature. Both the temperature of the operation and the rate of cooling depend upon the metal being treated, and the purpose for which it is to be used.

Annealing temperature for any metal should be slightly above the recrystallization point of the metal. Cast iron ordinarily must be heated to a point between 1400° and 1500°F. Pure aluminum can be annealed at temperatures from 625° to 700°F, but aluminum alloys require somewhat higher temperatures, depending upon their composition. Pure copper can be annealed at temperatures from 800° to 1200°F; most brasses (copper-zinc alloys) require annealing temperatures of from 475° to 650°F. Nickel-chromium alloys, which can withstand extremely high temperatures without appreciable damage, must be heated to annealing temperatures between 1800° and 1950°F.

Soaking or hold time depends upon the mass and the composition of the metal. Also, the rate at which a metal is cooled back to room temperature depends upon the composition of the metal. Alloys whose constituents precipitate on slow cooling from the solid solution temperature are of the age hardening type. Precipitation itself is a form of age hardening treatment; if the hardening constituent of an alloy is in excess of the amount soluble at room temperature, the excess amount will precipitate, causing an increase in hardness and strength.

Rapid cooling suppresses precipitation, and the alloy remains soft at room temperature. For metals whose constituents precipitate after or during fast cooling, it may be necessary to furnace-cool the metal in order to produce complete softening.

Cooling methods also differ according to the type of metal concerned. Pure aluminum can be cooled in air; pure copper can be cooled in air, or quenched in water. Steel must be furnace-cooled, and the cooling rate must be kept slow, to produce maximum softness.

In annealing, avoid overheating the metal being treated. Overheating will cause increased grain size. There is also danger of burning the metal and, in ferrous metals, decarburizing the surface if a protective atmosphere is not provided.

Normalizing

Normalizing is a heat treating process similar to annealing, but it is applied to ferrous metals only. The purpose of normalizing is to refine internal grain structure, and to relieve stresses and strains caused by welding, forging, uneven cooling of castings, machining, and bending. Where steel is to be hardened, it is advisable that it be normalized first; low carbon steels generally do not require normalizing, but giving them a normalizing treatment will cause no harmful results.

The process of normalizing—like other heat treatment processes—consists of three steps: heating the metal to a specified temperature, soaking it (that is, holding it at this temperature), and cooling it. In normalizing, the specified temperatures are, for each metal, a point from 100°F to 150°F above the transformation range. The holding time depends upon the thickness of the metal, but must be long enough to allow for uniform heating throughout. The metal should be allowed to cool evenly to room temperature in still air.

Hardening and Tempering

The primary purposes of HARDENING operations are to harden metal and, at the same time, increase the tensile strength. In steel, however, the hardening process increases brittleness; and, the rapid cooling of the metal from the hardening temperature sets up severe internal stresses. To reduce brittleness, and to relieve internal stresses, steel must be tempered after it has been hardened. Although hardening and tempering are separate steps in the heat treatment of a tool steel, the value of each procedure depends upon the other.

The hardening treatment for most steels consists of heating to the correct temperature, soaking it the required length of time, and then rapidly cooling it in oil, water, or brine. A point to remember is that too rapid a cooling rate will increase the danger of cracking or warping. The addition of alloys permits a slower rate of cooling, and several steels (high-speed tool steels) may be cooled in air.

The temperature to which you must raise steel for hardening should be about 50° to 100°F above its upper critical point. This is to ensure that every point in it will have reached critical temperature and to allow for some slight loss of heat when the metal is transferred to the cooling medium. Remember that it is cooled rapidly by quenching in oil, fresh water, or brine. Quenching firmly fixes the structural changes which occurred during heating, and thus causes the metal to remain hard.

If allowed to cool too slowly, the metal will lose its hardness. On the other hand, to prevent too rapid quenching—which would result in warping and cracking—it is sometimes necessary to use oil instead of fresh water or salt water for high carbon and alloy steels. (Note: Salt water gives a faster quench but does not necessarily give a higher hardness. Hardness is dependent to an extent upon the quenching medium; however, an oil hardening steel will not be harder if quenched in brine.)

In cooling, you have to bring carbon steel to a temperature somewhat below 1,000°F in less than 1 second; and from this point downward, a rapid cooling rate must still be maintained. Alloys added to steel increase this 1-second limit for lowering the temperature; therefore, alloy steels can be hardened in a slower quenching medium.

Although all ferrous metals can be hardened by heat treatment, the degree to which they can be hardened varies considerably. For example, such ferrous metals as pure iron, wrought iron, and low-carbon steels contain very little hardening element (carbon), and this type of heat treatment will have little appreciable effect in hardening them. Cast iron can be hardened, but here, too, the effect is limited. If cooled too rapidly, cast iron forms a hard and brittle white iron; if cooled too slowly, it forms a gray iron that is soft and brittle under impact.

Some nonferrous metals and alloys can be hardened by cold working and rolling. These processes increase the strength of nickel alloys, copper, and wrought brass; some aluminum alloys and several copper base alloys are hardened by an aging process.

TEMPERING, also called DRAWING, is a process generally applied to steel to reduce brittleness and relieve stresses developed during the hardening process. Tempering always follows, never precedes, hardening. It differs from annealing, normalizing, and hardening in that the tempering temperatures are always BELOW the lower critical point. As it reduces brittleness, the tempering process also softens the steel. One property must be sacrificed to some extent in order that another property may be improved. High speed steel is an exception, since tempering high speed steel increases its hardness to a limited extent.

Tempering is accomplished by heating the hardened steel to a temperature below the critical range, holding this temperature for a sufficient time to penetrate the whole piece, and then cooling the piece in water, oil, or air. The tempering temperature for hardened steel is determined by the degree of hardness and toughness desired.

Tools with cutting edges are not tempered above 650°F; the hardness required for penetration is lost if a hardened steel is heated beyond this temperature. However, the toughness and shock resistance of the steel improves as it is reheated beyond 650°F. When reheats beyond 650°F are employed, the operation is frequently called TOUGHENING. You will soon learn, by trial, the temperature at which a tool must be tempered. Table 8-1 gives the temperatures for tempering various plain carbon steel tools.

Table 8-1.—Temperatures for Tempering Various Plain Carbon Tools.

Degrees Fahrenheit	Tool
400	Hammer faces, machine cutting tools
460	Tape and dies
480	Punches, reamers, dies, knives
500	Twist drills
520	Drift pins, punches
540	Cold chisels
550	Screwdrivers, springs

The following description of a common method used to harden and temper chisels will help to clarify the meaning of hardening and tempering. Bring 2 1/2 to 3 inches of the cutting edge of the tool up to hardening temperature. Then, using tongs to hold the chisel, quench by plunging 1 1/2 to 2 inches of the heated end into the quenching medium. Jiggle the tool rapidly, using an up-and-down, forward-and-backward motion; and, as you do so, make sure you keep the point immersed 1/2 inch in the quenching medium.

When the metal has cooled down to a black heat (900° to 950°F), remove the tool from the quench tank. Then quickly polish the tapered end with an emery board and watch the temper color "run out" until the desired color appears (usually peacock to dark blue). Then quench the entire tool.

It is well to remember that every chisel you see is not a water-hardened chisel. Many are manufactured from special alloys and are oil-hardened. Most chisels of this type have directions for treating stamped on the shank as follows: 1350 W 400 or 1600 O. The first means to heat to 1,350°F, quench in water and temper at 400°F. The second means to heat to 1,600°F, and quench in oil. It is not necessary to temper this tool, as it is a special alloy. Other alloy chisels will have different directions stamped on the shank. Generally, it is safe to assume that an unmarked chisel is a carbon steel water-hardened tool.

Stress Relieving

Stress relieving is a heat treating process in which uniform heating is essential, but the temperature to which the part is raised is not as high as that required for annealing and normalizing. The purpose of stress relieving, as the name implies, is to relieve stresses developed in metals during mechanical working or solidification.

Stress relieving involves temperatures below the transformation point of ferrous metals. The main factors in stress relieving are the temperature of the treatment and the time the part is held at that temperature. Stress relief becomes more effective as the temperature is increased. For example, with gray cast iron, the percentage of stress relief at temperatures below 750°F is negligible. Above this temperature, the percentage of residual stress relieved increases rapidly with increase in temperature. However, if the temperature closely approaches the transformation range, structural changes will begin to occur. As a rule, when stress relieving is applied, structural changes are not desirable. Consequently, the temperature selected should give the greatest possible stress relief with the least possible change of properties. For gray cast iron, the stress relief temperature is 950°F. At this temperature from 60 to 90 percent of the original internal stress is relieved and a minimum of structural change occurs.

Stress relieving is accomplished by heating the metal slowly and uniformly to a predetermined temperature. The rate of heating should not be less than 400°F per hour for most metals. When the metal attains the desired temperature, hold or soak at this temperature no less than 1 hour for each inch of thickness of the thickest section. Then allow the part to cool very slowly to room temperature. The cooling rate should not exceed 200°F per hour for any metal. Since the majority of stress relief occurs during the first hour after the part attains the proper temperature, it is essential that hold time be counted from the time the metal, not the furnace, reaches the stress relieving temperature. Remember, slow cooling is essential. If the part is cooled rapidly, new internal stresses develop, defeating the purpose of the treatment.

In steel, stress relieving is often the final heat treatment. Here the stress relieving temperature is at least 50°F, but not more than 100°F, below that of the preceding heat treating temperature. A temperature of 750° relieves about 50 percent of the stress in a steel casting, while a temperature of 1,000°F relieves more than 90 percent. Typical practices for stress relieving common metals are presented in table 3-2.

Table 8-2.—Stress Relieving Data

Material	Temperature (°F)	Hold time (hours per inch thickness)
Gray cast iron	950	1
Low carbon steel	1,150	1
Carbon-molybdenum steel	1,250	2
Chromium-molybdenum steel:		
(0.5 Cr-0.5 Mo)	1,250	2
(2 Cr-0.5 Mo)	1,325	2
(9 Cr-1 Mo)	1,400	3
Copper	300	1/2
Brass:		
(70 Cu-30 Zn)	500	1
(60 Cu-40 Zn)	375	1/2
Bronze:		
(90 Cu-10 Sn)	375	1
Stainless steel	1,550	2
Monel	550	2

CHAPTER 9

MACHINE TOOL OPERATION—PART I

Machine tool operation requires a knowledge of certain mechanical principles that apply to all machine work. These are the principles of CUTTING TOOLS, CUTTING SPEEDS, and FEEDS, and action of GEARS, SCREWS, and CAMS.

All of these principles are applied in the construction of machines and in the various machine operations. The mechanical principles may be few, but there is no end to the methods of application in machine tool work. This chapter is not written to give you the knowledge to become a machinist, but to give you additional knowledge that will help you to become a better OPTICALMAN. It has long been recognized that optical and mechanical problems are two phases in the single problem of repairing optical instruments.

As an opticalman in the Navy, you will often be working on vital instruments where replacement parts and special tools are not available. When this situation arises, a good opticalman must be prepared to manufacture the part or tool that is needed.

This chapter gives a description of the machine tools common to optical shops and it will help you to gain a working knowledge of the machining operations that you will be required to perform. First and foremost, you must remember that NO JOB IS SO IMPORTANT AND NO SERVICE IS SO URGENT THAT WE CANNOT TAKE TIME TO PERFORM OUR WORK SAFELY.

LATHES

An engine lathe such as the one shown in figure 9-1, or one similar to it, is found in every optical shop, however small. It is used principally for turning, boring, facing, and thread cutting; but it may also be used for drilling, reaming, knurling, grinding, spinning, and spring winding. The work held in the engine lathe can be revolved at a number of different speeds, and the cutting tool can be accurately controlled by hand or power for longitudinal and cross feed. (Longitudinal feed is movement of the cutting tool parallel to the axis of the lathe; cross feed is movement of the cutting tool perpendicular to the axis of the lathe.)

Lathe size is determined by two measurements: (1) diameter of work it will swing over the bed, and (2) length of the bed. For example, a 14-inch x 6-foot lathe will swing work up to 14 inches in diameter, and has a bed 6 feet long. Engine lathes are built in various sizes, ranging from small bench lathes with a swing of 6 inches to very large lathes for turning work of large diameter, such as large turbine rotors. The average size of lathes found in optical shops is 8 inches to 16 inches.

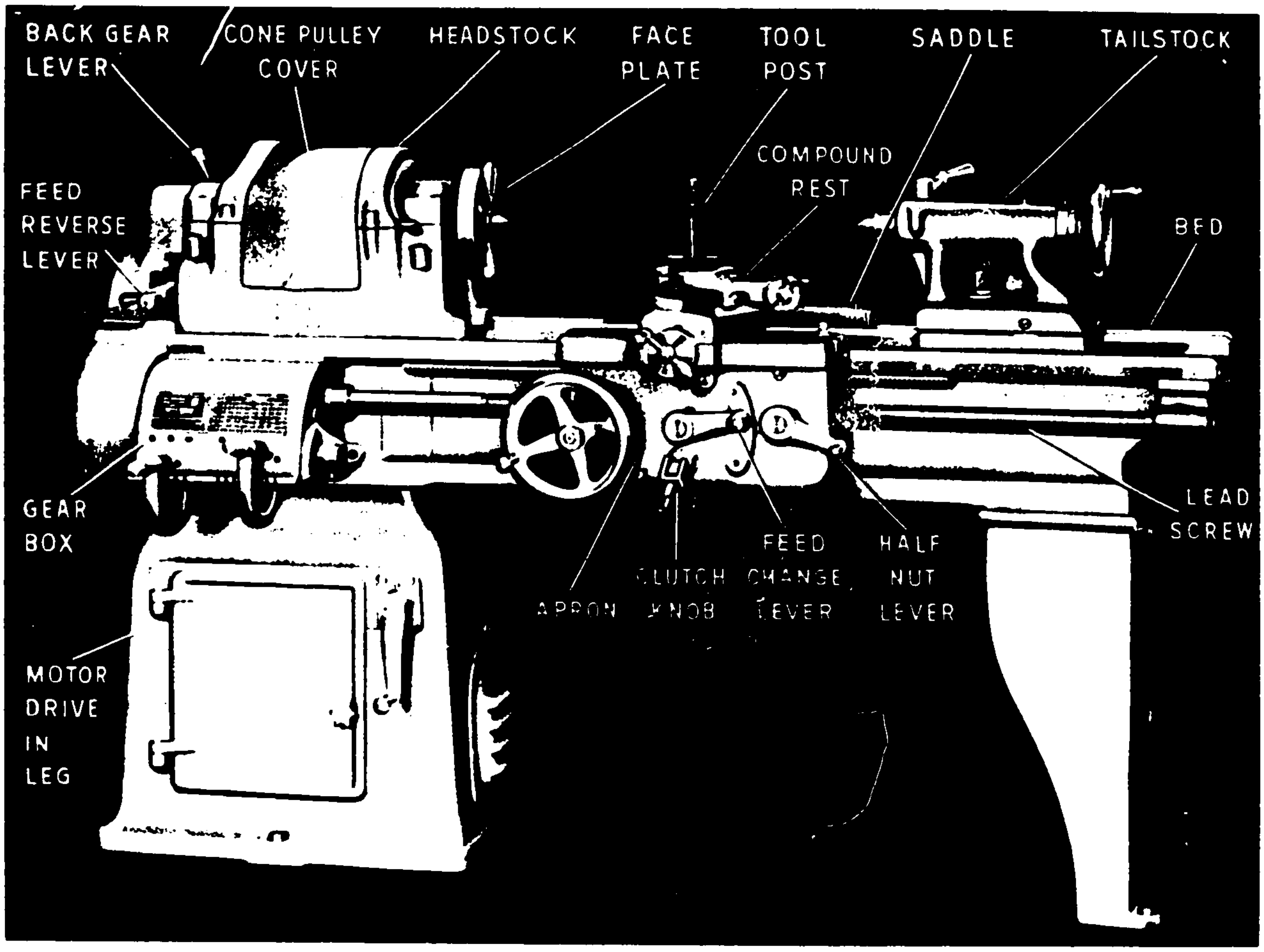
PRINCIPAL PARTS

To learn the operation of a lathe, you must first become familiar with the names and functions of the principal parts. In studying the principal parts in detail, bear in mind that lathes of different manufacture differ somewhat in details of construction, but all are built to provide the same general functional principles. As you read the description of each part, find its location on the lathe by referring to figure 9-1, which is labeled for this purpose. For specific details on the features of construction and operating techniques, refer to the manufacturer's technical manual for the machine you are using.

Bed

The bed is the base or foundation of the working parts of the lathe. The main features of its construction are the ways which are formed on its upper surface and run the full length of the bed. Ways provide the means for maintaining the tailstock and carriage, which slide on them, in alignment with the headstock, which is permanently secured by bolts at one end (at operator's left).

Figure 9-2 shows the ways of a typical lathe. The inverted V-shaped ways 1, 3, and 4, and the flat way 2, are accurately machined parallel to the axis of the spindle and to each other. The



28.69X(75)

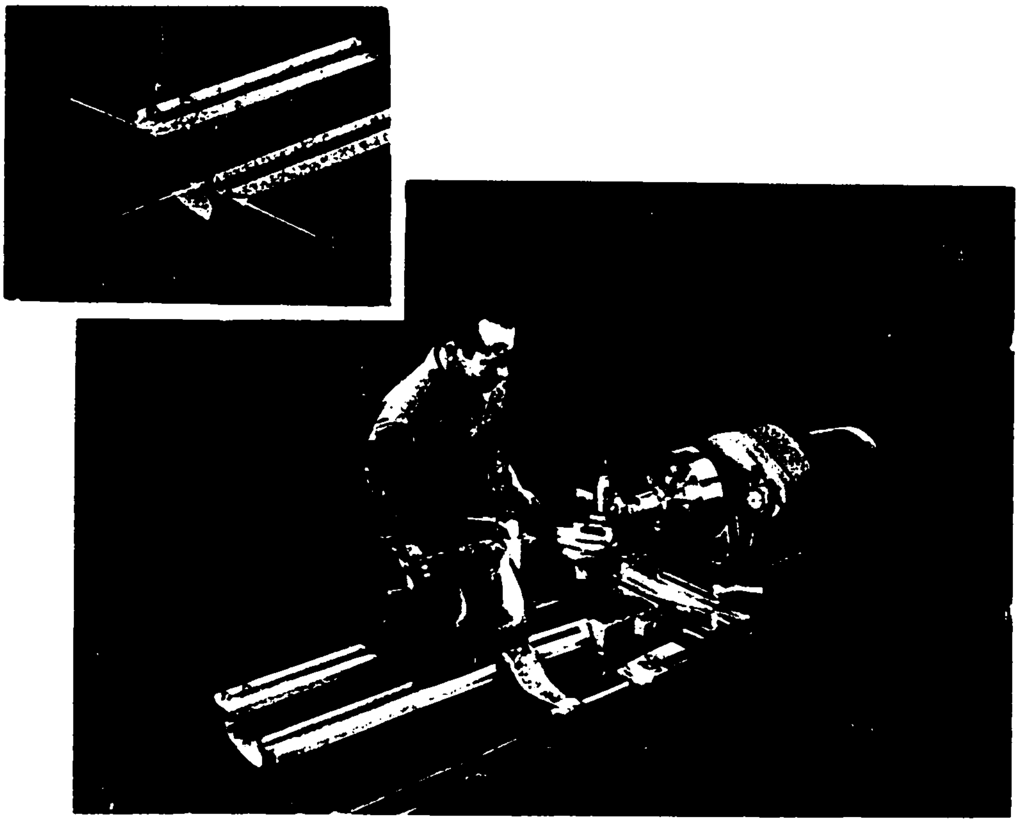
Figure 9-1.—An engine lathe.

V-ways are guides that allow movement over them in their long direction only. The headstock and tailstock are aligned by the V-ways. The flat way, number 2, takes most of the downward thrust. The carriage slides on the outboard V-ways (1 and 4), which, because they are parallel to number 3, keep it in alignment with the headstock and tailstock at all times—an absolute necessity if accurate lathe work is to be accomplished. Some lathe beds have two V-ways and two flat ways while some others have four V-ways.

For satisfactory performance of a lathe, it is essential that the ways be kept in good condition. A common fault of careless machinists is to use the bed as an anvil for driving arbors, or as a shelf for hammers, wrenches, and chucks. Never allow anything to strike a hard blow on the ways or damage their finished surface in any way. Keep them clean and free of chips. Wipe them off daily with an oiled rag to help preserve their polished surface.

Headstock

The headstock carries the headstock spindle and the mechanism for driving it. In the belt-driven type, shown in figure 9-3, the driving mechanism consists merely of a cone pulley that drives the spindle directly or through back gears. When being driven directly, the spindle revolves with the cone pulley; when being driven through the back gears, the spindle revolves more slowly than the cone pulley, which, in this



28.70X

Figure 9-2.—Rear view of lathe.

case, turns freely on the spindle. Thus two speeds are obtainable with each position of the belt on the cone; if the cone pulley has four steps as illustrated, eight spindle speeds can be obtained.

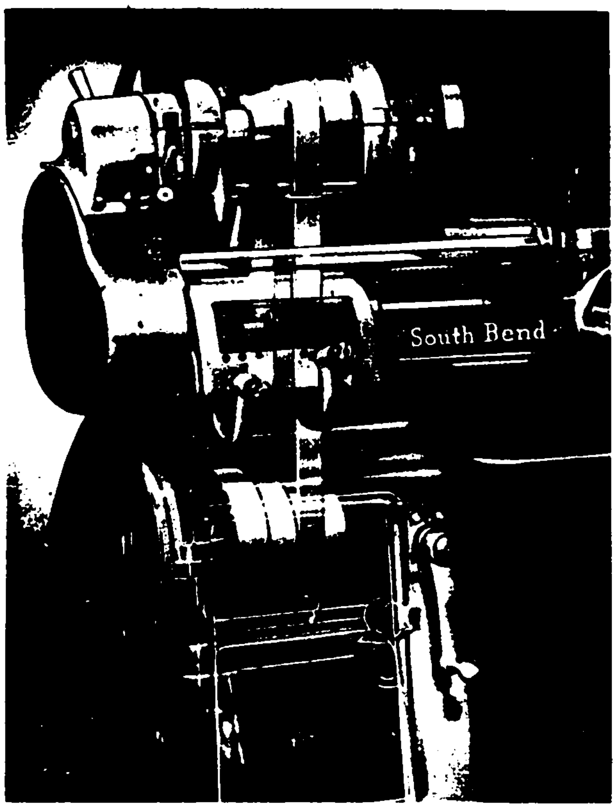
The geared headstock shown in figure 9-4 is more complicated but more convenient to operate, because speed changes are accomplished by the mere shifting of gears. It is similar to an automobile transmission except that it has more gear-shift combinations and therefore a greater number of speed changes. A speed index plate attached to the headstock indicates the lever positions for obtaining the different spindle speeds. Always stop the lathe when shifting gears in order to avoid possible damage to gear teeth.

The headstock casing is filled with oil for lubrication of the gears and shifting mechanism contained within it. Those parts not immersed in the oil are lubricated by the splash produced by the revolving gears. You should see that the oil is kept up to the oil level indicated on the oil gage, and that it is drained out and replaced when it becomes dirty or gummy.

The headstock spindle (fig. 9-5) is the rotating element of the lathe and is directly connected to the work which revolves with it. The spindle is supported in bearings (4) at each end of the headstock through which it projects. The section of the spindle between the bearings carries the pulleys or gears that turn the spindle. The nose of the spindle holds the driving plate, faceplate, or chuck. The spindle is hollow throughout its length so that bars or rods can be passed through it from the left (1) and held in a chuck at the nose. The chuck end of the spindle (5) is bored to a Morse taper to receive the LIVE center.

At the other end of the spindle is attached the gear (2) by which the spindle drives the feed and screw-cutting mechanism through a gear train located on the left end of the lathe. Part 3 is a collar for adjusting end play of the spindle.

The spindle is subjected to considerable torque because it not only drives the work



28.71X
Figure 9-3.—Belt-driven type headstock.

against the resistance of the cutting tool but also drives the carriage that feeds the tool into the work. For that reason adequate lubrication and accurately adjusted bearings are absolutely necessary. (Bearing adjustment should be attempted only by an experienced lathe repairman.)

Tailstock

The primary purpose of the tailstock, shown in figure 9-6, is to hold the DEAD center to support one end of work being machined. However, it can also be used to hold tapered shank drills, reamers, and drill chucks. It is movable on the ways along the length of the bed to accommodate work of varying lengths and can be clamped in the desired position by means of the tailstock clamping nut (13).

The dead center (11) is held in a tapered hole (bored to a Morse taper) in the tailstock spindle (6). You can move the spindle back and forth in the tailstock barrel for longitudinal adjustment by the handwheel (9), which turns the spindle-adjusting screw (7) in a tapped hole in the spindle at (8). The spindle is kept from revolving by a key at (4) that fits a spline or keyway (5) cut along the bottom of the spindle as shown. Part (10) is a binding clamp for locking the spindle in place after final adjustment.

The tailstock body is made in two parts. The bottom or base (1) is fitted to the ways; the top (2) is capable of lateral movement on its base. Setscrews provide close adjustment for this lateral movement. Zero marks inscribed on the base and top indicate the center position.

Before inserting a dead center, drill, or reamer, carefully clean the tapered shank and wipe out the tapered hole of the spindle. When holding drills or reamers in the tapered hole of a spindle, be sure they are tight enough so they will not revolve. If allowed to revolve, they will score the tapered hole and destroy its accuracy.

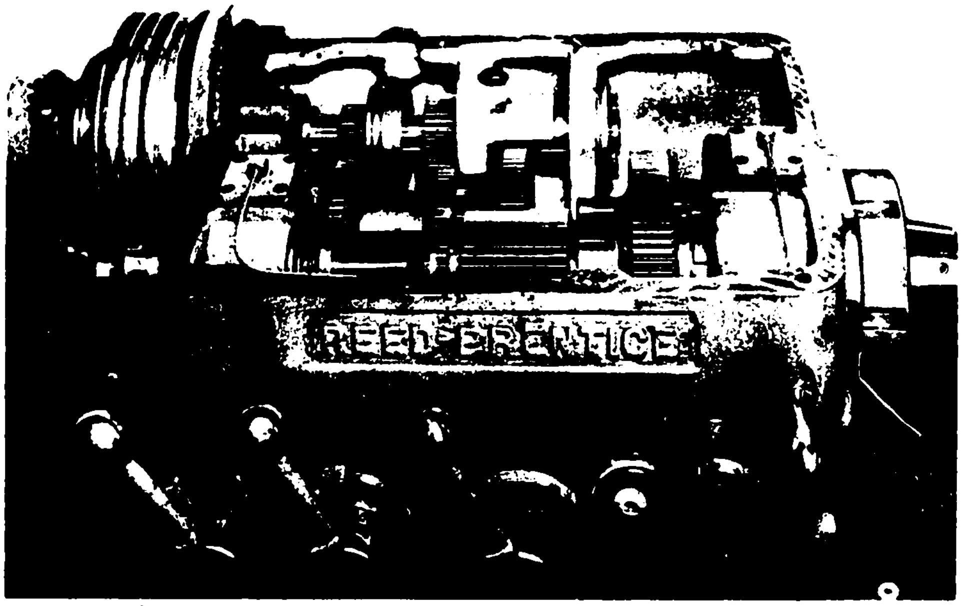
Quick-Change Gears

To do away with the inconvenience and loss of time involved in removing and replacing change gears, most modern lathes are equipped with a self-contained change gear mechanism commonly called the QUICK-CHANGE GEAR BOX. There are a number of types used on different lathes but they are all similar in principle (fig. 9-7).

The mechanism consists essentially of a cone-shaped group of change gears. You can instantly connect any single gear in the gear train by means of a sliding tumbler gear controlled by a lever. This cone of gears is keyed to a shaft which drives the lead screw directly or through an intermediate shaft. Each gear in the cluster has a different number of teeth and hence produces a different gear ratio when connected in the train. To increase the range, means are provided to produce other changes in the gear train (by means of sliding gears) which multiply the number of different ratios obtainable with the cone of change gears described above. All changes are made by shifting appropriate levers or knobs. An index plate or chart mounted on the gear box indicates the position for placing the levers to obtain the necessary gear ratio to cut the thread or produce the feed desired.

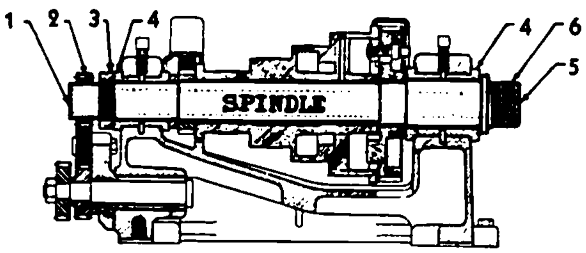
Carriage

The carriage (fig. 9-8) is the assembly that has the primary duty of supporting the cutting



28.72X

Figure 9-4.—Sliding gear type headstock.



28.74X

Figure 9-5.—Cross section of a belt-driven headstock.

tool and moving it with extreme accuracy in whatever direction required to machine a piece of work. The accuracy of cuts made parallel to the lathe bed are dependent upon the trueness of the ways; the accuracy of cross and angular cuts depends upon the precision that is built into the carriage.

Figure 9-9 shows how a carriage is constructed, and the major components of the carriage:

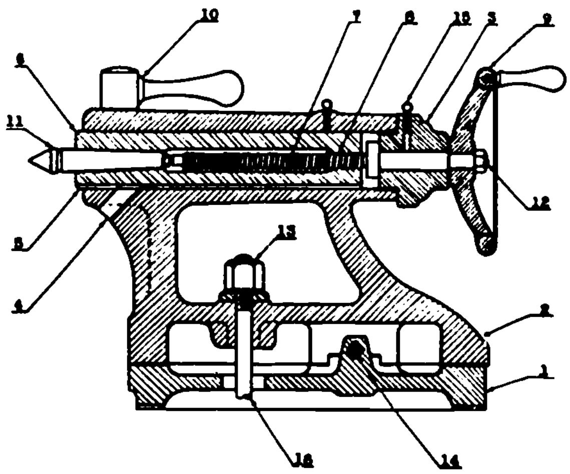
- saddle
- cross slide
- compound rest
- apron

The SADDLE, when viewed from the top, is shaped like the letter "H". The two arms having inverted V's machined in them which fit over the ways and guide the movement of the carriage along the ways.

The CROSS SLIDE is that part of the carriage which moves the cutting tool at right angles to the ways. The cross slide is mounted to the top of the saddle by means of a dovetail and it is used to carry the cutting tool at right angles to the ways of the bed.

The compound rest is fitted on the top of the cross slide by means of another dovetail, and its purpose is to hold the tool post in proper position. The compound rest (fig. 9-8), is pivoted at its center on a swivel. This allows for cutting small tapers and feeding the cutting tool at any angle desired.

Attached to the front of the carriage is the APRON. It contains the gearing and mechanism for controlling the movement of the carriage for LONGITUDINAL feed and thread cutting, and the lateral movement of the cross slide. The APRON should be thoroughly understood before you attempt to operate the lathe. Study



1. Tailstock base.
2. Tailstock top.
3. Tailstock nut.
4. Key.
5. Keyway (in spindle).
6. Spindle.
7. Tailstock screw.
8. Internal threads in spindle.
9. Handwheel.
10. Spindle binding clamp.
11. Dead center.
12. End of tailstock screw.
13. Tailstock clamp nut.
14. Tailstock set-over.
15. For oiling.
16. Tailstock clamp bolt.

28.75X

Figure 9-6.—Cross section of a tailstock.

figure 9-9 very closely as we describe the main parts of the APRON.

In general, a lathe APRON contains the following:

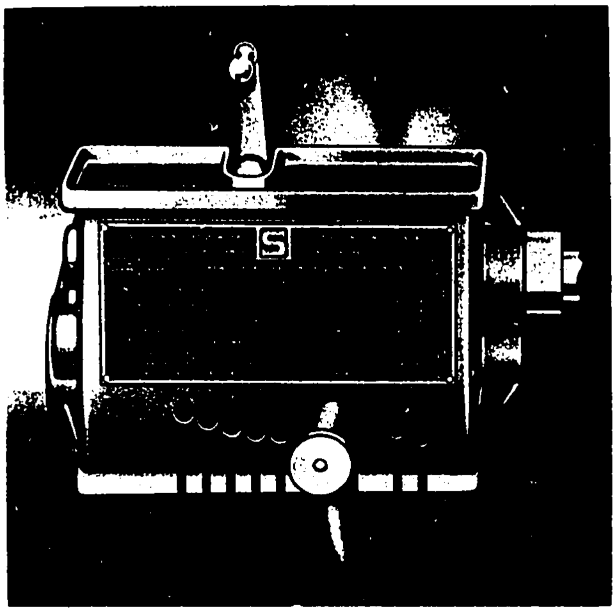
- A longitudinal feed HANDWHEEL for moving the carriage by hand along the bed. This handwheel turns a pinion that meshes with a rack gear secured to the lathe bed.
- Gear trains driven by the lead screw. These gear trains transmit power from the lead screw to move the carriage along the ways (longitudinal feed) and the cross-slide across the ways (cross feed), thus providing powered longitudinal feed and crossfeed.
- FRICTION CLUTCHES operate by levers on the apron to engage or disengage the power feed mechanism. Most lathes have separate clutches for longitudinal feed and crossfeed, while some lathes have a single clutch for both.
- FEED CHANGE LEVER for selecting power crossfeed, longitudinal feed or, in the center position, for cutting threads.
- HALF NUT CLOSURE LEVER to engage and disengage the lead screw when cutting threads. The half nuts fit the thread of the lead screw, which turns in them when they are clamped over it.

ATTACHMENTS AND ACCESSORIES

The equipment that is available as an accessory or attachment to a lathe makes it the most versatile machine tool in the shop. In the manufacturer's instruction book, all associated equipment will be listed for the particular lathe installed in the shop. This section will describe the most common parts that an opticalman will use.

Chucks

The lathe chuck is a device for holding lathe work. It is mounted on the nose of the spindle. The work is held by jaws which can be moved in radial slots toward the center to clamp down



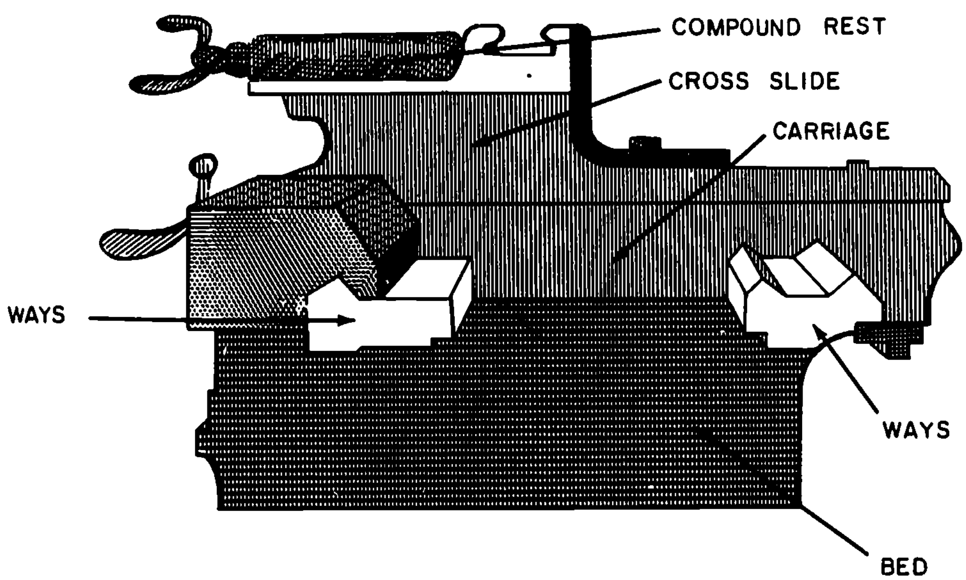
28.87X
Figure 9-7.—Quick-change gear box.

on the sides of the work. These jaws are moved in and out by screws turned by a chuck wrench applied to the sockets located at the outer ends of the slots.

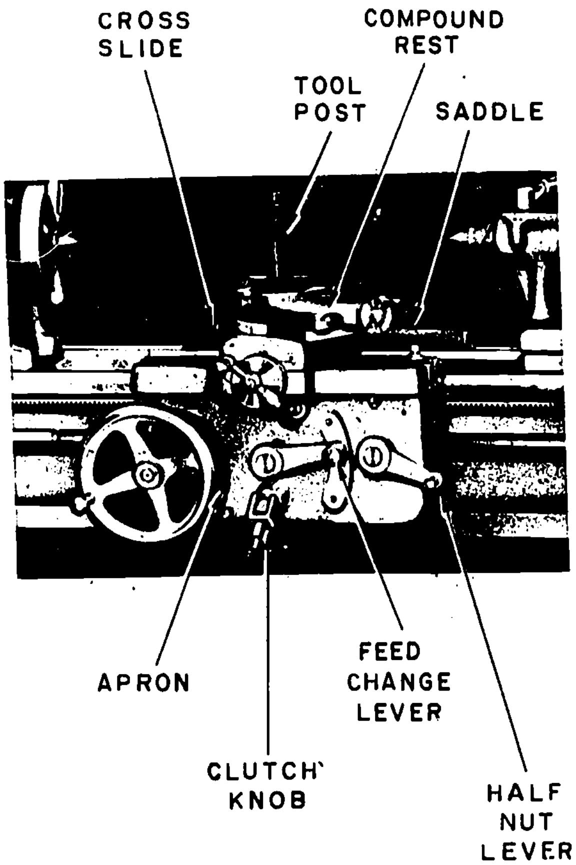
The 4-jaw independent lathe chuck, (fig. 9-10A) is the most practical for general work. The four jaws are adjusted one at a time, making it possible to hold work of various shapes and to adjust the center of the work to coincide with the center of the lathe. The jaws are reversible.

The 3-jaw universal or scroll chuck, (fig. 9-10B) can be used only for holding round or hexagonal work. All three jaws are moved in and out together in one operation. They move universally to bring the work on center automatically. This chuck is easier to operate than the four-jaw type, but when its parts become worn its accuracy in centering cannot be relied upon. Proper lubrication and constant care in use are necessary to ensure reliability.

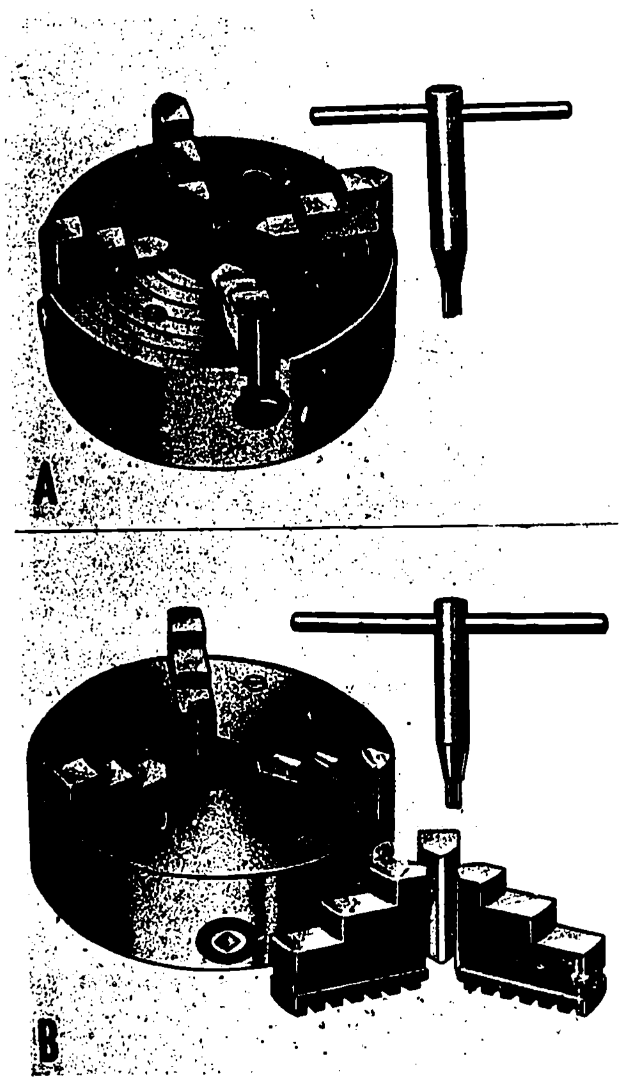
When you are required to hold small diameter work such as screws, pins, and small rods on a lathe, a small drill chuck such as that shown in figure 9-11 will usually be better suited for the job than the larger chucks previously described. This type of chuck has a Morse taper shank that will fit both the head spindle and the tailstock of the lathe. The drill chuck has universal self-centering jaws that will automatically center the work when it is clamped.



28.76X
Figure 9-8.—Side view of a carriage mounted on bed.



28.69(75)X
Figure 9-9.—Front view of carriage assembly.



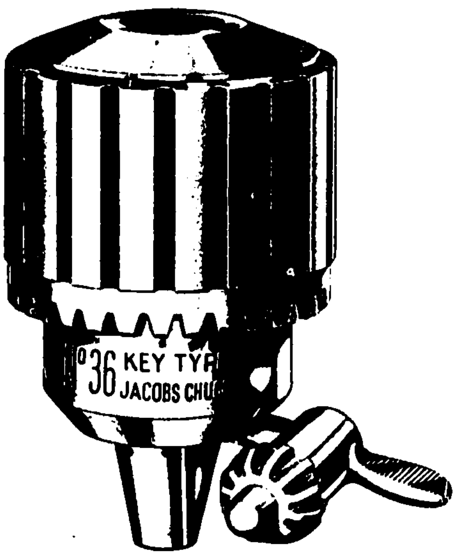
28.90X
Figure 9-10.—A. Four-jaw chuck.
B. Three-jaw chuck.

The drill chuck is used to hold center drills and straight shank drills in the tailstock when performing drilling operations on a lathe.

Collets

Another way of accurately holding small work in a lathe is with the draw-in collet. Figure 9-12 shows the collet assembled in place in the lathe spindle. The collet is a self-centering device that is very accurate and most often used for precision work in the optical shop. The collet which holds the work is a split cylinder with an outside taper that fits into a matching tapered closing sleeve and screws into the threaded end of a hollow draw bar. Turning the hardwheel of the hollow draw bar pulls the collet into the tapered sleeve, thereby closing the collet firmly around the work and centering it in the head spindle. The draw collet is quick acting and the size of the center hole determines the diameter of the work that can be held. Collets are made with center hole sizes ranging from 1/64 of an inch up, and graduated in 1/64-inch steps. The best results are obtained when the diameter of the work is the same size as the dimension stamped on the collet.

To ensure accuracy of the work when using the draw-in collet, it is important that the contact surfaces of the collet and closing sleeve are free of chips, dirt, and burrs.



28.92X
Figure 9-11.—Drill chuck.

Taper Attachment

The taper attachment (fig. 9-13) is used for turning and boring tapers. It is bolted to the back of the carriage saddle. In operation, it is so connected to the cross-slide that it moves the cross-slide laterally as the carriage moves longitudinally, thereby causing the cutting tool to move at an angle to the axis of the work to produce a taper.

The angle of the taper it is desired to cut is set on the guide bar of the attachment. The guide bar support is clamped to the lathe bed.

Since the cross-slide is connected to a shoe that slides on this guide bar, the tool follows along a line that is parallel to the guide bar and hence at an angle to the work axis corresponding to the desired taper.

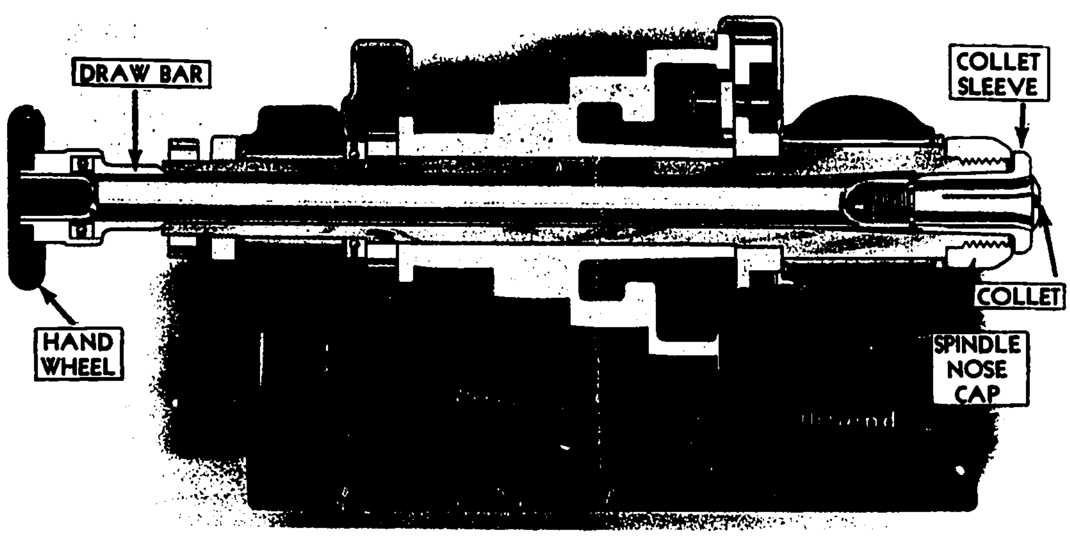
The operation and application of the taper attachment will be further explained under the subject of taper turning.

Center Rest

The center rest, also called the steady rest, is used for the following purposes:

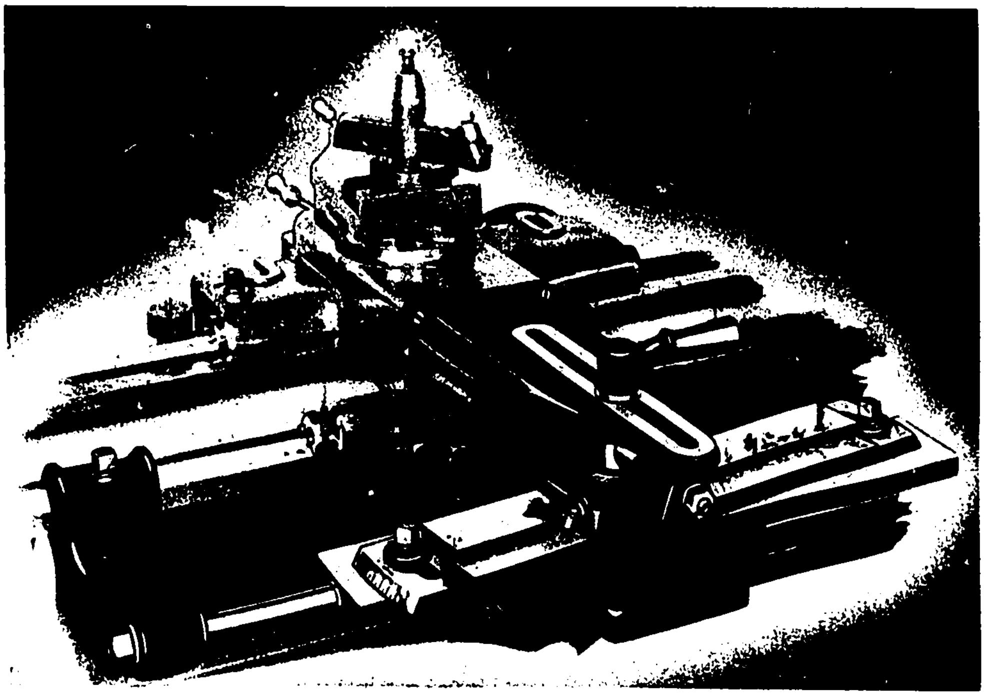
1. To provide an intermediate support or rest for long slender bars or shafts being machined between centers. It prevents them from springing under cut, or sagging as a result of their otherwise unsupported weight.

2. To support and provide a center bearing for one end of work, such as a spindle, being bored or drilled from the end when it is too long to be supported by a chuck alone. The center rest is clamped in the desired position on the



28.91X

Figure 9-12.—Draw-in collet chuck.



28.98X

Figure 9-13.—A taper attachment.

bed on which it is properly aligned by the ways, as illustrated in figure 9-14. It is important that the jaws A be carefully adjusted to allow the work B to turn freely, and at the same time keep it accurately centered on the axis of the lathe. The top half of the frame is hinged at C to facilitate placing it in position without removing the work from the centers or changing the position of the jaws.

Follower Rest

The follower rest is used to back up work of small diameter to keep it from springing under the stress of cutting. It gets its name from the fact that it follows the cutting tool along the work. As shown in figure 9-15, it is attached directly to the saddle by bolts B. The adjustable jaws bear directly on the finished diameter of the work opposite the cutting tool.

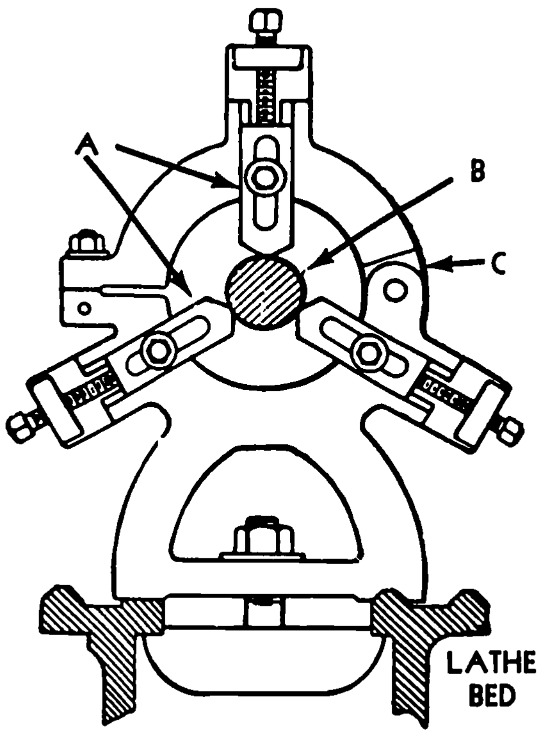
Thread Dial Indicator

The thread dial indicator, shown in figure 9-16, eliminates the necessity of reversing the lathe to return the carriage to the starting point to catch the thread at the beginning of each successive cut that is taken. The dial, which is geared to the lead screw, indicates when to clamp the half-nuts on the lead screw for the next cut.

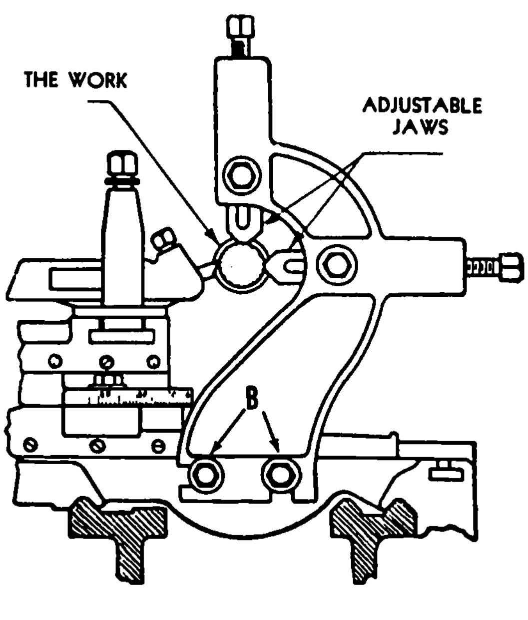
The threading dial consists of a worm wheel which is attached to the lower end of a shaft and meshed with the lead screw. On the upper end of the shaft is the dial. As the lead screw revolves, the dial is turned and the graduations on the dial indicate points at which the half-nuts may be engaged.

Carriage Stop

You can attach the carriage stop to the bed at any point where it is desired to stop the carriage. It is used principally when turning, facing, or boring duplicate parts, as it eliminates the necessity of repeated measurements of the same dimension. In operation, the stop is set at the point where it is desired to stop the feed. Just before reaching this point, the operator shuts off the automatic feed and carefully runs the carriage up against the stop. Carriage stops are provided with or without micrometer

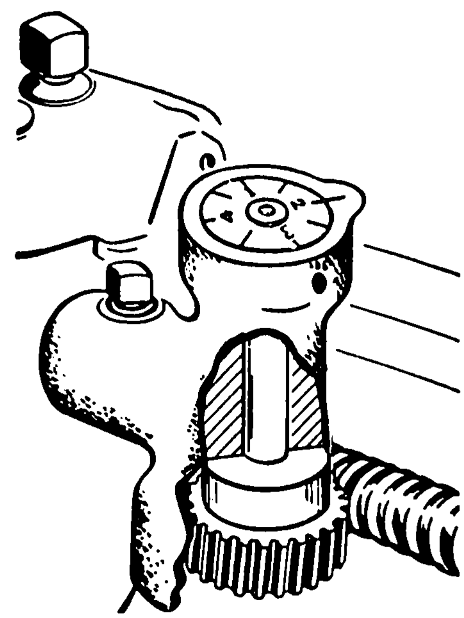


28.96X
Figure 9-14.—Center rest.

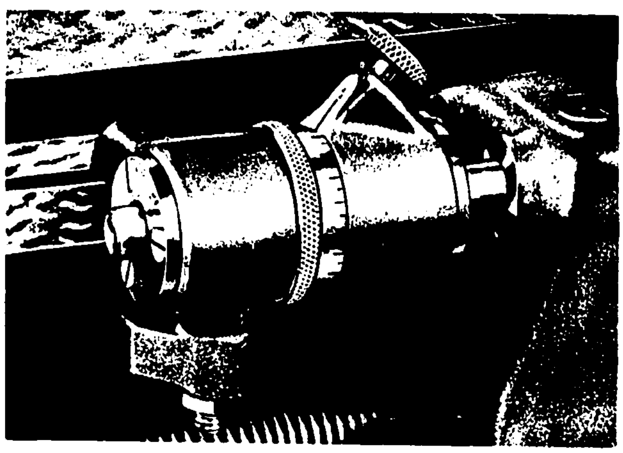


28.97X
Figure 9-15.—Follower rest.

adjustment. Figure 9-17 shows a micrometer carriage stop. It is clamped on the ways in the



28.99X
Figure 9-16.—Thread dial indicator.



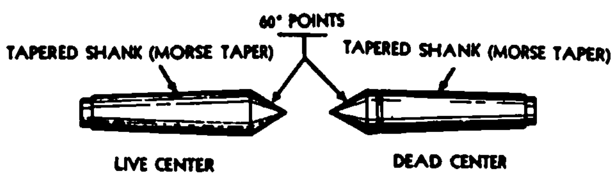
28.100
Figure 9-17.—Micrometer carriage stop.

approximate position required and then adjusted to the exact setting by means of the micrometer adjustment.

NOTE: Some carriages are equipped with a stop which automatically stops the carriage by disengaging the feed or stopping the lathe. This type of stop is called AUTOMATIC CARRIAGE STOP, and it is usually a built-in feature of the lathe design.

Lathe Centers

The function of the 60° lathe centers shown in figure 9-18 is to provide a means for holding the work between points so it can be turned accurately on its axis. The headstock spindle center is called the LIVE center because it revolves with the work. The tailstock center is called the DEAD center because it does not turn. Both live and dead centers have shanks turned to a Morse taper to fit the tapered holes in the spindles; both have points finished to an angle of 60°. They differ only in that the dead center is hardened and tempered to resist the wearing effect of the work revolving on it. The live center revolves with the work, and it is usually left soft. The dead center and live center must never be interchanged.



28.93
Figure 9-18.—Sixty-degree lathe centers.

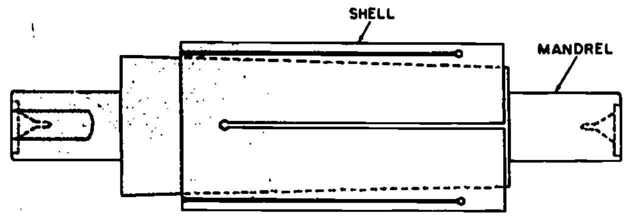
NOTE: There is a groove around the hardened tail center to distinguish it from the live center.

The centers fit snugly in the tapered holes of the headstock and tailstock spindles. If chips, dirt, or burrs prevent a perfect fit in the spindles, the centers will not run true.

To remove the headstock center, insert a brass rod through the spindle hole and tap the center to jar it loose; it can then be picked out with the hand. To remove the tailstock center, run the spindle back as far as it will go by turning the handwheel to the left. When the end of the tailstock screw bumps the back of the center, it will force it out of the tapered hole.

Mandrels

Very often an opticalman will find it necessary to machine a part that requires all finished external surfaces to run true with a hole which extends through it. This is best accomplished by holding the part to be machined on a mandrel. There are several types of mandrels used by a machinist, but the most common mandrel used in the optical shop is the expansion mandrel (fig. 9-19). The expansion mandrel is composed of two parts; a tapered pin and a split shell that is tapered on the inside to fit the tapered pin. As the tapered pin is pressed into the inside taper of the split shell, the shell expands evenly to grip the work firmly. Caution should be used when pressing in the tapered pin, so that pressure exerted on the work is not too great.



28.116
Figure 9-19.—A split-shell expansion mandrel.

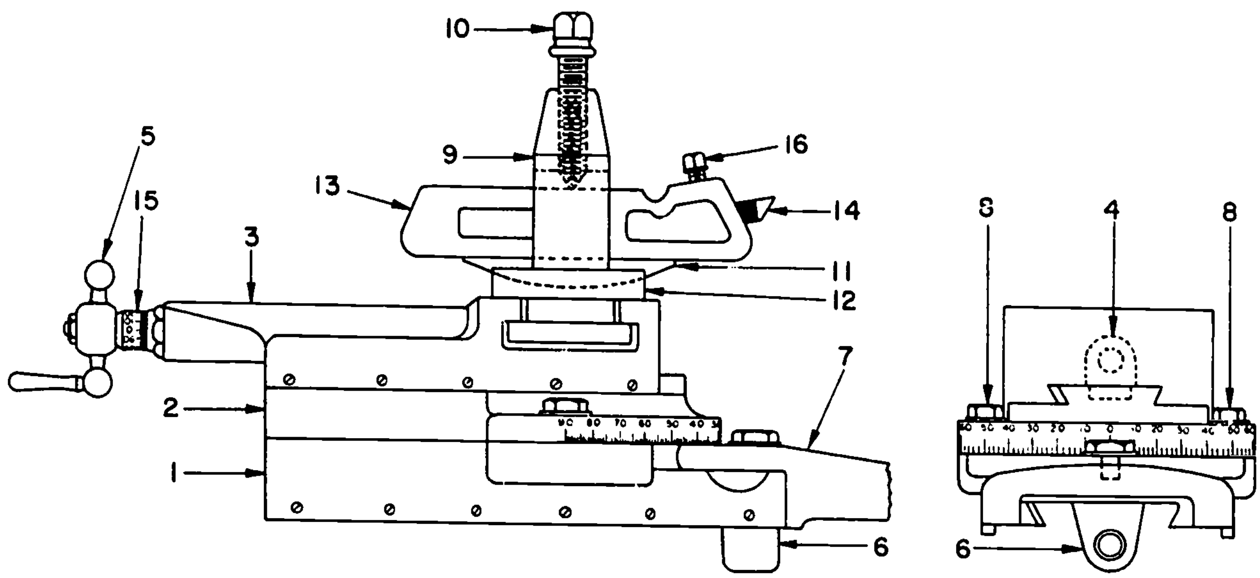
Toolpost

The sole purpose of the toolpost is to provide a rigid support for the tool. It is mounted in the T-slot of the compound rest top as shown in figure 9-20. A forged tool or a toolholder (13) is inserted in the slot in the toolpost and rests on the toolpost rocker (wedge) (11) and toolpost ring (12). By tightening setscrew (10), the whole unit is firmly clamped in place with the tool in the desired position.

CUTTING TOOLS

It would be extremely difficult to name one particular part or accessory of a lathe as being the most important to overall lathe operation. It is, however, very easy to realize that the one item most affecting the quality of the work done on a lathe is the cutting tool. The cutting tool directly affects the accuracy and the efficiency of all machine work performed on a lathe. For this reason, you must keep the cutting tools sharp and have them ground properly or the finished product will be of inferior quality, and in most cases, useless.

Most of the operations connected with operating a lathe are automatic features that were built into the machine when it was designed. The manufacturing of the cutting tool is not one of these features and it requires that the operator have the knowledge to design the proper tool and the skill to grind cuttingtools from tool blanks.



1. Cross-slide.
2. Compound rest swivel.
3. Compound rest top.
4. Compound rest nut.
5. Compound rest feed screw handle.
6. Crossfeed nut.
7. Chip guard.
8. Swivel securing bolts.
9. Toolpost.
10. Toolpost setscrew.
11. Toolpost wedge.
12. Toolpost ring.
13. Toolholder.
14. Cutting tool.
15. Micrometer collar.

28.88X

Figure 9-20.—Compound rest.

The major factors to be considered in designing and manufacturing a cutting tool are the properties of the material to be cut, the type of cut to be taken, and the material of the cutting tool.

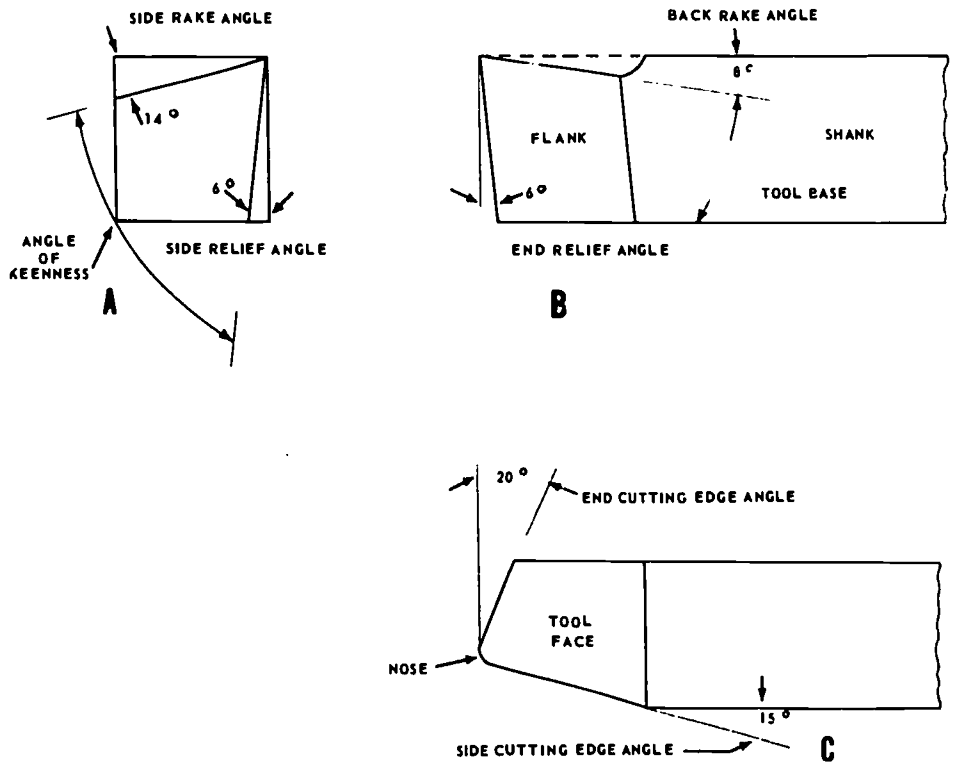
The majority of machine work done in optical shops is of the special setup/one-piece operation, and so the cutting tools are usually made of high-speed steel. For this reason, the discussion on cutting tools will deal only with high-speed steel.

It should be remembered that a metal cutting tool actually "pushes" the metal apart when performing machine tool operations. As a result, the pressures exerted on the cutting tool at its cutting edge are extremely high and the pressure increases as the rate of feed and depth of cut increase. The pressure causes friction and this in turn causes heat to be generated.

This pressure that is exerted on the cutting tool is necessary because it's what makes the cutting action possible. The objective, therefore, is to produce a cutting tool with an edge that will provide a minimum amount of pressure to force it through the metal and still withstand the cutting pressure without breaking or wearing. In order to fully understand the following discussion on grinding cutting tools, the reader must have a full understanding of the terminology used to describe the cutting tool.

Figure 9-21 shows the application of the angles and surfaces used in discussing single-edge or single-point cutting tools. Notice that there are two relief (clearance) angles and two rake angles, and the angle of keenness is formed by a rake and a relief angle.

Side rake (A of fig. 9-21) is the angle at which the face of the tool is ground away with respect to the top surface of the tool bit. The amount of side rake influences to some extent the size of the angle of keenness. It causes the clip to "flow" to the side of the tool away from the cutting edge. The side rake is positive if the angle slopes downward from the cutting edge



28.64

Figure 9-21.—Applications of tool terminology.

toward the back edge of the tool, and negative if it slopes upward.

The back rake (B of fig. 9-21) is the angle at which the face is ground with respect to a plane parallel with the top surface of the tool. It is ground primarily to cause the chip cut by the tool to "flow" back toward the shank of the tool. Back rake may be positive or negative; it is positive if it sloped downward from the nose of the tool toward the shank, or negative if a reverse angle is ground. The rake angles aid in forming the angle of keenness and in directing the chip flow away from the point of cutting.

The side clearance or side relief (A of fig. 9-21) is the angle that the side or flank of the tool is ground so that the cutting edge leads the flank surface when cutting. The side clearance angle, like the side rake angle, influences the angle of keenness. The total of the side rake and side clearance subtracted from 90° equals the angle of keenness. A tool with proper side clearance causes the side thrust to be concentrated on the cutting edge rather than on the flank of the tool.

The end clearance or end relief (B of fig. 9-21) is the angle at which the end surface of the tool is ground so that the endface edge of the tool leads the end surface.

The angle of keenness or wedge angle (A of fig. 9-21) is formed by the side rake and the side clearance ground in a tool. Generally, for cutting soft materials this angle is smaller than for cutting hard materials.

The side cutting edge angle (C of fig. 9-21) is ground to prevent the point of the tool from digging into the workpiece which would probably result in the tool being pulled into the workpiece deeper than intended. The end cutting edge angle is ground so that the end face edge of the tool does not drag over the machined surface.

A tool blank is an unground piece of tool stock. After it is ground it is called a tool bit. Tool blanks are available in sizes from 1/8 inch to 1 inch square and in proportional lengths from about 2 to 8 inches. The part of the tool back of the cutting edge is called the shank. The terms right-hand tool and left-hand tool are applied to tool bits in relation to the direction they move across the workpiece. If a tool cuts while moving from left to right (as you see it, standing in front of the machine), it is a left-hand tool. A right-hand tool is just the opposite.

Figure 9-22 shows the most popular shapes of ground lathe tool cutter bits and their application. In the following paragraphs each of the types shown is described.

Turning

LEFT-HAND TURNING TOOL.—This tool is ground for machining work when fed from left to right, as indicated in A, figure 9-22. The cutting edge is on the right side of the tool and the top of the tool slopes down away from the cutting edge.

ROUND-NOSED TURNING TOOL.—This tool is for general all-round machine work and is used for taking light roughing cuts and finishing cuts. Usually, the top of the cutter bit is ground with side rake so that the tool may be fed from right to left. Sometimes this cutter bit is ground flat on top so that the tool may be fed in either direction (B, fig. 9-22).

RIGHT-HAND TURNING TOOL.—This is just the opposite of the left-hand turning tool and is designed to cut when fed from right to left (C, fig. 9-22). The cutting edge is on the left side. This is an ideal tool for taking roughing cuts and for general all-round machine work.

LEFT-HAND FACING TOOL.—This tool is intended for facing on the left-hand side of the work, as shown in D, figure 9-22. The direction of feed is away from the lathe center. The cutting edge is on the right-hand side of the tool and the point of the tool is sharp to permit machining a square corner.

RIGHT-HAND FACING TOOL.—This tool is just the opposite of the left-hand facing tool and is intended for facing the right end of the work and for machining the right side of a shoulder. (See F, fig. 9-22.)

Threading

THREADING TOOL.—The point of the threading tool is ground to a 60° included angle for machining V-form screw threads (E, fig. 9-22). Usually, the top of the tool is ground flat and there is clearance on both sides of the tool so that it will cut on both sides.

INTERNAL-THREADING TOOL.—The internal-threading (INSIDE-THREADING) tool is the same as the threading tool in E, figure 9-22, except that it is usually much smaller. Boring and internal-threading tools may require larger relief angles when used in small diameter holes.

Parting

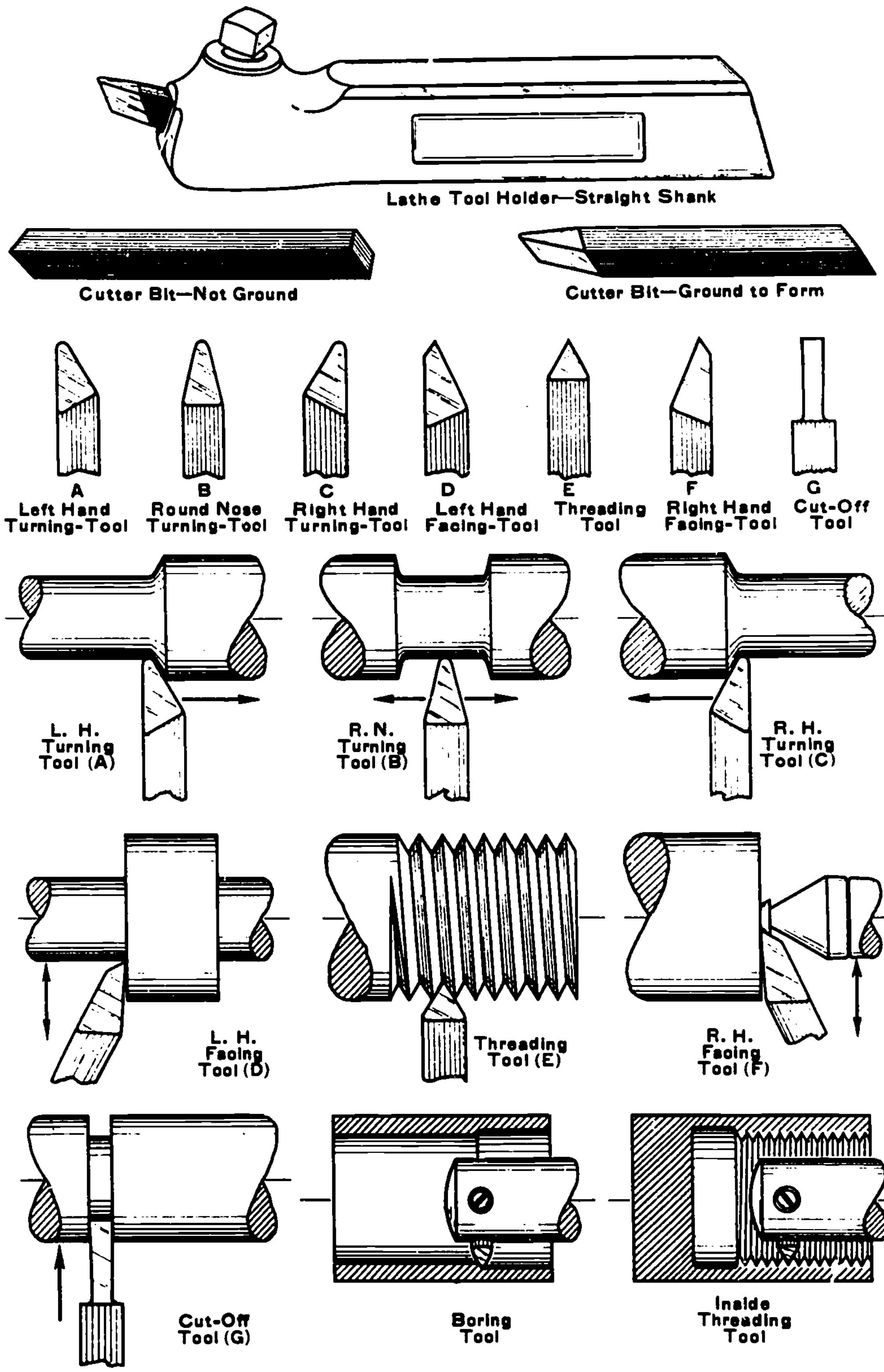
SQUARE-NOSED PARTING (CUT-OFF) TOOL.—The principal cutting edge of this tool is on the front. (See G, fig. 9-22.) Both sides of the tool must have sufficient clearance to prevent binding and should be ground slightly narrower at the back than at the cutting edge. This tool is convenient for machining necks, grooves, squaring corners, and for cutting off.

Boring

BORING TOOL.—The boring tool is usually ground the same shape as the left-hand turning tool so that the cutting edge is on the front side of the cutter bit and may be fed in toward the headstock.

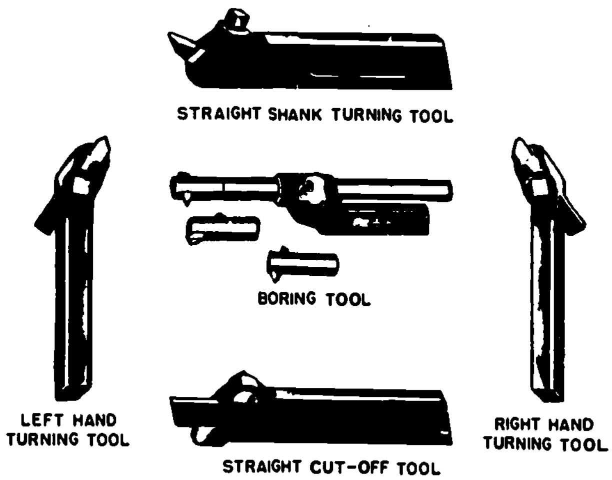
The contour of a cutting tool is formed by the side cutting edge angle and the end cutting edge angle of the tool. (Parts A through G of fig. 9-22 illustrate the recommended contour of several types of tools.) There are no definite guidelines on either the form or the included angle of the contour of pointed tool bits. Each machinist usually forms the contour as he prefers. For roughing cuts, it is recommended that the included angle of the contour of pointed bits be made as large as possible and still provide clearance on the trailing side or end edge. Tools for threading, facing between centers, and parting have specific shapes because of the form of the machined cut or the setup used.

The materials being machined and the machining technique used limit the angles of a tool bit. When grinding the angles, however, consideration must be given also to the type of toolholder and the position of the tool with respect to the axis of the workpiece. The angular offset and the angular vertical rise of the tool seat in a standard lathe toolholder affects the cutting edge angle and the end clearance angle of a tool when it is set up for machining. The position of the point of the tool bit with respect to the axis of the workpiece, whether higher, lower, or on center, changes the amount of front clearance. Figure 9-23 shows some of the common toolholders used in lathe work. Notice the angles at which the tool bits set in the various holders. These angles must



28.66

Figure 9-22.—Lathe tools and their applications.



28.67
Figure 9-23.—Common types of toolholders.

be considered with respect to the angles ground in the tools and the angle that the toolholder is set with respect to the axis of the work.

KNOWLEDGE OF OPERATION

Before attempting the operation of any lathe, make sure you know how to run it. Read all operating instructions supplied with the machine. Ascertain the location of the various controls and how to operate them. When you are satisfied that you know how they work, start the motor, but first check to see that the spindle clutch and the power feeds are disengaged. Then become familiar with all phases of operation, as follows.

1. Shift the speed change levers into the various combinations; start and stop the spindle after each change. Get the feel of this operation.

2. Before engaging either of the power feeds, operate the hand controls to be sure parts involved are free for running. With the spindle running at its slowest speed, try out the operation of the power feeds and observe their action. Take care not to run the carriage too near the limits of its travel. Learn how to reserve the direction of feeds and how to disengage them quickly.

3. Try out the operation of engaging the lead screw for thread cutting. Remember that the feed mechanism must be disengaged before the half-nuts can be closed on the lead screw.

4. Practice making changes with the QUICK-CHANGE GEAR MECHANISM by referring to the thread and feed index plate on the lathe you intend to operate. Remember that changes made in the gear box may be done with the lathe running slowly, but the lathe must be stopped for speed changes made by shifting gears in the main gear train.

Do not treat your machine roughly. When you shift gears for changing speed or feed, remember that you are putting solid gear teeth into mesh with each other; feel the gears into engagement. Disengage the clutch and stop the lathe before shifting.

Before engaging the longitudinal feed, be certain that the carriage CLAMP SCREW is loose and that the CARRIAGE can be moved by hand. Avoid running the carriage against the headstock or tailstock while under power feed; it puts an unnecessary strain on the lathe and may jam the gears or damage the chuck and compound rest.

Speeds and Feeds

CUTTING SPEED is the rate at which the surface of the work passes the point of the cutting tool. It is expressed in feet per minute.

To find the cutting speed, multiply the circumference of the work (in inches) by the number of revolutions it makes per minute (rpm) and divide by 12 (circumference = diameter x 3.1416). The result is the peripheral or cutting speed in feet per minute (fpm). For example, a 2-inch diameter piece turning at 100 rpm will produce a cutting speed of

$$\frac{(2 \times 3.1416) \times 100}{12} = 52.36 \text{fpm}$$

Conversely, the rpm required to obtain a given cutting speed is found by dividing the product of the given cutting speed and 12 by the circumference of the work (in inches).

FEED is the amount the tool advances in each revolution of the work. It is usually expressed in thousandths of an inch per revolution of the spindle. The index plate on the quick-change gear box indicates the setup for obtaining the feed desired. The amount of feed to use is best determined from experience.

Cutting speeds and tool feeds are determined by various considerations: the hardness and toughness of the metal being cut; the quality, shape, and sharpness of the cutting tool; the depth of the cut; the tendency of the work to spring away from the tool; and the strength and power of the lathe. Since conditions vary, it is good practice to find out what the tool and work will stand, and then select the most practicable and efficient speed and feed consistent with the finish desired.

If the cutting speed is too slow, the job takes longer than necessary and often the work produced is unsatisfactory. On the other hand, if the speed is too great the tool edge will dull quickly, and frequent grinding will be necessary. The cutting speeds possible are greatly affected by the use of a suitable cutting lubricant. For example, steel which can be rough turned dry at 60 rpm can be turned at about 80 rpm when flooded with a good cutting lubricant.

Some of the recommended, approximate cutting speeds for various metals, when using high speed steel bits, are shown in Table 9-1.

Table 9-1.—Cutting speeds for various metals

Type of metal	Roughing cut	Finishing cut	Thread-cutting
	Feet per minute (fpm)		
Cast iron . . .	60	80	25
Machine steel	90	125	35
Tool steel . .	50	75	20
Brass	150	200	50
Bronze	90	100	25
Aluminum . .	200	300	50

Rough Cuts

When ROUGHING parts down to size, use the greatest depth of cut and feed per revolution that the work, the machine, and the tool will stand at the highest practicable speed. On many pieces where tool failure is the limiting factor in the size of roughing cut, it is usually possible to reduce the speed slightly and increase the feed to a point where the metal removed is much greater. This will prolong tool life. Consider an example where the depth of cut is 1/4 inch, the feed 20 thousandths of an inch per revolution, and the speed 80 fpm. If the tool will not permit additional feed at this speed, it is usually possible to drop the speed to 60 fpm and increase the feed to about 40 thousandths of an inch per revolution without having tool trouble. The speed is, therefore, reduced 25 percent but the feed increased 100 percent, so that the actual time required to complete the work is less with the second setup.

Finish Cuts

On the FINISH TURNING OPERATION a very light cut is taken, since most of the stock has been removed on the roughing cut. A fine feed can usually be used, making it possible to run at a high surface speed. A 50-percent increase in speed over the roughing speed is commonly used. In particular cases the finishing speed may be twice the roughing speed. In any event, the work should be run as fast as the tool will withstand to obtain the maximum speed in this operation. A sharp tool should be used when finish turning.

Coolants

A cutting lubricant serves two main purposes—it cools the tool by absorbing a portion of the heat and reduces the friction between the tool and the metal being cut. A secondary purpose is to keep the cutting edge of the tool flushed clean.

The best lubricants to use for cutting metal must often be determined by experiment. Ordinary oil is often used, but soapy water or soda water is better for iron and steel shaftingand if used in conjunction with a sharp tool and light finish cut, the work will be smooth enough to polish without filing. Other cutting lubricants are mineral lard oil, kerosene, and turpentine. Special cutting compounds containing such ingredients as tallow, graphite, and white lead, marketed under various names, are also used, but these are expensive and used mainly in manufacturing where high cutting speeds are the rule.

The usual lubricants for turning the listed metals are:

Metal	Lubricant
Cast iron	Usually worked dry.
Mild steel.	Oil or soapy water.
Hard steel.	Mineral lard oil.
Monel metal . . .	Dry (or mineral lard oil).
Bronze	Dry (or mineral lard oil).
Brass.	Dry (kerosene or turpentine sometimes used on the hard compositions).
Copper	Dry (or mixture of lard oil and turpentine).

Metal	Lubricant
Babbitt.......	Dry (or mixture of lard oil and kerosene).
Aluminum.....	Dry (or kerosene or mixture of lard oil and kerosene).

For threading, a lubricant is more important than for straight turning. Mineral lard oil is recommended for threading in all steels and cast iron, kerosene mixed with oil for aluminum, white lead mixed with oil (to the consistency of glue) for Monel metal, and kerosene or turpentine for brass compositions.

Maintenance

Maintenance is an important part of operational procedure for lathes. The first requisite is PROPER LUBRICATION. Make it a point to oil your lathe daily where oil holes are provided. Oil the ways daily—not only for lubrication but to protect their scraped surfaces. Oil the lead screw often while it is in use, this is necessary to preserve its accuracy, for a worn lead screw lacks precision in thread cutting. Make sure the headstock is filled up to the oil level; drain out and replace the oil when it becomes dirty or gummy. If your lathe is equipped with an automatic oiling system for some parts, make sure all those parts are getting oil. Make it a habit to CHECK frequently for lubrication of all moving parts.

Do not neglect the motor just because it may be out of sight; check its LUBRICATION. If it does not run properly, notify the Electrician's Mate whose duty it is to care for it. He will cooperate with you to keep it in good condition. In a machine that has a belt drive from the motor to the lathe, avoid getting oil or grease on the belt when oiling the lathe or motor.

Keep your lathe CLEAN. A clean and orderly machine is an indication of a good mechanic. Dirt and chips on the ways, on the lead screw, and on the crossfeed screws will cause serious wear and impair the accuracy of the machine.

Never put wrenches, files, or other tools on the ways. If you must keep tools on the bed, a board should be provided to protect the finished surfaces of the ways.

Never use the bed or carriage as an anvil; remember that the lathe is a precision machine and nothing must be allowed to destroy its accuracy.

LATHE OPERATION

The basic function of a lathe is the removal of metal, by means of a suitable cutting tool, from a piece of work which is securely supported and made to revolve. This basic function is applied to general lathe operations for straight turning, taper turning, boring, facing, drilling, and thread cutting.

The wide range of operations that can be performed on a lathe make it the most valuable machine tool available. Up to this section, you have studied the construction of a lathe, the accessories, and the various tools used on it. Now the reader will be given the additional information needed to combine the tools and the machinery for effective applications.

It is important that you study the blueprint of the piece to be manufactured before you begin machining. Check over the dimensions and note the points or surfaces from which they are laid out. Plan the steps of your work in advance in order to determine the best method of procedure. Be sure from the overall dimensions that the stock you intend to use is large enough for the job.

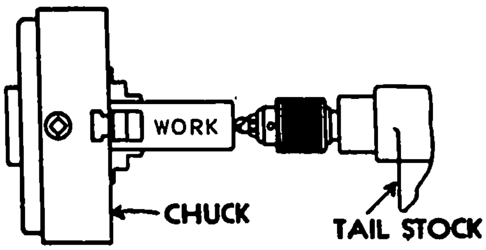
Mounting Work

Accurate work cannot be performed if work is improperly mounted. Requirements for proper mounting are:

1. The work centerline must be accurately centered with the axis of the lathe spindle.
2. The work must be rigidly held while being turned.
3. The work must not be sprung out of shape by the holding device.
4. The work must be adequately supported against any sagging caused by its own weight and against springing caused by the action of the cutting tool.

There are four general methods of holding work in the lathe: (1) between centers, (2) on a mandrel, (3) in a chuck, and (4) on a faceplate. Work may also be clamped to the carriage for boring and milling; the boring bar or milling cutter is held and driven by the headstock spindle.

CENTERING THE WORK.—To center finished round stock such as drill rod or cold-rolled steel, where the ends are to be turned and must be concentric with the unturned body, the work can be held on the head spindle in a universal chuck or a draw-in collet chuck. If the work is long and too large to be passed through the spindle, a center rest must be used to support one end. The center drill is held in a drill chuck in the tailstock spindle and is fed to the work by the tailstock handwheel (fig. 9-24).



28.111
Figure 9-24.—Drilling center hole.

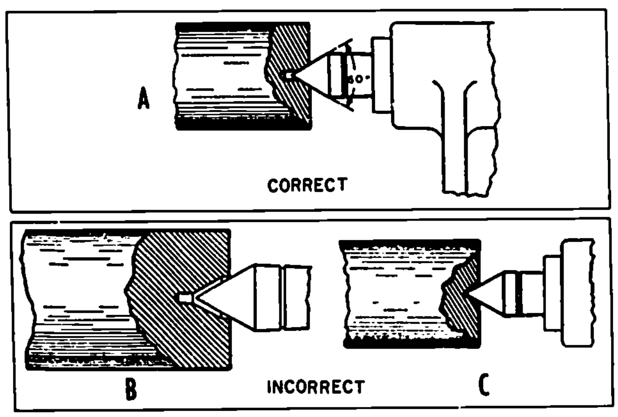
For center drilling a workpiece, the combined drill and countersink is the most practical tool. The combined drills and countersinks vary in size and the drill points also vary. Sometimes a drill point on one end will be 1/8 inch in diameter, and the drill point on the opposite end 3/16 inch in diameter. The angle of the center drill is always 60° so that the countersunk hole will fit the angle of the lathe center point.

The drawing and tabulation in figure 9-25 show the correct size of the countersunk center hole for the diameter of the work.

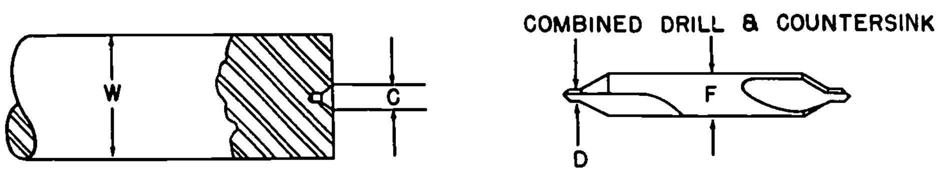
In center drilling, a drop or two of oil should be used on the drill. The drill should be fed slowly and carefully so as not to break the tip. Extreme care is needed when the work is heavy, because it is then more difficult to "feel" the proper feed on the work on the center drill.

If the center drill breaks while countersinking and part of the broken drill remains in the work, this part must be removed. Sometimes it can be driven out by a chisel or jarred loose, but it may stick so hard that it cannot be easily removed. If so, the broken part of the drill should be annealed and drilled out.

Figure 9-26 shows correct and incorrect forms for countersinking work to be machined. In part A, the correctly countersunk hole is deep enough so that the point of the lathe centers does not come in contact with the bottom of the hole.



28.114X
Figure 9-26.—Examples of center holes.



NO. OF COMB. DRILL AND COUNTERSINK	DIA. OF WORK W	LARGE DIAMETER OF COUNTERSUNK HOLE (C)	DIA. OF DRILL D	DIA. OF BODY F
1	3/16" TO 5/16"	1/8"	1/16"	13/64"
2	3/8" TO 1"	3/16"	3/32"	3/16"
3	1 1/4" TO 2"	1/4"	1/8"	3/16"
4	2 1/4" TO 4"	5/16"	5/32"	7/16"

28.113X

Figure 9-25.—Correct size of center holes.

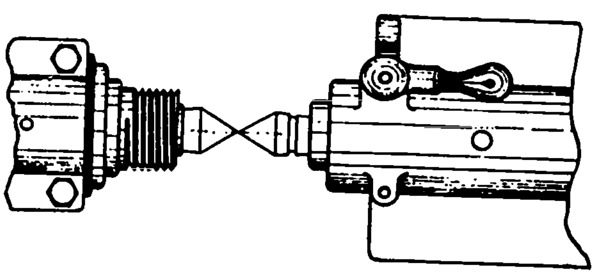
In part B of figure 9-26, the COUNTERSUNK HOLE IS TOO DEEP, causing only the outer edge of the work to rest on the lathe center.

Part C shows a piece of work that has been countersunk with a tool of an IMPROPER ANGLE. This work rests on the point of the lathe center only. It is evident that this work will soon destroy the end of the lathe center, thus making it impossible to do an accurate job.

Before starting a lathe machining operation, always ensure that the machine is set up for the job you are doing. Ensure that the toolholder and cutting tool are set at the proper height and angle. Check the workholding accessory to ensure that the workpiece is held securely. Use the center rest or follower rest for support of long workpieces.

The EXPANSION mandrel is used to hold work that is reamed or bored to nonstandard size. Figure 9-19 shows an expansion mandrel composed of two parts: a tapered pin which has a taper of approximately 1/16 inch for each inch of length and an outer split shell that is tapered to fit the pin. The split shell is placed in the work and the tapered pin forced into the shell, causing it to expand the necessary amount.

When machining work on a mandrel, it is necessary, of course, that the lathe centers be true and accurately aligned; otherwise the finished turned surface will not be true (fig. 9-27). Before turning accurate work, it is advisable to



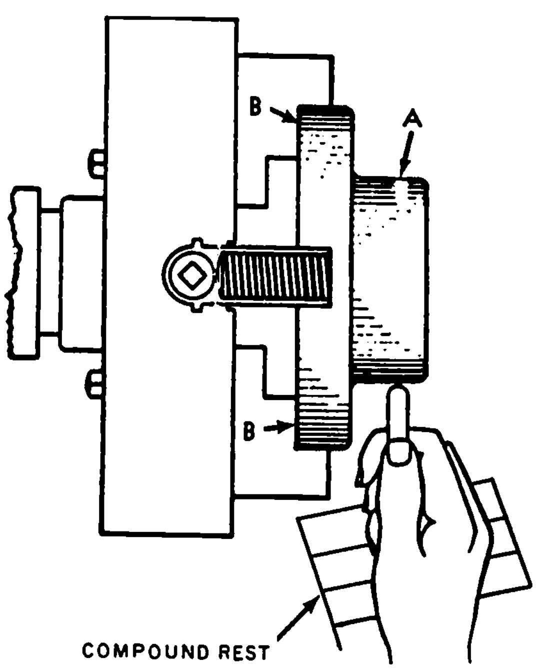
28.106
Figure 9-27.—Aligning lathe centers.

test the mandrel on centers before placing any work on it. The best test for run-out is made with an indicator. The indicator is mounted on the toolpost, and applied to the mandrel as it is turned slowly between centers; any run-out will then be registered on the dial which is graduated in thousandths of an inch. If run-out is indicated, and it cannot be corrected by adjusting the tailstock, the mandrel itself is at fault (assuming that the lathe centers are true) and cannot be used. The countersunk holes may have been damaged or the mandrel bent by careless handling. Be sure you always protect the ends of the mandrel when pressing or driving it into the work.

When taking roughing cuts on a piece of work mounted on a mandrel it is necessary to have a tighter press fit than for finishing. Therefore, thin walled metal should be removed from the mandrel after the roughing cut and reloaded lightly on the mandrel before taking the finish cut.

The independent chuck and universal chuck are used more often than are other workholding devices in performing lathe operations. The universal chuck is used for holding relatively true cylindrical work when accurate concentricity of the machined surface and holding power of the chuck are secondary to the time required to do the job. When the work is irregular in shape, must be accurately centered, and must be held securely for heavy feeds and depth of cuts, the independent chuck should be used.

FOUR-JAW INDEPENDENT CHUCK.—Figure 9-28 shows a rough casting mounted in



28.119
Figure 9-28.—Work mounted in a 4-jaw chuck.

a four-jaw independent lathe chuck on the spindle of the lathe. Before truing the work, determine which part you wish to have turn true. To mount a rough casting in the chuck, proceed as follows:

1. Adjust the chuckjaws to receive the casting. Each jaw should be concentric with the ring marks indicated on the face of the chuck. If there are no ring marks, be guided by the circumference of the body of the chuck.

2. Fasten the work in the chuck by turning the adjusting screw on jaw No. 1 and jaw No. 3, a pair of jaws which are opposite each other. Next tighten jaws No. 2 and No. 4.

3. At this stage the work should be held in the jaws just tight enough so it will not fall out of the chuck while being trued.

4. Revolve the spindle slowly and, with a piece of chalk, mark the high spot (A in fig. 9-28) on the work while it is revolving. Steady your hand on the toolpost while holding the chalk.

5. Stop the spindle. Locate the high spot on the work and adjust the jaws in the proper direction to true the work by releasing the jaw opposite the chalk mark and tightening the one nearest the mark.

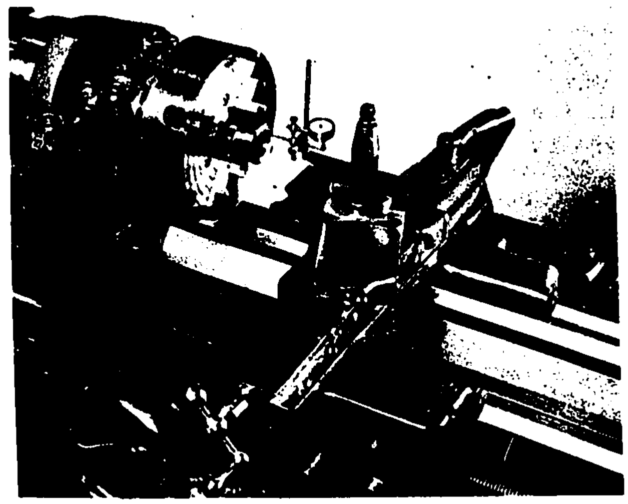
6. Sometimes the high spot on the work will be located between adjacent jaws. When it is, loosen the two opposite jaws and tighten the jaws adjacent to the high spot.

7. When the work is running true in the chuck, tighten the jaws gradually, working the jaws in pairs as described previously, until all four jaws are clamping the work tightly. Be sure that the back of the work rests flat against the inside face of the chuck, or against the faces of the jaw steps (B in fig. 9-28).

The same procedure is followed in clamping semifinished or fully finished pieces in the chuck, except that the position is necessarily held to a closer limit before chucking is considered completed. A dial indicator may be used to ascertain the run-out if the limit is extremely close.

Figure 9-29 illustrates the application of a dial test indicator in centering work that has a bored hole in the piece. As the work is revolved, the high spot is indicated on the dial of the instrument to a thousandth of an inch. The jaws of the chuck are adjusted on the work until the indicator hand registers no deviation as the work is revolved.

When the work consists of a number of duplicate parts that are to be tightened in the chuck, release two adjacent jaws and remove the work. Place another piece in the chuck and tighten the two jaws just released.



28.120X

Figure 9-29.—Centering work with a dial indicator.

Each jaw of a lathe chuck, whether an independent or a universal chuck, has a number stamped on it to correspond with a similar number on the chuck. When you remove a chuck jaw for any reason, you should always put it back into the proper slot.

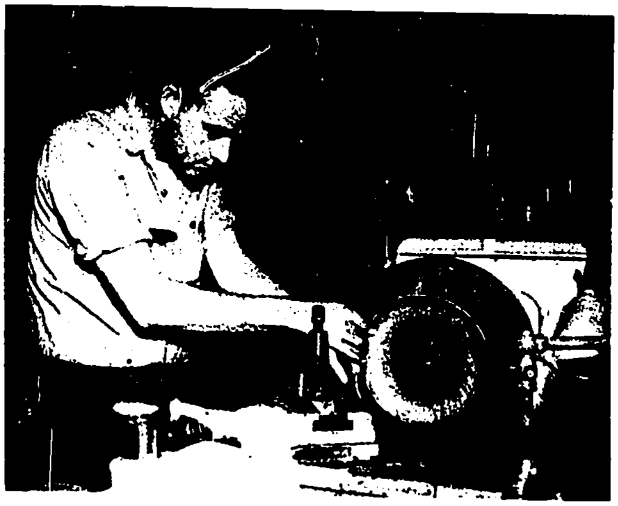
When the work to be chucked is frail or light, the jaw should be tightened carefully so that the work will not bend, break, or spring.

In chucking rings and cylindrical disks, the work can be held from the inside with the jaws pressing outward. (See fig. 9-30.)

Never leave a chuck wrench in a chuck while the chuck is on the spindle of the lathe.

THREE-JAW UNIVERSAL CHUCK.—The three-jaw universal or scroll chuck is made so that all jaws move together or apart in unison. A universal chuck will center almost exactly at the first clamping, but after a period of use it is not uncommon to find inaccuracies of from 2- to 10-thousandths of an inch in centering the work, and consequently the run-out of the work must be corrected. Sometimes this may be done by inserting a piece of paper or thin shim stock between the jaw and the work on the high side.

When chucking thin sections, be careful not to clamp the work too tightly, as then the



28.121
Figure 9-30.—Work held from inside by a 4-jaw independent chuck.

diameter of the piece will be machined when it is in a distorted position. When the pressure of the jaws is released after the cut, there will be as many high spots as there are jaws, and the turned surface will not be true.

Occasionally, you may have to chuck a piece of work and you do not want the surface to be marred by the chuck jaws. In this case, a copper or brass shim may be used between each chuck jaw and the work.

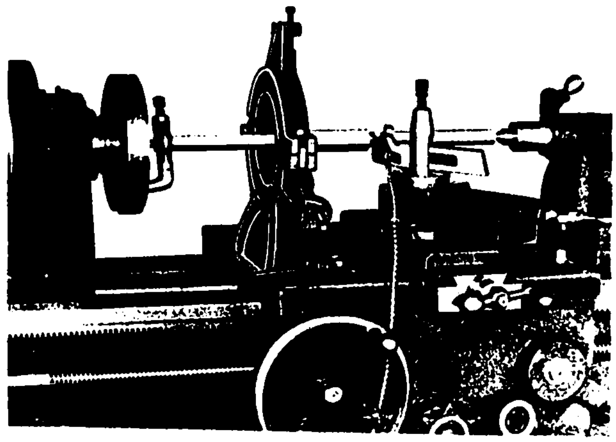
CARE OF CHUCKS.—To preserve a chuck's accuracy, handle it carefully and keep it clean and free from grit. Never force a chuck jaw by using a pipe as an extension on the chuck wrench.

Before mounting a chuck, remove the live center and fill the hole with a rag to prevent chips and dirt from getting into the taper hole of the spindle.

Clean and oil the threads of the chuck and the spindle nose. Dirt or chips on the threads will not allow the chuck to run true when it is screwed up to the shoulder. Screw the chuck on carefully. Avoid bringing it up against the shoulder so fast that the chuck comes up with a shock. This will strain the spindle and the threads and make removal difficult. Never use mechanical power in screwing on the chuck. Rotate the spindle with the left hand while holding the chuck in the hollow of the right arm.

To remove a small chuck, place an adjustable jaw wrench on one of the jaws and start it by a smart blow with the hand on the handle of the wrench. To remove a heavy chuck, rotate it against a block of wood held between a jaw and the lathe bed. When mounting or removing a heavy chuck, lay a board across the bed ways to protect them; the board will serve as a support for the chuck as it is put on or taken off.

In addition to being supported at the ends by a chuck and center long slender work often requires support between ends while being turned; otherwise the work would spring away from the tool and chatter. The center rest is used to support such work so it can be accurately turned with a faster feed and cutting speed than would be possible without it (see fig. 9-31).

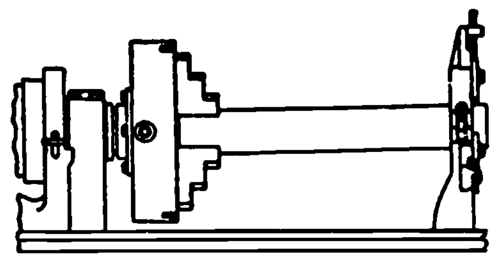


28.125X
Figure 9-31.—Use of a center rest to support work between centers.

The center rest should be placed where it will give the greatest support to the piece to be turned. This is usually at about the middle of its length.

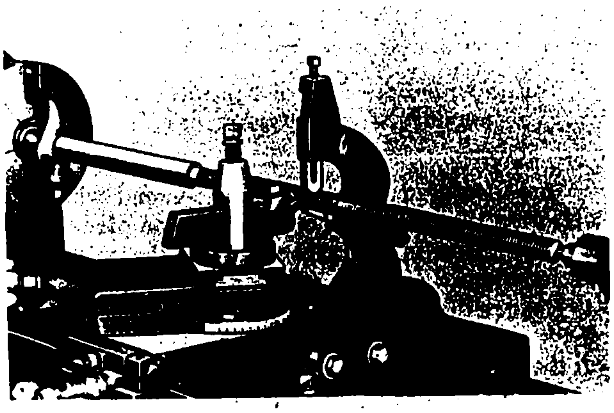
Ensure that the center point between the jaws of the center rest coincides exactly with the axis of the lathe spindle. To do this, place a short piece of stock in a chuck and machine it to the diameter of the workpiece to be supported. Without removing the stock from the chuck, clamp the center rest on the ways of the lathe and adjust the jaws to the machined surface. Without changing the jaw settings, slide the center rest into position for supporting the workpiece. Remove the stock used for setting the center rest and set the workpiece in place. Use a dial indicator to true the workpiece at the chuck. Figure 9-32 shows how a chuck and center rest are used when machining the end of a workpiece.

The follower rest differs from the center rest in that it moves with the carriage and provides support against the forces of the cut only. The tool should be set to the diameter selected and a "spot" turned about 5/8 to 3/4 inch wide. Then the follower rest jaws should be adjusted to the finished diameter to follow the tool along the entire length to be turned.



28.126X
Figure 9-32.—Work mounted in a chuck and center rest.

The follower rest (fig. 9-33) is indispensable when chasing threads on long screws, as it allows the cutting of a screw with a uniform pitch diameter. Without the follower rest, the screw would be inaccurate, because it would spring away from the tool.



28.127X
Figure 9-33.—Follower rest supporting screw while thread is being cut.

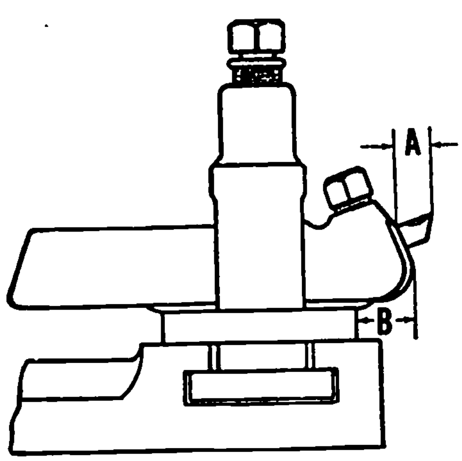
Use a thick mixture of white lead and oil on the jaws of the center rest and follower rest to prevent "seizing" and scoring the workpiece. Check the jaws frequently to see that they do not become hot. The jaws may expand slightly if they get hot thus pushing the work out of alignment (when using the follower rest) or binding (when using the center rest).

The draw-in collet chuck is used for very fine accurate work of small diameter. Long work can be passed through the hollow drawbar, and short work can be placed directly into the collet from the front. The collet is tightened on the work by rotating the drawbar to the right. This draws the collet into the tapered closing sleeve, the opposite operation releases the collet.

Accurate results are obtained when the diameter of the work is exactly the same size as the dimension stamped on the collet. For some work, the diameter may vary as much as 0.002 inch; that is, the work may be 0.001 inch smaller or larger than the collet size. If the work diameter varies more than this, it will impair the accuracy and efficiency of the collet. That is why a separate collet should be used for each small variation of work diameter, especially if precision is desired.

Setting The Cutting Tool

The first requirement for setting the tool is to have it rigid. Make sure the tool sets squarely in the toolpost and that the setscrew is tight. Reduce overhang as much as possible to prevent springing when cutting. If the tool has too much spring, the point of the tool will catch in the work causing chatter and damaging both the tool and the work. The distances represented by A and B in figure 9-34 show the correct overhang for the tool bit and the holder.



28.110X
Figure 9-34.—Tool overhang.

The point of the tool must be correctly positioned on the work. The cutting edge is placed slightly above the center for straight turning of steel and cast iron, and exactly on the center for all other work. To set the tool at the height desired, raise or lower the point of the tool by moving the wedge in or out of the toolpost ring. By placing the tool point opposite the tailstock center point, the setting can be accurately adjusted.

If you are unaware of the meaning of the word "chatter," you will learn all too soon while working with a machine tool of any description.

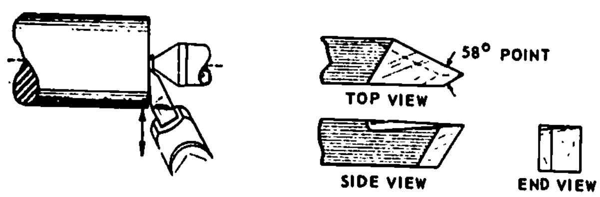
Briefly, chatter is vibration in either the tool or the work. The finished work surface appears to have a grooved or lined finish instead of the smooth surface that is to be expected. The vibration is set up by a weakness in the work, work support, tool, or tool support, and is about the most elusive thing to find in the entire field of machine work. As a general rule, strengthening the various parts of the tool support train will help. It is also advisable to support the work by a center rest or follower rest.

Possibly the fault may be in the machine adjustments. Gibs may be too loose; bearings may, after a long period of heavy service, be worn; the tool may be sharpened improperly, etc. If the machine is in perfect condition, the fault may be in the tool or tool setup. Grind the tool with a point or as near a point as the finish specified will permit; avoid a wide round leading edge on the tool. Reduce the overhang of the tool as much as possible and be sure that all the gib and bearing adjustments are properly made. See that the work receives proper support for the cut, and, above all, do not try to turn at a surface speed that is too high. Excessive speed is probably the greatest cause of chatter, and the first thing you should do when chatter occurs is to reduce the speed.

Facing

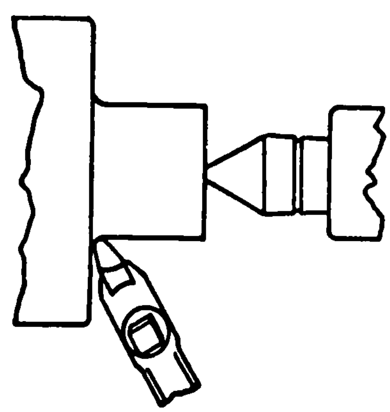
Facing is the machining of the end surfaces and shoulders of a workpiece. In addition to squaring the ends of the work, facing provides a means of accurately cutting the work to length. Generally in facing the workpiece, only light cuts are required as the work will have been cut to approximate length or rough machined to the shoulder.

Figure 9-35 shows the method of facing a cylindrical piece. A right-hand side tool is used as shown, and a light cut is taken on the end of the work, feeding the tool (by hand or power crossfeed) from the center toward the outside. One or two chips are taken to remove sufficient stock to true the work.



28.129X
Figure 9-35.—Right-hand side tool.

Figure 9-36 shows the application of a turning tool in finishing a shouldered job having a fillet corner. A finish cut is taken on the small diameter. The fillet is machined with a light cut; then the tool is used to face from the fillet to the outside diameter of the work.



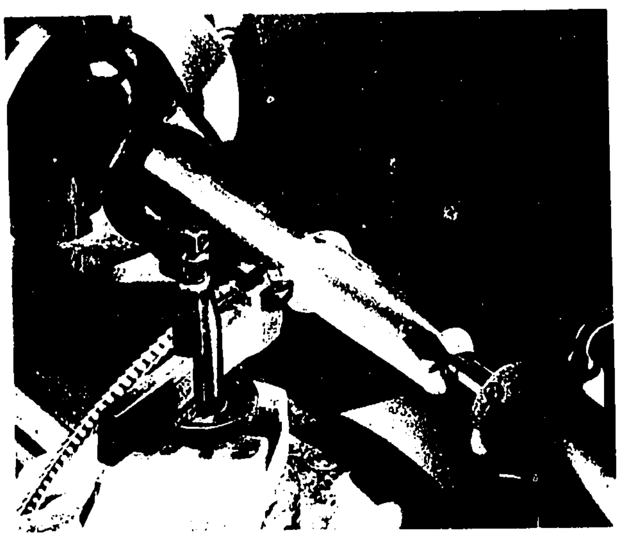
28.130X
Figure 9-36.—Facing a shoulder.

In facing large surfaces the carriage should be locked in position, since only cross-feed is required to traverse the tool across the work. With the compound rest set at 90° (parallel to the axis of the lathe), the micrometer collar can be used to feed the tool to the proper depth of cut in the face. For greater accuracy in obtaining a given size in finishing a face, the compound rest may be set at 30°. In this position, one-thousandth of an inch movement of the compound rest will move the tool exactly a half of a thousandth of an inch in a direction parallel to the axis of the lathe. (In a 30°-60° right triangle, the length of the side opposite the 30° angle is equal to one-half the length of the hypotenuse.)

Turning

Turning is the machining of excess stock from the periphery of the workpiece to reduce the diameter. In most lathe machining requiring removal of large amounts of stock, a series of roughing cuts is taken to remove most of the excess stock; then a finishing cut is taken to accurately "size" the workpiece.

Figure 9-37 illustrates a lathe taking a heavy cut. This is called rough turning. When a great deal of stock is to be removed, heavy cuts should be taken in order to complete the job in the least possible time.



28.131X
Figure 9-37.—Rough turning.

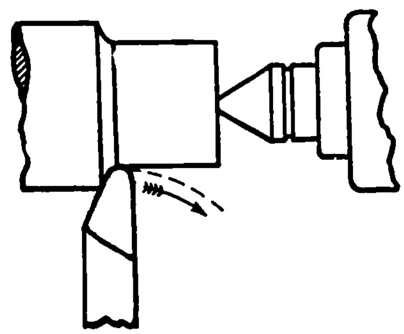
The proper tool should be selected for taking a heavy chip. The speed of the work, and the amount of feed of the tool should be as great as the tool will stand.

When taking a roughing cut on steel, cast iron, or any other metal that has a scale upon its surface, be sure to set the tool deep enough to get under the scale in the first cut. Unless you do, the scale on the metal will dull the point of the tool.

The work should be rough machined to almost the finished size; then care in measuring is required.

Bear in mind the fact that the diameter of the work being turned is reduced by an amount equal to twice the depth of the cut; thus, if you desire to reduce the diameter of a piece by one-fourth of an inch, one-eighth of an inch of metal must be removed from the surface.

Figure 9-38 shows the position of the tool for taking a heavy chip on large work. The tool should be set so that if anything occurs while machining to change the position of the tool, it will not dig into the work, but rather it will move in the direction of the arrow—away from the work. Setting the tool in this position sometimes prevents chatter.



28.132X
Figure 9-38.—Position of tool for heavy cut.

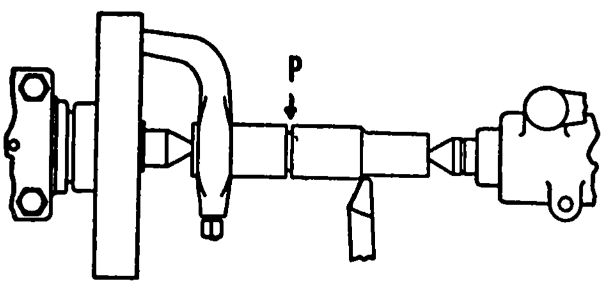
When the work has been rough turned to within about 1/32 inch of the finished size, take a finishing cut. A fine feed, the proper lubricant, and above all a keen-edged tool are necessary to produce a smooth finish. Measure carefully to be sure that you are machining the work to the proper dimension. Stop the lathe when measuring.

Where very close limits are to be held, it is advisable to see that the work is not hot when the finish cut is taken. Cooling of the piece will leave it undersized if it has been turned to the exact size.

Perhaps the most difficult operation for a beginner in machine work is to make accurate measurements. So much depends on the accuracy of the work that you should make every effort to become proficient in the use of measuring instruments. A certain "feel" in the application of micrometers is developed through experience alone; do not be discouraged if your first efforts do not produce perfect results. Practice taking micrometer measurements on pieces of known dimensions. You will acquire skill if you are persistent.

Machining to a shoulder is often done by locating the shoulder with a parting tool. The parting tool is inserted about 1/32 inch back of the shoulder line, and enters the work within 1/32 inch of the smaller diameter of the work. Then the stock may be machined by taking heavy chips up to the shoulder thus made. Shouldering eliminates detailed measuring and speeds up production.

Figure 9-39 illustrates the method of shouldering. A parting tool has been used at P and the turning tool is taking a chip. It will be unnecessary to waste any time in taking measurements. You can devote your time to rough machining until the necessary stock is removed. Then you can take a finishing cut to accurate measurement.



28.133X
Figure 9-39.—Matching to a shoulder.

Regardless of how the work is held in the lathe, the tool should feed toward the headstock. This results in most of the pressure of the cut being exerted on the workholding device and spindle thrust bearings. When it is necessary to feed the cutting tool toward the tailstock, take lighter cuts at reduced feeds. In facing, the general practice is to feed the tool from the center of the workpiece out toward the periphery.

Boring

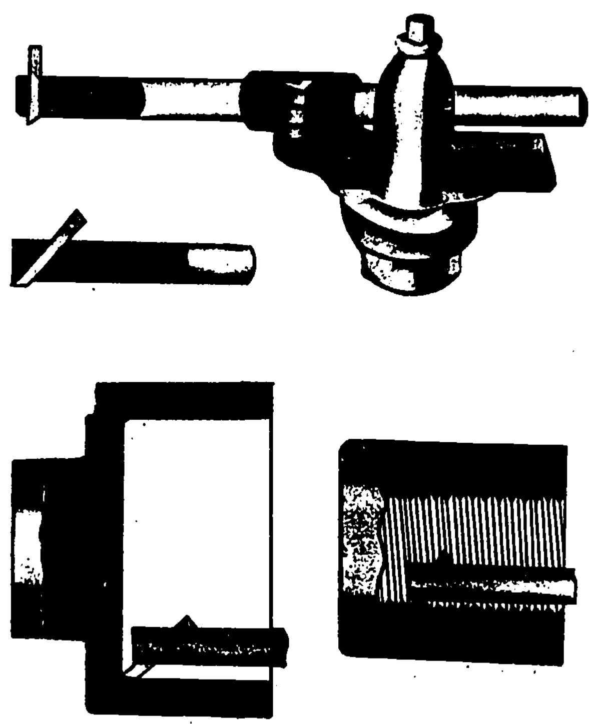
Boring is the machining of holes or any interior cylindrical surface. The piece to be bored must have a drilled or cored hole, and the hole must be large enough to insert the tool. The boring process merely enlarges the hole to the desired size or shape. The advantage of boring is that a perfectly true round hole is obtained, and two or more holes of the same or different diameters may be bored at one setting, thus ensuring absolute alignment of the axis of the holes.

It is the usual practice to bore a hole to within a few thousandths of an inch of the desired size and then finish it with a reamer to the exact size.

Work to be bored may be held in a chuck, bolted to the faceplate, or in a collet. Long pieces must be supported at the free end in a center rest.

When the boring tool is fed into the hole in work being rotated, the process is called single point boring. It is the same as turning except that the cutting chip is taken from the inside. The cutting edge of the boring tool resembles that of a turning tool. Boring tools may be of the solid forged type or the inserted cutter bit type.

Figure 9-40 shows a common type of boring bar holder and applications of the boring bar for boring and internal threading. The drilling



28.135
Figure 9-40.—Application of boring bar holder.

operation should be started by drilling a center hole in the work using a combination center drill and countersink. The combination countersink-center drill is held in a drill chuck which is mounted in the tailstock spindle. After the work has been center drilled, the drill chuck is replaced by a taper shank drill. (NOTE: Prior to inserting any tool in the tailstock spindle inspect the shank of the tool for burrs. If the shank is burred, remove the burrs with a headstone.) The drill is hand fed into the work by means of the tailstock handwheel. Sufficient pressure must be maintained on the drill to prevent chatter and yet not enough pressure to overheat the drill.

If the hole is quite long, back the drill out occasionally to clear the flutes of metal chips. Large-diameter holes may require that a pilot hole be drilled first. This is done with a drill that is smaller than the finished diameter of the hole. After drilling to depth with the pilot drill, the finish drill is run through the hole. If the hole is to be completely through the length of the work, slow the feed down as the drill breaks through the end.

If the job requires that the hole be reamed, it is good practice to first take a cleanup cut through the hole with a boring tool. This will true up the hole for the reaming operation. Be sure to leave about 1/64 inch for reaming. The machine reamer has a taper shank and is held in and fed by the tailstock. To avoid overheating the reamer, the work speed should be about half that used for the drilling operation. During the reaming operation, keep the reamer well lubricated. This will keep the reamer cool and also flush the chips from the flutes. Do not feed the reamer too fast as it may tear the surface of the hole and ruin the work.

Tapering

The term "taper" may be defined as the gradual lessening of the diameter of thickness of a piece of work toward one end. The amount of taper in any given length of work is found by subtracting the size of the small end from the size of the large end. Taper is usually expressed as the amount of taper per foot of length, or as an angle.

EXAMPLE 1.—Find the taper per foot of a piece of work 2 inches long: Diameter of small end is 1 inch; diameter of the large end is 2 inches.

The amount of the taper is 2 inches minus 1 inch, which equals 1 inch. The length of the taper is given as 2 inches. Therefore, the taper is 1 inch in 2 inches of length. In 12 inches of length it would be 6 inches. (See fig. 9-41.)

EXAMPLE 2.—Find the taper per foot of a piece 6 inches long. Diameter of small end is 1 inch; diameter of large end is 2 inches.

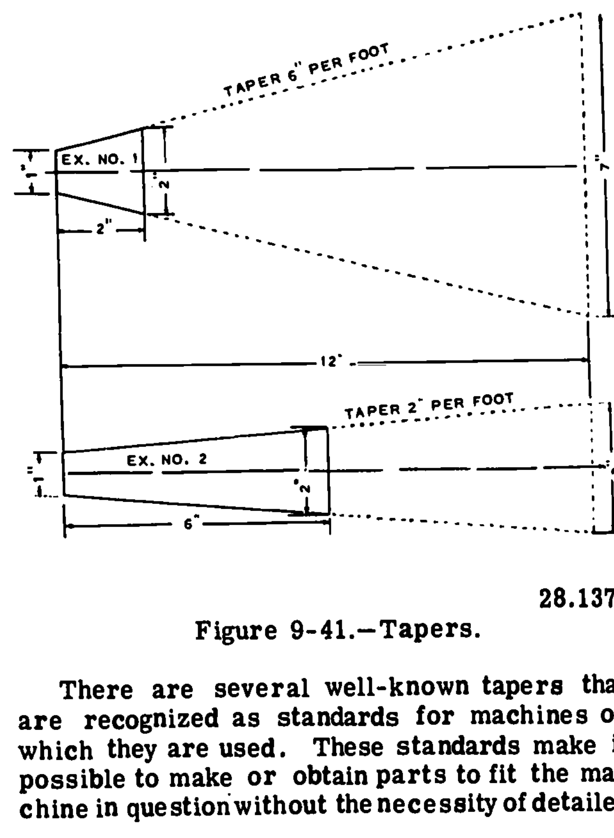
The amount of taper is the same as in example 1; that is, 1 inch. (See fig. 9-41.) However, the length of this taper is 6 inches; hence the taper per foot is 1 inch x 12/6 = 2 inches per foot.

From the foregoing, it may be seen that the length of a tapered piece is very important in computing the taper. If you bear this in mind when machining tapers you will not go wrong. Using the formula:

$$\text{Taper per foot} = T \times \frac{12}{L},$$

where T represents the amount of taper in length, L, both expressed in inches.

Now let us consider the angle of the taper. In a round piece of work, the included angle of the taper is twice the angle that the surface makes with the axis or centerline. In straight turning, the diameter of a piece is reduced by twice the depth of the cut taken from its surface. For the same reason, the included angle of the taper is twice the angle that the path of the cutting tool makes with the axis or centerline of the piece being turned. There are tables or charts in most machinist's handbooks that give the angles for different amounts of taper per foot.



28.137

Figure 9-41.—Tapers.

There are several well-known tapers that are recognized as standards for machines on which they are used. These standards make it possible to make or obtain parts to fit the machine in question without the necessity of detailed measuring and fitting. By designating the name and number of the standard taper being used—the length, the diameter of the small and large ends, the taper per foot, and all other pertinent measurements are immediately obtainable by reference to appropriate tables found in most machinist's handbooks.

In ordinary straight turning, the cutting tool moves along a line parallel to the axis of the work, causing the finished job to be the same diameter throughout. If, however, in cutting, the tool moves at an angle to the axis of the work, a taper will be produced. Therefore, to turn a taper, it is necessary either to mount the work in the lathe so that axis upon which it turns is at an angle to the axis of the lathe, or to cause the cutting tool to move at an angle to the axis of the lathe.

There are three methods in common use for turning tapers:

1. SETTING OVER THE TAILSTOCK, which moves the dead center away from the axis of the lathe and hence causes work supported between centers to be at an angle with the axis of the lathe.

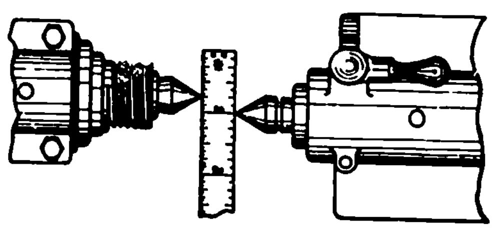
2. USING THE COMPOUND REST set at an angle, which causes the cutting tool to be fed at the desired angle to the axis of the lathe.

3. USING THE TAPER ATTACHMENT, which also causes the cutting tool to move at an angle to the axis of the lathe.

In the first method, the cutting tool is fed by the longitudinal feed parallel to the lathe axis, but a taper is produced because the work axis is at an angle. In the second and third methods, the work axis coincides with the lathe axis, but a taper is produced because the cutting tool moves at an angle.

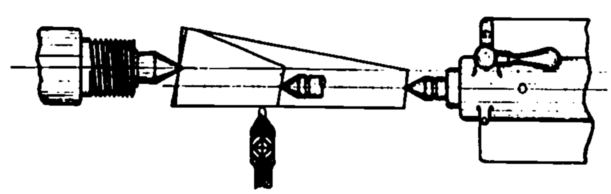
As stated previously, the tailstock top may be moved laterally on its base by means of adjusting screws. In straight turning, you will recall that these adjusting screws were used to align the dead center with the tail center by moving the tailstock to bring it on the centerline. The taper turning, we deliberately move the tailstock off center, and the amount we move it determines the taper produced. The amount of set-over can be approximately set by means of the zero lines inscribed on the base and top of the tailstock. Then for final adjustment, the set-over is measured with a scale between center points as illustrated in figure 9-42.

In turning a taper by this method, the distance between centers is of utmost importance. To illustrate, figure 9-43 shows two very different tapers produced by the same amount of set-over of the tailstock, because in one taper the length of the work between centers is greater than in the other. THE CLOSER THE DEAD CENTER IS TO THE LIVE CENTER, THE STEEPER THE TAPER PRODUCED.



28.140X
Figure 9-42.—Measuring set-over of dead center.

The compound rest is generally used for short, steep tapers. It is set at the angle which the taper is to make with the centerline (that is, half the included angle of the taper). The tool is then fed to the work at this angle by means of the compound rest feed screw. The length of taper that can be machined is necessarily short because of limited travel of the compound rest top.



28.141X
Figure 9-43.—Set-over of tailstock showing importance of considering length of work.

Truing a lathe center is one example of the use of the compound rest for taper work. Other examples are the refacing of an angle type valve disk, the machining of the face of a bevel gear, and similar work. Such jobs are often referred to as working to an angle rather than as taper work.

The graduations marked on the compound rest provide a quick means for setting it to the angle desired. When set at zero, the compound rest is perpendicular to the lathe axis. When set a 90° on either side, the compound rest is parallel to the lathe axis.

On the other hand, when the angle to be cut is measured from the centerline, the setting of the compound rest corresponds to the complement of that angle (the complement of an angle is that angle which added to it makes a right angle; that is, angle plus complement = 90°). For example, to machine a 50° included angle (25° angle with the centerline), the compound rest is set at 90°−25°, or 65°.

When a very accurate setting of the compound rest is to be made to a fraction of a degree, for example, run the carriage up to the faceplate and set the compound rest with a vernier bevel protractor set to the required angle. The blade of the protractor is held on the flat surface of the faceplate, and the stock is held against the finished side of the compound rest.

For turning and boring long tapers with accuracy, the taper attachment is indispensable. It is especially useful in duplicating work; identical tapers can be turned and bored with one setting of the taper guide bar.

The guide bar is set at an angle to the lathe axis corresponding to the taper desired. By means of a shoe which slides on the guide bar as the carriage moves longitudinally, the tool cross-slide is moved laterally. The resultant movement of the cutting tool is along a line that is parallel to the guide bar, and therefore a taper is produced whose angular measurement is the same as that set on the guide bar. The guide bar is graduated in degrees at one end, and in inches per foot of taper at the other end to facilitate rapid setting. Figure 9-44 is a view of the end that is graduated in inches per foot of taper.

When preparing to use the taper attachment, run the carriage up to the approximate position of the work to be turned. Set the tool on line with the centers of the lathe. Then bolt or clamp the holding bracket to the ways of the bed (the attachment itself is bolted to the back of the carriage saddle) and tighten clamp C, figure 9-45. The taper guide bar now controls the lateral movement of the cross-slide. Set the guide bar for the taper desired and the attachment is ready for operation. The final adjustment of the tool for size must be made by means of the compound rest feed screw, since the crossfeed screw is inoperative.

Taper boring may be accomplished only by the use of the compound rest or the taper attachment.

The rules that are applicable to outside taper turning also apply to the boring of tapered holes.

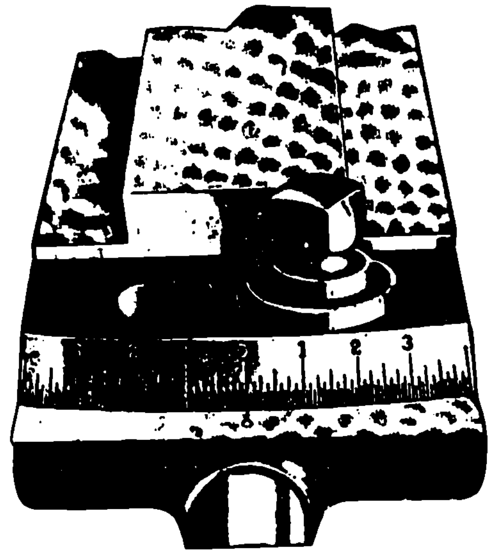


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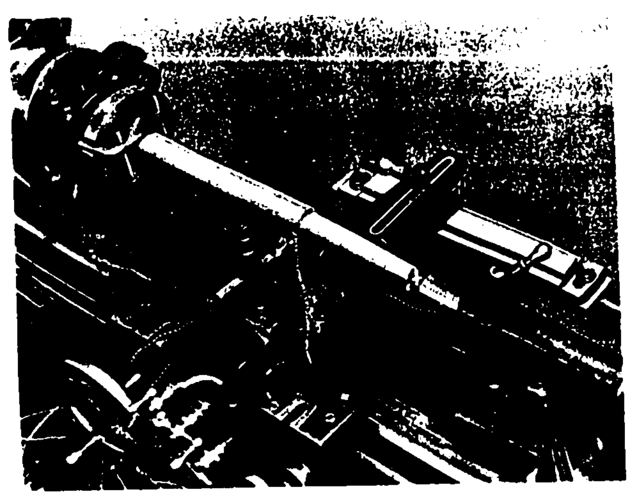
Figure 9-44.—End view of taper guide bar.



28.143X

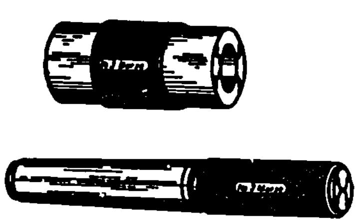
Figure 9-45.—Turning a taper using taper attachment.

The cutting point of the tool is placed on center and, if the taper attachment is used, care must be exercised to eliminate the backlash of the slide fittings so that the hole will not be bored straight at the start. Measurement of the size and taper of the hole is generally made with a taper plug gage by the cut and try method. After a cut or two has been taken, the bore is cleaned. Then the gage is rubbed lightly with chalk, inserted in the hole, and twisted slightly so that the chalk will show where the gate is bearing. Any necessary corrections may then be made and the boring continued until the taper is brought to size. A very light application of prussian blue to the gage will give better results than chalk for accurate work.

When making a blind tapered hole, such as may be required in drill sockets, it is best to drill the hole carefully to the correct depth with a drill of the same size as specified for the small end of the hole. This gives the advantage of boring to the right size without the removal of metal at the extreme bottom of the bore, which is rather difficult, particularly in small, deep holes.

For turning and boring tapers, the tool cutting edge should be set exactly at the center of the work. That is, set the point of the cutting edge even with the height of the lathe centers.

In testing the taper on a piece of work that is to fit a spindle and is nearly finished, make a chalk mark along the side of the test piece. Place the test piece in the taper hole and turn the piece carefully by hand. Then remove the test piece and the chalk mark will show where the taper is bearing. If the taper is a perfect fit, the entire length of the chalk mark will smear. If the fit is not perfect, the chalk mark will show where the adjustment is needed. Make the adjustment, take another light cut and test again. Be sure the taper is correct before turning to the finished diameter.

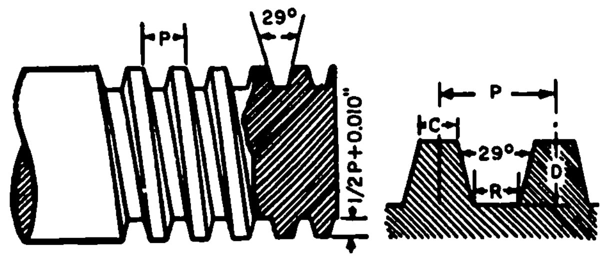


28.144X
Figure 9-46.—Morse taper socket gage and plug gage.

Figure 9-46 shows a Morse standard taper plug and a taper socket gage. They not only give the proper taper, but also show the proper distance that the taper should enter the spindle.

Threading

Most of the machine work done by an opticalman will include V-form threads even though normal duties will bring you in contact with



28.147X
Figure 9-47.—Acme thread.

acme threads, and square threads (figs. 9-47 and 9-48).

Each of these thread forms is used for specific applications. V-form threads are commonly used on fastening devices such as bolts and nuts as well as on machine parts. Acme screw threads are generally used for transmitting motion such as that between the lead screw and lathe carriage. Square threads are used to increase mechanical advantage and to provide good clamping ability as in the screw jack or vise screw.

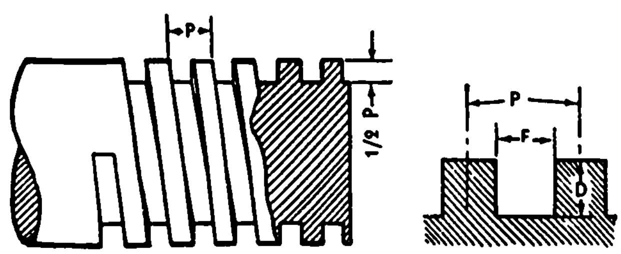


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Figure 9-48.—Square thread.

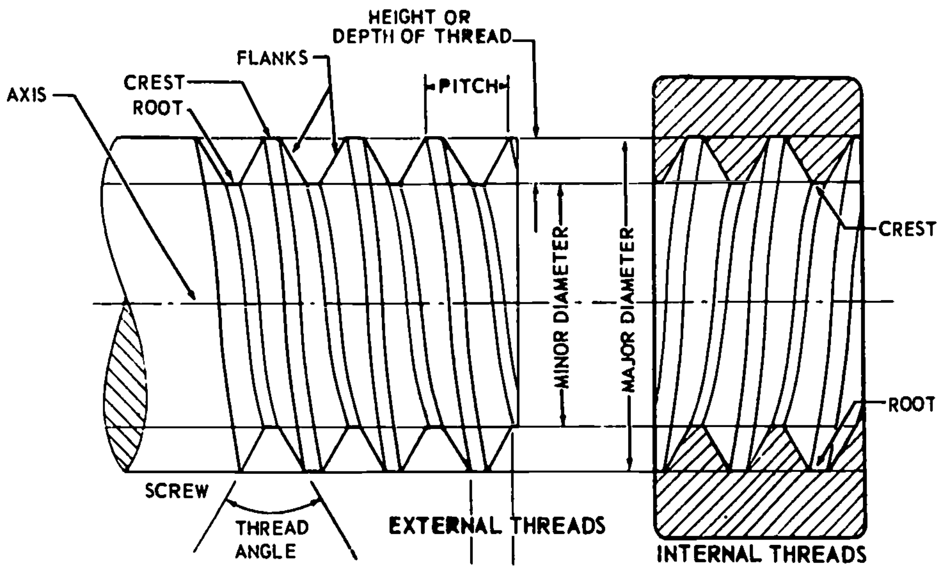
There are several terms used in describing screw threads and screw thread systems which you must know before you can calculate and machine screw threads. Figure 9-49 illustrates the application of some of the following terms:

External thread.—A thread on the external surface of a cylinder.

Internal thread.—A thread on the internal surface of a hollow cylinder.

Right-hand thread.—A thread which, when viewed axially, winds in a clockwise and receding direction.

Left-hand thread.—A thread which, when viewed axially, winds in a counterclockwise and receding direction.



28.145

Figure 9-49.—Screw thread nomenclature.

Lead.—The distance a threaded part moves axially in a fixed mating part in one complete revolution.

Pitch.—The distance between corresponding points on adjacent threads.

Single thread.—A single (single start) thread having the lead equal to the pitch.

Multiple thread.—A multiple (multiple start) thread has a lead which is equal to the pitch multiplied by the number of starts.

Class of threads.—Classes of threats are distinguished from each other by the amount of clearance between mating parts (nut and bolt). A 1/2 inch bolt with 13 threads could be very tight, snug, or loose, depending on the class of fit.

Thread form.—The axial plane profile of a thread for a length of one pitch.

Flank.—The side of the thread.

Crest.—The top of the thread (bounded by the major diameter on external threads; by the minor diameter on internal threads).

Root.—The bottom of the thread (bounded by the minor diameter on external threads; by the major diameter on internal threads).

Thread angle.—The angle formed by adjacent flanks of a thread.

Major diameter.—The diameter of a cylinder that bounds the crest of an external thread or the root of an internal thread.

Minor diameter.—The diameter of a cylinder that bounds the root of an external thread or the crest of an internal thread.

Height of thread.—The distance from the crest to the root of a thread measured perpendicular to the axis of the threaded piece (also called depth of thread).

Slant depth.—The distance from the crest to the root of a thread measured along the angle forming the side of the thread.

Thread series.—Groups of diameter pitch combinations which are distinguished from each other by the number of threads per inch to a specific diameter. The common thread series are the coarse series and the fine series.

The Naval Ship Systems Command and naval procurement activities use American Standard threading systems whenever possible; this system is recommended for use by all naval activities. The American Standard thread was chosen so that a unified series of threads, which permit interchangeability of standard thread fastening devices manufactured in the United States, Canada, and the United Kingdom, could be used in the U.S.

To cut a V-form screw thread, you need to know (1) the pitch of the thread, (2) the straight depth of the thread, (3) the slant depth of the thread, and (4) the width of the flat at the root of the thread. The pitch of a thread is the basis for calculating all other dimensions and is equal to 1 divided by the number of threads per inch. Twice the straight depth of an internal thread subtracted from the outside diameter of the externally threaded part is the basis for determining the bore diameter of a mating part to be threaded internally. When the thread-cutting tool is fed into the workpiece at one-half of the included angle of the thread, the slant depth is the dimension necessary to determine how far to feed the tool into the work. The point of the threading tool must have a flat equal to the width of the flat at the root of the thread (external or internal thread, as applicable). If the flat at the point of the tool is too wide, the resulting thread will be too thin if the cutting tool is fed in the correct amount. If the flat is too narrow, the thread will be too thick.

The following FORMULA will provide you with the information you need to know for cutting V-form threads:

AMERICAN STANDARD THREAD

Pitch = 1 ÷ number of threads per inch $= \frac{1}{n}$

Depth of external thread = 0.61343 x pitch = 0.61343p

Depth of internal thread = 0.541266 x pitch = 0.541266p

Width of flat at point of tool for external threads = 0.166 x pitch = 0.166p

Width of flat at point of tool for internal threads = 0.125 x pitch = 0.125p

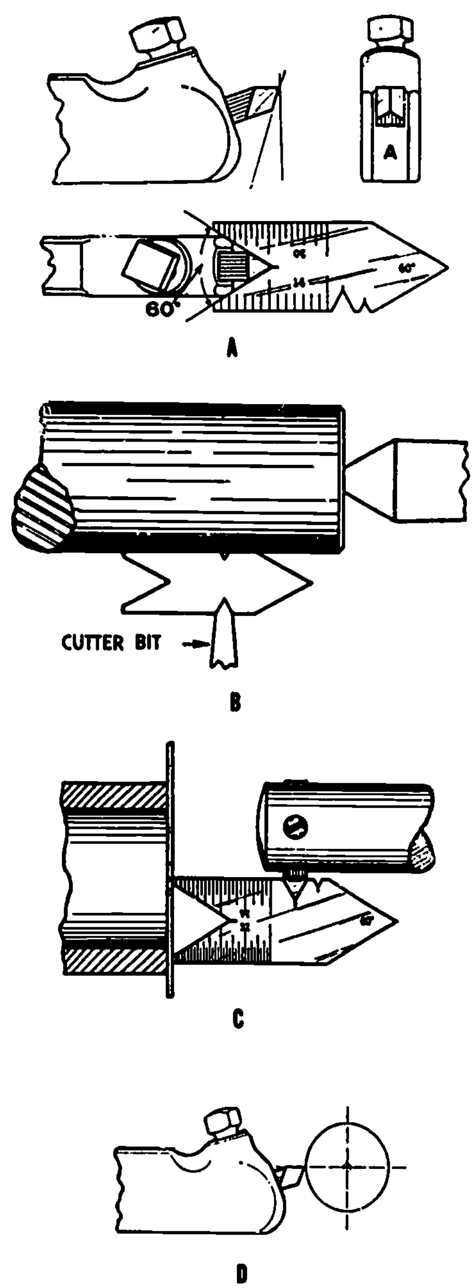
Slant depth of external thread = 0.708 x pitch = 0.708p

Slant depth of internal thread = 0.625 x pitch = 0.625p

To produce the correct thread profile, the cutting tool must be accurately ground to the correct angle and contour. Also the cutting tool must be set in the correct position. Figure 9-50 shows how a tool must be ground and set.

(Note: MULTIPLYING the constant by the pitch as in the preceding formulas produces the same result as is obtained by DIVIDING the constant by the number of threads per inch.)

The point of the tool must be ground to an angle of 60°, as shown in A of figure 9-50. A center gage or a thread-tool gage is used for grinding the tool to the exact angle required. The top of the tool is usually ground flat, with no side rake or back rake. However, for cutting threads in steel, side rake is sometimes used.



28.146X
Figure 9-50.—Threading tool setup for V-form threads.

The threading tool must be set square with the work, as shown in B and C of figure 9-50. The center gage is used to adjust the point of the threading tool and if the tool is carefully set, a perfect thread will result. Of course, if the threading tool is not set perfectly square with the work, the angle of the thread will be incorrect.

For cutting external threads, the top of the threading tool should be placed exactly on center as shown in D of figure 9-50. Note that the top of the tool is ground flat and is in exact alignment with the lathe center. This is necessary to obtain the correct angle of the thread.

Size of the threading tool for cutting an internal thread is important. The tool head must be small enough to be backed out of the thread and still leave enough clearance to be drawn from the threaded hole without injuring the thread. However, the boring bar which holds the threading tool for internal threading should be both as large in diameter as possible and as short as possible to prevent its springing away from the work while cutting.

Cutting screw threads on the lathe is accomplished by connecting the headstock spindle of the lathe with the lead screw by a series of gears so that a positive carriage feed is obtained, and the lead screw is driven at the required speed with relation to the headstock spindle. The gearing between the headstock spindle and lead screw may be arranged so that any desired pitch of the thread may be cut. For example, if the lead screw has 8 threads per inch and the gears are arranged so that the headstock spindle revolves four times while the lead screw revolves once, the thread cut will be four times as fine as the thread on the lead screw, or 32 threads per inch. By means of the quick-change gear box, the proper gearing arrangement can be made quickly and easily by placing the levers as indicated on the index plate for the thread desired.

When the lathe is set up to control the carriage movement for cutting the desired thread pitch, the next consideration is shaping the thread. The cutting tool is ground to the shape required for the form of the thread to be cut; that is—V, acme, square, etc. The depth of the thread is obtained by adjusting the cross-slide.

When threading work in the lathe chuck, be sure the chuck jaws are tight and the work is well supported. Never remove the work from the chuck until the thread is finished.

When threading long slender shafts, use a follower rest. The center rest must be used for supporting one end of long work that is to be threaded on the inside.

When cutting V-form threads and when maximum production is desired, it is customary to place the compund rest of the lathe at an angle of 29°, as shown in part A of figure 9-51. When the compound rest is set in this position, and the compound rest screw is used for adjusting the depth of cut, most of the metal is removed by the left side of the threading tool (B of fig. 9-51). This permits the chip to curl out of the way better than if the tool is fed straight in, and prevents tearing the thread. Since the angle on the side of the threading tool is 30°, the right side of the tool will shave the thread smooth and produce a better finish; although it does not remove enough metal to interfere with the main chip, which is taken by the left side of the tool.

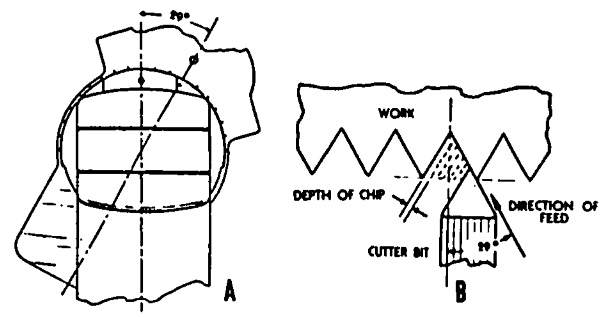


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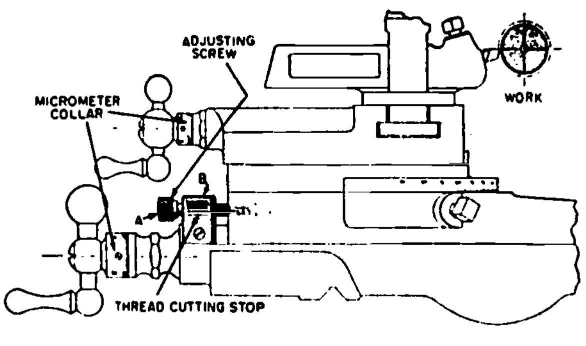
Figure 9-51.—Compound rest set at 29°.

Using the Thread-Cutting Stop

On account of the lost motion caused by the play necessary for smooth operation of the change gears, lead screw, half-nuts, etc., the thread-cutting tool must be withdrawn quickly at the end of each cut. If this is not done, the point of the tool will dig into the thread and may be broken off.

To reset the tool accurately for each successive cut, and to regulate the depth of the clip, the thread-cutting stop is useful.

First, set the point of the tool so that it just touches the work, then lock the thread-cutting stop and turn the thread-cutting stop screw A (fig. 9-52) until the shoulder is tight against stop B (fig. 9-52). When ready to take the first chip, run the tool rest back by turning the crossfeed screw to the left several times and move the tool to the point where the thread is to start. Then turn the crossfeed screw to the right until the thread-cutting stop screw strikes the thread-cutting stop. The tool is now in the original position, and by turning the compound rest feed



28.151X
Figure 9-52.—Adjustable thread-cutting stop mounted on carriage saddle (clamped to dovetail).

screw in 0.002 inch or 0.003 inch, the tool will be in a position to take the first cut.

For each successive cut after the carriage is returned to its starting point, the tool can be reset accurately to its previous position. Turn the crossfeed screw to the right until the shoulder of screw A strikes stop B. Then the depth of the next cut can be regulated by adjustment of the compound rest feed screw as it was for the first chip.

For cutting an internal thread, the adjustable thread-cutting stop should be set with the head of the adjusting screw on the inside of the stop. The tool is withdrawn by moving it toward the center or axis of the lathe.

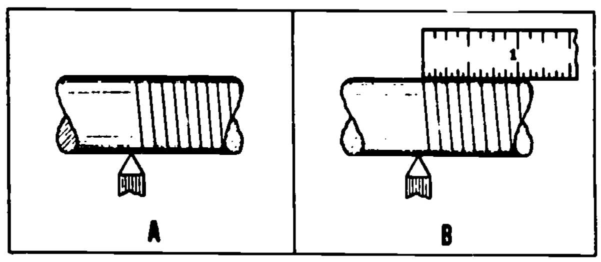
The micrometer collar on the crossfeed screw may be used in place of the thread-cutting stop, if desired. To do this, first bring the point of the threading tool up so that it just touches the work; then adjust the micrometer collar on the crossfeed screw to zero. All adjustments for obtaining the desired depth of cut should be made with the compound rest screw. Withdraw the tool at the end of each cut by turning the crossfeed screw to the left one complete turn; return the tool to the starting point and turn the crossfeed screw to the right one turn, stopping at zero. The compound rest feed screw may then be adjusted for any desired depth.

When threads are being cut on a lathe, the half-nuts are clamped over the lead screw to engage the threading feed and released at the end of the cut by means of the threading lever. The threading dial (discussed in this training course and illustrated in fig. 9-16) provides a means for determining the time to engage the half-nuts so that the cutting tool follows the same path during each cut. When an index mark on the threading dial is aligned with the witness mark on its housing, the half-nuts may be engaged. For some thread pitches however, the half-nuts may be engaged only when certain index marks are aligned with the witness mark. On most lathes the half-nuts can be engaged as follows:

For all even-numbered threads per inch, close the half-nuts at any line on the dial.

For all odd-numbered threads per inch, close the half-nuts at any numbered line on the dial.

For all threads involving one-half of a thread in each inch, such as 11 1/2, close the half-nuts at any odd-numbered line.



28.152X
Figure 9-53.—The first cut.

After setting up the lathe, as explained previously, take a very light trial cut just deep enough to scribe a line on the surface of the work, as shown in A of figure 9-53. The purpose of this trial cut is to be sure that the lathe is arranged for cutting the desired pitch of thread.

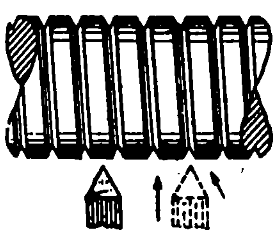
To check the number of threads per inch, place a rule against the work, as shown in B of figure 9-53 so that the end of the rule rests on the point of a thread or on one of the scribed lines. Count the scribed lines between the end of the rule and the first inch mark, and this will give the number of threads per inch.

It is quite difficult to accurately count fine pitches of screw threads. A screw pitch gage, is very convenient for checking the finer screw threads. The gage consists of a number of sheet metal plates in which are cut the exact form of threads of the various pitches; each plate is stamped with a number indicating the number of threads per inch for which it is to be used.

Final check for both diameter and pitch of the thread may be made with the nut that is to be used or with a ring thread gage, if one is available. The nut should fit snugly without play or shake but should not bind on the thread at any point.

If the thread-cutting tool needs resharpening or gets out of alignment, or if you are chasing the threads on a previously threaded piece, you must reset the tool so that it will follow the original thread groove. This may be done by using the compound rest feed screw and crossfeed screw to jockey the tool to the proper position, by disengaging the change gears and turning the spindle until the tool is positioned properly, or by loosening the chuck and turning the work until the tool is in proper position with the thread groove. Regardless of which method is used, the micrometer collars on the crossfeed screw and compound rest screw will usually have to be reset.

Before adjusting the tool in the groove, use the appropriate thread gage to set the tool square with the workpiece. Then with the tool a few thousandths of an inch away from the workpiece, start the machine and engage the threading mechanism. When the tool has moved to a position such as is shown in figure 9-54, stop the lathe without disengaging the thread mechanism.



28.154X
Figure 9-54.—Tool must be reset to original groove.

The most practical and commonly used method for resetting a threading tool for machining angular form threads is the compound rest and crossfeed positioning method. By adjusting the compound rest slide forward or backward the tool is moved parallel to the axis of the work as well as toward or away from the work. When the point of the tool coincides with the original thread groove (see phantom view of tool in fig. 9-54), the crossfeed screw is used to bring the tool point directly into the groove. When a good fit between the cutting tool and thread groove is obtained the micrometer collar on the crossfeed screw is set on zero and the micrometer collar on the compound rest feed screw is set to the depth of cut previously taken or to zero as required. (Note: Be sure that the thread mechanism is engaged and the tool is set square with the work before adjusting the position of the tool along the axis of the workpiece.)

SAFETY PRECAUTIONS

Before starting the operation of any machine tool, the novice must realize the importance of observing safety precautions. You have studied the lathe and its operating procedures, but before you can apply this knowledge, the principles of safety must be understood and observed. Thought guided by common sense is the surest safeguard against accidents.

Moving machinery is always a danger, and when associated with a sharp cutting tool, the hazard is greatly increased. Treat a machine with respect and there will be no need for fearing it.

When operating a lathe or any machine tool, be sure that the area is free of personnel and objects that could make the job more hazardous. It is the operator's responsibility to look out for others as well as himself when chips are flying and his machine is in motion.

Safety precautions are posted in the work area for all machinery in the shop, so never begin an operation without reading these precautions. The posted precautions will give you detailed instructions that apply to the machine you are operating. In this chapter we can list only the general safety rules that apply.

- Always protect your eyes and your limbs from chips and moving parts by wearing safety goggles and not wearing any loose clothing that could get caught in revolving parts.
- Never attempt to clean, repair, or adjust a moving machine.
- Before starting a machine, ensure that chuck keys and loose tools have been removed from the machine.
- Make sure that all gear covers and safety guards are in place.
- Never lean against a moving machine or attempt to stop a moving machine by any means other than the proper control levers.

The most important thing that an operator can learn about a lathe or any other machine tool is the SAFETY PRECAUTIONS.

CHAPTER 10

MACHINE TOOL OPERATION—PART II

GRINDERS

Grinding is the removal of metal by the cutting action of an abrasive. Offhand grinding is a term used to describe the manual holding and manipulation of a workpiece when grinding. To grind accurately and safely, using the offhand method, you must have experience and practice. In addition, you must know how to select and install grinding wheels, how to sharpen or dress them, and you must have a knowledge of the safety precautions concerning grinding.

To properly grind small handtools, single-edged cutting tools, and twist drills, you must have a knowledge of the terms used to describe the angles and surfaces of the tools, you must know for what operations each tool is used, and you must know the composition of the tool material.

Bench and pedestal grinders are relatively simple machines. The main components of these grinders are: a motor with an extended shaft for mounting of grinding wheels, a mounting base for the motor, grinding wheel guards which are mounted over the grinding wheel as a safety feature, a provision for coolants, an adjustable toolrest for steadying the workpiece, and a shield which is fastened to the wheel guards to protect the operator from flying chips. Figure 10-1 shows a representative bench grinder.

Bench grinders are mounted on workbenches. They are used for grinding and sharpening of small tools. These grinders do not have installed coolant systems; however, a container for the coolant is usually mounted or placed near the grinder. Grinding wheels up to 8 inches in diameter and 1 inch in thickness are normally used on bench grinders.

Pedestal grinders are usually heavy duty bench grinders which set on a pedestal fastened to the deck. They normally have a coolant system which includes a pump, storage pump, and a hose and fittings to carry the coolant to the wheel surface. Pedestal grinders are particularly useful for rough grinding such as "snagging" castings. Figure 10-2 shows a pedestal grinder in use.

When operating a bench or pedestal grinder, observe all safety precautions for the machine. Ensure that all safety guards and shields are secured in the proper position.

GRINDING SAFETY

The grinding wheel is a fragile cutting tool which operates at high speeds. Great emphasis must be given, therefore, to the safe operation of bench and pedestal grinders. Observance of safety precautions, posted on or near all grinders used in the Navy, is mandatory for the safety of the operator and the safety of personnel in the nearby vincinity.

What are the most common sources of injury during grinding operation? Hazards leading to eye injury caused by grit generated by the grinding process are the most common and the most serious. Abrasions caused by bodily contact with the wheel are quite painful and can be serious. Cuts and bruises caused by segments of an exploded wheel, or a tool "kicked" away from the wheel are other sources of injury. Cuts and abrasions can become infected if not protected from grit and dust from grinding.

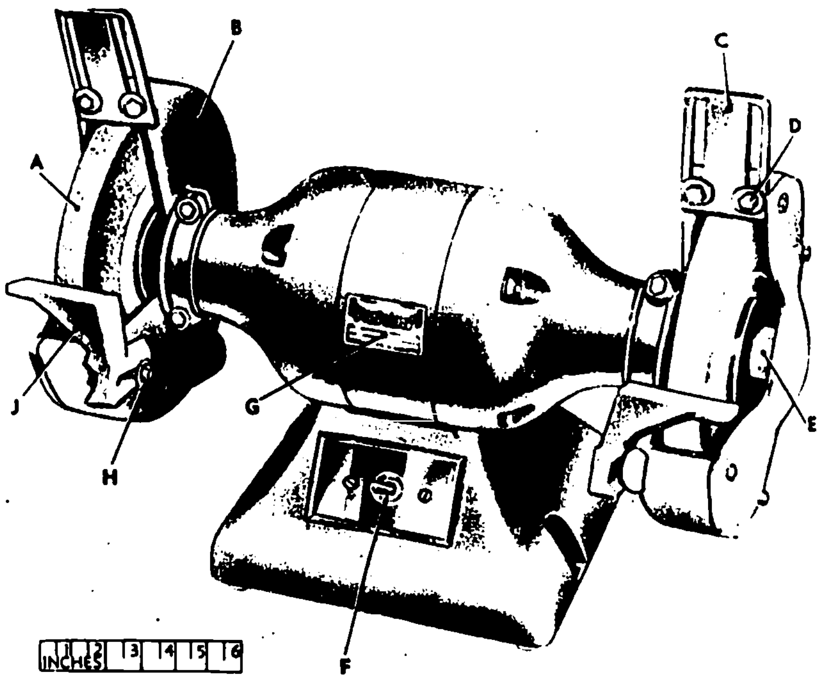
Safety in using bench and pedestal grinders is primarily a matter of using common sense and concentrating on the job at hand. Each time you start to grind a tool, stop briefly to consider how observance of safety precautions and the use of safeguards protect you from injury. Consider the complications that could be caused by your loss of sight, or loss or mutilation of an arm or hand.

Some guidelines for safe grinding practices are:

1. Read posted safety precautions before starting to use a machine. In addition to refreshing your memory about safe grinding practices, this gets your mind on the job at hand.

2. Secure all loose clothing and remove rings or other jewelry.

3. Inspect the grinding wheel, wheel guards, the toolrest, and other safety devices to ensure they are in good condition and positioned properly. Set the toolrest so that it is within 1/8



A—GRINDING ABRASIVE WHEEL
B—LEFT HAND WHEEL GUARD ASSY
C—EYE SHIELD
D—5/16-24NF-2 X 7/8 HEX-HD CAP SCREW
E—RIGHT HAND WHEEL CLAMP NUT
F—TOGGLE SWITCH
G—NAME PLATE
H—5/16-24NF-2 X 1 HEX-HD CAP SCREW
J—LEFT HAND TOOL REST

44.61

Figure 10-1.—Electric powered grinder.

inch of the wheel face and level with the center of the wheel.

4. Clean transparent shields, if installed, and put on goggles. Transparent shields do not preclude the use of goggles as the dust and grit may get around a shield. Goggles, however, provide for full eye protection.

5. Stand aside when starting the grinder motor until operating speed is reached. This prevents injury if the wheel explodes from a defect that has not been noticed.

6. Use light pressure when starting grinding; too much pressure on a cold wheel may cause failure.

7. Grind only on the face or periphery of a grinding wheel on bench and pedestal grinders, unless the grinding wheel is specifically designed for side grinding.

METALS

The metals that an opticalman will use in the performance of his duties are as varied as any rate in the Navy. They range from the soft copper in wire to the very hard steels used as cutters. Metals fall into two general categories, ferrous and nonferrous. A ferrous metal is one that contains iron, and all the various types of steel come under this category. The nonferrous metals are those that do not contain iron and included in this category are copper, brass, bronze, and aluminum.

The bench or pedestal grinder that is installed in optical shops is primarily for the purpose of sharpening cutting tools and forming special handtools. It is not used to grind any nonferrous metal because the wheel would collect the metal that is ground, causing accidents and spoilage when used to grind steel. Always check the wheel of any grinder to make sure that no metal has adhered to the wheel. When metal has collected on the wheel of a grinder, it should be dressed down with a proper dressing tool until the wheel is completely free of foreign particles.

Grinding Wheels

A grinding wheel is a cutting tool. The abrasive particles in the wheel provide thousands of small cutting edges that remove metal chips from the stock being ground. For most efficient use of a grinding wheel, you must select the correct wheel and ensure that it is installed properly. You must know how to "sharpen" or dress the wheel.

Composition and structure are the most important factors to consider when selecting a grinding wheel. The two basic elements of a grinding wheel are the abrasive and the bond. The abrasive performs the cutting action, and the bond cements the abrasive grains into a wheel shape.

There are two types of abrasives: natural and manufactured. Natural abrasives, such as emery, corundum, and diamond, are used only in honing stones and in special types of grinding wheels. The common manufactured abrasives are aluminum oxide and silicon carbide. They have superior qualities and are more economical than natural abrasives. Aluminum oxide (designated by the letter A) is used for grinding steel and steel alloys, and for heavy duty work such as cleaning up steel castings. Silicon carbide (designated by the letter C), which is harder but not as tough as aluminum oxide, is used mostly for grinding nonferrous metals and carbide tools.

The bond determines the strength of the wheel. The most common types of bonds are the vitrified and the silicate. The vitrified bond (designated by V) is most common. It is a glasslike substance that makes a strong rigid grinding wheel which is porous, free cutting, and unaffected by temperature, oils, water, and acids. The silicate bond (designated by the letter S) is softer (releases abrasive grains more readily) than the vitrified bond. Silicate bond is used when heat generated in the grinding process must be kept to a minimum, as when grinding edged tools.

In general, the softer materials to be ground require harder bonds, and the harder materials require softer bonds. A proper bond for a specific grinding application should retain the abrasive grains until they become dull.

Other terms used in relation to grinding wheels are grain size, grade, and structure. The grain size (from 24 to 600) indicates the size of the abrasive grains in a wheel. It is determined by the size of mesh of a sieve through which the grains can pass. The grade (designated alphabetically A to Z, soft to hard) of a grinding wheel is the term used to designate the ability of the bond to retain the abrasive grains in the wheel. In the grinding operation, a soft grade bond releases the abrasive grains relatively easily as compared to a hard grade bond. The structure (designated numerically from 1 to 15, dense to porous) indicates the spacing between the abrasive grains.

A standard wheel marking is used combining the letter and number symbols given in the preceding paragraphs. For example:

A 36 K 10 V

Abrasive type — A
Grain size — 36
Grade — K
Structure — 10
Bond type — V

A manufacturer's record symbol is sometimes found in this position.

The standard markings of some wheels used to grind cutting tools are as follows:

	Grinding Wheels	
Cutting Tools	Roughing	Finishing
Carbon and High Speed Steel Tools	A3605V	A60N5V
Drills		
1/4 to 1 inch	A46M5V	
less than 1/4 inch	A80M5V	
Tungsten and Tantalum Carbide Tools	C69J7V	C10017V
General Purpose Shop Tools	A30P5V	

The wheel of a bench or pedestal grinder must be properly installed; otherwise accidents may occur and the wheel will not operate properly. Before a wheel is installed, it should be

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Figure 10-2.—Grinding on a pedestal grinder.

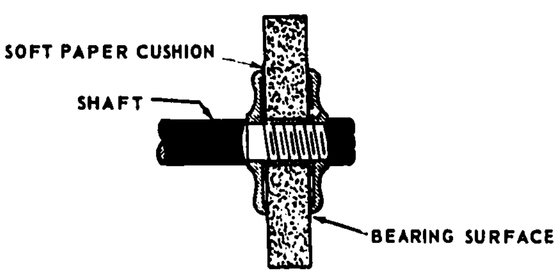

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Figure 10-3.—Method of mounting a grinding wheel.

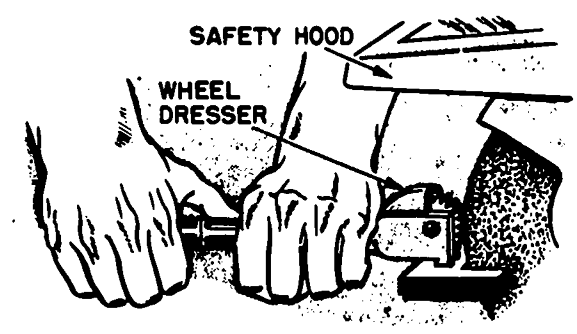
inspected for visible defects and "sounded" by tapping lightly with a piece of hard wood to determine whether it has invisible cracks. A good wheel gives out a clear ringing sound when tapped, but if the wheel is cracked a dull thud is heard.

Ensure that the wheel fits on the spindle without play. Force should not be used, however, as this may cause the wheel to crack when placed in operation, or cause the wheel to be slightly out of axial alignment. Recessed flanges (fig. 10-3) must be used on both sides of the wheel to spread the pressure of the securing nut. The flanges should be at least one-third the diameter of the wheel. Use thin cardboard or rubber washers between the flanges and the wheel to ensure even pressure on the wheel, and to dampen the vibration between the wheel and shaft when the grinder is in operation. Tighten the securing nut sufficiently to hold the wheel firmly; tightening too much may damage the wheel.

Grinding wheels, like other cutting tools, require frequent reconditioning of cutting surfaces to perform efficiently. Dressing is the term used to describe the process of cleaning the periphery of grinding wheels. This cleaning breaks away dull abrasive grains and smooths the surface so that there are no grooves. Truing is the term used to describe the removal of material from the cutting face of the wheel so that the resultant surface runs absolutely true to some other surface such as the grinding wheel shaft.

The wheel dresser (fig. 10-4) is used for dressing grinding wheels on bench and pedestal grinders. To dress a wheel with this tool, start the grinder and let it come up to speed. Set the wheel dresser on the rest as shown in figure 10-4 and bring it in firm contact with the wheel. Move the wheel dresser across the periphery of the wheel until the surface is clean and approximately square with the sides of the wheel.

If grinding wheels get out of balance because of out-of-roundness, dressing the wheel will usually remedy the condition. A grinding wheel can get out of balance by being left sitting with part of the wheel immersed in the coolant; if this happens, the wheel should be removed and dried out by baking. If the wheel gets out of balance axially, it probably will not affect the efficiency of the wheel on bench and pedestal grinders. This unbalance may be remedied simply by removing



28.63
Figure 10-4.—Using a grinding wheel dresser.

the wheel and cleaning the shaft spindle and spindle hole in the wheel and the flanges.

Operation

The general operations of a grinder are well covered in Basic Handtools, NavPers 10085-A, so there is no need in repeating that text.

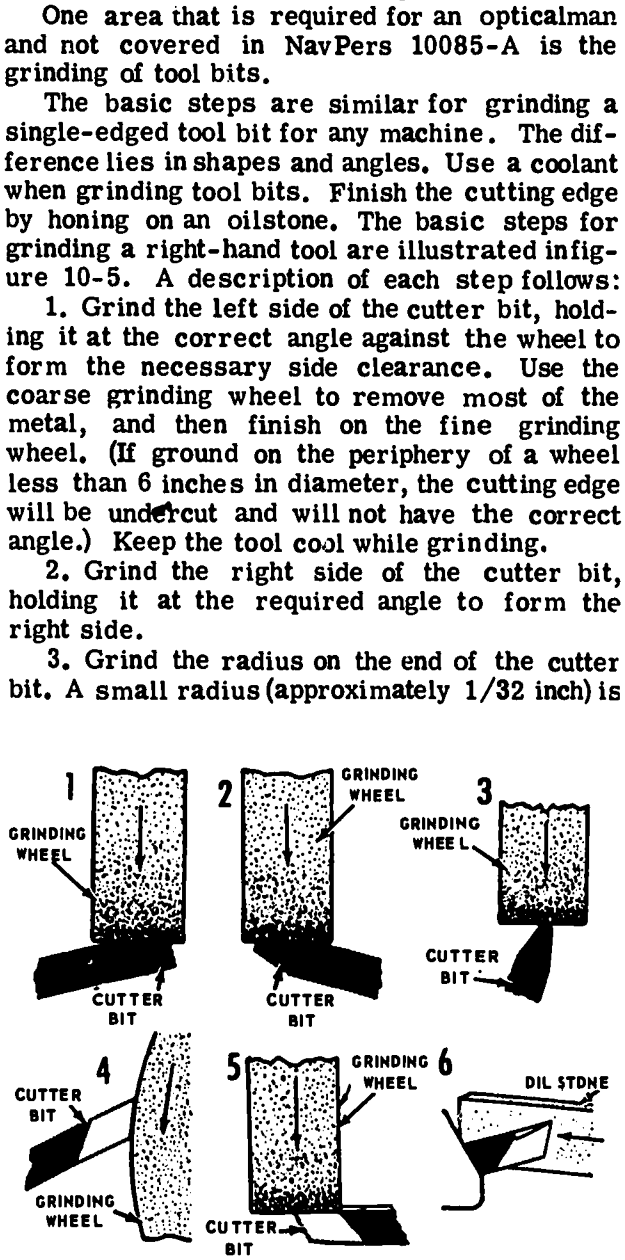
One area that is required for an opticalman and not covered in NavPers 10085-A is the grinding of tool bits.

The basic steps are similar for grinding a single-edged tool bit for any machine. The difference lies in shapes and angles. Use a coolant when grinding tool bits. Finish the cutting edge by honing on an oilstone. The basic steps for grinding a right-hand tool are illustrated in figure 10-5. A description of each step follows:

1. Grind the left side of the cutter bit, holding it at the correct angle against the wheel to form the necessary side clearance. Use the coarse grinding wheel to remove most of the metal, and then finish on the fine grinding wheel. (If ground on the periphery of a wheel less than 6 inches in diameter, the cutting edge will be undercut and will not have the correct angle.) Keep the tool cool while grinding.

2. Grind the right side of the cutter bit, holding it at the required angle to form the right side.

3. Grind the radius on the end of the cutter bit. A small radius (approximately 1/32 inch) is preferable, as a large radius may cause chatter. Hold the cutter bit lightly against the wheel and turn from side to side to produce the desired radius to obtain the proper front clearance.



28.65

Figure 10-5.—Grinding and honing a lathe cutter bit.

4. Grind the top of the cutter bit, holding it at the required angle to obtain the necessary side rake and back rake. Too much of the cutter bit should not be removed in grinding, as the more metal left on the bit, the better it absorbs the heat produced while cutting.

5. Hone the cutting edge all around and on top with an oilstone until you have a keen cutting edge. Use a few drops of oil on the oilstone when honing. Honing will not only improve the cutting quality of the cutter bit, but it will produce a better finish on the work and the cutting edge of the tool will stand up much longer than if it is not honed. The cutting edge should be sharp in order to shear off the metal instead of tearing it off.

MILLING MACHINES

The milling machine removes metal by means of a revolving cutting tool called a milling cutter. With various attachments, milling machines may be used for boring, broaching, circular milling, dividing, and drilling; the cutting of keyways, racks, and gears; and the fluting of taps and reamers.

To advance in rating you must demonstrate the ability to set up and perform basic operations using the milling machine. To set up and operate a milling machine you must compute feeds and speeds, select and mount the proper holding device, and select and mount the proper cutter to handle the job.

Like other machines in the shop, milling machines are equipped with manual and power feed systems, a selective spindle speed range and a coolant system.

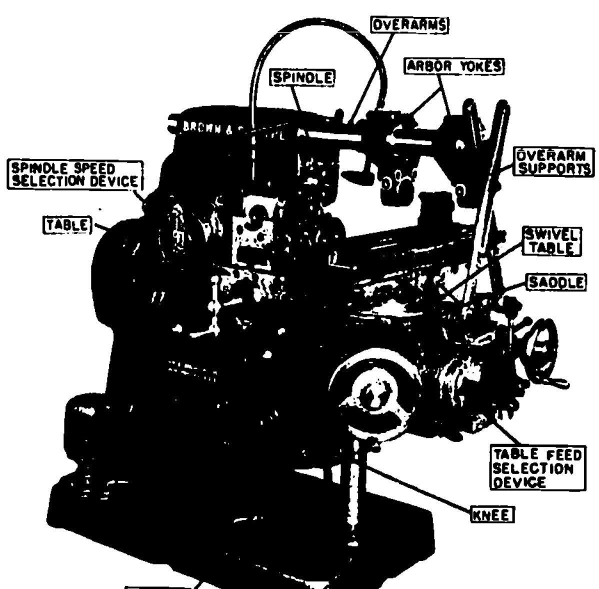
TYPES

The type of milling machine most commonly used in the Navy is the KNEE AND COLUMN TYPE. Because of its ease of setup and its versatility, this machine is more efficient than other types. The main casting consists of an upright column, to which is fastened a bracket, or "knee," which supports the table. The knee is adjustable on the column, so that the table can be raised or lowered to accommodate various size pieces of work.

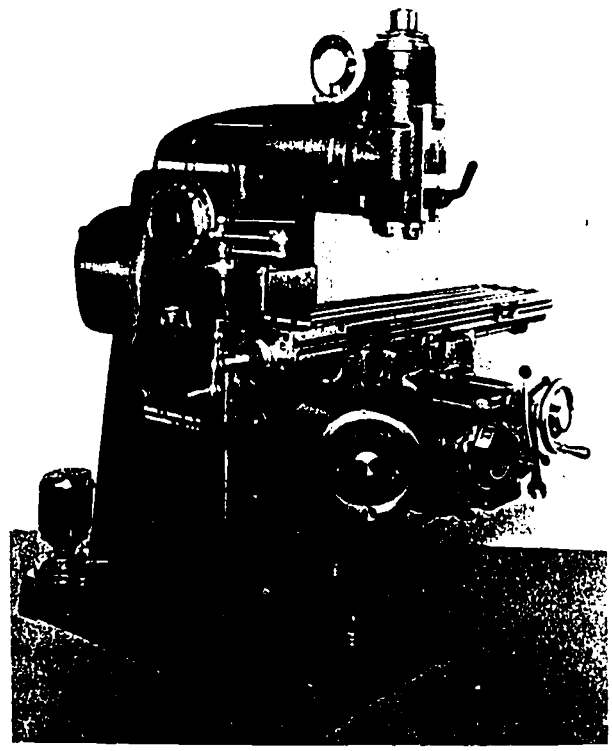
Vertical cuts may be taken by feeding the table up or down. The table may be moved in the horizontal plane in two directions; either at right angles to the axis of the spindle or parallel to the axis of the spindle. Because of this, work can be mounted at practically any location on the table. Knee and column milling machines are made in three designs: plain, universal, and vertical spindle.

As in all milling machines of this type, the table of the PLAIN MILLING MACHINE can be moved in three directions: longitudinal (at right angles to the spindle), transverse (parallel to the spindle), and vertical (up and down). The ability of this machine to take heavy cuts at fast speeds with coarse feeds is its chief value and is made possible by the machine's rigid construction.

The UNIVERSAL MILLING MACHINE (fig. 10-6) embodies all the principal features of the other types of milling machines. It is designed to handle practically all classes of milling work. Its principal advantage over the plain mill is that the table can be swiveled on the saddle so that it moves at an angle to the spindle on a horizontal plane. This machine is used to cut most types of gears, milling cutters, and twist drills, and is used for various kinds of straight and taper work.



28.197X
Figure 10-6.—Universal milling machine.



28.198X
Figure 10-7.—Vertical milling machine.

The VERTICAL SPINDLE MILLING MACHINE, (fig. 10-7) has the spindle in a vertical position and is similar in construction and operation to the other two types of milling machines. Since the cutter and the surface being cut may be readily observed, face milling and end milling operations are accomplished more easily on the vertical spindle milling machine than on mills of other types. Vertical spindle mills embody the principles of the drill press. The spindle and table both have a vertical movement, and the table also has longitudinal and transverse movement. This type of machine is used for face milling, profiling, and die sinking, and for various odd-shaped jobs; it can also be advantageously used for boring holes.

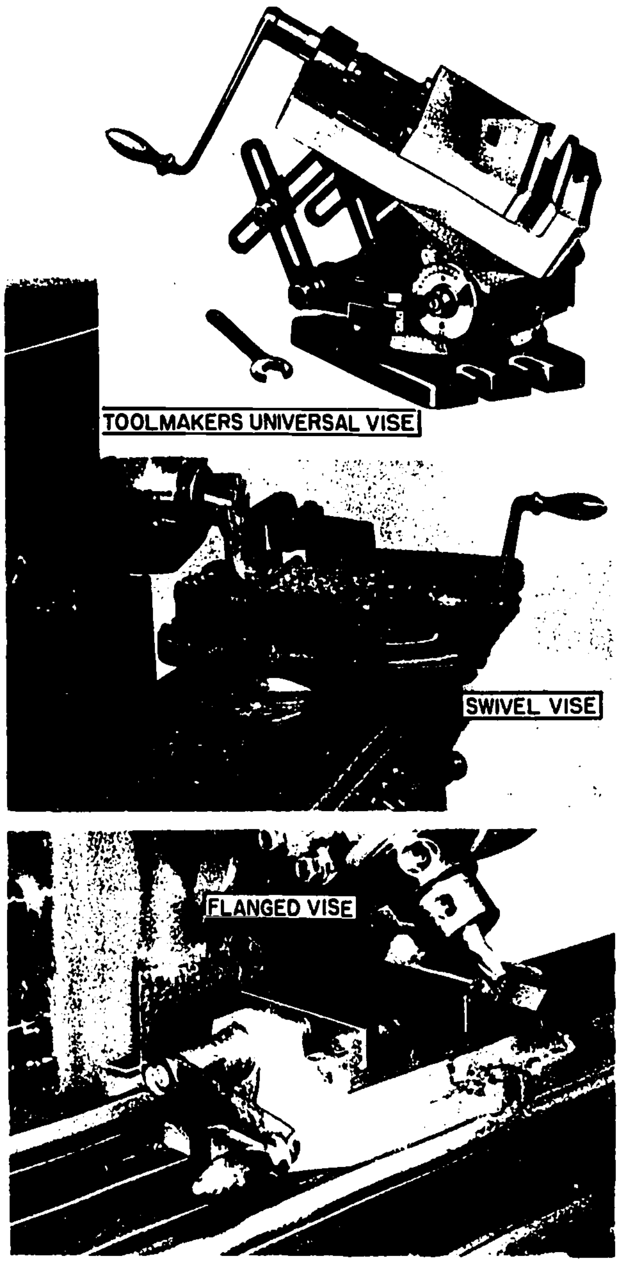
Although knee and column milling machines vary slightly in design depending on the manufacturer, the components labeled in figure 10-6 are common to most milling machines. The column has an accurately machined and scraped vertical dovetail. The knee is firmly gibbed to the column dovetail, thus providing a means of vertical movement of the knee. The saddle slides on a horizontal dovetail (which is parallel to the axis of the spindle) on the knee. The swivel table (on universal machines only) is attached to the saddle and can be swiveled approximately 45° in either direction.

The spindle nose has a standard internal taper. Driving keys or lugs are provided on the face of the spindle nose for driving the cutter directly, or for driving an arbor or adapter on which the cutter is mounted. The overarms, yokes, and overarm supports are used to provide accurate alignment and to support arbors. The overarms may be retracted into the column or extended out of the column by the amount necessary to support any length arbor. The overarm supports are extremely beneficial for supporting the cutter when taking heavy cuts and are used in conjunction with the yokes and overarms.

STANDARD EQUIPMENT

The standard equipment provided with milling machines on Navy ships includes workholding devices, spindle attachments, cutters and arbors, and any special tools needed for setting-up the machine for milling. This equipment permits holding and cutting the great variety of milling jobs that are encountered in Navy repair work.

The VISES commonly used on milling machines are the flanged plain vise, the swivel vise, and the toolmakers universal vise (fig. 10-8). The flanged vise provides a rigid workholding setup when the surface to be machined must be parallel to the surface seated in the vise. The swivel vise is used similarly to the flanged vise, but the setup is less rigid, and permits the workpiece to be swiveled in a horizontal plane to any required angle. The toolmakers universal vise is used when the workpiece must be set up at a complex angle in relation to the axis of the spindle and to the table surface.

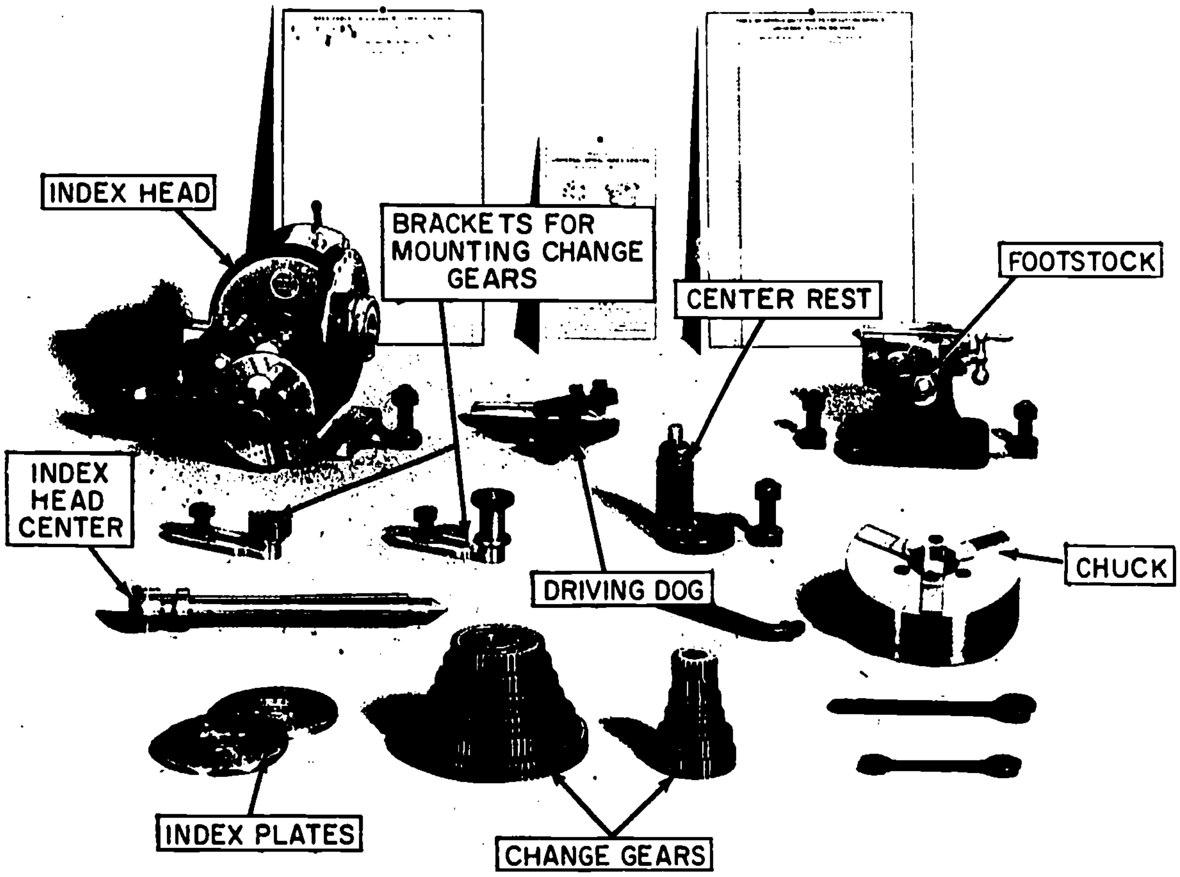


28.199X
Figure 10-8.—Milling machine vises.

Index Head

INDEXING EQUIPMENT provided with milling machines is illustrated in figure 10-9. Indexing equipment is used to hold the workpiece and to provide a means of turning the workpiece so that a number of accurately spaced cuts may be made (gear teeth for example). The workpiece is held in a chuck, attached to the index head spindle. The center rest may be used to provide support for long slender work. The center of the footstock may be raised or lowered as required for setting up tapered workpieces.

The basic components of an index head are shown in figure 10-10. The ratio between the worm and gear is 40 to 1, thus by turning the worm one turn the spindle is rotated 1/40 of a revolution. The index plate, which has a series of concentric circles of holes, permits accurate



28.200X

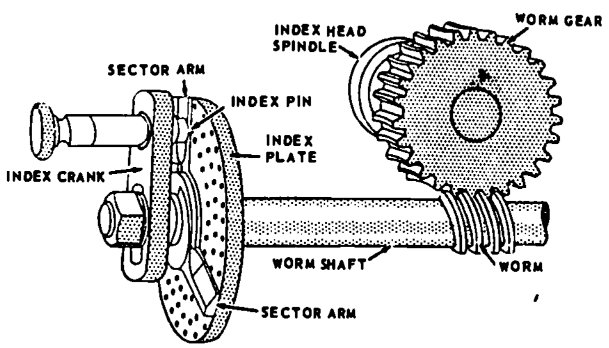
Figure 10-9.—Index head with footstock.

gaging of partial turns of the worm shaft and allows the spindle to be turned accurately in amounts smaller than 1/40 of a revolution. The index plate may be secured to the index head housing or to the worm shaft. The crankpin can be adjusted radially for use in any circle of holes. The sector arms can be set to span any number of holes in the index plate to provide a guide for rotating the index crank for partial turns.

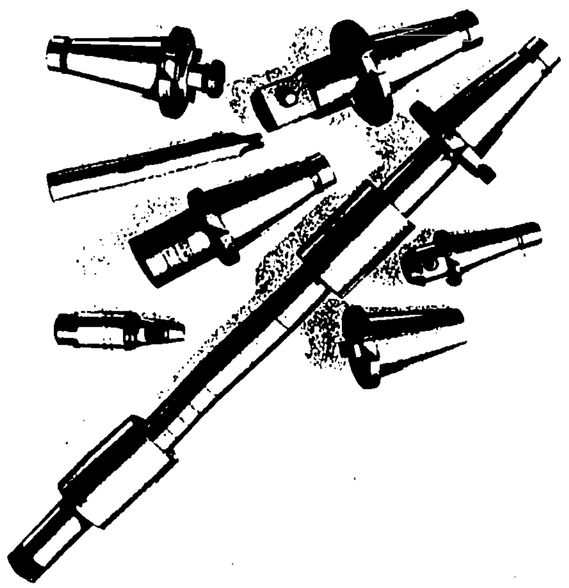
The index head spindle can be turned directly by hand, by the index crank through the worm and worm gear, or by the table feed mechanism through a gear train. The first two methods are used for indexing, while the third is used for rotating the workpiece (while it is being cut) to provide a means of making helical cuts. The spindle is set in a swivel block so that the spindle can be set at any angle from slightly below horizontal to slightly past vertical. An index plate, usually having a 24-hold circle, is provided to be placed back of the chuck or center so that the spindle can be indexed rapidly by hand for commonly required divisions.

Cutters

Milling machine cutters are generally classified according to methods of mounting. Arbor cutters are cutters with straight, tapered, or



28.201
Figure 10-10.—Index head mechanism.



28.204X
Figure 10-11.—Arbors, sleeves, and special adapters.

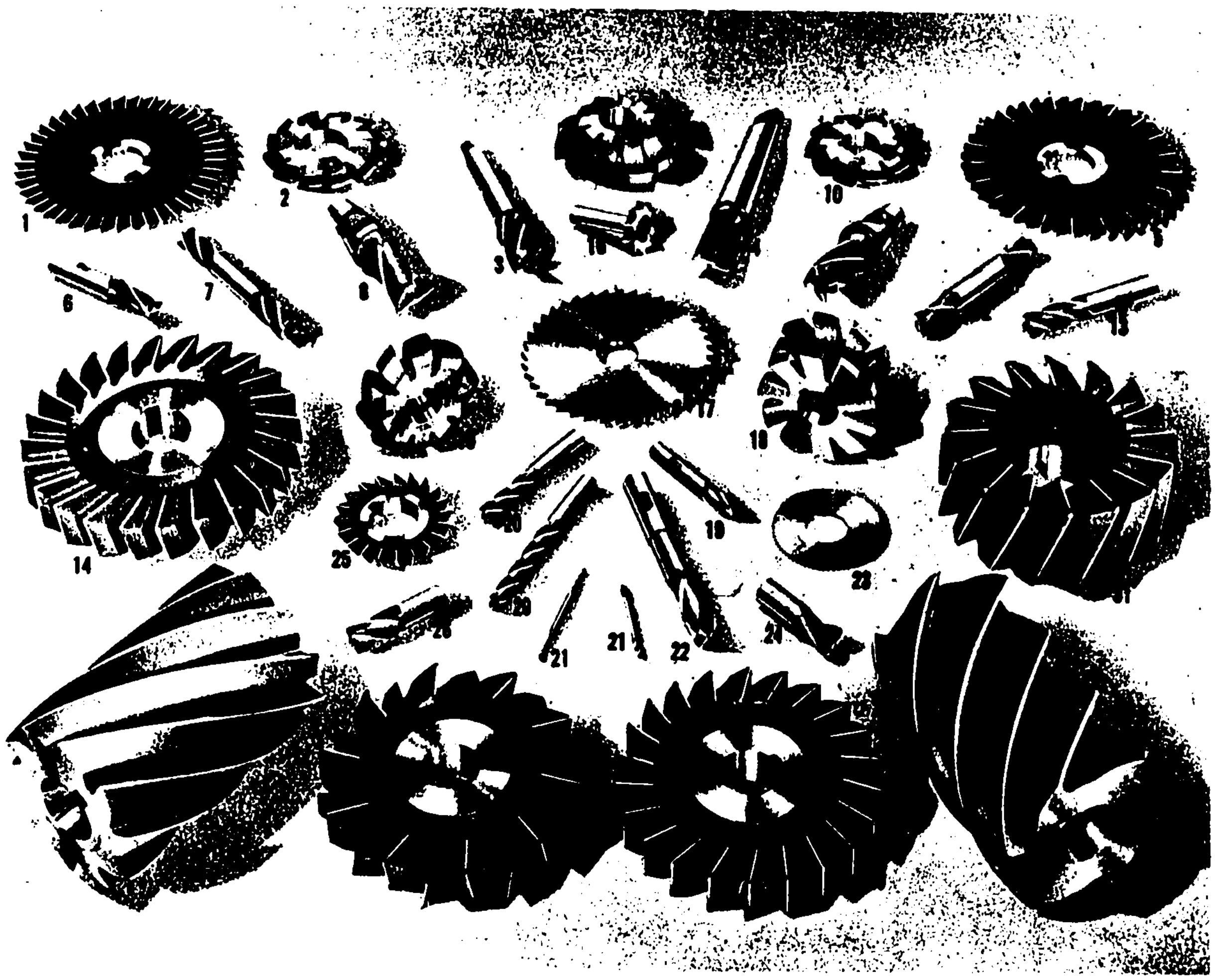
threaded holes for mounting on an arbor. The most common type has a straight hole with a keyway through it or across one end. By means of a key inserted in this keyway, the cutter is prevented from turning on the arbor. Shank cutters have straight or tapered shanks and are mounted in collets or adapters. Facing cutters are attached to either a stub arbor or directly to the milling machine spindle. Figure 10-11 illustrates various arbors, sleeves, and adapters for mounting cutters.

The milling cutters with which you will come in contact in the normal course of your work as an Opticalman are illustrated in figure 10-12. These cutters are made from carbon steel, high-speed steel, Stellite, or tool steel with cemented carbide teeth. The types of cutters most used, and the operations to which they are best suited, are as follows:

PLAIN MILLING CUTTERS (numbers 27 and 30 of fig. 10-12) are the most widely used of all cutters. They are used for milling flat surfaces parallel to the cutter's axis. The cutter is cylindrical and has teeth cut on the periphery only. Plain milling cutters are made in a variety of diameters and widths. The teeth may be either straight or spiral in shape, but the latter type is generally used when the cutter is more than 3/4 inch wide. A cutter tooth that is straight or parallel to its axis receives a distinct shock as the tooth starts to cut. To eliminate this shock and thereby produce a free cutting action, cutters are often made with helical teeth. A spirally gashed cutter, particularly when used on wide surfaces, gives a much smoother result than a straight gashed cutter. Spirally gashed cutters also require less power to operate and, since the stress on the cutter is relieved, the tendency to chatter is reduced. When the plain milling cutter is made with relatively few teeth and a fairly steep angle of spiral, the cutter is commonly called a coarse tooth cutter. Such cutters are used because of their ability to remove considerable quantities of metal with minimum power consumption. Plain mills with very few teeth and helical milling cutters have a very steep angle of spiral. They are particularly efficient on heavy slabbing cuts. Owing to the shearing action of the teeth, they can be used to advantage in removing an uneven amount of stock without gouging. They are made in both "hole" and "arbor" types for milling forms from solid metal.

SIDE MILLING CUTTERS (numbers 14, 28, and 29 of fig. 10-12) are comparatively narrow milling cutters and may have teeth on one side only or on both sides as well as on the outer surface. When used in pairs, with an appropriate spacer between them, these cutters can mill parallel sides such as on bolt heads, tongues, nuts, etc. Side milling cutters more than 8 inches in diameter are usually made with inserted teeth. Another type of side cutter is the STAGGERED-TOOTH CUTTER, designed for deep cuts in steel (number 28 of fig. 10-12).

METAL SLITTING SAWS (numbers 1, 5, and 17 of fig. 10-12) used on milling machines are essentially thin, plain milling cutters. The



1. Metal slitting saw.
2. Involute spur gear cutter (undercut teeth).
3. Spiral end mill, taper shank.
4. Two-lipped spiral mill, taper shank.
5. Metal staggered-tooth slitting saw.
6. Long two-lipped end mill, single end.
7. Long spiral end mills, double end.
8. Two-lipped spiral end mill, double end.
9. Corner rounding cutter.
10. Involute form cutter.
11. Spiral end mill, cam-locking.
12. Long two-lipped spiral end mill, double end.
13. Long spiral end mill, single end.
14. Half side milling cutter.
15. Convex cutter.
16. Woodruff kevseat cutter.
17. Metal slitting saw.
18. Concave cutter.
19. Ball end mills.
20. Long single-end end mill.
21. Double-end end mills.
22. Two-lipped long single-end end mill.
23. Screw slotting cutter.
24. Two-lipped spiral end mill, straight shank.
25. Angular cutter.
26. Spiral end mill, straight shank.
27. Plain heavy duty milling cutter.
28. Staggered tooth side milling cutter.
29. Side milling cutter.
30. Helical plain milling cutter.
31. Shell end miss for use with shell end mill arbor.

28.205X

Figure 10-12.—Milling machine cutters.

thickness of a metal slitting saw tends to decrease toward the center. This is to provide clearance between cutter and work when you are milling deep slots or cutting off thick sections of metal. Slitting saws are usually less than 3/16 inch thick. Generally, slitting saws have more teeth for a given diameter than plain milling cutters. Metal slitting saws are usually used to cut off work and to mill very narrow slots. Some slitting saws are made with side teeth. For heavy sawing in steel, staggered tooth slitting saws, from 3/16 to 3/8 inch thick, are generally used.

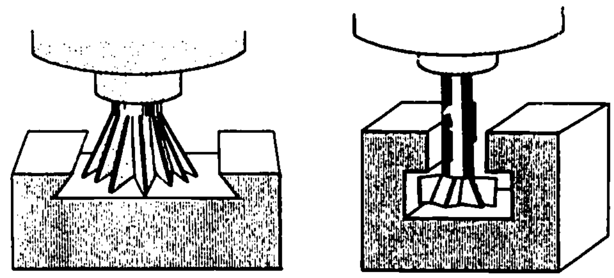
ANGLE (OR ANGULAR) CUTTERS (number 25 of fig. 10-12) are very often used in the manufacture of other milling cutters. If used in milling spiral cutters, the angle cutters must have an angle on each side. Customary angles for such use are 40°, 43°, 45°, or 48° on one side, and 12° on the reverse side.

There are single-angle and double-angle cutters. The common single angle cutters may vary from 40° to 80° to either right or left and are either manufactured with straight keyed holes for mounting on a plain arbor or are threaded for screw arbor mounting. The latter type of mounting eliminates arbor interference on such work as the cutting of dovetails. Double-angle cutters are available in 45°, 60°, or 90° included angles.

END MILLS (numbers 3, 4, 6, 7, and 8 of fig. 10-12) are cutters with teeth on the outer surface and on the end. The end mill has an integral shank and fits or can be "sleeved" directly in the milling machine spindle hole. Two-lipped end mills can be fed directly down into solid stock to the depth required. Multi-lipped end mills, because they have a hole in the center of their diameters, cannot be fed into solid stock until a lead hole slightly larger than the center hole is made.

The SHELL END MILL, number 31 of figure 10-12, has a diameter of more than 2 inches, and is made so that the cutterhead is detachable from a special kind of arbor. A shell end mill is held on a special arbor by means of a capscrew. The arbor head fits into the counterbored face of the cutter, and screws into the arbor. Provided with a tongue or key, the arbor fits a keyway, or slot, in the back face of the cutterhead and drives the cutter.

The T-SLOT CUTTER (fig. 10-13) is a special adaption of the end mill, used for making T-slots in jigs, fixtures, and table tops. The T-slot cutter is made with a solid taper shank



28.206X

Figure 10-13.—Application of T-slot and dovetail cutters.

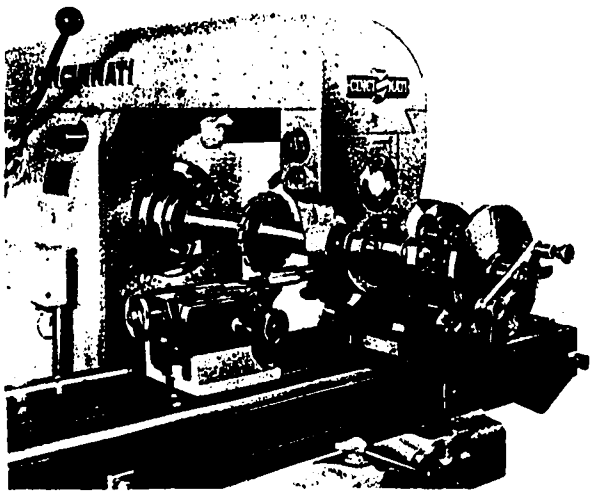
and is provided with few teeth, to leave plenty of chip clearance. The teeth are generally staggered so that each tooth will cut with one side only. These cutters are used for milling slots to receive bolt heads. The central groove is milled with a side cutter first, and then the wide-grooved T-slot is machined with the T-slot cutter.

The DOVETAIL CUTTER (fig. 10-13) is a form of angle cutter, used for cutting angular slots in such things as sliding tables, compound rests, etc. It is shaped like the T-slot cutter except that the cutting edges are at an angle to the shank.

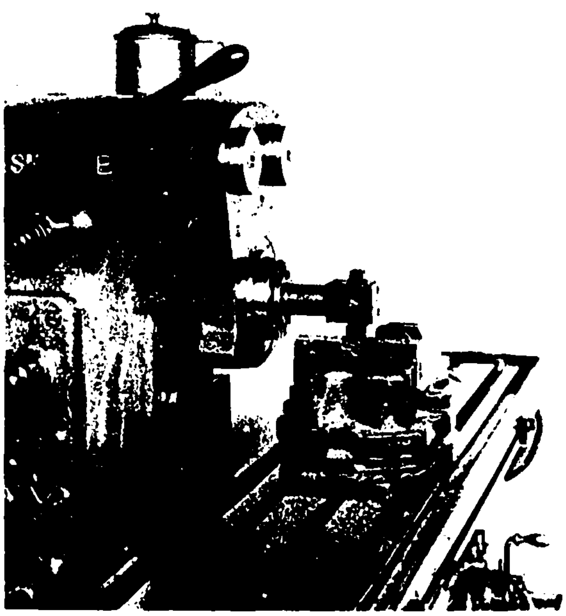
WOODRUFF KEYSEAT CUTTERS are used for cutting semicylindrical keyways in shafts. Cutters under 1 1/2 inches in diameter are provided with a shank and have teeth on the circumferential surface. Their sides are ground slightly concave for clearance. Cutters larger than 1 1/2 inches in diameter are usually of the arbor type. The larger cutters have staggered teeth on the circumferential surface and on the sides. The side teeth are ground for clearance but not for cutting.

FORMED CUTTERS include the convex, concave, corner rounding, gear, sprocket wheel, and hobbing cutters. The curved tooth outline of formed cutters makes possible the accurate and rapid duplication of varying outlines and shapes. Figure 10-14 shows the application of a formed cutter to flute a tap.

The FLY CUTTER, illustrated in figure 10-15, is an improvised cutter used when a multiple tooth type cutter is not suitable. The cutter should be securely held in an arbor driven by the milling machine spindle. A fly cutter may be ground to any desired shape and may be used as a revolving cutter, by feeding the work slowly into it, or as a stationary cutter for



28.207X
Figure 10-14.—Application of a formed cutter.



28.208X
Figure 10-15.—Application of a fly cutter.

finish-scraping work which is fed past the cutter.

The fly cutter, shaped and ground to a special form, is a single tool bit much like the lathe bit. Fly cutters reproduce their shape in the work, but are not very efficient because they remove but one chip per revolution of the spindle. Their gest work is accomplished when a high speed and a fine feed are used. Fly cutters are not expensive to make and can be made as formed cutters.

INSERTED TOOTH CUTTERS have cutting teeth of high-speed steel, Stellite, or carbide-tipped steel inserted in a body of less expensive material; this allows tooth replacement, which reduces the cost of tool upkeep. These cutters are generally made to cut on both the circumferential surface and each side, as is the side milling cutter. Inserted tooth cutters may be applied to an arbor or attached directly to the end of the milling machine spindle.

Universal Milling Attachment

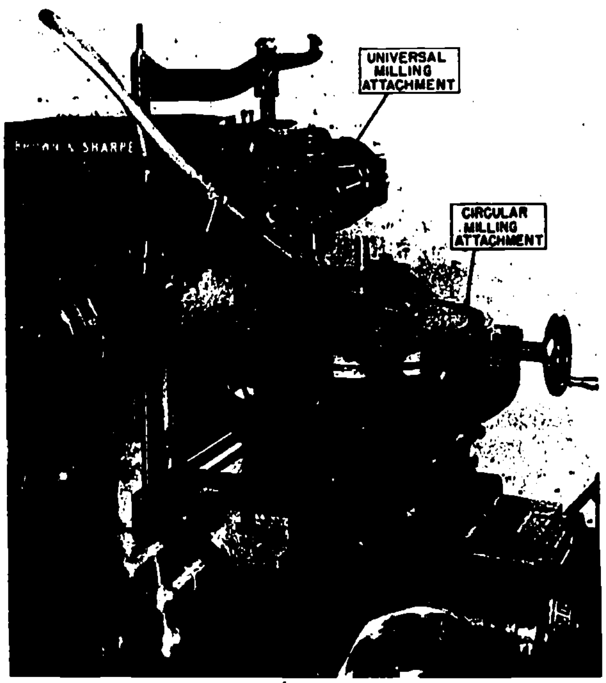
The UNIVERSAL MILLING (HEAD) ATTACHMENT, shown in figure 10-16, is clamped to the column of the milling machine. The cutter can be secured in the spindle of the attachment and then—by means of the two rotary swivels—can be set so that the cutter will cut at any angle to the horizontal or the vertical plane. The spindle of the universal milling attachment is driven by gearing connected to the milling machine spindle.

Circular Milling Attachment

The CIRCULAR MILLING ATTACHMENT or rotary table, shown in figure 10-16, provides a means of setting-up work which must be rotated in a horizontal plane. The worktable is graduated (1/2° to 360°) around its circumference. The table may be turned by hand or by the table feed mechanism through a gear train. An 80 to 1 worm and gear drive contained in the rotary table and index plate arrangement makes this device useful for accurate indexing of horizontal surfaces.

SET UP PROCEDURES

Before starting a milling operation, ensure that the workpiece and the milling machine are arranged properly. Ensure that the workpiece is firmly secured to the holding device. If indexing is required, select the correct method and calculate the number of turns required in the indexing operation. Ensure that the cutter is correctly secured to the spindle, positioned properly over the workpiece, and set to rotate in the proper direction. Select the correct cutting speeds and feeds; consider each job individually, as speeds and feeds for milling often vary considerably even on similar jobs.



28.202X
Figure 10-16.—Circular milling attachment and universal (head) attachment.

An efficient and positive method of holding work on the milling machine is most important if the machine tool is to be used to its best advantage. Regardless of the method used in holding the work, there are certain factors that should be observed in every case. The work must not be sprung in clamping; the work must be secured to prevent it from springing or moving away from the cutter; and the work must be aligned so that it may be correctly machined.

Milling machine tables are provided with several T-slots which are used either for clamping and locating the work itself or for mounting the various holding devices and attachments. These T-slots extend the length of the table and are parallel to the table's longitudinal axis. Most milling machine attachments, such as vises and index heads, have keys or tongues on the underside of their bases; these make it possible to locate the attachments correctly in relation to the T-slots.

There are various methods of holding work, each method being dependent upon the type of work and the operation to be performed. The methods in common use are:

CLAMPING TO THE TABLE.—When work is clamped to the milling machine table, the table and work should be free from dirt and burrs. Work having smooth machined surfaces may be clamped directly to the table, provided the cutter does not come in contact with the table surface during the machining operation. When work with unfinished surfaces is clamped in this way, the table face should be protected with pieces of soft metal. Clamps should be placed squarely across the work to give a full bearing surface. These clamps are held by bolts inserted in the table's T-slots. Clamping bolts should be placed as near the work as possible so that full advantage of the fulcrum principle may be obtained. When it is necessary to place a clamp on an overhanging part, a support should be provided between the overhang and the table to prevent springing or breakage. When heavy cuts are to be taken, fasten a sturdy stop piece to the table at the tail end of the workpiece to help prevent the workpiece from sliding.

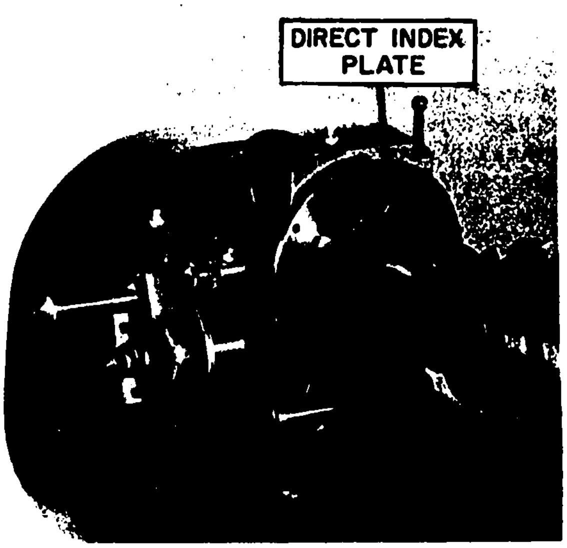
CLAMPING TO THE ANGLE PLATE.—When work is clamped to an angle plate, surfaces may be machined parallel, perpendicular, or at an angle to a given surface. When this method of holding work is used, precautions similar to those recommended for clamping directly to the table should be taken. Angle plates may be either of the adjustable or nonadjustable type and are generally held in alignment by means of keys or tongues that fit into the table's T-slots.

CLAMPING-IN FIXTURES.—Fixtures are generally used in production work when a number of similar pieces are to be machined. The design of the fixture depends upon the shape of the work and the operations to be performed. Fixtures reduce the time required for setting up the work because they are always constructed with maximum clamping surfaces and require a minimum number of clamps or bolts. Fixtures should always be provided with keys or other guides which will assure positive alignment with the table T-slots.

MOUNTING BETWEEN CENTERS.—Index centers are used to support work which is centered on both ends. When the work has been previously reamed or bored, it may be pressed on a mandrel and then mounted between centers.

CLAMPING-IN VISES.—As previously mentioned, three types of vises are manufactured for holding milling machine work. These vises have locating keys or tongues on the underside of the base so that they may be located correctly in relation to the T-slots on the milling machine table.

DIRECT INDEXING.—Direct indexing, sometimes called rapid indexing, makes use of the direct index plate which is mounted just back of the work end of the index head spindle (fig. 10-17). With the index pin out of contact with the direct index plate, disengage the spindle and index by turning the spindle by hand. To divide work into two equal parts, the index pin should be disengaged and the plate and spindle revolved until 11 holes in a 24-hole circle have passed the index pin. The index pin is then inserted into the 12th hole in the plate to hold the spindle in the proper position. IN ANY INDEXING OPERATION ALWAYS START COUNTING FROM THE HOLE ADJACENT TO THE CRANKPIN. During heavy cutting operations, the spindle should be clamped by means of the clamp screw to relieve strain on the index pin.



28.209X

Figure 10-17.—Direct index plate.

PLAIN INDEXING.—Plain indexing, accomplished by using the universal index head, is governed by the number of times the index crank must be turned to cause the work to make one revolution. Charts specifying the required number of turns or fractions of a turn and giving the proper index plate for various divisions are furnished by index head manufacturers. If these charts are unavailable, the required number of turns and parts of turns may be determined by simple calculation.

The number of turns of the index crank required to index a fractional part of a revolution is determined by dividing 40 by the number of divisions required. For example, if you are required to make 40 divisions on a piece of work, 40 would be divided by 40, indicating that one complete turn of the index crank is required for each division. If 10 divisions were required, 40 would be divided by 10 and 4 complete turns of the index crank would be required for each division. Index plates are used to assist in making the division when the quotient of the ratio of the index head and the division desired results in a fraction, thus making it necessary to turn the crank a part of a revolution in indexing. The numerator of the fraction, determined by dividing 40 by the number of divisions required, represents the number of holes in a circle of holes that the index crank should be moved for each desired division. The denominator of this fraction represents the number of holes in the correct circle of holes which should be selected on the index plate. For example, the calculation for determining 800 divisions when an index plate with 20 holes is available, is as follows:

$$\frac{40}{800} = \frac{1}{20}$$

or 1 hole on the 20-hole circle.

When the fraction is such that none of the available index plates contain the number of holes represented by the denominator, multiply both the numerator and denominator by a common multiplier. For example, the calculation for determining 9 divisions when an index plate having a 27-hole circle is available, is as follows:

$$\frac{40}{9} \times \frac{3}{3} = \frac{120}{27} = 4\frac{12}{27}$$

or 4 complete turns plus 12 holes on the 27-hole circle.

If the denominator of the fraction is larger than the number of holes that are available in an index plate, divide both the numerator and denominator by a common divisor that will give a fraction in which the denominator represents the number of holes for which the index plate is available. For example, the calculation for determining 76 divisions when an index plate having a 19-hole circle is available, is as follows:

$$\frac{40}{76} \div \frac{4}{4} = \frac{10}{19}$$

or 10 holes in the 19-hole circle.

If when reducing the fraction, as discussed in the foregoing paragraph, the denominator becomes so small that no available index plate contains the number of holes represented by the denominator, the fraction should be raised to an available number. For example, the calculation for determining 52 divisions when an index plate with a 39-hole circle is available, is as follows:

$$\frac{40}{52} \div \frac{4}{4} = \frac{10}{13} \times \frac{3}{3} = \frac{30}{39}$$

or 30 holes in a 39-hole circle.

ANGULAR INDEXING.—When it is necessary to divide work into degrees or fractions of degrees by plain indexing, remember that one turn of the index crank will rotate a point on the circumference of the work 1/40 of a revolution. Since there are 360° in a circle, one turn of the index crank will revolve the circumference of the work 1/40 of 360°, or 9°. Hence, when using the index plate and fractional parts of a turn, 2 holes in an 18-hole circle equals 1°, 1 hole in a 27-hole circle equals 2/3°, 3 holes in a 54-hole circle equals 1/2°, and 2 holes in a 54-hole circle equals 1/3°. To determine the number of turns and parts of a turn of the index crank for a desired number of degrees, the number of degrees should be divided by 9, and the quotient will represent the number of complete turns and fractions of a turn that the index crank should be rotated. For example, the calculation for determining 15° when an index plate with a 54-hole circle is available, is as follows:

$$\frac{15}{9} = 1\frac{6}{9} = 1\frac{36}{54}$$

or 1 complete turn plus 36 holes on the 54-hole circle. The calculation for determining 13 1/2° when an index plate with an 18-hole circle is available, is as follows:

$$\frac{13.5}{9} = 1\frac{4.5}{9} = 1\frac{9}{18}$$

or 1 complete turn plus 9 holes on the 18-hole circle.

When indexing angles are given in minutes, and approximate divisions are acceptable, movement of the index crank and the proper index plate may be determined by the following calculations. The number of minutes represented by one turn of the index crank can be determined by multiplying the number of degrees covered in one turn of the index crank by 60. Thus,

$$9^\circ \times 60' = 540'$$

Therefore, one turn of the index crank will rotate the index head spindle 540 minutes.

The number of minutes, 540, divided by the number of minutes in the division desired, indicates the total number of holes the index plate circle to be used should have. (Moving the index crank one hole will rotate the index head spindle through the desired number of minutes of angle.) This method of indexing can be used only for approximate angles since ordinarily the quotient will come out in mixed numbers or in numbers for which there are no index plates available. However, when the quotient is nearly equal to the number of holes in an available index plate, the nearest number of holes can be used and the error will be very small. For example, the calculation for 24 minutes would be:

$$\frac{540}{24} = \frac{22.5}{1}$$

or one hole on the 22.5-hole circle. Since there is no 22.5-hole circle on the index plate, a 23-hole circle plate would be used.

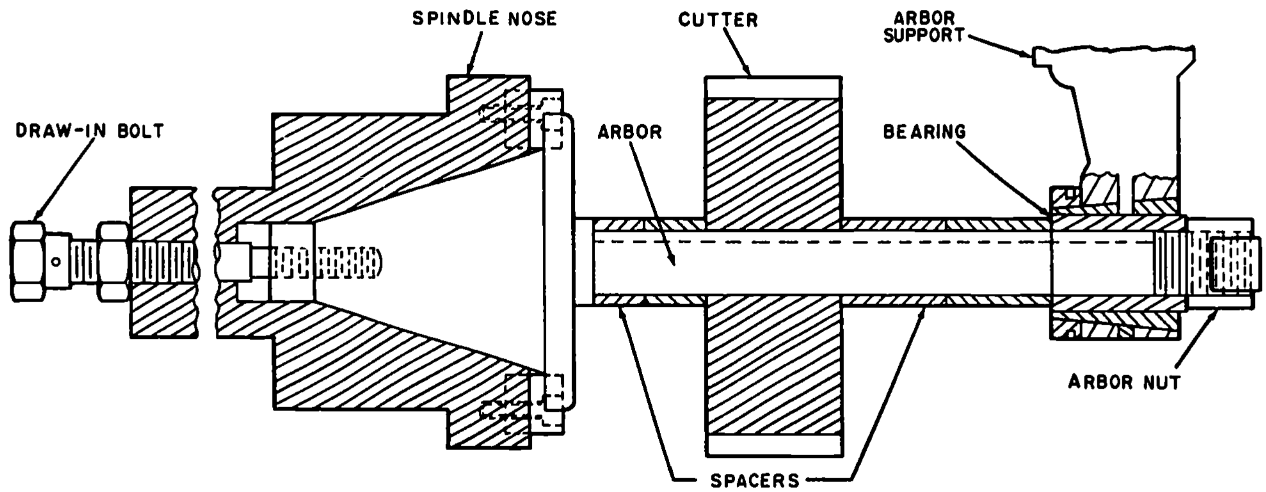
If a quotient is not approximately equal to an available circle of holes, then multiply by any trial number which will give a product equal to the number of holes in one of the available index circles. The crank can then be moved the required number of holes to give the desired division. For example, the calculation for determining 54 minutes when an index plate having a 20-hole circle is available, is as follows:

$$\frac{540}{54} = \frac{10}{1} \times \frac{2}{2} = \frac{20}{2}$$

or 2 holes on the 20-hole circle.

To mount a cutter on an arbor (fig. 10-18):

1. Select an arbor having the same diameter as the hole in the cutter.



28.211

Figure 10-18.—Standard arbor.

2. Remove the arbor nut and as many spacers as necessary so that the cutter can be positioned as near the spindle nose as feasible. Remember that the cutter must be far enough away from the spindle nose to permit the workpiece to clear the column during the milling cut.

3. Place the cutter on the arbor and align the cutter and arbor keyways and insert a key.

4. Replace the required number of spacers so that tightening the arbor nut will clamp the cutter between the spacers.

5. Screw the arbor nut on the arbor by hand.

6. Place the arbor in the milling machine spindle and insert the draw-in bolt through the spindle, screw the bolt into the arbor by hand as far as possible. Then back the draw-in bolt out of the arbor about one turn.

7. Tighten the draw-in bolt locking nut with a wrench until the arbor is tightly secured in the spindle.

8. Position the overarm and yoke to provide adequate support for the cutter. Then, using a wrench, take up on the arbor nut so that the cutter is clamped securely.

The procedure for installing an adapter for tapered shank cutters is similar to installing the arbor in the mill spindle. The taper shank cutter is then inserted in the tapered hole of the adapter. Tap the cutter end lightly with a rawhide mallet to ensure that it seated securely.

Face mills are usually mounted directly on the spindle nose of the mill. The back of the face mill is counterbored to fit the spindle nose and has radial slots which fit the driving lugs of the spindle. The cutter is secured to the spindle nose by bolts which are inserted through the face of the cutter and screwed into the spindle nose.

Before mounting a cutter always ensure that the cutter, adapter, arbor, and mill spindle are clean and free of burrs and upset edges.

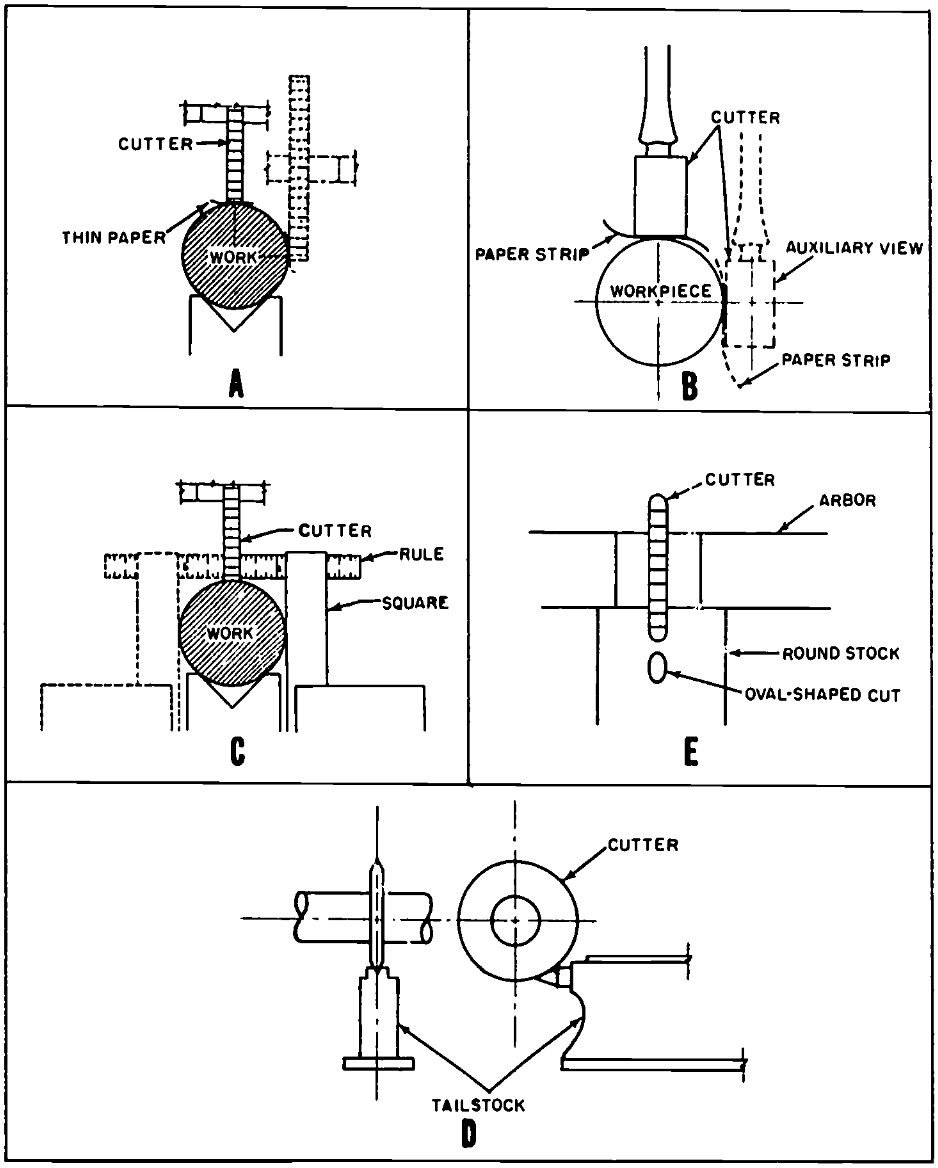
CENTERING THE CUTTER.—Figure 10-19 shows common methods of positioning a cutter. Methods A, B, and C of figure 10-19 can be used on cylindrical or noncylindrical workpieces. Methods D and E are used when centering the cutter on the axis of cylindrical workpieces; method E is used when the workpiece is mounted between centers.

The methods illustrated in A and B of figure 10-19 are the most accurate methods and should be used when possible. To position a cutter by these methods:

1. Move the workpiece into position as shown by the auxiliary views in A and B of figure 10-19 with the cutter about 0.010 inch away from the workpiece.

2. Insert a strip of paper (0.003 inch thick) between the cutter and the side of the workpiece and hold in place.

3. Start the cutter turning slowly and feed the workpiece toward the cutter until the cutter tears the paper strip; feed the table toward the cutter another 0.003 inch (thickness of the paper). The cutter will now be in very light contact with the workpiece.



28.212

Figure 10-19.—Methods of positioning cutter.

4. Lower the workpiece so that the cutter will clear the top of the workpiece.

5. Set the micrometer collar on the transverse feed handwheel to zero.

6. Move the worktable transversely by an amount equal to one-half the thickness of the cutter plus one-half the diameter of the workpiece (fig. 10-19A). The cutter is now centered on the axis of the shaft.

The method just described works equally well on cylindrical and noncylindrical workpieces and with end mills as well as arbor type cutters. If the cutter is so small that the arbor or spindle nose touches the workpiece, the cutter can be aligned with some degree of accuracy by using a straightedge placed on the side of arbor type cutters or periphery of end mills for aligning the cutter to a zero point. In moving the workpiece transversely always remember that the thickness (of an arbor cutter) or the diameter (of an end mill) will affect the final transverse position of the cutter. Be very careful to keep your hands clear of the cutter when using the paper strip.

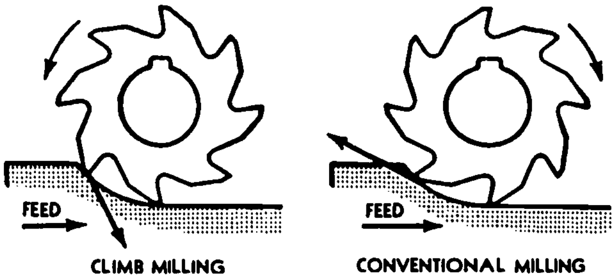
Part E of figure 10-19 illustrates a method of centering a cutter on the axis of a workpiece which is used when the tooth profile of the cutter is convex. The work is adjusted so that the cutter is approximately centered over the work. Then the work is moved up until the rotating cutter takes a light depth of cut. If a regular oval-shaped cut appears the cutter is centered; if the profile of one side of the oval differs from the other side, the workpiece must be adjusted transversely.

DIRECTION OF CUTTER ROTATION.—When you select the direction of cutter rotation and table travel, the conventional milling practice, sometimes called the UP METHOD, is to make the cutter revolve against the advancing table (fig. 10-20). In milling deep slots or in cutting off thin stock with a metal slitting cutter, another system known as the CLIMB MILLING process is used. In this process you should move the work with the cutter, making the cutter cut down into the work. With this latter system there is less chance of producing crooked slots as a result of the cutter being drawn to one side.

When the work moves with the cutter, you must take care to eliminate any looseness and lost motion in the table by setting the table gibs snugly. If you fail to eliminate looseness the cutter teeth may draw the work in. The result may be a sprung arbor, a badly damaged cutter, a ruined piece of work, or serious personal injury.

FEEDS AND SPEEDS

Milling machines usually have a spindle speed range from 25 to 2,000 rpm and a feed range from 1/4 inch to 30 inches per minute (ipm). The feed is independent of the spindle



28.213X
Figure 10-20.—Conventional and climb milling.

speed; thus a workpiece can be fed at any rate available in the feed range regardless of what spindle speed is being used. Some of the factors concerning the selection of appropriate feeds and speeds for milling are discussed in the following paragraphs.

SPEEDS.—Heat generated by friction between the cutter and the work may be regulated by the use of proper speed, feed, and cutting coolant. Regulation of this heat is very important because the cutter will be dulled or even made useless by overheating. It is almost impossible to set down any fixed rules that will govern cutting speeds, because of conditions which vary from job to job. Generally speaking, a cutting speed should be selected which will give the best compromise between maximum production and longest life of the cutter. In any particular operation, the following factors should be considered in determining the proper cutting speed:

1. HARDNESS OF THE MATERIAL BEING CUT. The harder and tougher the metal being cut, the slower should be the cutting speed.
2. DEPTH OF CUT AND DESIRED FINISH. The amount of friction heat produced is directly proportional to the amount of material being removed. Finishing cuts may, therefore, often be made at a speed 40 to 80 percent higher than that used in roughing.
3. CUTTER MATERIAL. High-speed steel cutters may be operated from 50 to 100 percent faster than carbon steel cutters because high-speed steel cutters have better heat resistant properties than carbon steel cutters.
4. TYPE OF CUTTER TEETH. Cutters which have undercut teeth cut more freely than those having a radial face; therefore cutters with undercut teeth may be run at higher speeds.
5. SHARPNESS OF THE CUTTER. A sharp cutter may be run at a much higher speed than a dull cutter.
6. USE OF COOLANT. Sufficient coolant will usually cool the cutter so that it will not overheat even at relatively high speeds.

The approximate values given in table 10-1 may be used as a guide when you are selecting the proper cutting speed. If you find that the machine, the cutter, or the work cannot be suitably operated at the suggested speed, immediate readjustment should be made.

The proper revolutions per minute of the cutter may be determined by means of the formula:

(a) $$\text{rpm} = \frac{\text{Cutting speed} \times 12}{3.1416 \times \text{Diameter}}$$

Table 10-1.—Surface Cutting Speeds

	Carbon steel cutters (ft. per min.)		High Speed steel cutters (ft. per min.)	
	Rough	Finish	Rough	Finish
Cast iron:				
Malleable	60	75	90	100
Hard castings	10	12	15	20
Annealed tool steel	25	35	40	50
Low carbon steel	40	50	60	70
Brass	75	95	110	150
Aluminum	460	550	700	900

The proper revolutions per minute of the cutter may be determined by means of the formula:

(a) $$\text{rpm} = \frac{\text{Cutting speed x 12}}{\text{3.1416 x Diameter}}$$

or $$\text{rpm} = \frac{\text{fpm}}{0.2618 \times D}$$

Where:

rpm = revolutions per minute of the cutter

fpm = required surface speed in feet per minute

D = diameter of cutter in inches

$0.2618 = \text{constant} = \frac{\pi}{12}$

EXAMPLE:—What is the spindle speed for a 1/2-inch cutter running at 45 fpm?

$$\text{rpm} = \frac{45}{0.2618 \times 0.5}$$

$$\text{rpm} = 343.7$$

$$\text{fpm} = \frac{3.1416 \times \text{Diameter} \times \text{rpm}}{12}$$

$$\text{fpm} = 0.2618 \times D \times \text{rpm}$$

EXAMPLE.—What is the cutting speed of a 2-1/4-inch end mill running at 204 rpm?

$$\text{fpm} = 0.2618 \times D \times \text{rpm}$$

$$\text{fpm} = 0.2618 \times 2.25 \times 204$$

$$\text{fpm} = 120.1$$

FEEDS.—The rate of feed is the rate of speed at which the workpiece travels past the cutter. When selecting the feed, you should consider the following factors:

1. Forces are exerted against the work, the cutter, and their holding devices during the cutting process. The force exerted, varying directly with the amount of metal removed, can be regulated by the feed and depth of cut. The feed and depth of cut, therefore, seem to be interrelated, and, in turn, are dependent upon the rigidity and power of the machine. Machines are limited by the power they can develop to turn the cutter, and by the amount of vibration they can withstand when coarse feeds and deep cuts are being used.

2. The feed and depth of cut also depend upon the type of cutter being used. For example, deep cuts or coarse feeds should not be attempted with a small diameter end mill, as such an attempt would spring or break the cutter. Coarse cutters with strong cutting teeth can be fed at a relatively high rate of feed because the chips will be washed out easily by the cutting lubricant.

3. Coarse feeds and deep cuts should not be used on a frail piece of work or on work mounted in such a way that the holding device will spring or bend.

4. The desired degree of finish affects the amount of feed. When a fast feed is used, metal is removed rapidly with the result that the finish will not be very smooth. However, a slow feed rate and a high cutter speed will produce a finer finish. For roughing, it is advisable to use a comparatively low speed and a coarse feed. More mistakes are made by overspeeding the cutter than by overfeeding the work. Overspeeding may be detected by a squeaking, scraping sound. If chattering occurs in the milling machine during the cutting process, reduce the speed and increase the feed. Excessive cutter clearance, poorly supported work, or a badly worn machine gear are also common causes of chattering.

COOLANTS

The purpose of a cutting coolant is to reduce frictional heat and thereby extend the life of the cutter's edge. Coolant also serves to lubricate the cutter face and to flush away the chips, thus reducing the possibility of damage to the finish.

If a commercial cutting coolant is not available, a good substitute may be made by thoroughly mixing 1 ounce of sal soda and 1 quart of lard oil in 1 gallon of water. Since the coolant tank holds 4 or 5 gallons, increase the ingredients proportionally. This emulsion is suitable for the machining of most metals.

In the machining of aluminum, kerosene should be used as a cutting coolant. Cast iron should be machined dry, although a blast of compressed air may be used to cool the work and the cutter.

The coolant should be directed to the point where the cutter strikes the work. The coolant should be allowed to flow freely on the work and cutter.

MACHINE OPERATION

Milling operations performed in the optical shop commonly require shifting the workpiece, changing the cutter and readjusting feeds and speeds before the job is finished. Each change in setup can usually be considered as a separate job. The methods of cutting and typical examples of milling jobs described here provide information that can be applied to almost any milling operation.

Methods of cutting may be classified under four general headings:

FACE MILLING—machining flat surfaces which are at right angles to the axis of the cutter.

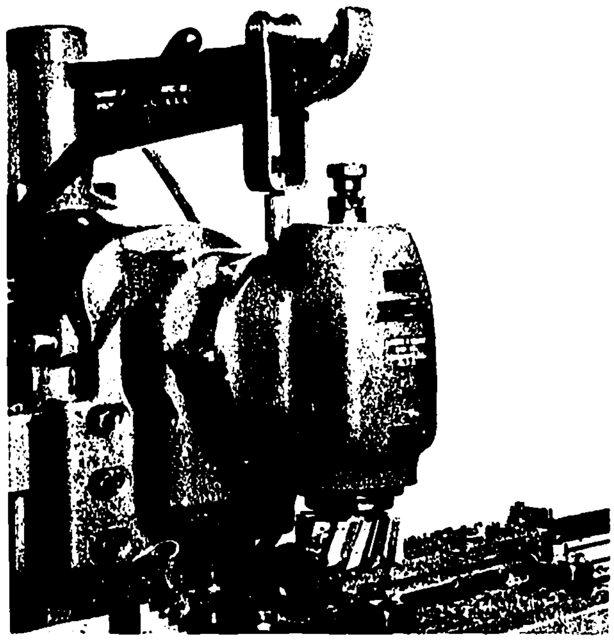
PLAIN OR SLAB MILLING—machining flat surfaces which are parallel to the axis of the cutter.

ANGULAR MILLING—machining flat surfaces which are on an inclination to the axis of the cutter.

FORM MILLING—machining surfaces having an irregular outline.

Explanatory names, such as sawing, slotting, and gear cutting, have been given to special operations. Routing is the term applied to milling of an irregular outline while controlling the work movement by hand feed. The grooving of reamers and taps is called fluting. Gang milling is the term applied to an operation in which two or more cutters are used together on one arbor. Straddle milling is the term given to an operation in which two or more milling cutters are used to mill two or more sides of a piece of work at the same time.

End and side milling cutters are used for face milling operations, the size and nature of the work determining the type and size of cutter required. In face milling (fig. 10-21), the teeth on the periphery of the cutter do practically all of the cutting. The face teeth actually remove a small amount of stock left from the spring of the work or cutter, thereby producing a finer finish. Be sure that all end play of the spindle is eliminated and that the cutter is properly placed.



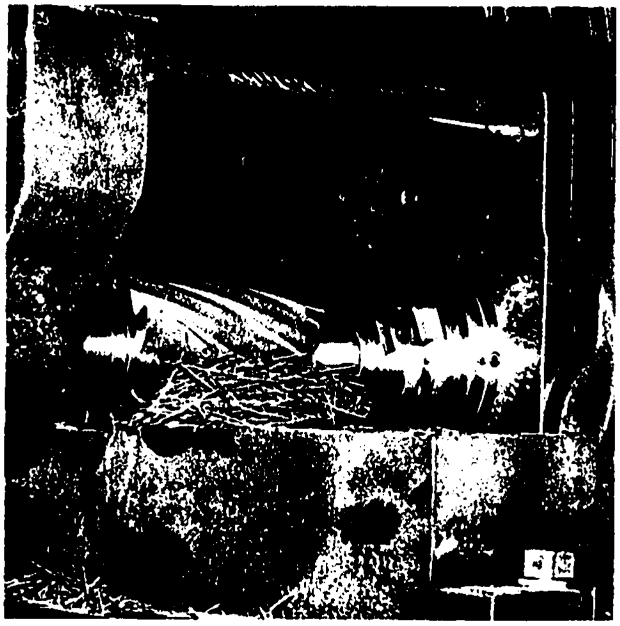
28.214X

Figure 10-21.—Face milling.

When face milling, the work may be clamped to the table or an angle plate or held in a vise, fixture, or jig. The work should be fed against the cutter in such a way that the pressure of the cut is downward, thereby holding the work against the table.

When setting the depth of cut on a flat surface, the work should be brought up to the cutter so that a .002-inch feeler gage, held between the work and the cutter, can just be inserted (or a thin piece of paper will just tear when held between the cutter and the work). At this point, the graduated dial on the transverse feed should be locked and used as a guide in determining the depth of cut. When starting the cut, move the work so that the cutter is nearly in contact with the edge of the work; then the automatic feed may be engaged. If a cut is started by hand, avoid pushing the corner of the work between the cutter teeth too quickly as this may cause the cutter teeth to break. The feed trips should be adjusted to stop the table travel just as the cutter clears the work; this will avoid idle time during the milling operation.

Plain mil... and slab milling are terms generally used to describe the removal of stock



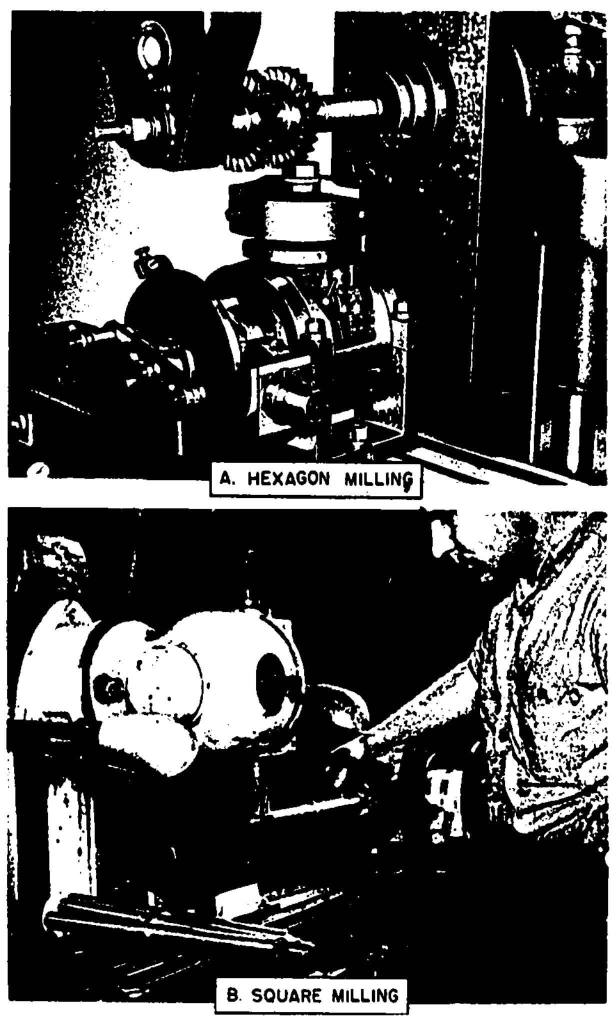
28.215X
Figure 10-22.—Slab milling.

from an uninterrupted horizontal surface as shown in figure 10-22. As slabbing (or plain milling) usually removes a great amount of stock in a short time it is essential that maximum rigidity of the workpiece and cutter be provided. Cutters with coarse teeth (to withstand heavy cutting pressures) and large helix angles, up to 45°, (to maintain continuous tooth contact and an even cutting pressure) are generally used in slab milling. Note in figure 10-22 that the cutter is mounted on a large diameter arbor and that the distance between the yoke and column is just enough to permit the workpiece to clear as it passes. Notice also that an overarm support bracket provides additional support for the cutter setup.

Angular milling is the milling of surfaces at an angle (other than horizontal or vertical) to the reference, or base, surface. Angular milling may be done with formed angular cutters such as dovetail cutters, by mounting the workpiece at an angle to the cutting surface of the cutter, or by setting the cutter at an angle to the base surface of the workpiece as when using the universal milling attachment.

Form milling is the production of irregularly profiled cuts such as gear teeth. The major difficulty in form milling is the setting or centering of the cutter because the formed cutting edges of the cutter teeth do not provide a ready reference point from which the movement in aligning the workpiece can be gaged. Unusual shaped cuts can be milled by using a fly cutter with an inserted cutter ground to the shape required.

When milling a hexagon (fig. 10-23) or a square on a bolt or similar piece, the cutting operation may be accomplished by end milling, side milling, or straddle milling. Regardless of the method used, work should be indexed with the index head—direct indexing is generally recommended. The work, may be held in the chuck, on centers, or in the chuck and supported by the footstock.



28.216
Figure 10-23.—Milling flats on round stock.

When side milling or straddle milling, the work is usually held in the chuck. For end milling, the work may be held in the chuck, on centers, or in the chuck and supported by the footstock.

Long work, such as a reamer that is to be squared, may be mounted between centers or held in the chuck and supported on the outer end by the footstock center. The cutter used should be an end mill and the work should be fed vertically. During this operation, the clamp provided at the front of the table should be brought into position to prevent longitudinal movement.

Where the number of pieces to be machined warrants the additional setup time required, the work may be held in a vertical position and straddle milled. A pair of side milling cutters, which are of like diameter and of such a size that the space collar placed between them will clear the work, should be used. In adjusting the milling cutters for the proper width of hexagon or square, spacers are used to obtain the required spacing of the cutters. The work should be held in the chuck which in turn is fastened to the index head. The spindle of the index head may then be adjusted to the required vertical position. When the work is held in the chuck, be careful to align the work so that all sides of the hexagon or square will be milled to the same length. As two sides of the work are finished at a cut, a square is completed with two cuts and a hexagon with three cuts.

Side and end milling cutters are used to cut hexagons and squares except in the production of a number of like parts as just described. When the side or end milling cutter is used, work is generally held in a chuck fastened to the index head. The spindle of the index head may be adjusted to either the vertical or horizontal position. The vertical position is preferred, since the work is more easily observed and handled. To eliminate loosening of the chuck when only one cutter is used, the feed should be so arranged that it will operate in a direction that will tend to tighten the chuck thread.

Usually, an opticalman will be able to get the repair parts you need from the supply department of your ship. On occasions however, this may not be true and it is necessary to manufacture spur gears or other parts. The following discussion on gear nomenclature, and gear manufacture by utilization of spur gear formulas, will assist you in your tasks. You must bear in mind that only through application of this information and good experience will you be able to satisfactorily manufacture gears that will work properly.

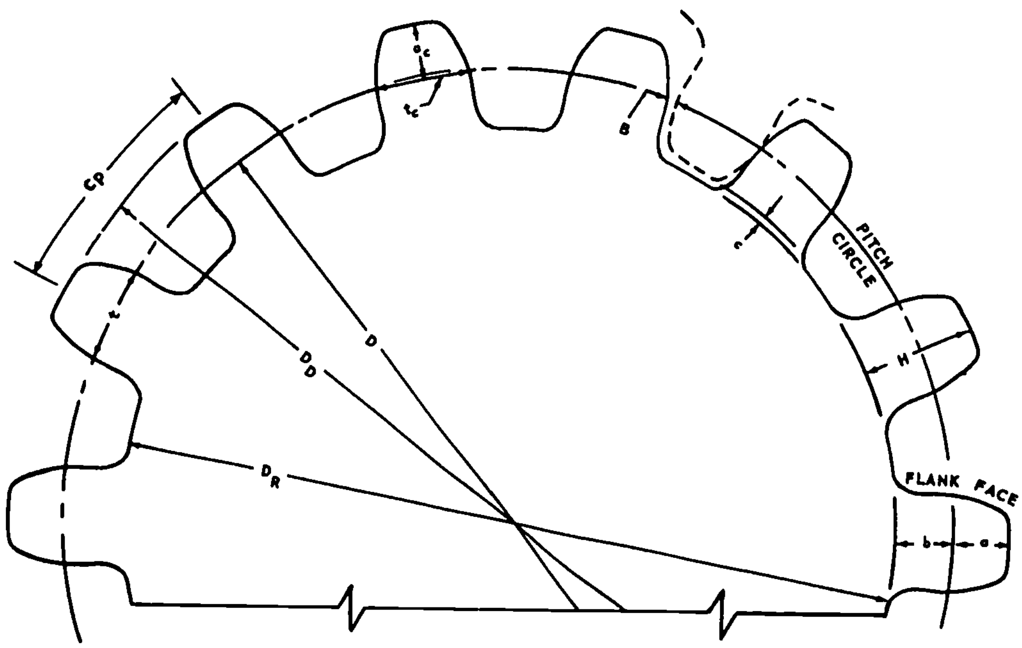
The two most important things pertaining to the manufacture of a gear are: (1) calculating gear dimensions, and (2) selecting the proper cutter for machining the gear teeth.

In order for you to calculate dimensions of a gear, you need to know the terms used to designate the parts of a gear. The brief discussion which follows provides this information.

Refer to illustration 10-24 for terms used in referring to or describing gears and gear teeth. The symbols in parentheses are standard gear nomenclature symbols.

1. Outside diameter (D_O) is the overall diameter of a gear.
2. Pitch diameter (D) represents the diameter of a circle used to calculate the dimensions of a gear. This pitch diameter is less than the outside diameter by an amount equal to twice the addendum.
3. Diametral pitch (P) is a ratio or number of teeth per inch of pitch diameter.
4. Circular pitch (Cp) represents the length of an arc of the pitch circle measured from a point on one tooth to a corresponding point on the next tooth. There are as many circular pitches (of equal length) in a gear as there are teeth in that gear.
5. Addendum (a) is the height of a tooth above the pitch circle along a radial line.
6. Dedendum (b) is the depth of a tooth below the pitch circle along a radial line.
7. Whole depth of tooth (H) represents the total depth of a tooth groove. It consists of one addendum plus (+) one dedendum.
8. Root diameter (D_R) is the outside diameter less TWICE the whole depth.
9. Although not shown in the illustration, center distance (C) is the distance between the axes of a pair of gears correctly meshed.
10. Chordal addendum (a_c) represents the distance (measured on a radial line) from the top of a gear tooth to a chord subtending the intersections of the tooth-thickness arc and the sides of the tooth. Chordal tooth thickness (t_c) represents the length of a chord subtended by the circular-tooth-thickness arc.

Several methods have been devised for checking the accuracy of gear teeth, one of which is checking the thickness of a gear tooth on a straight line through the points at which the pitch circle touches the gear tooth. This is the measurement of CHORDAL THICKNESS.



a--addendum
a_c--chordal addendum
b--dedendum
c--clearance

t_c--chordal tooth thickness
t--arc tooth thickness on pitch circle
c_p--circular pitch

H--whole depth of tooth
D--pitch diameter
D_O--outside diameter
D_R--root diameter
B--backlash

28.259

Figure 10-24.—Gear nomenclature.

Various instruments are used for measuring chordal thickness, including a gear-tooth vernier caliper with a horizontal scale and a vertical scale. Tables of chordal thicknesses and corrected addenda are shown in standard engineering handbooks for a range of gears from 10 teeth to 140 teeth (and over), based on a diametral pitch of 1. For other pitches, divide the values in the tables by the specific diametral pitches.

11. Backlash (B) represents the difference between the tooth thickness and the tooth space of engaged gear teeth at the pitch circle.

Gear calculations and measurements were greatly simplified by perfection of the diametral pitch system, which is based on the diameter of the pitch circle—not the circumference. The circumference of a circle is 3.1415 times its diameter, and you must always consider this constant when you calculate measurements based on the pitch circumference; and in order to simplify computations, this constant (3.1416 x diameter) has been BUILT IN, or made a part of, the diametral pitch system.

When you use the diametral pitch system, you need not calculate circular pitch or chordal pitch—indexing devices based on the system accurately space the teeth, and the formed cutter associated with the indexing device forms the teeth within required accuracy. Calculations of teeth depth, center distances, and all other calculations, have been simplified by the diametral pitch system.

Usually the outside diameter (D_O) of a gear and the number of teeth (N) are listed on the blueprint for a gear. By using these factors, and appropriate gear formulas, you can calculate the data you need for making a gear.

Suppose, for example, that you must make a gear with 24 teeth and a diameter of 3.250 inches. The procedure for doing this is:

1. Find the pitch diameter with this formula:

$$D = \frac{ND_o}{N + 2}$$

When you make proper substitutions in this formula and solve for D, you get:

$$D = \frac{24 \times 3.250}{24 + 2} \quad \frac{78}{26} = 3.000 \text{ inches}$$

2. Find the diametral pitch (P) by solving (with proper substitutions) the following formula:

$$P = \frac{N}{D}, \text{ or } P = \frac{24}{3} = 8$$

3. Make proper substitutions in the following formula and solve for H to get the whole depth of the tooth:

$$H = \frac{2.157}{P}, \text{ or } H = \frac{2.157}{8} = 0.2696 \text{ inch}$$

After you compute the diametral pitch for your gear, select the proper gear cutter to cut 24 teeth on it.

Formed gear cutters are made with eight (8) different forms (numbered from 1 to 8) for each diametral pitch, in accordance with the number of teeth for which the cutter is to be used. The accompanying chart indicates the range of teeth

Number of Cutter	Range of teeth
1	135 to a rack
2	55 to 134
3	35 to 54
4	26 to 34
5	21 to 25
6	17 to 20
7	14 to 16
8	12 to 13

Since the gear in this example must have 24 teeth, you need a number 5 cutter, which cuts gears which have from 21 to 25 teeth. Most cutters are stamped by number, diametral pitch, range, and depth.

After you cut the teeth on your gear, check your dimensional accuracy with a vernier caliper. Find first the arc tooth thickness and the addendum by using the following formulas, respectively:

$$t = \frac{1.5708}{P} = 0.1964 \text{ inch, in your example}$$

$$a = \frac{3.000}{24} = 0.125 \text{ inch}$$

Then adjust the vertical scale of the caliper to the chordal addendum, the formula for calculating which is:

$$a_c = a + \frac{t^2}{4D}, \text{ or } a_c = 0.125 = \frac{(0.1964)^2}{4 \times 3}$$

$$0.125 + \frac{0.0286}{12} \; 0.128 \text{ inch}$$

MILLING MACHINE PRECAUTIONS

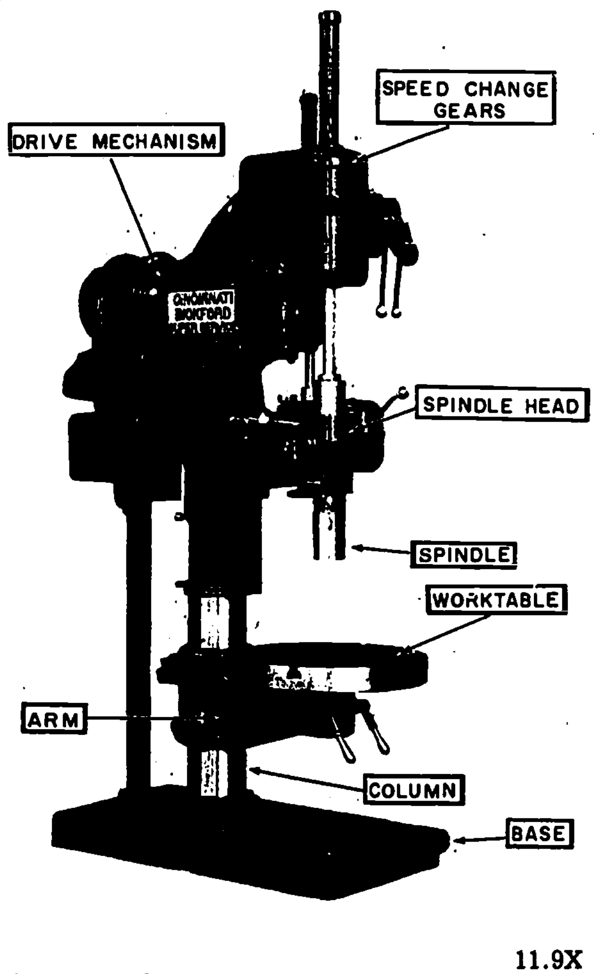
A milling machine operator's first consideration should be for his own safety, and he should attempt nothing that may endanger his life and limb. CARELESSNESS and IGNORANCE are the two great menaces to personal safety. Milling machines are not playthings and must be accorded the respect due any machine tool. For your own safety, observe the following precautions:

1. Never attempt to operate a machine unless you are sure you thoroughly understand it.
2. Do not throw an operating lever without knowing in advance the outcome.
3. Do not play with control levers, or idly turn the handles of a milling machine, even though it is not running.
4. Never lean against or rest your hands upon a moving table. If it is necessary to touch a moving part, be certain you know in advance the direction in which it is moving.
5. Do not take a cut without making sure that the work is secure in the vise or fixture, and that the holding member is rigidly fastened to the machine table.
6. Always remove chips with a brush or other suitable agent—never with the fingers or hands.
7. Before you attempt to operate any milling machine, study its controls thoroughly so that if an emergency arises during operation you can stop it immediately.
8. Above all, you must keep clear of the cutters. Do not touch a cutter, even when it is stationary, unless there is a good reason for doing so; and if you must touch it, be very careful.

If you follow certain safety practices, operation of a milling machine is not dangerous. There is always danger, however, of getting caught in the cutter. CAUTION: Never attempt to remove chips with the fingers at the point of contact of the cutter with the work. There is some danger to the eyes from flying chips and you must always protect your eyes with goggles and keep them out of line of the cutting action.

DRILL PRESSES

Although drilling machines or drill presses are commonly used by untrained personnel, you cannot assume that operating these machines proficiently is simply a matter of inserting the proper size drill and starting the machine. As an opticalman, you will be required to perform drilling operations with a great degree of accuracy. It is therefore necessary for you to be well acquainted with the types of machines and



11.9X
Figure 10-25.—General purpose drill press.

the methods and techniques of operation of drill presses and drills found in Navy shops.

Upright drill presses discussed in this section will be the general purpose, the heavy duty, and the sensitive drill presses. One or more of these types will be found on practically all ships. They are classified primarily by the size of drill that can be used, and by the size of the work that can be set up.

MAJOR ASSEMBLIES

The GENERAL PURPOSE DRILL PRESS (ROUND COLUMN) (fig. 10-25) is perhaps the most common upright type of machine and has flexibility in operational characteristics. As you can see in the illustration, the basic components of this machine are:

1. The BASE has a machined surface with T-slots for heavy or bulky work.
2. The COLUMN supports the worktable, the drive mechanism and spindle head.
3. The WORKTABLE and ARM can be swiveled around the column and can be moved up or down to adjust for height. In addition, the worktable may be rotated 360° about its own center.
4. The SPINDLE HEAD guides and supports the spindle and can be adjusted vertically to provide maximum support near the spindle socket.
5. The SPINDLE is a splined shaft having a Morse taper socket for holding the drill. The spline permits vertical movement of the spindle while it is rotating.
6. The DRIVE MECHANISM includes the motor, speed and feed change gears, and mechanical controls.

HEAVY DUTY DRILL PRESSES (BOX COLUMNS) are normally used in drilling large holes. They differ from the general purpose drill presses in that the worktable moves vertically only. The worktable is firmly gibbed to vertical ways or tracks on the front of the column and is further supported by a heavy adjusting screw from the base to the bottom of the table. As the table can be moved vertically only, it is necessary to position the work for each hole.

The SENSITIVE DRILL PRESS (fig. 10-26) is used for drilling small holes in work under conditions which make it necessary for the operator to "feel" what the cutting tool is doing. The tool is fed into the work by a very simple device—a lever, a pinion and shaft, and a rack which engages the pinion. These drills are nearly always belt driven because the vibration caused by gearing would be undesirable. Sensitive drill presses are designed for use in drilling holes less than one-half inch in diameter. The high speed range of these machines and the holding devices used, make them unsuitable for heavy work.

SPEEDS AND FEEDS

The cutting speed of a drill is expressed in feet per minute (fpm). This speed is computed by multiplying the circumference of the drill (in inches) by the revolutions per minute (rpm) of the drill. The result is then divided by 12. For example, a 1/2-inch drill, which has a circumference of approximately 1 1/2 inches, turned at 100 rpm has a surface speed of 150 inches per minute. To obtain fpm, divide this figure by 12 which results in a cutting speed of approximately 12 1/2 feet per minute.

The correct cutting speed for a job depends upon the degree of machinability of the metal and the type of drill used. The following speeds are recommended when using high speed drills.

Alloy steel	50-70 fpm
Machine steel	70-100 fpm
Cast iron	70-150 fpm
Brass	200-300 fpm

Carbon steel drills should be run at approximately one-half the speeds given above. With practice, you will be able to determine for yourself the correct speed for each piece of work.

The speed of the drill press is given in rpm. Tables giving the proper rpm at which to run a drill press for a particular metal are usually available in the machine shop, or they may be found in machinist's handbooks. A formula may be used to determine the rpm required to give a specific rate of speed in fpm for a specific size of drill. For example, if you wish to drill a hole 1 inch in diameter at the speed of 50 fpm, you would compute the rpm as follows:

$$\text{rpm} = \frac{\text{fpm} \times 12}{\pi \times D}$$

$$= \frac{50 \times 12}{3.1416 \times 1}$$

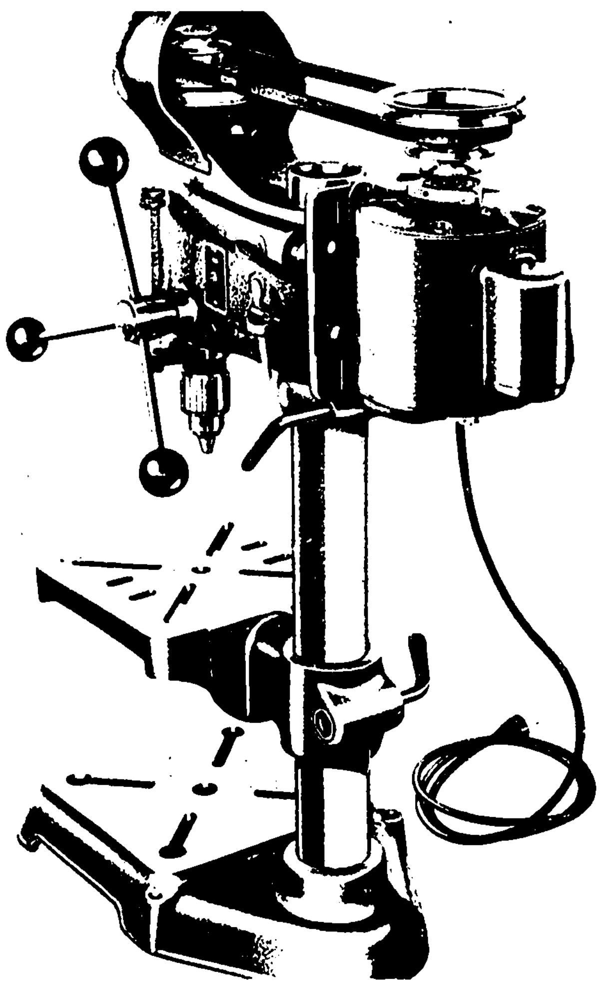
$$= \frac{600}{3.1416}$$

$$= 190$$

where

fpm = required speed in feet per minute
π = 3.1416
12 = constant
D = diameter of drill in inches

The FEED of a drill is the rate of penetration into the work for each revolution. Feed is expressed in thousandths of an inch per revolution. In general, the larger the drill, the heavier the feed that may be used. Always decrease feed pressure as the drill breaks through the bottom of the work to prevent drill breakage and rough edges. The rate of feed generally depends on the size and speed of the drill, the material being drilled, and the rigidity of the setup.



44.59
Figure 10-26.—Sensitive drill press.

Experience will help you in selecting the best feeds and speeds for drilling. While you are learning, it is best to start slowly and feel your way until you reach the right combination.

It is necessary to use a cutting oil when drilling steel and wrought iron. Cast iron, aluminum, brass, and other metals may be drilled dry, although at high drilling speeds it is advisable to use some medium of cooling these metals. Compressed air may be used for cast iron; kerosene, for aluminum; oleic acid, for copper; sulphurized mineral oil, for Monel metal; and water, lard, or soluble oil and soda water, for ferrous metals (the soda water reduces heat, overcomes rust, and improves the finish).

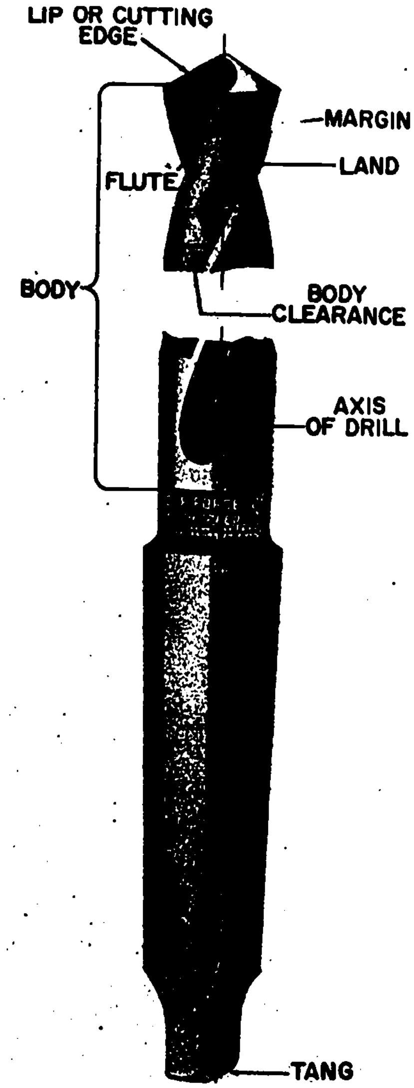
OPERATING PROCEDURE

Using the drill press is one of the first skills that you will learn as an opticalman. Although it is relatively more simple to operate and understand than other machine tools in the shop, the skill for accuracy and efficiency in its use are just as important as for any machine. The drill press and hand-held drills are used by an opticalman more than all other machine tools combined. The skill that you develop in using a drill will often be the determining factor in whether an optical instrument is made serviceable, or is scrapped.

In figure 10-27 you see the principal parts of a twist drill: the BODY, the SHANK, and the POINT. The portion of the LAND behind the MARGIN is relieved to provide BODY CLEARANCE. It is the body clearance that assists in the reduction of friction when drilling. The LIP is the cutting edge, and on the CONE of the drill is the area called the LIP CLEARANCE, DEAD CENTER is the sharp edge located at the tip of the CONE. The WEB of the drill is the metal column which separates the flutes. It runs the entire length of the body between the flutes and gradually increases in thickness toward the shank, giving additional rigidity to the drill.

The TANG is found only on tapered shank tools. It fits into a slot in the socket or spindle of the drill press and bears a portion of the driving strain. Its principal purpose is to make it easy to remove the drill from the socket with the aid of a drill drift. (Never use a file or screwdriver to do this job.)

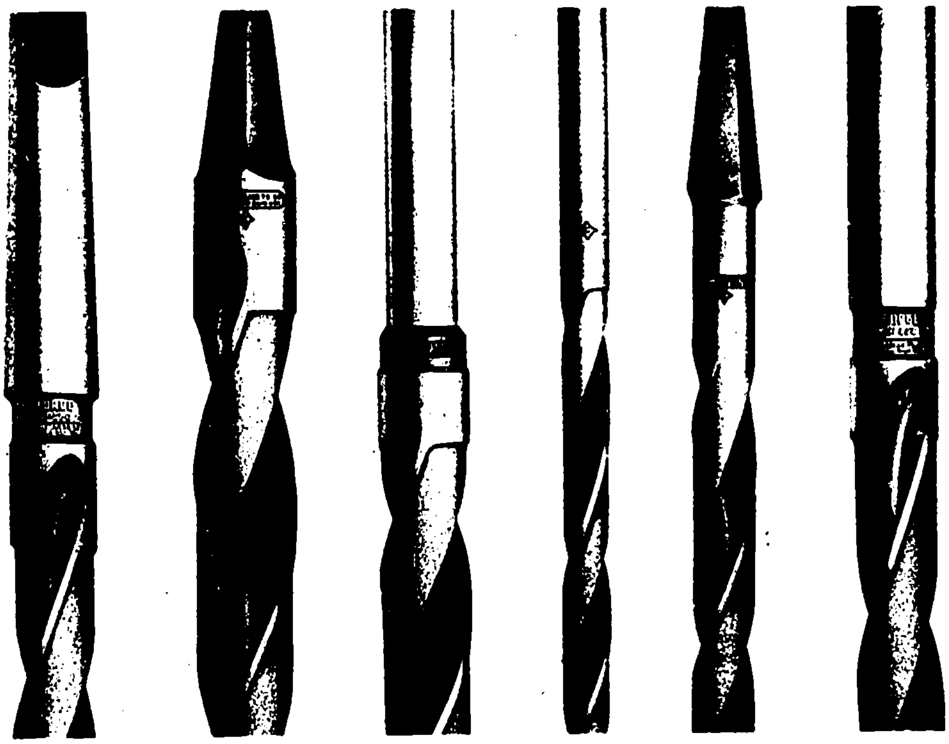
The SHANK is the part of the drill which fits into the socket, spindle, or chuck of the drill press. There are several types of shanks, the most common of which are shown in figure 10-28.



44.20(11)
Figure 10-27.—The parts of a twist drill.

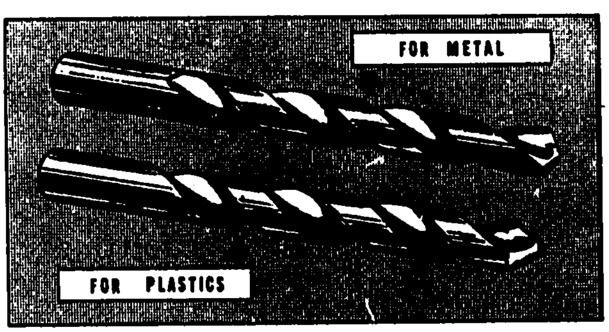
Twist drills are made of carbon steel or high speed steel. Figure 10-29 shows a typical plastic cutting drill and a typical metal cutting drill. Notice the smaller angle on the drill used when working with plastics.

Drill sizes are indicated in three ways: by inches, letter, and number. The nominal inch sizes run from 1/64 inch to 4 inches or larger, in 1/64-inch steps. The letter sizes run from "A" to "Z" (0.234 inch to 0.413 inch). The number sizes run from No. 80 to No. 1 (0.0135 inch to 0.228 inch).



44.20(11)

Figure 10-28.—Six popular shanks.



44.20(11)

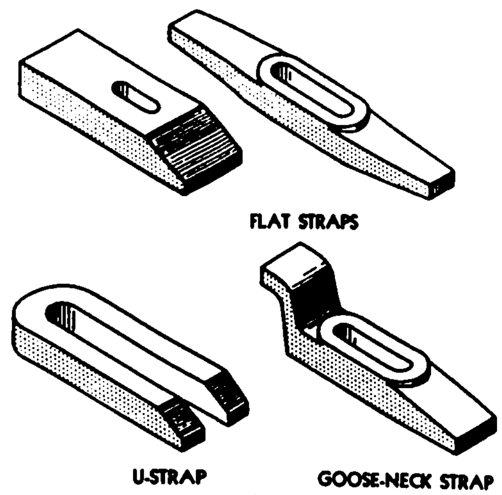
Figure 10-29.—Comparison of a twist drill for plastics with one for metals.

Before putting a drill away, wipe it clean and then give it a light coating of oil. Do not leave drills in a place where they may be dropped or where heavy objects may fall on them. Do not place drills where they will rub against each other.

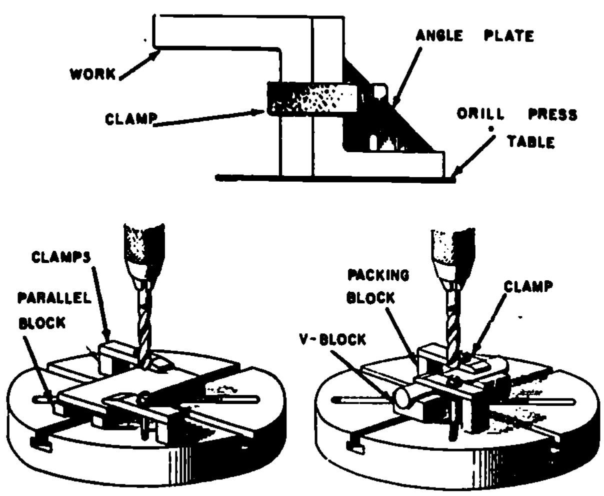
Before drilling, be sure your work is well clamped down. On a sensitive drill press you will probably have to use a drill vise, and center the work by hand. Because the work done on this drill press is comparatively light, the weight of the vise is sufficient to hold the work in place.

The larger drill presses have slotted tables to which work of considerable weight may be bolted or clamped. T-bolts, which fit into the T-slots on the table, are used for securing the work. Various types of clamping straps, shown in figure 10-30 also can be used. (Clamping straps are also identified as clamps or dogs.) The U-strap is the most convenient for many setups, because it can be adjusted without removing the nut.

It is often necessary to use tools such as steel parallels, V-blocks, and angle plates for supporting and holding the work. Steel parallels are used to elevate the work above the table so that you may better observe the progress of the drill. V-blocks are used for supporting round stock, and angle plates are used to support work where a hole is to be drilled at an angle to another surface. Some examples of setups are shown in figure 10-31.



11.15X
Figure 10-30.—Common types of clamping straps.



11.16X
Figure 10-31.—Work mounted on the table.

28.57X
Figure 10-32.—Combined drill and countersink (center drill).

Drilling Hints

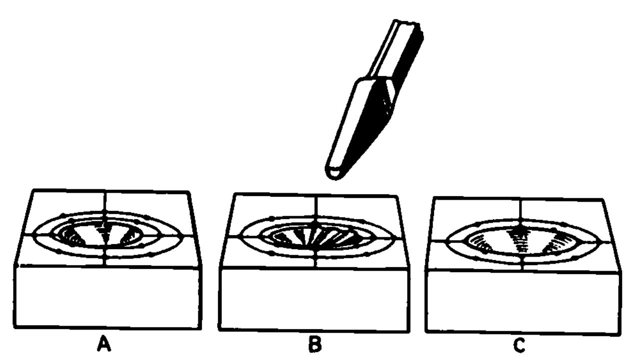
To ensure accuracy in drilling, position the work accurately under the drill, and use the proper techniques to prevent the drill from starting offcenter or from moving out of alignment during the cut. Here are some hints that will aid you in correctly starting and completing a drilling job.

1. Before setting up the machine, wipe all foreign matter from the spindle and table of the machine. A chip in the spindle socket will cause the drill to have a wobbling effect that tends to make the hole larger than the drill. Foreign matter on the work holding device under the workpiece tilts it in relation to the spindle, causing the hole to be out of alignment.

2. Center punch the work at the point to be drilled. Position the center-punched workpiece under the drill; use a dead center inserted in the spindle socket to align the center-punch mark on the workpiece directly under the axis of the spindle.

3. Bring the spindle with the inserted center down to the center-punch mark and hold it in place lightly while fastening locking clamps or dogs. This will prevent slight movement of the workpiece, table, or both when they are clamped in position.

4. Insert a center drill (fig. 10-32) in the spindle and make a center hole to aid in starting the drill. This is not necessary on small drills on which the dead center of the drill is smaller than the center-punch mark, but on large drills it will prevent the drill from "walking" away from the center-punch mark. This operation is especially important when drilling holes on curved surfaces.



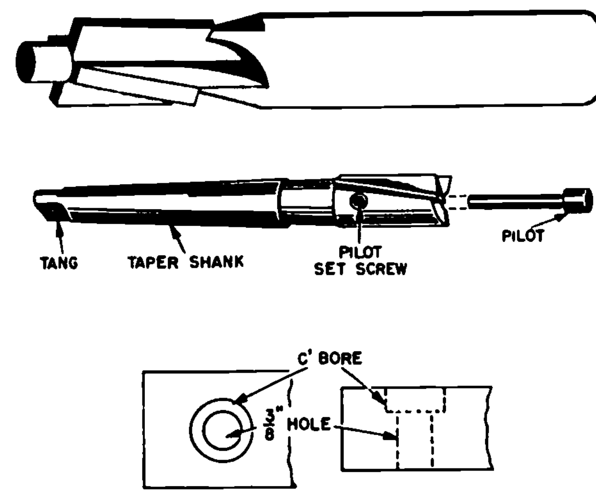
11.17X
Figure 10-33.—Using a half-round chisel to guide a drill to the correct center.

5. Using a drill smaller than the required size to make a lead hole will increase accuracy by eliminating the need of the dead center of the finishing drill to do any cutting, decreasing the pressure required for feeding the finishing drill, and decreasing the width of cut taken by each drill. In drilling holes over 1 inch in diameter, it may be necessary to use more than one size of lead drill to increase the size of the hole by steps until the finished size is reached. When aligning work to be drilled with small drills, mount the drill in the chuck and bring the drill point down to the center punch mark without turning the machine on. Check from several angles to see if the drill point bends off center. Adjust the work until the drill does not bend when it touches the center punch mark.

A drill may start offcenter, because of improper center drilling, careless starting of the drill, improper grinding of the drill point, or hard spots in the metal. To correct this condition in larger holes, take a half-round nose chisel and cut a groove on the side of the hole toward which the center is to be drawn (fig. 10-33). The depth of this groove depends upon the eccentricity (deviation from center) of the partially drilled hole with the hole to be drilled. When the groove is drilled out, the drill is lifted from the work and the hole is checked for concentricity with the layout line. The operation is repeated until the edge of the hole and the layout line are concentric. When the drill begins to cut its full diameter, the prick-punch marks on the layout should be evenly cut at the centers.

When using this method to correct an off-center condition, you must be very careful that the cutting edge or lip of the drill does not grab in the chisel groove. It is generally necessary to use very light feeds until the new center point is established. (Heavy feeds cause a sudden bite in the groove which may result in the work being pulled out of the holding device, or the drill being broken.)

A counterbore is a drilling tool used in the drill press to enlarge portions of previously drilled holes to allow the heads of fastening devises to be flush with or below the surface of the workpiece. The parts of a counterbore that distinguish it from a regular drill are a pilot which aligns the tool in the hole to be counterbored, and the cutting edge of the counterbore, which is flat so that a flat surface is left at the bottom of the cut, enabling fastening devices



28.58

Figure 10-34.—One type of counterbore.

28.59X

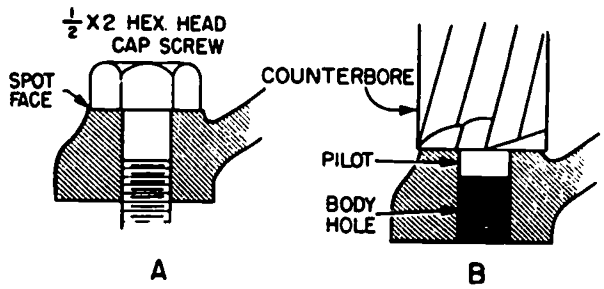
Figure 10-35.—Countersinks.

to seat flat against the bottom of the counterbored hole.

Figure 10-34 shows a type of counterbore and an example of what a counterbored hole looks like. The basic difference between the counterbores illustrated is that one has a removable pilot and the other does not. The counterbore with provisions for a removable pilot can be used in counterboring a range of hole sizes by simply using the appropriate size pilot. The use of the counterbore with a fixed pilot is limited to holes of the same dimension as the pilot.

Countersinks are used to permit the setting of flathead screws flush with the surface. The basic difference in countersinking and counterboring is that a countersink makes an angular sided recess where the counterbore forms straight sides. The angular point of the countersink acts as a guide to center the tool in the hole being countersunk. Figure 10-35 shows two common types of countersinks.

Spotfacing is an operation that is used to clean up the surface around a hole so that a fastening device may be seated flat on the surface. This operation is commonly required on rough surfaces that have not been machined and



28.60
Figure 10-36.—Examples of spotfacing.

on the circumference of concave or convex workpieces. Figure 10-36 shows an example of spotfacing and the application of spotfacing in using fastening devices. This operation is commonly accomplished by using a counterbore.

Reaming

In addition to drilling holes, the drill press may be used for reaming. For example, when specifications call for close tolerances, the hole must be drilled slightly undersize and then reamed to the exact dimension. Reaming is also done to remove burrs in a drilled hole or to enlarge a previously used hole for new applications.

Machine reamers are equipped with tapered shanks so that they fit the drilling machine spindle. Be sure not to confuse them with hand reamers, which have straight shanks. Hand reamers will be ruined if used in a machine.

The steps outlined below should be followed in reaming:

1. Drill the hole about 1/64 inch less than the reamer size.

2. Substitute the reamer in the drill press, without removing the work or changing the position of the work.

3. Adjust the machine for the proper spindle speed. (Reamers should turn at about one-half the speed of the twist drill.)

4. Use a cutting oil to ream. Use just enough pressure to keep the reamer feeding into the work; excessive feed may cause the reamer to dig in and break.

5. The starting end of a reamer is slightly tapered; always run it all the way through the hole. NEVER RUN A REAMER BACKWARD because the edges are likely to break.

CHAPTER 11

TELESCOPES

At this point of the training manual, you will begin to study the various instruments that you will be required to repair. This chapter is written to familiarize you with telescopes that are fairly simple in design and construction. Remember when you are actually working on an instrument, you should refer to the technical manual that covers the specific instrument.

The only section of this chapter that will give details for repair work is the section on OOD and QM spyglasses. These instruments do not have technical manuals and the appropriate NavShips blueprints should be used as a reference during overhaul.

OOD AND QM SPYGLASSES

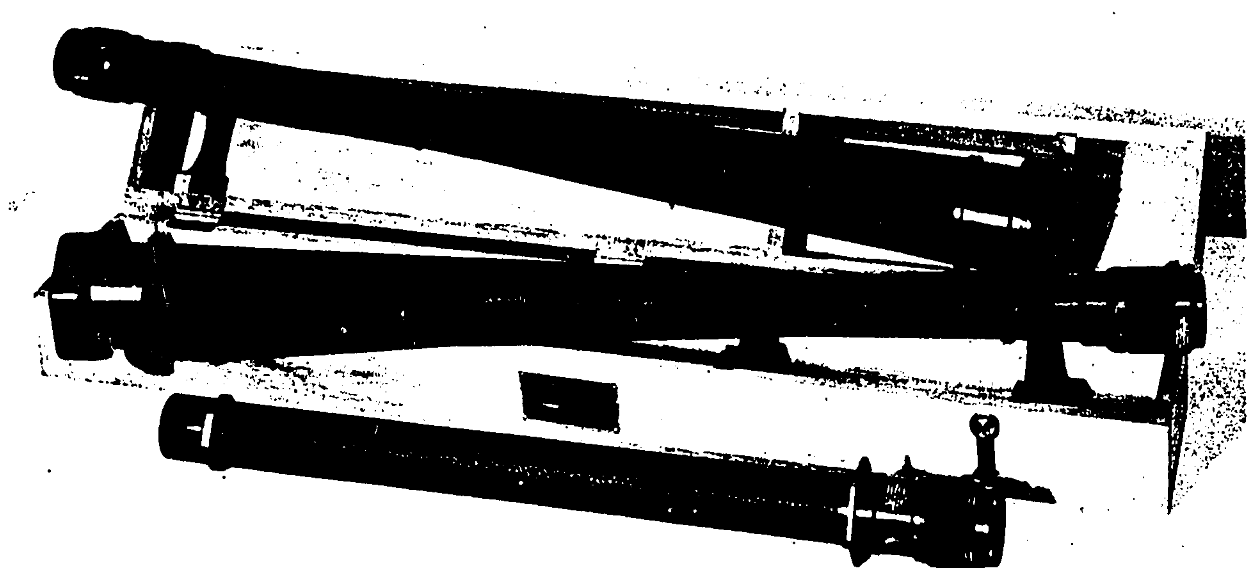
Figure 11-1 shows three of the most basic telescopes used in the Navy today. The two larger telescopes lying on the case and 16 power Quartermaster (QM) spyglasses and the instrument in the foreground is a 10 power Officer of the Deck (OOD) spyglass. The OOD spyglass is an instrument used by the officer of the deck on a ship in port, to read flags and other signals and to observe small boats in the harbor.

The QM spyglass is generally used by the quartermaster or signalman for reading flags and observing distant objects that are beyond the practical range of hand held binoculars.

In construction the QM and OOD spyglasses are similar and little comparison of the two will be made in this chapter. When you understand thoroughly the coverage given on the OOD spyglass, you will have no difficulty with the repair of the QM spyglass.

The mechanical differences in the QM and OOD glasses are mainly in the construction of the main body tube and objective lens mount.

Due to the focal length and size of the objective lens, the main body tube of the QM glass is longer and of a greater diameter at the objective end than that of the OOD glass. The objective mount of the QM glass has adjustable



37.3

Figure 11-1.—An OOD spyglass and two QM spyglasses.

spacers on both sides to allow for variations in the focal length. The objective mount of the OOD glass seats against a machined shoulder in the body tube.

FEATURES

The optical system of the QM and OOD glass is illustrated in figure 11-2. It is basically a single erector telescope with a collective lens placed in the focal length of the objective lens and a sealing window in back of the erector lens.

The differences in the optical features of the two spyglasses are as follows:

	OOD	QM
Magnification	10x	16x
True field	5°30'	3°30'
Apparent field	55°	56°
Eye distance	29.0 mm	28.0 mm
Exit pupil diameter	3.5 mm	4.0 mm

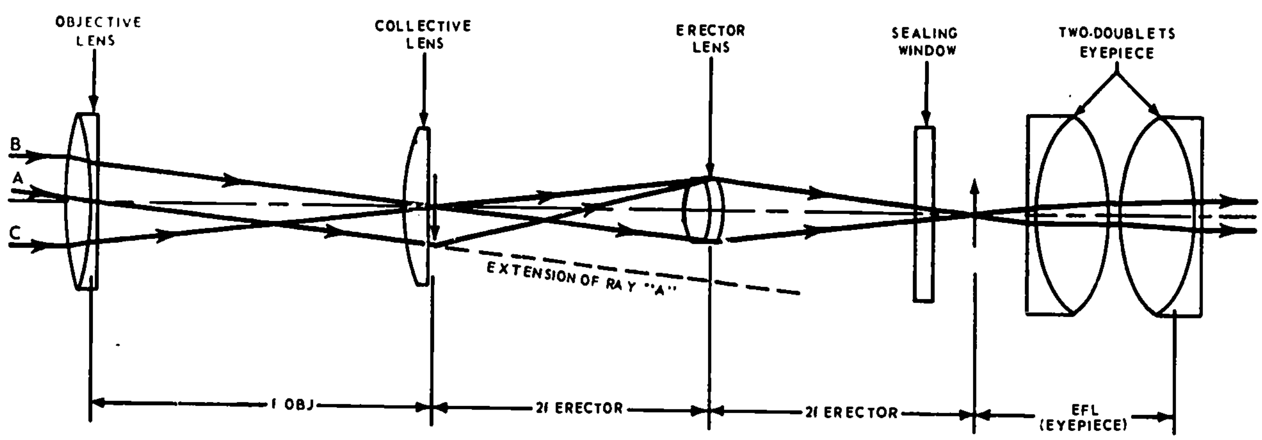
The objective lens is a cemented doublet which refracts the incident rays to the principal focal plane, on or near the plano surface of the collective lens. The image formed by the objective lens is not affected by the collective lens and is therefore real and inverted.

The collective lens, a convexo-plano singlet receives its name from the fact that it collects the extreme principal rays of light (fig. 11-2) which otherwise would be lost and refracts them into the erector lens. Thus, without the collective lens, the center of the field would be well illuminated but the edges of the field would appear quite dark. Because the collective lens is placed within the focal length of the objective lens, it has little effect on the focal length of the objective lens, or the magnifying power of the telescope. The only purpose of the collective lens is to collect rays and send them into the erector lens to produce a well illuminated field and IMAGE.

The erector lens is a cemented doublet, with its greatest curvature on the exposed surface of the negative lens. The primary purpose of the erector lens is to erect the inverted image formed by the objective lens; hence, the erector is placed two focal lengths from the objective image in order to produce an erect, real image two focal lengths behind the erector lens. A plano-plano sealing window is placed between the erector lens and the image created by it, and it is used to seal the telescope near the eyepiece end. Because of its position, the sealing window has an effect of lengthening the erector lens' focal distance—NOT the focal length.

The eyepiece of the QM spyglass and the OOD spyglass is TWO-DOUBLET (asymmetrical). The difference between the two lenses is that the eyelens is smaller in diameter, with a longer focal length, as compared to the field lens. A bevel is ground on the rear edge of the eyelens to aid in sealing the eyepiece assembly.

The objective lens mount, with the objective spacing rings, is slid into the forward end of the body tube against a machined shoulder. The spacing rings and the lens mount are securely held in place by a lock ring threaded into the



137.243

Figure 11-2.—Optical elements for OOD and QM spyglasses.

objective end of the body tube. Permanently fixed and spaced at intervals along the interior of the body tube are metal diaphragms which aid in controlling aberrations and preventing internal reflections.

The collective and erector lenses are in their respective mounts in a short support tube, one on either end. The support tube slides with a bearing fit into the forward end of the eyepiece mount support tube and is secured with a single screw. The eyepiece mount support tube is in turn threaded into the eyepiece end of the telescope body tube and secured with a single set screw. The sealing window mount and its lockring are threaded in the opposite end of the eyepiece mount support tube. Threaded onto that end of the eyepiece mount support tube is the SPIRAL KEYWAY MECHANISM and the eyepiece drawtube containing the eyepiece lenses. A diopter scale ring is secured to the eyepiece mount with a single screw, and the scale is graduated from -6 diopter to +6 diopters.

In the eyepiece drawtube, just forward of the field lens, is mounted a single metal diaphragm which serves to control chromatic aberrations. A single lockring secures the eyepiece lenses and their spacer. The lockring is threaded into the drawtube just aft of the diaphragm to lock against the field lens. A spacing ring between the field lens and the eyelens serves to separate the two lenses the distance required for them to function according to their design.

The eyepiece mount, eyepiece mount support tube, and the collective-erector mount support tube may be threaded into and removed from the after end of the body tube as a single unit. This is an advantage in collimating the telescope.

The QM and the OOD spyglasses are provided with gassing and drying screws which permit drying of the instruments from their sealing windows, to their objective lenses. On the OOD spyglass, the inlet gassing screw is located just forward of the hexagonal flange on the eyepiece mount support tube, and the gas outlet screw is located on the hexagonal objective end of the body tube. The inlet and outlet gassing screws are located similarly on the QM spyglass.

DISASSEMBLY

Prior to disassembly the QM and the OOD spyglasses are checked and inspected in the same manner as for any other optical instrument; therefore, review chapter 7 for inspection procedures of these instruments. Write your findings on an inspection sheet and proceed with the disassembly, or consult your shop supervisor for advice concerning overhaul of the instruments.

The procedure for disassembling a Mk 2 Mod 2, OOD spyglass follows:

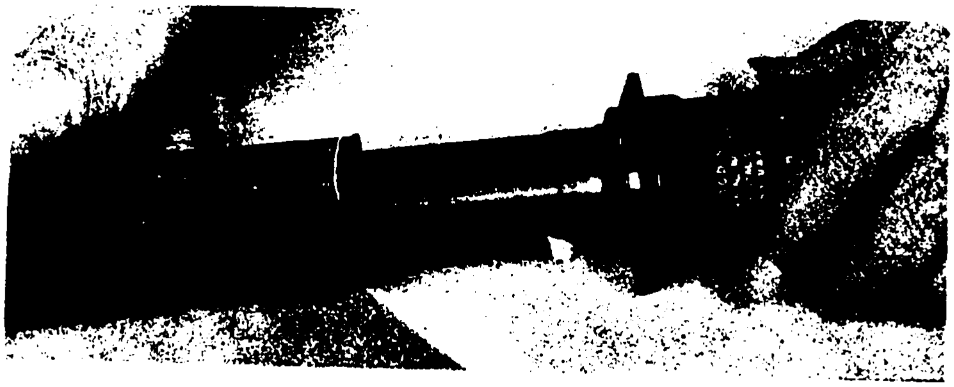
1. Remove the setscrew which secures the eyepiece mount support tube in the body tube (fig. 11-3). Then unscrew the eyepiece mount support tube and pull it from the body tube (fig. 11-4).

137.244

Figure 11-3.—Releasing the eyepiece mount support tube setscrew.

2. Remove the setscrew which secures the eyepiece mount to the eyepiece mount support tube (fig. 11-5) and unscrew and separate the eyepiece mount from the eyepiece mount support tube (fig. 11-6).

3. The knurled focusing ring is held in a movable position by two threaded rings. One acts as a retainer for the focusing ring and the other is a lockring for the retainer. Remove the setscrew from the lockring (fig. 11-7). Unscrew the lockring and then the retainer ring from the eyepiece mount (fig. 11-8). Notice that these two rings are not identical. The lockring has a bevel on each side and the retainer ring has only one bevel.



137.245
Figure 11-4.—Removing the eyepiece mount support tube.

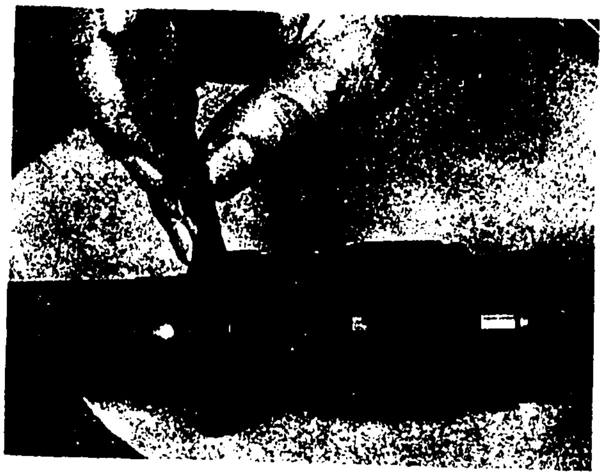


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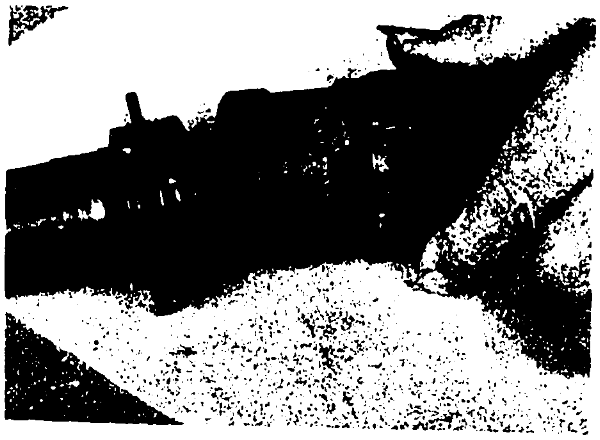
Figure 11-5.—Removing the eyepiece mount setscrew.



137.247
Figure 11-6.—Removing the eyepiece mount from the eyepiece mount support tube.

4. Remove the eyepiece cap from the eyepiece drawtube by unscrewing it, and slip off the lock and retainer rings.

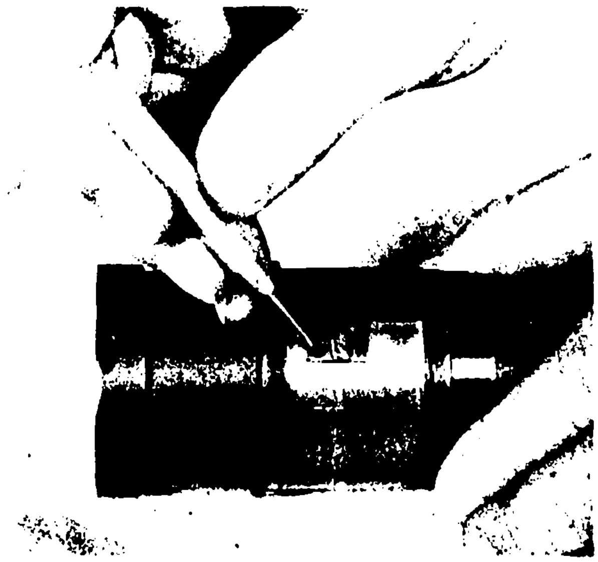
5. Remove the knurled focusing ring first by rotating it counterclockwise to disengage it from the focusing key and then slide it from the eyepiece mount.

6. Remove the focusing key. It is aligned with two dowel pins and secured with two screws. When the screws have been removed (fig. 11-9) with a jeweler's screwdriver, lift the focusing key from the longitudinal slot with a pair of tweezers. The dowel pins should come out with the focusing key; if they do not, remove them from the eyepiece drawtube with a pair of tweezers. The drawtube is now free within the eyepiece mount; remove it by pulling straight out (fig. 11-10).

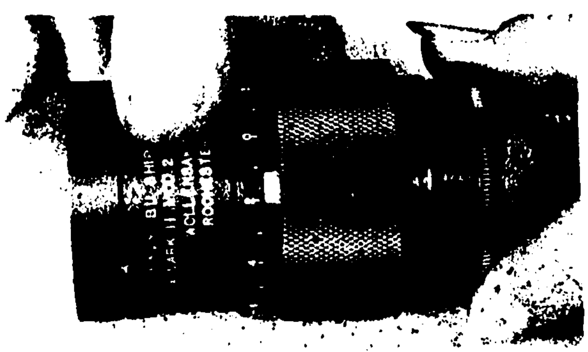
7. With an adjustable retainer ring wrench, loosen the diaphragm lockring (fig. 11-11) just enough so that it turns freely. Do not use the retainer wrench to remove the lockring completely from the drawtube, as the wrench may damage the fine threads on the inner wall of the drawtube. Use a pegwood stick to remove the lockring (fig. 11-11). Measure and record the distance the diaphragm is in the drawtube. (NOTE: The position of the diaphragm is very important, for it controls chromatic aberration.) Remove the diaphragm in the same manner you remove its lockring.

8. Remove the lockring which secures the eyepiece lenses and their spacer. CAUTION: When you remove the lockring, the eyepiece

137.248
Figure 11-7.—Removing the actuating ring retaining ring lockring setscrew.



137.250
Figure 11-9.—Removing the focusing key screws.



137.249
Figure 11-8.—Removing the actuating ring retaining ring.

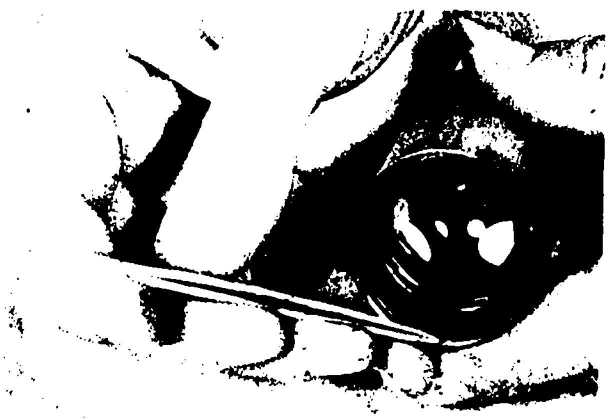
137.251
Figure 11-10.—Removing the eyepiece drawtube from the eyepiece mount.

lenses and their spacers are loose and they can easily fall out. This lockring is almost the s?.ne diameter as the lockring diaphragm; do not get these rings mixed.

9. With a piece of lens tissue on the plano surfaces of the field lens and the eyelens, slowly turn the eyepiece drawtube over to allow the spacer and the eyelens to slide out into your hand. The rear surface of the eyelens is sealed, so apply a little pressure with your thumb to break the seal. CAUTION: The clearance between the lenses and the inner wall of the drawtube is so small that the lenses may become cocked. When the lenses and spacers are removed from the drawtube, mark them to indicate the manner in which they fit in the drawtube; there is only one correct way in which they fit when assembled. Wrap the lenses in lens tissue and stow them in a safe place, AWAY FROM THE METAL PARTS OF THE INSTRUMENT.

10. Remove the setscrew which secures the collective-erector mount support tube in the eyepiece mount support tube (fig. 11-12) and pull STRAIGHT OUT on the tube to remove it from the eyepiece mount.

11. Loosen the collective lens mount lockring and unscrew the collective lens mount from the support tube. Remove the collective lens



137.252
Figure 11-11.—Removing the diaphragm lockring.

lockring and remove the collective lens. Then wrap it in lens tissue. NOTE: If this lens has pits, scratches, or chips, it must be replaced; because the lens is near the focal plane of the objective lens, any fault of the collective lens is very apparent in the field.

12. Remove the erector lens mount lockring from the support tube. Use precaution to prevent damage to the fine threads on the inner wall of the support tube. Remove the erector lens mount from the support tube. (NOTE: The erector lens mount may come out of the support tube in reverse of that shown in figure 11-13; to facilitate collimation, this mount is designed for mounting either way.) Remove the erector lens lockring and then the erector lens. Note that the exposed surface of its negative element has the greatest amount of curvature. Mark the lens and wrap it in lens tissue.

13. Loosen and remove the sealing window mount lockring in the eyepiece end of the eyepiece mount support tube. Remove the sealing window mount and the sealing window lockring; then withdraw the sealing window. The window is sealed with sealing compound. If necessary, apply heat to soften the wax and use a suction cup pressed tightly against the window to help break the seal.

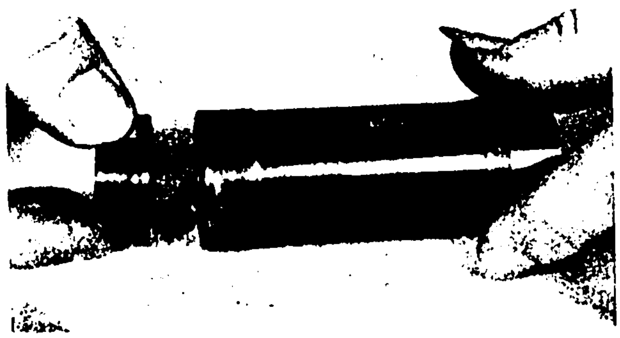
14. Loosen the objective mount support with a fiber grip wrench and remove the objective mount support. (NOTE: No setscrew secures the objective mount support to the body tube. The objective mount support of a QM spyglass is PART OF THE BODY TUBE, and therefore cannot be removed.)

15. Loosen and remove the lockring which secures the objective lens spacing rings and the objective lens [illegible] to the interior of the objective mount support. Remove the front spacing rings, the objective mount, and the rear spacing rings by pulling them straight out of objective mount support. Mark each spacer when you remove it. Press on the objective lens to break the seal which secured it in the mount.

16. Remove the two gassing screws, one of which is located just forward of the hexagonal flange on the eyepiece mount support tube, and the other is on the hexagonal section of the body tube. Check both gassing screw orifices for freedom from obstructions.

You have now completed disassembly of the OOD spyglass. Continue with overhaul and

137.253
Figure 11-12.—Removing the collective-erector support tube setscrew.



137.254

Figure 11-13.—Removing the erector lens mount from its support tube.

repair of the instrument. Follow the procedures listed in chapter 7, and also the additional reassembly procedures discussed in the next paragraphs.

REPAIR AND REASSEMBLY

When you reassemble the collective lens in its mount, mark on the plano surface of the lens near the center with a wax pencil, or pass a thin wire through the gas orifices in the collective lens mount and draw it taut by twisting the ends together. The wax pencil mark or the wire will act as a reference point to aid in the proper positioning of the collective lens during collimation.

Before you reassemble the eyepiece drawtube, check the mechanical 0 diopter setting of the eyepiece assembly at MID-THROW. You can do this by reassembling the complete mechanical section of the eyepiece mechanism, with the exception of the inner lens and parts of the drawtube. When you have the mechanical parts of the eypeiece assembled, turn the eyepiece focusing ring until the drawtube stops on the IN position. Then, with a lead pencil, mark on the drawtube a line where it protrudes from the eyepiece mount. Next, turn the focusing ring clockwise until the drawtube stops on the OUT position. Then measure the full amount the drawtube traveled from STOP to STOP and divide the amount by 2 to get the MID-THROW position of the drawtube. Put a mark on the drawtube to indicate its mid-throw position and turn the focusing ring until the drawtube moves in, to the mark for the mid-throw position.

Now observe where the index mark on the focusing ring is pointing; it must point to 0 diopters on the diopter scale ring when the eyepiece is at the mid-throw position. If it does NOT point to 0 diopters, remove the setscrew which secures the diopter scale ring and rotate the ring until the 0 diopter mark is aligned with the index mark of the focusing ring. Then drill and tap a new hole for the diopter scale ring setscrew. When you complete this task, you will have the mechanical 0 diopter setting at MID-THROW.

Disassemble the mechanical parts of the eyepiece and begin reassembly of the lenses and the inner parts of the eyepiece drawtube. Reposition the drawtube diaphragm to its original position in the tube. After you insert the diaphragm, check its position by looking through the eyepiece lenses. When correctly positioned, the diaphragm is sharp and clear; if it is not, screw the diaphragm in or out until it is sharp and clear, and note the bright-yellow fringe which should be around the diaphragm field. You can check the diaphragm later for correct positioning, after you collimate the instrument, by checking the overhauled instrument for chromatic aberration (chapter 7).

Reseal all assemblies during reassembly, except the eyepiece mount support tube, which is withdrawn several times during collimation and must therefore be sealed ONLY after the instrument is collimated.

COLLIMATION

You can collimate this telescope in the same manner as for any telescope with a single erector lens. The procedure for collimating a single erector telescope is outlined in chapter 7 of this manual. All you need is an infinity target such as an outside target or the crossline of a collimator. Then place the telescope on V-blocks in front of the collimator and proceed with collimation.

First, remove the parallax between the instrument's crossline and that of the collimator's, using an auxiliary telescope. The reference mark (wax pencil mark) on the plano surface of the collective lens or the wire through the collective lens mount serves as a temporary crossline for positioning the collective lens in the optical system. To remove parallax in this system, adjust the collective lens mount by screwing it in or out of the support tube. The eyepiece mount support tube must be removed from the body tube each time the collective lens mount is adjusted; therefore, tighten the eyepiece mount support tube against the shoulder of the body tube after each adjustment to eliminate possible errors in the parallax readings. Furthermore, the setscrew which secures the collective-erector support tube in the eyepiece mount support tube must be in place in order to eliminate such errors.

If you CANNOT remove parallax because of insufficient movement of the collective lens mount in the support tube, re-position one or more of the objective lens spacing rings in order to re-locate the objective lens in the desired direction. When you do this, the collective lens mount is so adjusted that you can remove the final errors in parallax. After you completely remove parallax from the telescope, lock the collective lens mount lockring against the shoulder of the support tube and make another test for parallax.

Now set the eyepiece to 0 diopters optically by adjusting the erector lens mount. Review the procedure in chapter 7. You may find, however, that there is insufficient movement of the erector lens mount. If this is true, remove the erector lens mount from the support. Then remove the erector lens, turn it over in the mount, and replace the erector mount in the support tube in the opposite direction to what you had it before. The mount is so designed that it may be placed in the support tube in either direction. CAUTION: If you do turn the mount over, remember that the erector lens MUST ALSO BE TURNED OVER in its mount.

When you have optical 0 diopters set on the eyepiece, lock the erector lens mount lockring and give the instrument a final check for parallax and diopter setting.

For the last time, remove the eyepiece mount support tube from the body tube and clean off the wax pencil mark from the collective lens. Do this by removing the collective lens lockring without tampering with the collective lens mount itself. If you remove the collective lens mount during removal of the collective lens, you will not have the collective lens in proper position; so be very careful to avoid this.

When you complete the task just explained, place a string of sealing wax around the eyepiece mount support tube and seal and secure it in the body tube. Then give the instrument a final inspection.

The procedure for gassing and drying a Mk 2 Mod 2, spyglass is as follows:

1. Remove the inlet and outlet gassing screws from the telescope and connect a gassing hose to the inlet hole.

2. Run dry nitrogen through the instrument and purge it at the same time.

3. After you completely dry the instrument, replace the two gassing screws and seal them.

BORESIGHT TELESCOPES

In order for a gun to fire accurately when using gunsights, the gun barrel and gunsight must use the same points of aim. If the two are not in proper alignment, the gunsight will be on the target but the gun barrel will be on a point of aim removed from the target by an angle equal to the error of alignment. Figure 11-14 illustrates how these errors may exist in (A) deflection and (B) elevation. The procedure for setting proper alignment between the lines of sight of the gunsight telescopes and the axis of the bore of the gun is called boresighting. The equipment to boresight a gun is as varied as the guns themselves, and the ordnance pamphlet for each gun specifies the kind of boresighting equipment to be used.

Figure 11-15 represents a breech bar boresight using a Mk 8 Mod 6 boresight telescope as an accessory. This equipment generally consists of an adaptor (breech bar) with a central hole which mounts the telescope in the center of the gun breech, and a muzzle disc with which the telescope line of sight is aligned. The breech bar is bolted directly to the breech of the gun, and the muzzle disc with its small center hole is machined to be an exact fit in the muzzle of the gun.

Although boresighting is not a duty of an opticalman, the telescopes used in the process must function properly in order for the boresighting to be satisfactory. Ordnance Pamphlet 1449 (Boresight and Boresight Telescopes) is a comprehensive list of boresights and it includes complete instructions for the overhaul and repair of boresight telescopes in the Navy. Always use this pamphlet for technical reference when overhauling a boresight telescope.

In this section we will use the Mk 8 Mod 6 and the Mk 75 Mod 1 (fig. 11-16) as examples since they are the telescopes most widely used in the Navy.

CHARACTERISTICS

In design, a boresight telescope must be short in length for the amount of magnification

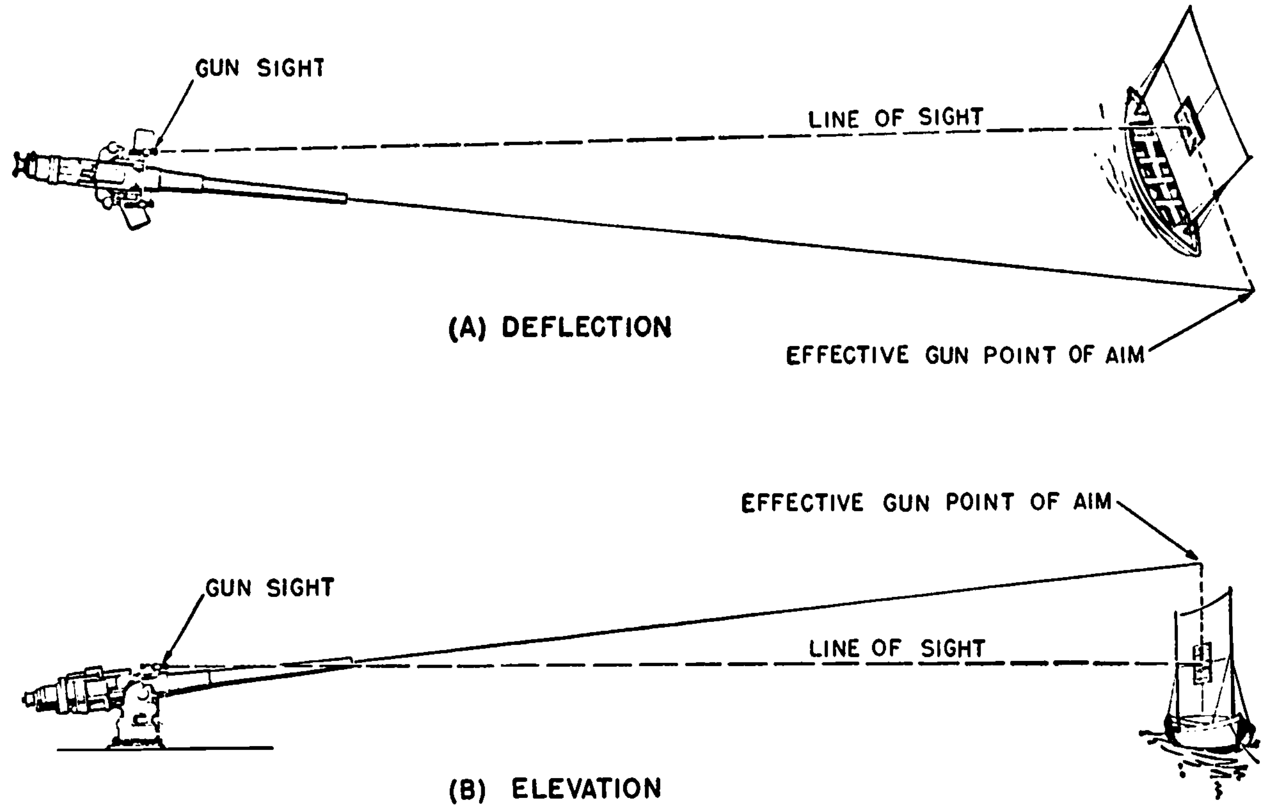


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Figure 11-14.—Effect of sight misalignment.

required, and its diameter must be correspondingly small. The characteristics are necessary in order to mount the telescope in breech bars and to facilitate handling.

Because of its short length, a boresight telescope must have an objective lens of short focal length; and it must be capable of focusing at distances of approximately 10 feet to infinity. This characteristic makes focusing on the boresight muzzle disc, as well as on the target possible. The short objective focal length permits this type of focusing with little adjustment of distance between the objective lens and the crossline plate (plano-plano, with a reticle engraved on one surface).

Since there is very little motion between a boresight telescope and the target during boresighting, and also because of the small size of the target, the instrument need not have great width of field. Because of its short objective length, however, a boresight telescope may have some curvature of the field; but since only the center of the field where the crosslines intersect is used, this effect can be discounted.

Optical Characteristics

The optical characteristics of Telescope Mk 8 Mod 6 are listed below:

Magnification	9.6x
Field	2°30'
Exit pupil	2.3 mm
Eye distance	11.0 mm

The image presented to the eye by Telescope Mk 8 Mod 6 is erect and normal. That is, it is exactly as it would appear to the naked eye except for the magnification provided by the telescope, and any distortions, such as curvature of the field, which may be introduced by the optical system.

Optically, the telescope consists of a doublet objective lens, a plano crossline lens with

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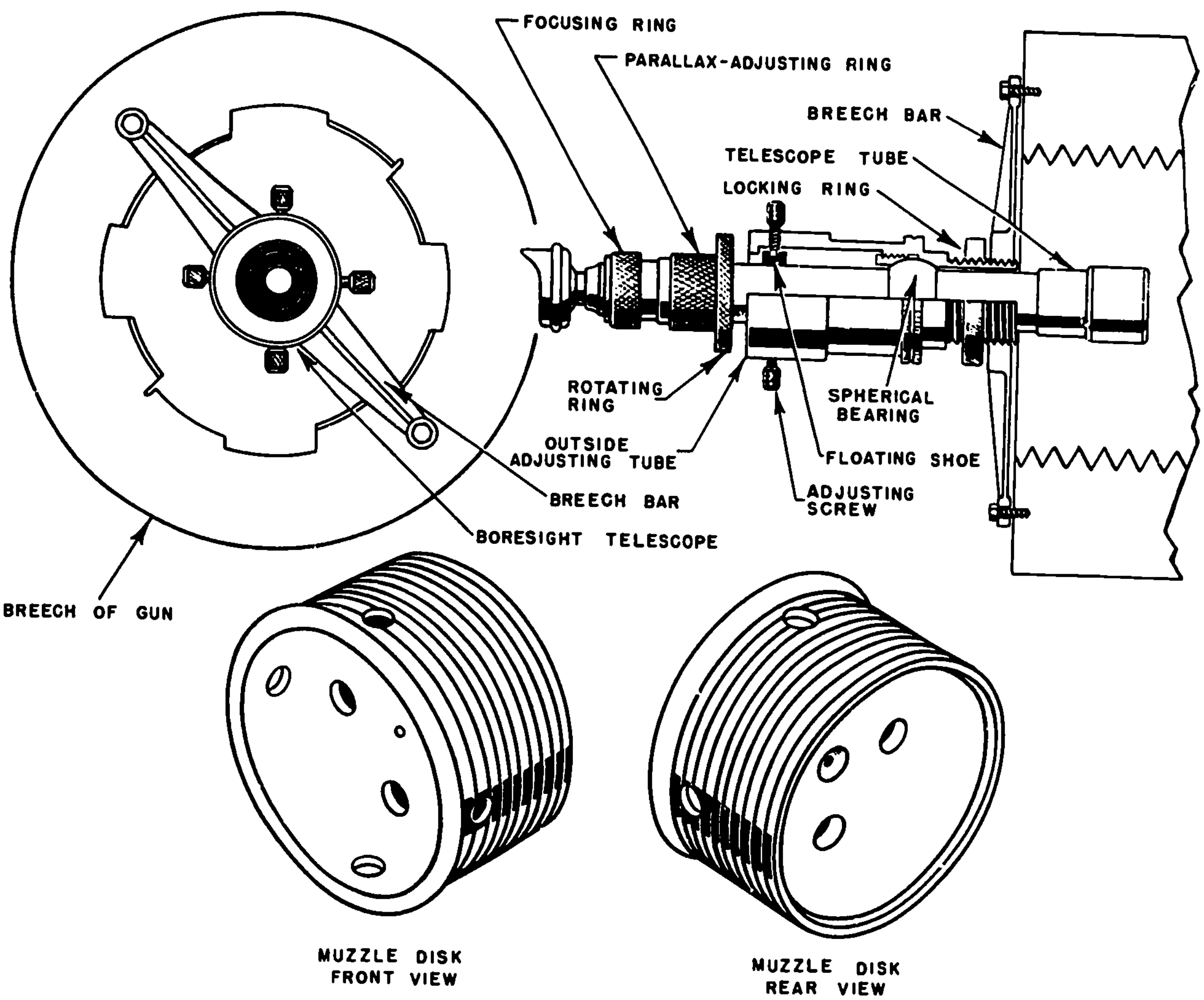


Figure 11-15.—Boresighting equipment. 110.80

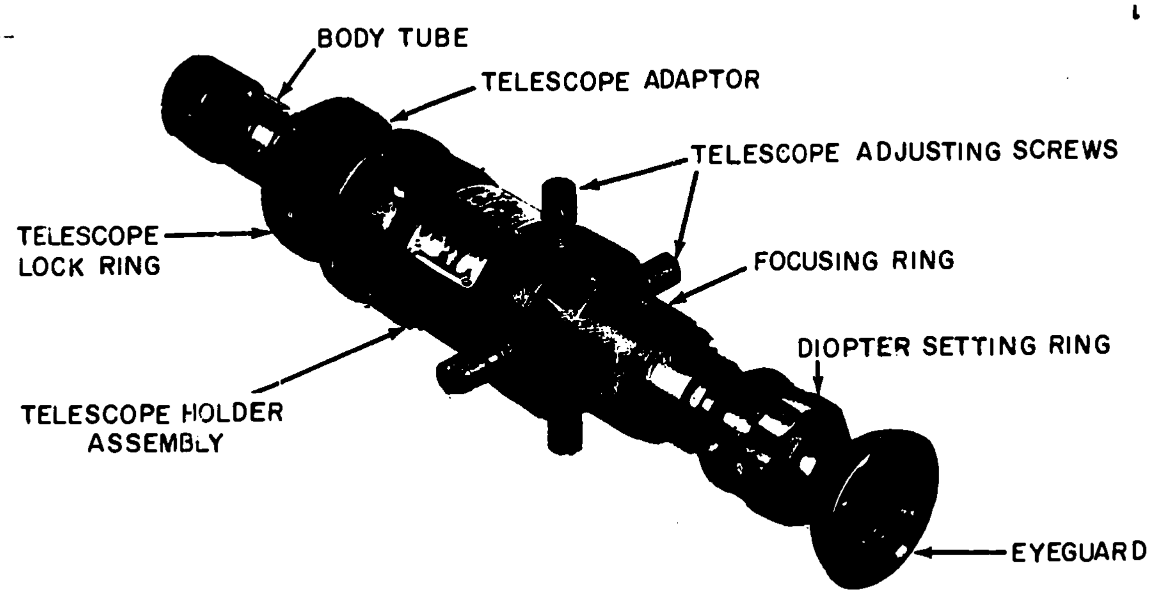
crosslines etched into the objective side of the lens, two singlet erecting lenses, a singlet collective lens and a singlet eyelens. The arrangement of the optical system is shown in figure 11-17. The objective lens is mounted in a draw tube and arrangement is made so that its position relative to the crossline lens may be adjusted to permit focusing, free of parallax, on objects from a distance of 6 feet to infinity. The erecting lenses are mounted in another drawtube which may be adjusted in position to focus the crosslines.

The optical characteristics of Telescope Mk 75 Mod 1 are:

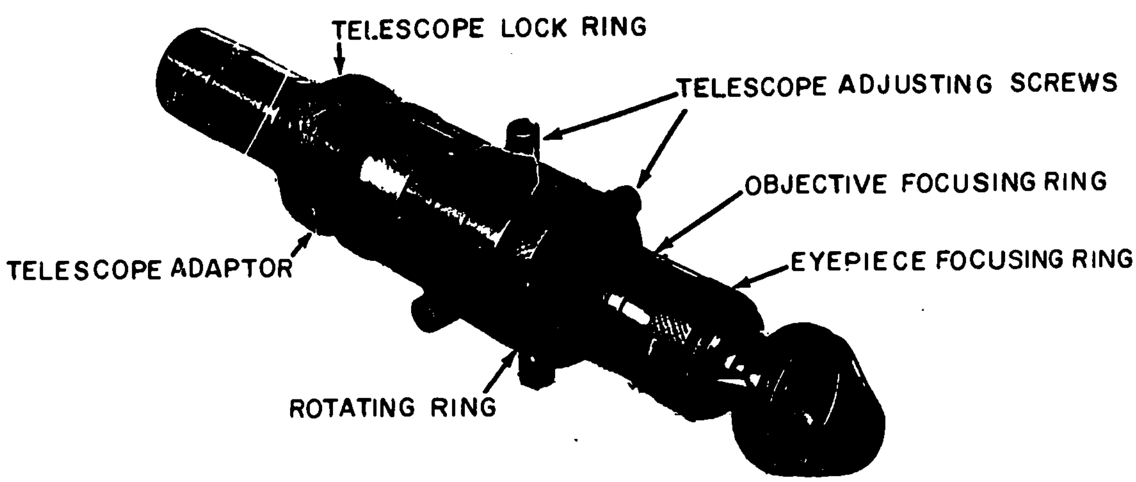
Magnification	8x
Field	3°30'
Exit Pupil	2.5 mm
Eye Distance	19.4 mm

The image presented by the Mk 75 telescope is the same as that of the Mk 8. It is magnified, erect and normal and has some curvature of field.

Optically, the telescope consists of a doublet objective lens, a plano crossline lens with crosslines etched into the surface on the eyepiece side, two doublet erecting lenses, a doublet collective lens and a doublet eyelens. The



Telescope Mk 75 Mods 0 and 1 (Boresight).



Telescope Mk 8 Mod 6 (Boresight).

137.527

Figure 11-16.—Boresight telescopes.

arrangement of the optical system is shown in figure 11-18. The objective lens is mounted in a fixed position in the telescope body tube. The crossline lens and all other lenses are mounted in a drawtube which slides in the body tube and may be adjusted to focus the telescope, free of parallax, on objects from 10 feet distant to infinity. The erecting lenses are mounted in a fixed position relative to the crossline lens. The crosslines of the telescope are in permanent focus if the telescope is properly collimated.

The collective lens and eyelens are mounted in a second draw tube which slides within the first drawtube. This arrangement allows for variation of the eyepiece diopter setting to suit the individual eye.

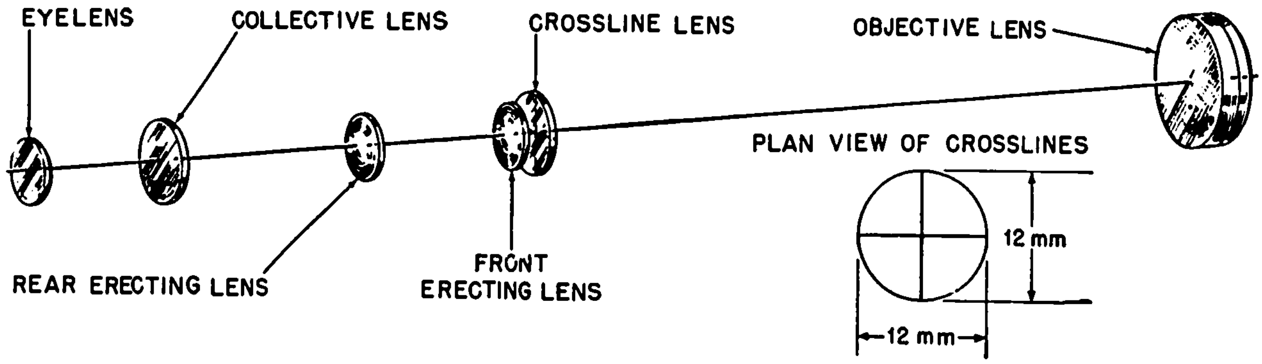


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Figure 11-17.—Optical system of a Mk 8 Mod 6 boresight telescope.

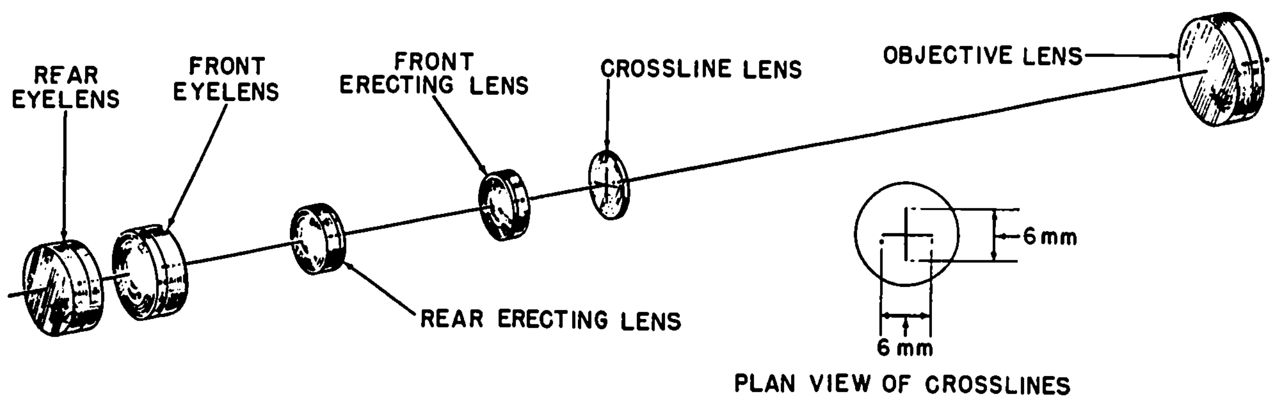

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Figure 11-18.—Optical system of a Mk 75 boresight telescope (Mods 0 and 1).

Mechanical

Telescope Mk 8 Mod 6 (Boresight) consists of the telescope proper, telescope adaptor, and adjusting screw housing assembly (fig. 11-19). The telescope body tube has a spherical journal soldered to it. The telescope adaptor forms the spherical bearing which supports the telescope. Sufficient clearance is left between the adaptor and the body tube to allow for adjustment of the telescope within the bearing.

The adaptor carries external threads with the telescope assembly may be mounted in a breech bar, and a lockring to permit securing the telescope in any desired position in the bar. The adjusting screw housing surrounds the telescope proper and is secured to the telescope adaptor. The four adjusting screws, located 90° apart, terminate in four shoes which bear against the telescope body tube. The shoes are lapped in to be an exact fit onthe circumference of the body tube. Adjustment of the screws moves the telescope proper within the spherical bearing, thus changing the alignmnet of the telescope with respect to the adaptor. This is the adjustment made when aligning the telescope with the muzzle disc during installation of a boresight.

The arrangement of spherical bearing and adjusting shoes allows the telescope proper to be rotated about its axis without disturbing its mechanical alignment. The rotating ring, mounted on the body tube just behind the adjusting screw housing, provides a positive grip for this purpose. This feature of Telescope Mk 8 Mod 6 is of value in adjusting the crossline lens during collimination of the telescope.

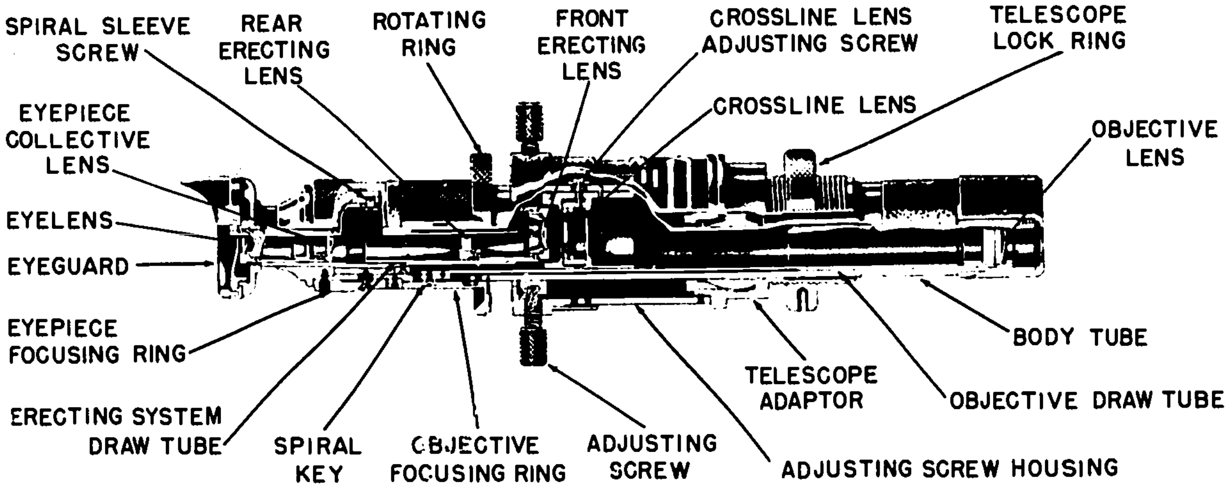

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Figure 11-19.—Cutaway view of a Mk 8 Mod 6 boresight telescope.

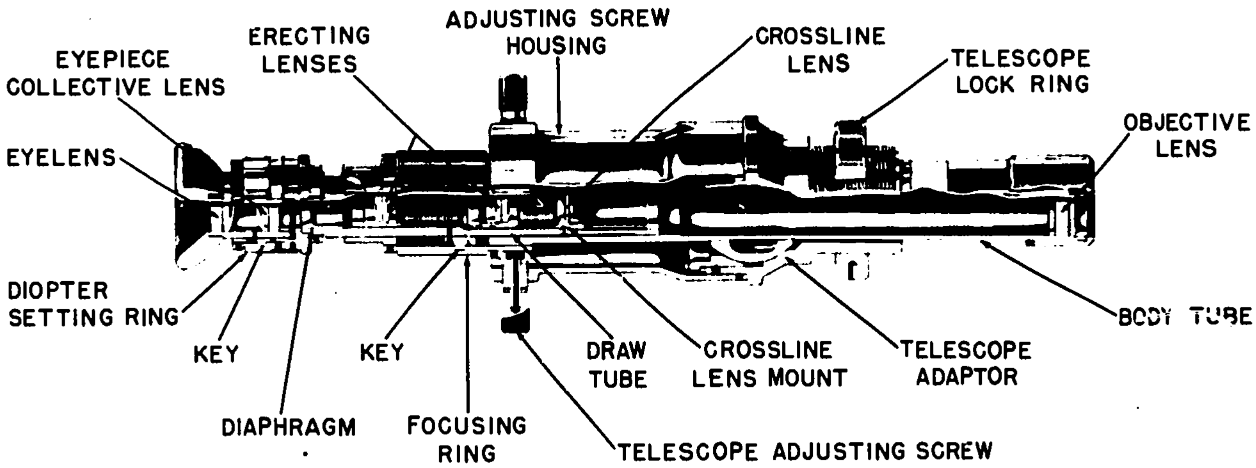

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Figure 11-20.—Cutaway view of a Mk 75 Mod 1 boresight telescope.

Telescope Mk 75 Mod 1 consists of the telescope proper, telescope adaptor, and adjusting screw housing assembly (fig. 11-20). The telescope body tube has a spherical journal soldered to it. The telescope adaptor forms the spherical bearing which supports the telescope about this journal. Sufficient clearance is left between the adaptor and body tube to allow for adjustment of the telescope within the bearing. The adaptor carries the external threads with which the telescope may be mounted in a breech bar, and a lock ring with which it may be locked in any desired position. The adjusting screw housing surrounds the body tube and is secured to the telescope adaptor. The four telescope adjusting screws, located 90 degrees apart, work against four flat surfaces on a bearing ring soldered to the body tube. Manipulation of the adjusting screws moves the telescope within its spherical bearing, thus changing its alignment with respect to the adaptor. This is the adjustment made when lining up the telescope with the muzzle disc. Note that this arrangement of adjusting screws does not permit the telescope to be rotated within the adaptor and housing as in Telescope Mk 8 Mod 6.

DISASSEMBLY

Ordnance Pamphlet, OP 1449, gives detailed procedures for the disassembly, repair, and reassembly of boresight telescopes during overhaul in an optical repair shop. Along with the instructions are complete exploded drawings and parts lists for the telescopes under discussion. It is mandatory that a repairman use this OP 1449 when performing repairs.

As a routine before disassembly, the repairman should always:

- Examine the telescope for any obvious damage such as bent or broken tubes, damaged adjusting screws, broken lenses and faulty focusing ring action. Note any such damage, for repair or replacement before reassembling.
- Place the telescope in a boresight fixture on a collimator table with the telescope adjusting screws in vertical and horizontal positions. Adjust the telescope so the crossline intersection is superimposed on that of the collimator. Rotate the sight through 360 degrees stopping at each 90 degree point to note the drift of the sight intersection from that of the collimator. If there is drift, the crossline lens positioning is incorrect.
- Check the field for full field and sharp definition of the crosslines. If the field is not completely full and circular, one or more of the tubes may be bent or dented or a lens may be out of position. If the definition of the telescope crosslines is not sharp and clear after focusing, the positioning of one or more of the lenses within the telescope is incorrect.

REPAIR AND REASSEMBLY

During the repair and reassembly of a boresight telescope always follow the procedures that are outlined in the appropriate technical manual and maintenance requirements that apply to all optical instruments.

Some important items that apply specifically to boresight telescopes are:

- The body tube should be checked on a mandrel for straightness. If it is slightly bent or dented, it may be straightened on a lathe by spinning it between centers and forcing a mandrel through it. If there is a pronounced bend or dent in the tube it must be replaced.
- If you have removed burrs from the spherical bearing or the journal, it may be necessary to lap in the bearing. Be thorough in your check, as the telescope must be free to move smoothly in the journal.
- Check the fit of all draw tube systems for ease and smoothness of operation, without any lateral play. If they do not meet requirements, lap them in and make any other repairs as needed.

GUNSIGHT TELESCOPES

In this section, we will discuss and illustrate two of the fixed prism Gunsight Telescopes used in the Navy. They are the Mk 74 and Mk 79. These telescopes are used as examples of gunsight telescopes because they are basic in design and construction. The Mk 74 telescope (fig. 11-21) is a deviated line of sight telescope and the Mk 70 (fig. 11-22) is an offset line of sight telescope. Both telescopes are designed for use on the sights of antiaircraft gun mounts.

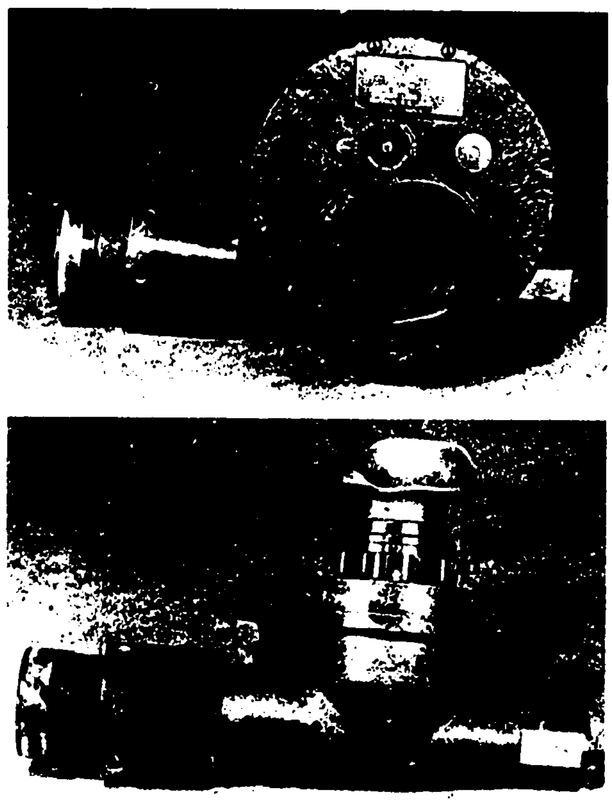

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Figure 11-21.—Two views of a Mk 74 telescope.

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Figure 11-22.—Mk 79 telescope.

A complete list of drawings and detailed instructions for disassembly and repair is given in OP 582 for all telescopes installed on antiaircraft gun mounts. Use this OP and the recommended drawings when work is being done on an instrument.

FEATURES

The telescopes described in this section improve the observer's view of distant targets in the following ways:

- They gather and concentrate upon the lens of the eye a greater quantity of light from the distant target than the unaided eye can gather, rendering the target more distinct.
- They erect the target image and superimpose crosslines upon it, thus sharply defining the line of sight to the target.
- They magnify the target image so that the distant target appears closer.

Mk 74 Telescope

Two views of the MK 74 telescope are shown in figure 11-21. The telescope has a magnification power of 6, with a field of 10 degrees. The exit pupil is .22 inches in diameter and the eye distance is 1.02 inches. The eyepiece axis is deviated at an angle of 90 degrees with the line of sight.

A diagram of the optical system of the Mk 74 telescope is illustrated in figure 11-23.

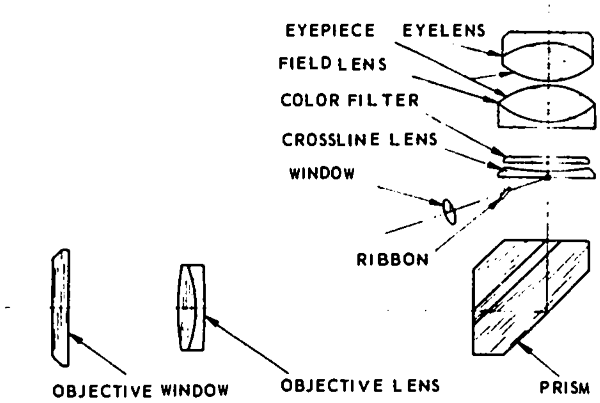

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Figure 11-23.—Diagram of the optical system of a Mk 74 telescope.

The objective window is a plano-plano disc that acts as a seal to exclude dirt and moisture at the objective end of the instrument. The objective lens is a cemented doublet that is corrected for COLOR, SPHERICAL ABBERRATION, and COMA.

The RIGHT ANGLE ROOF PRISM deviates the line of sight 90 degrees and erects the image by twice reflecting the light from the objective.

The crossline lens is a plano-concave disc with the crosslines engraved on its plano face. This negative lens diverges the light passing through it, thus lengthening the eye distance in order to protect the observer's eye from the gun fire shock.

The four ray filters are RED, YELLOW, VARIABLE-DENSITY, and CLEAR. The red and yellow filters increase target contrast and the variable-density filter reduces glare.

The eyepiece of the Mk 74 telescope is symmetrical with the eyelens acting as the eyepiece seal.

The mechanical construction of the MK 74 telescope (fig. 11-24) makes it a composition of several sub-assemblies which are:

- Body tube
- Objective-window mount and cover

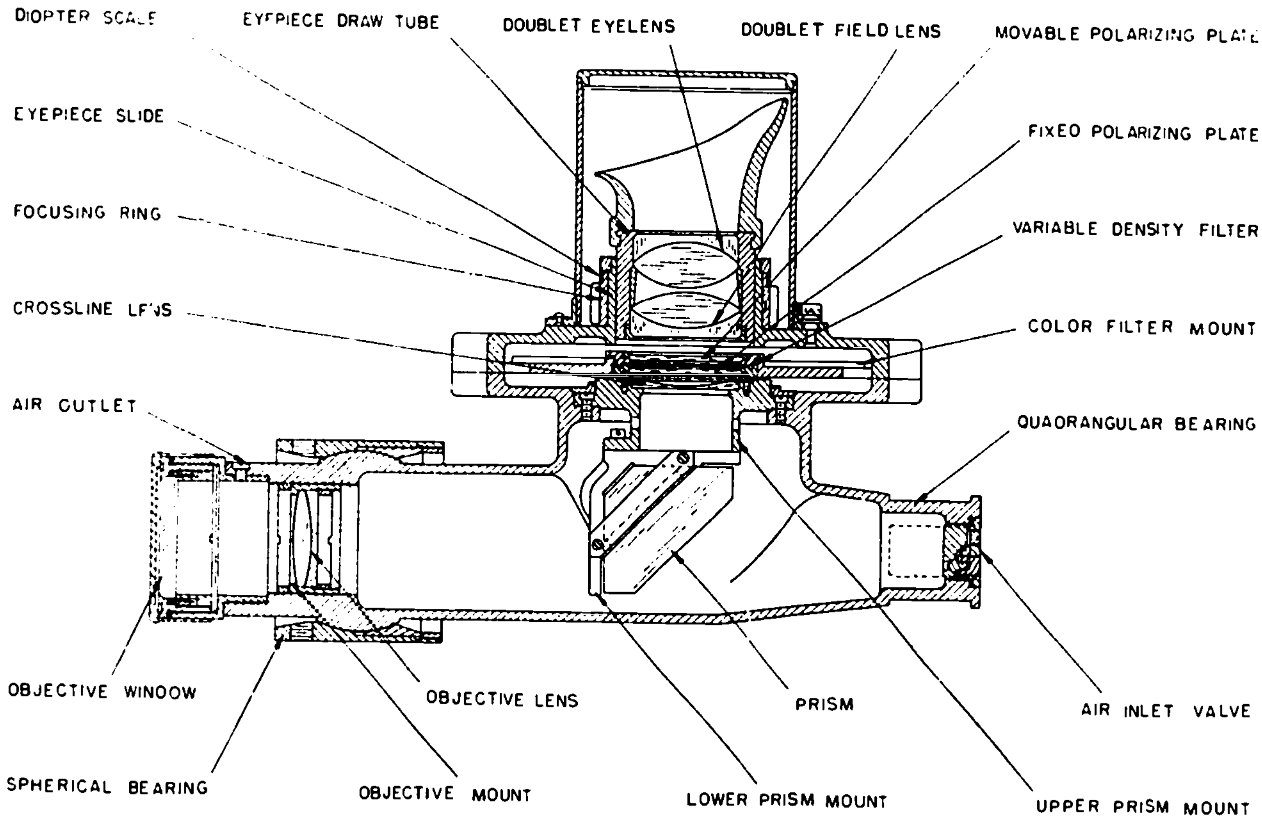

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Figure 11-24.—Mechanical features of a Mk 74 telescope.

- Objective-lens mount
- Roof-prism mount
- Crossline-lens mount
- Color filter assembly
- Eyepiece assembly
- Crossline illuminator

The cast bronze body tube is Y shaped and houses the objective window, objective lens, roof prism, and crossline lens. In addition, the body tube supports the color filter and eyepiece assemblies. Externally, the tube forms a quadrangular bearing at the rear end, and near the front end a spherical bearing is sweated. These bearings are used for mounting the telescope in the gun sight. At the front end of the body tube is an air-outlet screw and at the rear end the air-inlet screw is housed.

The objective window mount and objective lens mount are threaded into the front end of the body tube and held in place by lockrings. The objective window cover slides over the window mount.

The roof prism mount is a bronze casting shaped to hold the 90-degree angle roof prism inside of the body tube. The flanged upper end of the mount is secured to the body tube by screws.

The crossline lens mount holds the crossline lens rigid in a recess in the upper end of the roof prism mount.

The crossline illuminator (fig. 11-25) consists of a lamp housing that is fitted into a body tube cavity below the color filter housing, a Mk 9 lamp socket, a plano window, and a plastic illuminator ribbon. The plano window makes a pressure-tight seal in the body tube by means of a gasket. Light from the lamp passes through a glass plate at the end of the lamp housing and into the illuminator window. From the window, light is directed through the polished ribbon to the crossline lens.

The color filter plates are held in a bronze mounting disc which is rotated about a pivot by internal gearing and an external knob. The same pivot is used in the gearing to rotate the

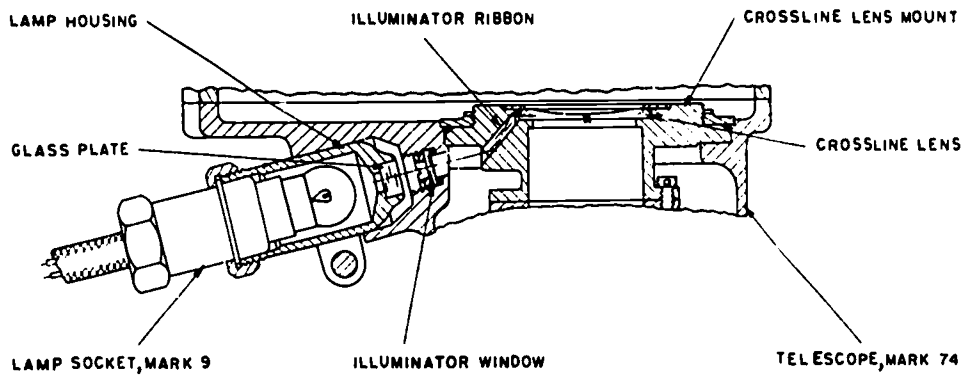

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Figure 11-25.—Crossline illuminator of a Mk 74 telescope.

upper polarizing plate of the variable-density filter assembly in the eyepiece housing.

Originally the eyepiece assembly of the Mk 74 Mod 0 and Mod 1 telescopes were focusing eyepieces (figs. 11-21 and 11-24). If you should receive one of these Mods into the shop for repair, perform OrdAlt 2039-2 on the instrument. This OrdAlt will convert it to a Mk 74 Mod 3, making it a fixed focus eyepiece.

In addition to housing the color filter assembly, the eyepiece housing holds the symmetrical eyepiece.

Mk 79 Telescope

The Mk 79 telescope (fig. 11-22) is a single eyepiece instrument with fixed power, and offsets the line of sight both horizontally and vertically. It has a poro prism erecting system, a magnification power of 4, and a field of view of 10 degrees. The exit pupil has a diameter of .28 inches, with an eye distance of 1.33 inches. Note the difference between the optical system of the Mk 79 telescope (fig. 11-26) and the Mk 74 (fig. 11-23).

The objective window is a plano-parallel disc that acts as the objective seal in the same manner as the Mk 74 telescope.

The objective lens is an achromatic doublet corrected for coma, and spherical aberration.

Each of the poro prisms twice reflect the line of sight through 90 degrees, thus working together to erect the target image and offset the line of sight.

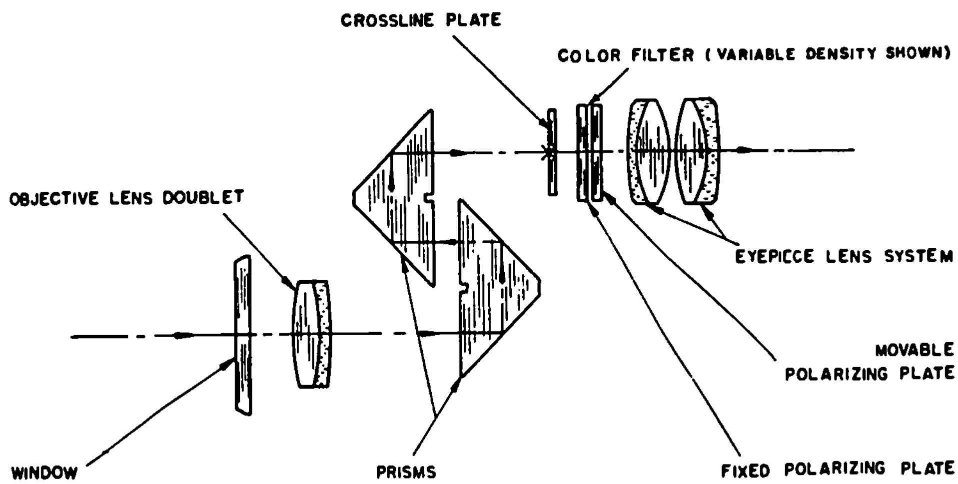

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Figure 11-26.—Diagram of the optical system of Mk 79 telescopes.

The RETICLE is a plano-parallel plate with crosslines engraved on the surface located in the focal plane and facing the objective.

The COLOR FILTERS consist of a red, a yellow, and a clear plate, and a pair of polarizing plates for a variable density filter.

The eyepiece system of the Mk 79 telescope, like the Mk 74, is symmetrical and the eyelens seal the instrument at the eyepiece end.

The small assemblies (fig. 11-27) that compose the Mk 79 telescope are:

- Telescope body
- Objective-window mount
- Objective-lens mount
- Poro prism mount
- Crossline-plate mount
- Color filter assembly
- Eyepiece mount assembly
- Crossline illuminator

The TELESCOPE BODY is a bronze, box-like casting with a front tubular extension, and houses the objective window, objective lens, erecting prism assembly, and crossline plate. The body also supports the eyepiece mount and is fitted with air inlet and outlet valves.

The OBJECTIVE SEALING WINDOW fits into a machined recess in the telescope body and the window retainer threads on to the telescope body. The objective lens mount is threaded into the inner ring of a pair of eccentrics and is secured by a lock ring. The outer eccentric is a sliding fit in the telescope body and it is secured in place by a lock ring.

The objective window cap is placed over the window retainer when the instrument is not in use.

Except for dimensional variations, the PORO PRISM assembly is the same as the poro prism erector discussed in chapter 6. The poro prism assembly is located in the center of the telescope body, within the focal length of the objective lens.

The CROSSLINE PLATE MOUNT is tubular, and is fastened to the poro prism mount by

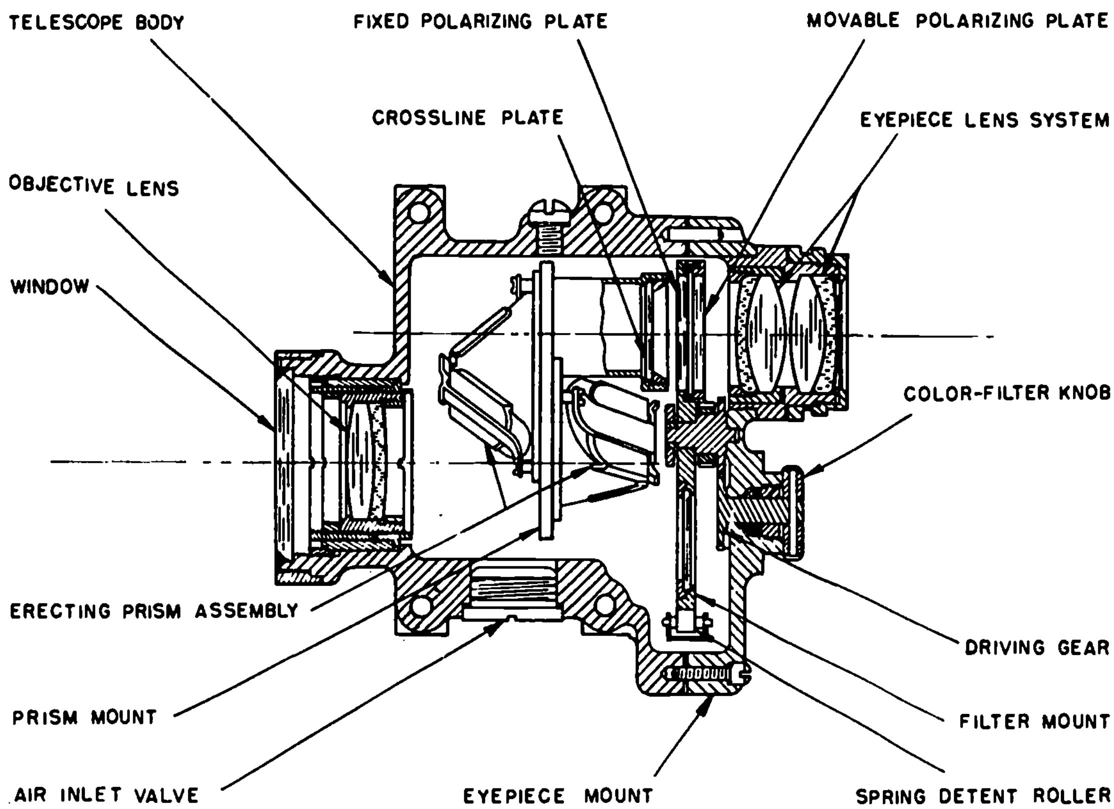


Figure 11-27.—Mechanical features of a Mk 79 telescope.

machine screws that are fitted through its flange.

The COLOR FILTER assemblies vary in size from that of the Mk 74 telescope, but the general construction is the same.

The EYEPIECE MOUNT assembly consists of a flange-like bronze casting that houses the symmetrical eyepiece, and the color filter assembly. Two packing glands built into the eyepiece mount seal the shafts for the color filter knob and the variable density knob.

Attached to the side of the telescope body is the CROSSLINE ILLUMINATOR housing, in which the Mk 9 lamp socket is inserted. Light from the lamp passes through the illuminator window (fig. 11-28) and is directed to the crossline by the plastic illuminator pri .

DISASSEMBLY

After a thorough inspection and areas of repair have been noted on the inspection sheet, disassembly should proceed by removing the major subassemblies in the following order:

- Remove the objective window cap, the objective window mount, and the objective eccentric assembly.
- Remove the eyepiece mount with the color filter and eyepiece assemblies in place.
- Remove the crossline mount and the prism mount from the front of the telescope body.

After the subassemblies have been removed from the telescope body, only those parts that require attention should be dismantled completely.

REPAIR AND REASSEMBLY

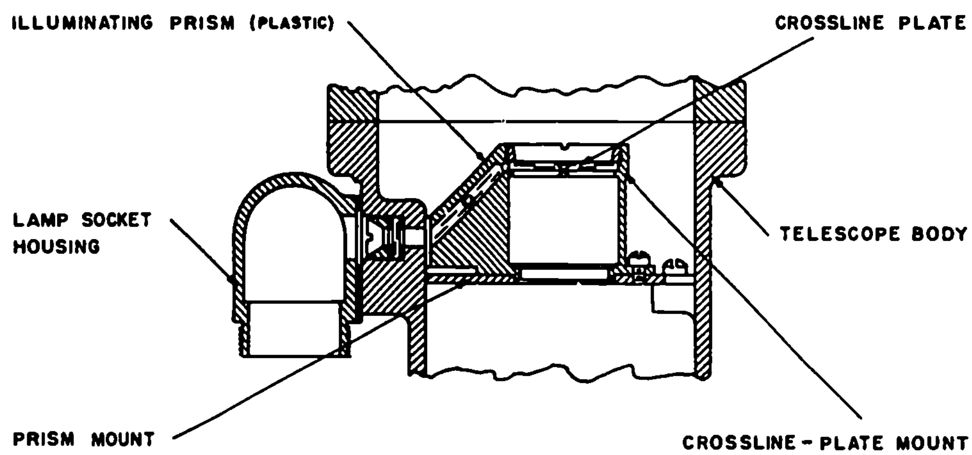
When all repairs have been accomplished according to chapter 7 (Maintenance Procedures) and OP 582, the telescope will be assembled in the reverse order of the disassembly procedure.

During reassembly of the telescope, the following alignment steps must be performed very accurately:

- Position the erecting prisms in the prism mount so that the line of sight has the deviation or offset that design specifications call for, and no lean is introduced in the image.
- Adjust the crossline for proper orientation by rotating it in the crossline mount.

COLLIMATION

The collimation of a gunsight telescope calls for the alignment of the optical axis of the optical system to the mechanical axis or the referenced surface of the instrument. The detailed procedure and illustrations for the collimation of gunsight telescopes is covered in OP 1417. In general, this process includes the adjustment of the mechanical elements so the optical axis of each unit conforms to the optical axes of all other optical units. Also, the objective and



137.277

Figure 11-28.—Crossline illuminator of a Mk 79 telescope.

erecting systems are adjusted in order to allow for focus of the target image, without parallax, upon the crossline.

Fixed Focus Eyepiece

The fixed focus eyepiece on the Mk 74 and Mk 79 telescopes are set at minus 3/4 diopters. This means that rays of light which leave the eyelens are slightly divergent. This value is set to accommodate the average operator of optical instruments, because most operators need a MINUS setting of the eyepiece to use the instrument.

To obtain a minus dioptric setting for a fixed eyepiece, the final, real image produced in the instrument, and/or the reticle, MUST BE LOCATED WITHIN the focal length of the eyepiece system. When an image, or object, is placed within the focal length of any positive lens, the rays emitted by the image are diverging, strike the lens, are refracted, and are still divergent when they emerge.

Because most fixed eyepiece mounts are a part of the telescope housing, the eyepiece mount, or lenses, cannot be adjusted in any manner. How, then, can the crossline of the instrument be positioned within the focal length of the eyepiece if (1) the eyepiece is not adjustable, (2) the crossline itself cannot be adjusted without the introduction of parallax, and (3) the instrument has a prism erecting system?

Most small instrument body housings which contain the fixed eyepieces are cast in two parts; the main body housing, and the ray filter housing. The main body housing contains the objective lens, the prism erecting systems, and the crossline. The ray filter housing contains the ray filters and the eyepiece. The two castings are secured together with screws and sealed with a gasket.

Since the optical system itself cannot be adjusted to obtain proper dioptric setting, without disturbing the previous steps in collimation, mechanical adjustment is the only means left. This can be accomplished by increasing or decreasing the thickness of the gasket between the two housing castings.

A thin gasket moves the ray filter housing closer to the main body housing and thus moves the eyepiece mount and lenses closer to the crossline. The gasket selected must allow the ray filter housing to be so positioned that the crossline is properly located within the focal length of the eyepiece system.

If the dioptric value of the rays leaving the eyepiece must be minus 3/4 diopter (diverging rays), how can you determine when this value is reached? When you use a standard auxiliary telescope, the telescope crossline must come into focus WHEN THE INDEX MARK OF THE AUXILIARY TELESCOPE POINTS TO PLUS 8 DIOPTERS (graduations), plus your own eye correction. One example will explain this.

If the observer normally uses a -2 setting on the auxiliary telescope, when checking a telescope set at -3/4 diopters, the crossline will be in focus at +6 diopters (graduations) on the auxiliary telescope.

NOTE: The ONLY time you focus the eyepiece of the auxiliary telescope to set diopters is when you set a fixed eyepiece; otherwise, you focus the eyepiece of the telescope being collimated.

When you set a fixed eyepiece to minus 1-1/2 diopters, the telescope crossline must come into focus at plus 17 diopters (graduations) on the auxiliary telescope. The auxiliary telescope, however, will not focus out to plus 17 diopters. A special auxiliary telescope must therefore be constructed from a standard auxiliary telescope to allow the eyepiece to conform to the reading. Ask your shop supervisor to demonstrate the use of this special auxiliary telescope.

The rules to follow when you set dioptric value to any fixed eyepiece are as follows:

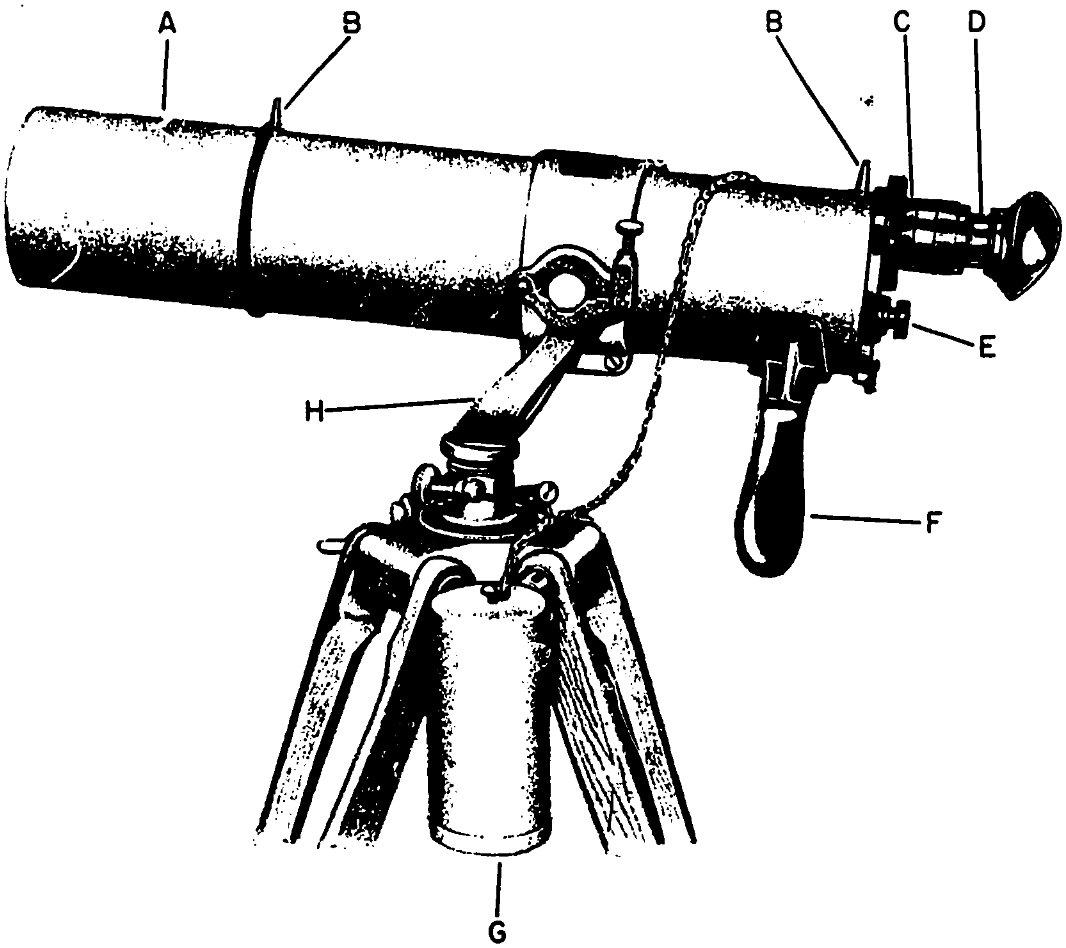
- If the dioptric reading (number of graduations) on the auxiliary telescope is PLUS (more than required), use a THICKER gasket between the ray filter housing and the main body housing.
- If the dioptric reading is MINUS, use a THINNER gasket.

DRYING AND GASSING

The procedure for drying and gassing a gunsight telescope is basically the same as the general procedure discussed in chapter 7. When the opticalman is working on a telescope, he must refer to the technical manual for the instrument under repair, or any other publication that gives the particulars for the type of gas and pressure requirements. In the case of ordnance telescopes, the information is given in OD 2847.

SHIP TELESCOPES

The ship telescope (fig. 11-29) is the Mk 1 Mod 0 and is used as an example in this section.



A. Sunshade assembly.
B. Sighting vane.
C. Diopter scale.
D. Eyepiece assembly.
E. Filter shaft knob.
F. Grip handle.
G. Eyepiece cover.
H. Yoke assembly.

37.2

Figure 11-29.—Mark 1 Mod 0 ship telescope.

The ship telescope is usually mounted on or near the open bridge of a ship for the use of watch personnel to view distant objects that would otherwise be indistinguishable. The Signalman uses it to read visual signals and the Quartermaster will use it to identify navigational aids or other vessels. For detailed instructions on repair consult NAVSHIPS 250-624-3.

CHARACTERISTICS

The ship telescope is referred to as a change of power instrument since it has four interchangeable eyepieces which give magnification powers of 13x, 21x, 25x, and 32x. The telescope is mounted in a yoke assembly that allows it to be turned horizontally through a complete circle, and vertically from 25 degrees below the horizontal to 90 degrees above. Except for the eyepieces, the optical system is housed in a metal tube approximately 29 inches long. The eyepiece assemblies, when in use, are screwed into the eyepiece focusing assembly.

Optical

The optical system, as illustrated in figure 11-30, consists of an air spaced achromatic objective lens, 3-element changeable filter system, a prism cluster erector, and four interchangeable eyepieces.

The objective lens elements are separated by three tinfoil shims 1.001 or 1.002 inch thick. The prism cluster is made up of two poro prisms set at 90 degrees to each other. The filter assembly consists of a light (didymium), a dark (polaroid), and a clear filter set in a rotating mount. By turning an external knob, the observer can select the filter needed to cut down glare. The clear filter has no effect on image brightness and it is used to keep the diopter setting the same. If a clear filter was not used, the observer would be required to refocus when using a filter.

The 21x eyepiece is orthoscopic and the others are Kellner eyepieces. All four eyepieces are so constructed that when threaded into the eyepiece focusing mount, their front focal planes coincide with the image plane of the objective.

Mechanical

Figure 11-31 is an exploded view of the Mk 1 Mod 0 ship telescope, and it gives the nomenclature of all major parts and subassemblies. Study this illustration carefully to familiarize yourself with the names, appearance, and relative positions for all assemblies and parts. This will help you understand the mechanical description that follows.

The main body of the telescope is the tube assembly. It houses the prism box and objective mount, which are threaded into each end. The telescope cradle is clamped to the outside of the tube assembly in a position that allows it to act as a balance point for the assembled telescope. The cradle has a round bearing on each side that sets in the yoke assembly and is held in place by screw clamps.

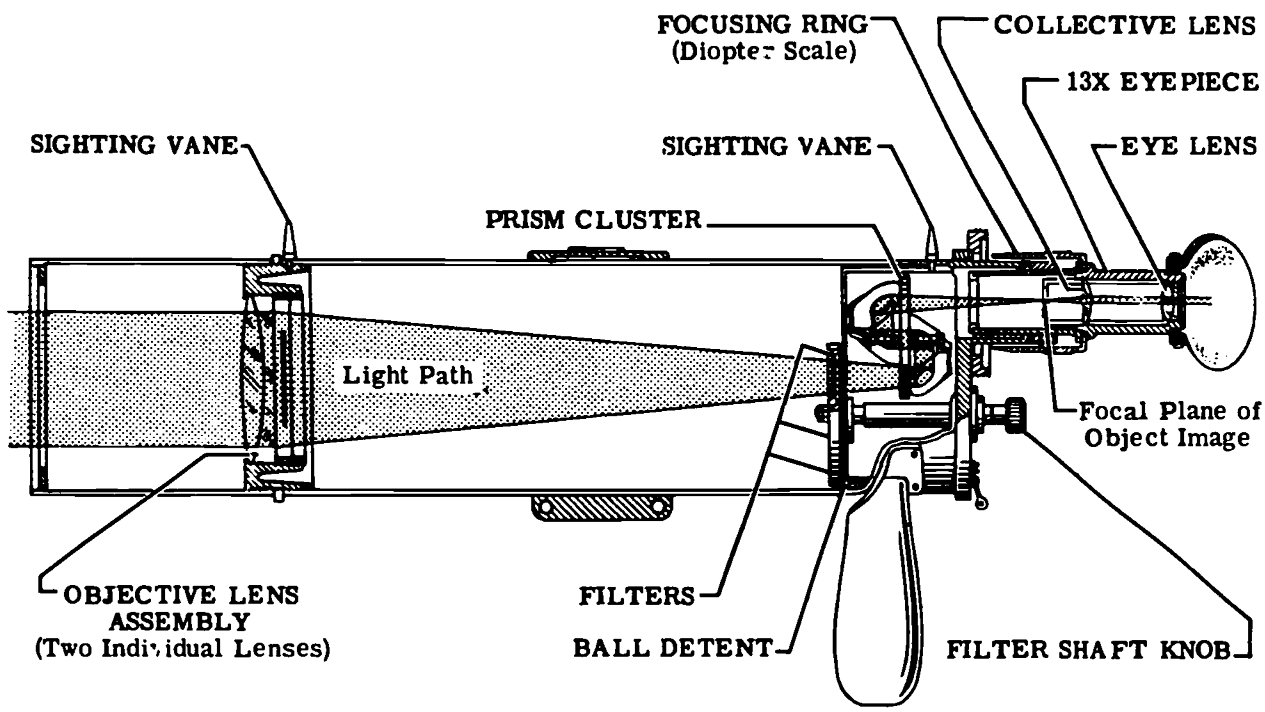


Figure 11-30.—Optical system of a Mk 1 Mod 0, ship telescope.

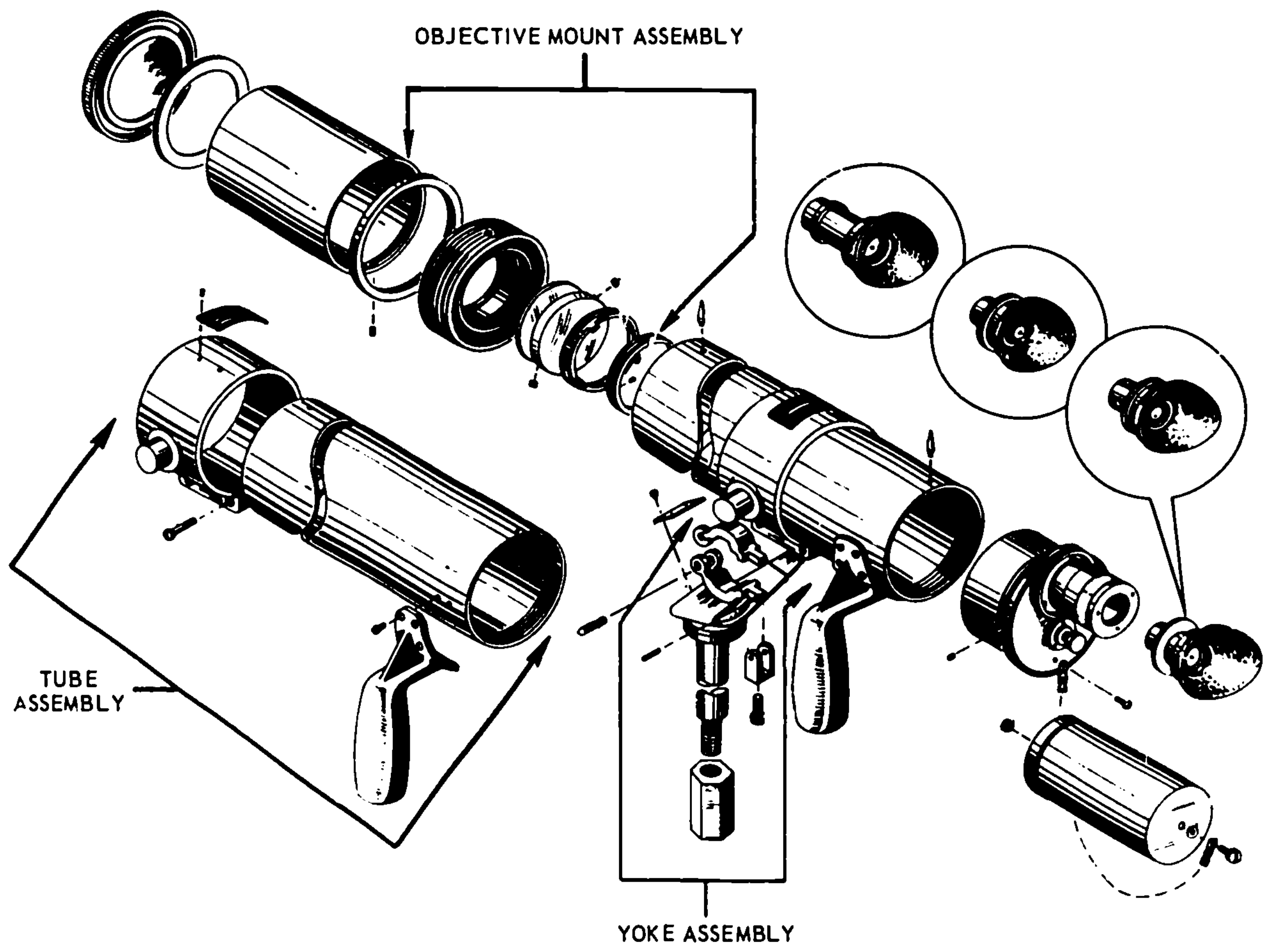


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Figure 11-31.—Ship telescope assembly—exploded view.

The rear side of the objective mount is partially threaded into the tube and held in position by a lockring. The sunshade is threaded to the front side of the objective mount and butted to the lockring.

The prism box assembly (fig. 11-32) houses the ray filters, poro prism cluster, and the eyepiece focusing assembly.

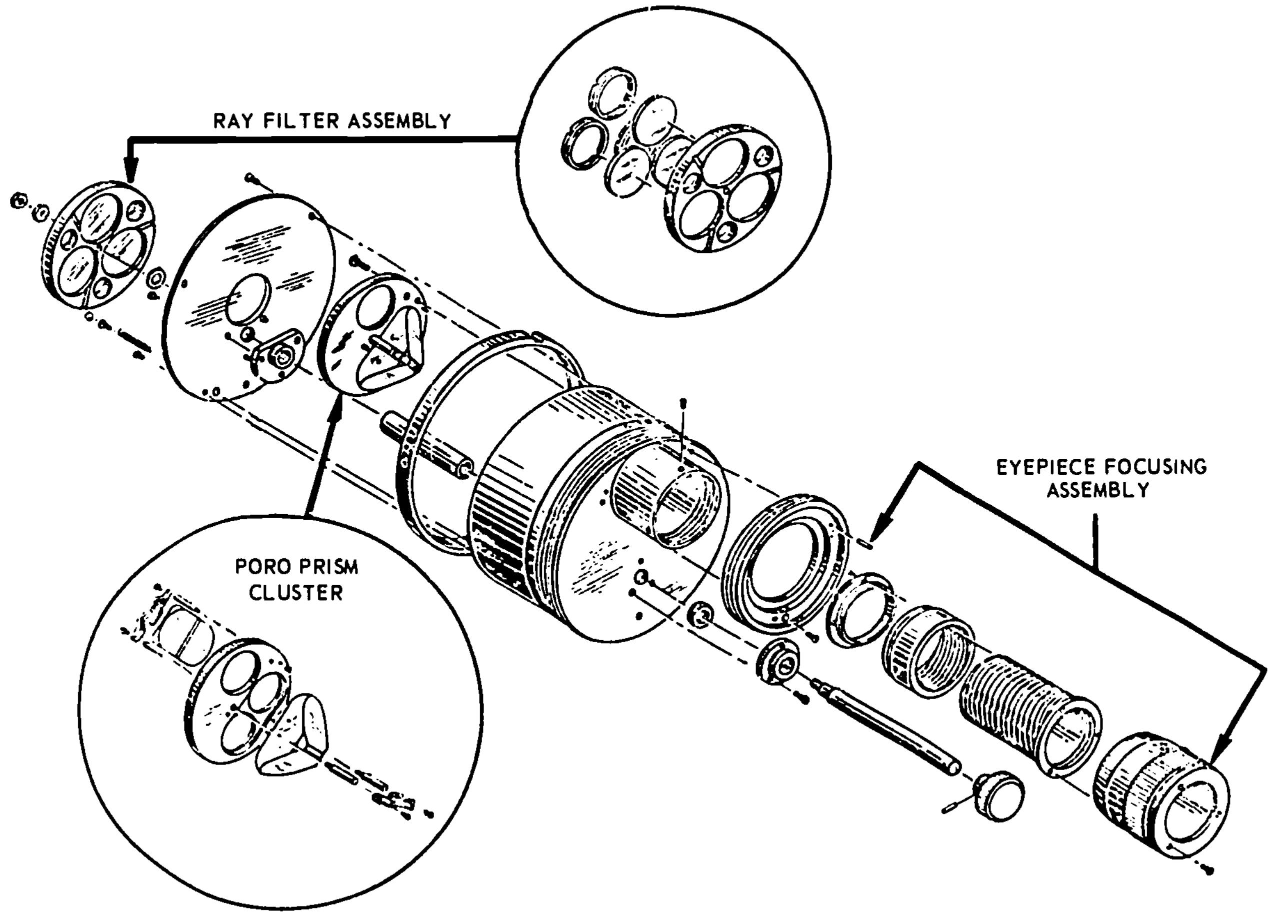
DISASSEMBLY

The standardized procedure for the complete disassembly of the ship telescope is given as a detailed step-by-step operation in Technical Manual, NAVSHIPS 250-624-3. Since this manual must be used when making repairs, only major points will be discussed in this training manual.

Each telescope should have attached to it an identifying tag and a predisassembly inspection report on which the inspector has written specific instructions on what repairs are to be made. Perform only the amount of disassembly required to effect the repairs needed.

All parts disassembled from a specific ship telescope should be kept together in a parts tray for reassembly to each other. Many parts are fitted and matched at the time of manufacture and are not interchangeable. As a general rule, it is much easier to reassemble original parts because replacement parts may vary within tolerances far enough to cause difficulty in reassembly. Mark or tag the matched parts with the serial number of the instrument from which they are disassembled.

All major subassemblies are removed from the telescope as a complete unit. The



137.529
Figure 11-32.—Prism box, filter, and eyepiece focusing assembly—exploded view.

subassemblies are then disassembled individually.

REPAIR AND REASSEMBLY

Standard procedures for repair and reassembly work were discussed in chapter 7, however, some of the more critical points relating to the ship telescopes are:

- The ship telescope will be closed with sealing compound at every possible entrance point, such as around exterior lenses, body joints, and even under screw heads.
- You will save considerable extra work and trouble in reassembly and test and adjustment if you use the same parts (except for replacements) that were matched and fitted by the manufacturer. Take advantage of the work already done; this applies to both mechanical and optical parts. Bear in mind that there are matched parts which may not at first be obvious to you, such as the components of the eyepiece.
- The diopter scale readings will be incorrect if the four eyepieces are not reassembled with their original components; the same will be true if the four eyepieces are not used with their original ship telescope. They were parfocalized to each other and the particular ship telescope.
- The two lenses of the objective lens assembly are positioned relative to each other for best overall image fidelity and they should be marked on their edges to so indicate. If this positioning is not maintained, poor optical performance will result. You will mark them before disassembly and look for the manufacturer's marking after disassembling the parts.
- The prisms are paired in a cluster to cancel the inherent angular and pyramidal

errors in each. Their relative positions must also be maintained since the errors will cancel only when in this position. Reversing the position may make the errors ADD to each other. If it is necessary to replace a prism, one having the same inherent errors should be substituted or else the cluster should be replaced with a matched pair. See "Prism Pairing" as referenced in the index of the Control Manual.

- The eyepiece tube and eyepiece adaptor are fitted together with a sextuple thread that is lapped for smooth focusing action. This matching of threads also affects the diopter scale readings. The assembly of the two parts screws into the neck of the prism box. Its position in relation to the prism box also affects the diopter readings. Once again, the manufacturer's marks may be obscured, so make your own marks before disassembling these parts.

- To be fully effective, the polaroid filter must be positioned in the filter plate so as to make the axis of transmission vertical when the filter is in position for use. The filtering action will be decreased as the axis is turned toward the horizontal. The manufacturer scribed two short lines on the filter to indicate the axis.

- While the mechanical parts are not as easily damaged as are optical parts, reasonable caution should be exercised to protect them. For example, if the end of the telescope tube is dented, the thread for the objective mount or prism box may be permanently damaged.

COLLIMATION

The primary purpose of collimating a Mk 1 Mod 0 ship telescope is to ensure the accuracy of the diopter scale reading and to make it constant for all four eyepieces. Alignment of the mechanical sighting vanes with the optical axis must also be checked.

During collimation, you must test and adjust the eyepieces as necessary to make all four of them give a focused image for a fixed diopter setting. Each one must have the same distance between its mounting shoulder and its focal plane, which is represented by A in illustration 11-33. In other words, the diopter reading for sharpest focus will not change when the four eyepieces are interchanged. The eyepieces are said to be PARFOCALIZED when they are

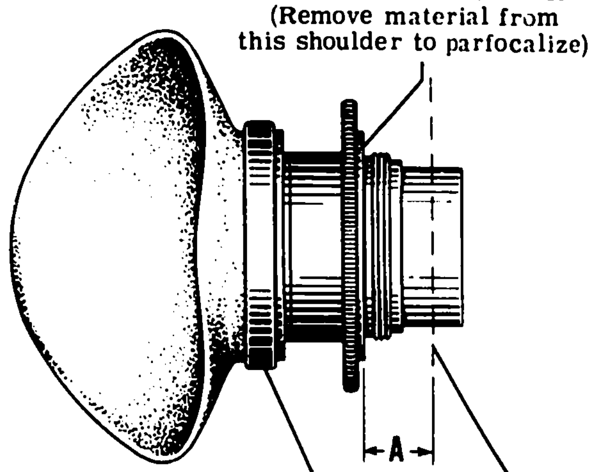


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Figure 11-33.—Correct distance between the mounting shoulder and the focal plane of an eyepiece assembly, represented by A.

adjusted in this manner. Each eyepiece must indicate a diopter reading of 0 diopters, plus or minus one quarter, when the telescope is focused on a distant object.

Test equipment required for collimating a ship telescope consists of an auxiliary telescope and a ship telescope collimator. Study figure 11-34.

After you reassemble and seal a ship's telescope, it should be in perfect condition and ready for use aboard ship. Before you release the instrument for use, however, give it a final inspection, as follows:

- Look through both ends of the telescope and the four eyepieces for dirt, grease, and fingerprints on the optics, or fogginess in the optical system.
- Check the mechanical parts for finish, and tightness in assembly, and check all screws for tightness.
- Inspect the yoke assembly for freedom of movement of parts.
- Assemble one eyepiece in the telescope and put the other three in the eyepiece case.
- Place the eyepiece case, the yoke assembly, the telescope cover, and the telescope in the carrying case.

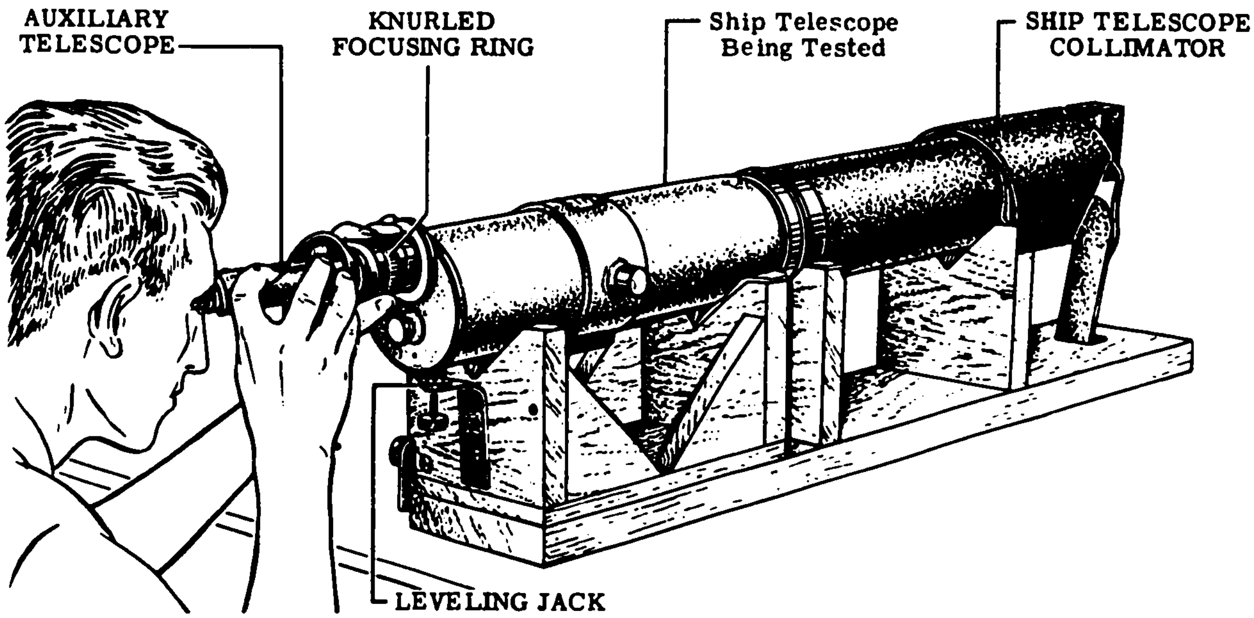

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Figure 11-34.—Test equipment for collimating a ship telescope.

CHAPTER 12
NAVIGATION INSTRUMENTS

In this chapter, we will describe six navigation instruments that are maintained and repaired by Opticalmen. These are: the magnetic compass; azimuth and bearing circles; the sextant; the stadimeter; and the telescopic alidade.

We also will give you the complete overhaul and repair procedures for the magnetic compass, since there are no technical manuals for you to use when repairing this instrument. The other instruments are described just enough for you to understand their theory and function. When you are required to overhaul these instruments, use only the referenced NAVSHIPS manuals for technical guidance and repair procedures.

As an opticalman, you should never navigate a ship, as this is the job of the ship's navigator. However, some understanding of navigation will help you to realize the importance of your work on the instruments. You should know that navigation consists of calculating position and plotting a safe course from where you are to where you are going. After you have made these calculations and set your course, the helmsman uses a compass to keep the ship on that course. Because of ocean current and wind, the ship will periodically be drawn away from the projected path of travel and course corrections must be made. If you are within sight of land, you can use a bearing circle or telescopic alidade to measure the bearing of two or more landmarks to determine your ship's position and what corrections are required.

More often, the navigator must find the ship's position when there is no land in sight and he bases his calculation on the angular height and bearing of celestial bodies. The sextant is used to measure the angular height above the horizon of the sun, planets, and stars. The azimuth circle is used to measure their bearing. The accuracy of these measurements depend solely on the skill of the navigator and the skill of the opticalman in maintaining the instruments. Support your end of the team by always performing your job in the best manner possible.

MAGNETIC COMPASS

After the navigator has used his sextant and chronometer to find the position of his ship, he can set his course. In setting a course, he merely decides what direction his ship will sail to get where it's going. Than the helmsman must keep the ship on its course. To do that, he must constantly consult a COMPASS, to see what direction his ship is heading in (fig. 12-1).

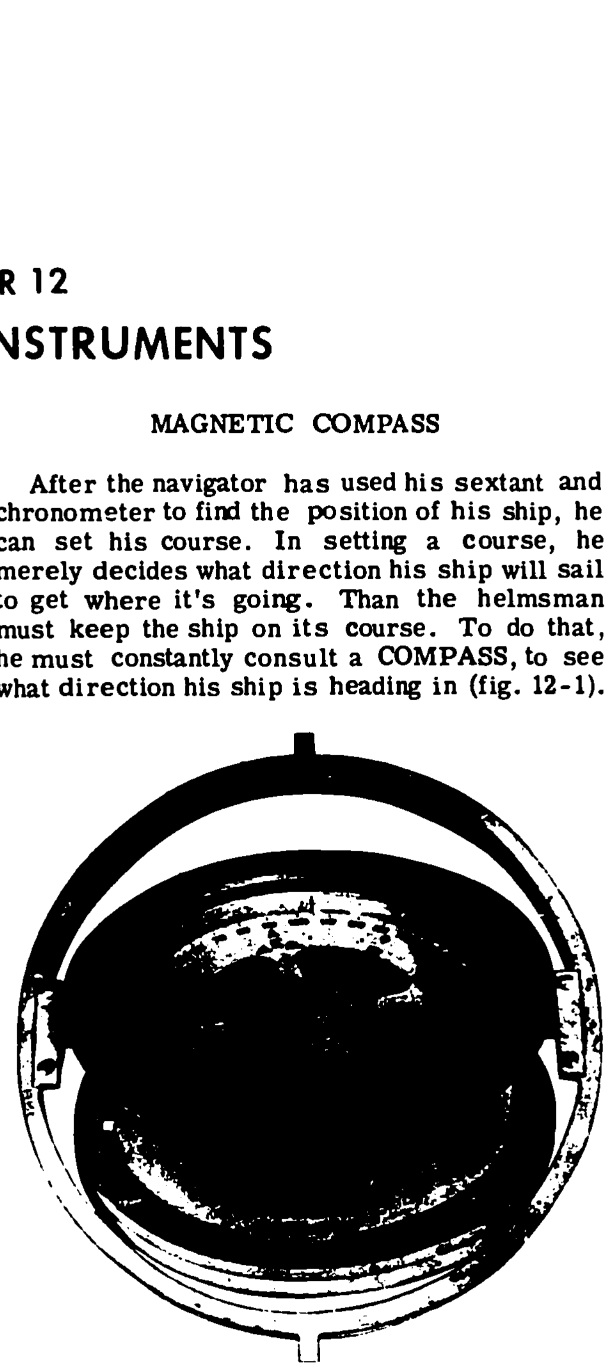

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Figure 12-1.—U. S. Navy 7 1/2-inch magnetic compass.

The Navy has equipped all its ships with GYROCOMPASSES. (Repair of the gyrocompass isn't one of your duties, so we won't discuss it in this course.) But the large ships all have MAGNETIC COMPASSES too. And ship's boats depend entirely on the magnetic compass.

When a magnetic compass is damaged or broken, it's sent to the optical shop for repairs.

PRINCIPLE OF OPERATION

Somebody in Magnesia (on the coast of the Aegean Sea) discovered a long time ago that certain stones (magnetite or lodestone) could attract iron. Another person learned that when he rubbed an iron bar with a piece of lodestone the bar became a magnet. A Chinaman then learned that when he attached little floats to a magnetized needle and put it in water the needle pointed approximately North and South. Some time later, an Italian navigator balanced the needle on a pivot and learned that its action then was the same as when it was balanced on water.

These people learned through experimentation the principle of operation of a magnetic compass. From the needle on floats or a wooden disk to the compass box and hanging compass, action of the compass needle has always been the same—only the method for holding it has changed.

You can learn how a magnetic compass operates by doing a little experimenting on your own. Hold a small compass level and observe the action of its needle. Regardless of the direction you turn the compass, its needle always points north; and by turning the compass until the N on the card is under the point of the needle, you can determine any direction.

If you take the needle out of the compass, you will find that it is magnetized at both ends. Each end attracts iron; but ONLY ONE end will point North. The reason for this action is that there are TWO KINDS of magnetism North and South and every magnet has both kinds. If we call the points where magnetism in a magnet is strongest the magnetic poles, every magnet has a NORTH-SEEKING pole and a SOUTH-SEEKING pole. In a bar magnet, or in a compass needle, the two poles are at the ends.

The earth itself is a HUGE magnet, with a north magnetic pole in northern Canada and a south magnetic pole in Antarctica. Like poles REPEL each other; unlike poles ATTRACT each other. Put two bar magnets side by side, with both north poles together. and observe what happens. The two magnets repel each other; but if you turn ONE magnet end for end, the two magnets attract each other.

Most ships carry two or more magnetic compasses like the one illustrated in figure 12-1. This is a U.S. Navy 7 1/2-inch compass.

Wet compasses are liquid filled, usually with varsol or alcohol and water. Other compasses contain no liquid and are designated as dry compasses, but this type of compass is seldom used in the Navy. A wet compass consists of a bowl filled with liquid, which supports a hollow float to which the compass card and magnets are attached. The liquid steadies the compass against the motion of the ship and the shock of gunfire; and since the liquid supports most of the weight of the magnets, it reduces the pressure and friction on the pivot.

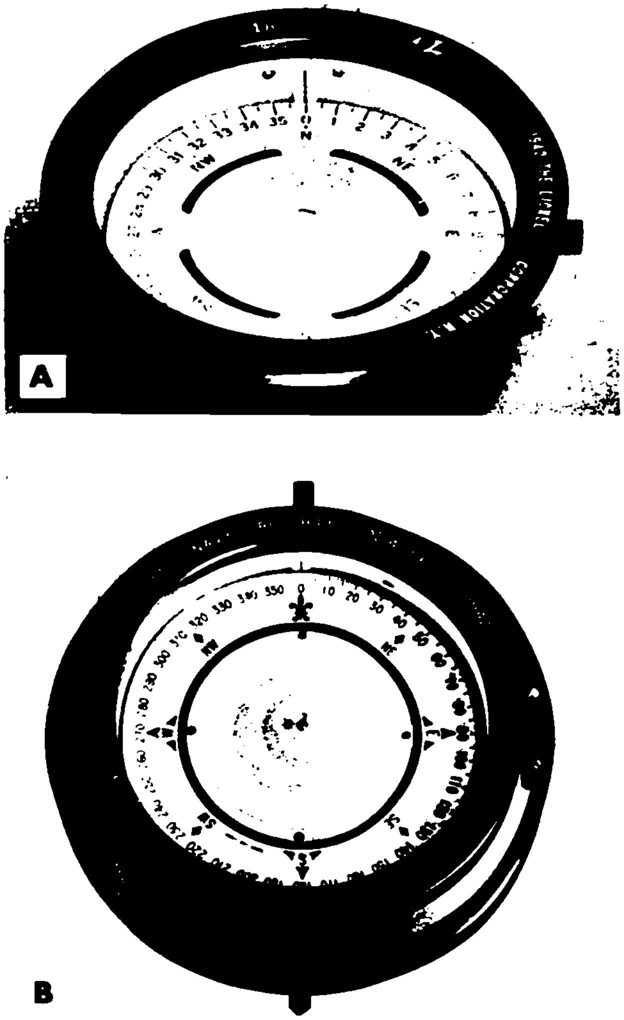
Navy magnetic compasses vary slightly with respect to purpose. Part A of figure 12-2 shows a standard 4-inch boat compass, and part B of this illustration shows a 6 3/4-inch steering compass.

The size of a compass is designated by the diameter (in inches) of its card. The compass shown in figure 13-3 has a translucent card, or one with perforated markings; and a light in its stand shines up through a ground-glass plate in the bottom of the compass to illuminate the card.

The compass card of a pocket compass is printed on the bottom of the case, and its needle is not hindered in its motion. A Navy compass, on the other hand, has no needle. The steersman is not interested in knowing the direction of North; all he wants to know is the direction his ship is heading.

The compass card of a magnetic compass is mounted on a pivot and the magnets are attached to the card, so that the card itself will swing and point its zero mark to the north. Observe on the bowl of the compass shown in figure 12-2 the LUBBER'S LINE. The compass is always mounted so that an imaginary line from the compass pivot to the lubber's line is parallel to the ship's keel; so, to read the ship's heading, you read the graduation on the compass card AT THE LUBBER'S LINE. When the ship changes its course, the compass card still points its zero graduation toward north; but the ship, the compass bowl, and the lubber's line all turn—under the card.

In order that it will stay level even when the ship is rolling and pitching, the bowl of a magnetic compass is mounted in gimbal rings. The bottom of the bowl is very heavy, to help keep the compass level. The compass is mounted in a stand, called a BINNACLE. See illustration 12-3. The two hollow soft iron spheres on the sides of the binnacle are called quadrantal correctors for deviation. (Deviation changes direction every 90°, hence the name QUADRANTAL.) The earth's magnetic field magnetizes these spheres by induction. The induced magnetism of the spheres counteracts the induced magnetism



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A. Standard 4-inch boat compass.
B. Steering compass.

Figure 12-2.—Types of magnetic compasses.

of the ship and forces the compass needle to point toward magnetic north. The force exerted by these spheres can be altered by their distance from the compass. The size of a sphere also affects its force.

A cross section of a typical magnetic compass is shown in figure 12-4. Refer to the

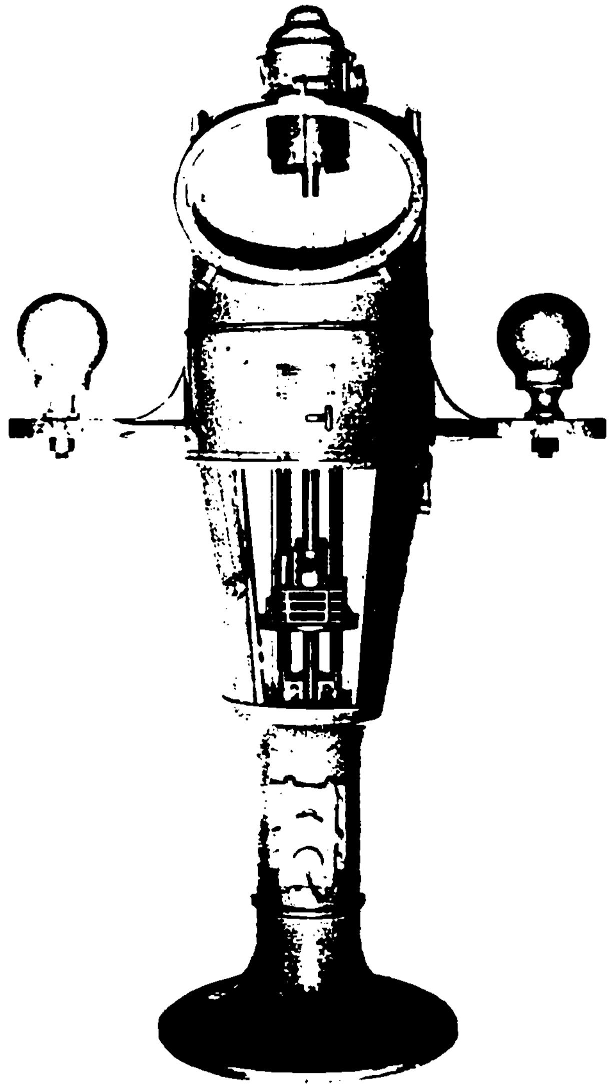

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Figure 12-3.—Magnetic compass and binnacle.

nomenclature as you study the discussion of the illustration.

The bowl of the compass is filled with a liquid, and there is an expansion chamber in the bottom of the bowl to hold excess liquid created by expansion. The expansion chamber is made of thin, flexible metal; so, when the compass liquid gets warm and expands, the extra liquid is forced by pressure into the expansion chamber and expands the chamoer.

The top of the bowl is covered with a glass plate, secured by a BEZEL ring. A rubber gasket is placed between the ring and the glass

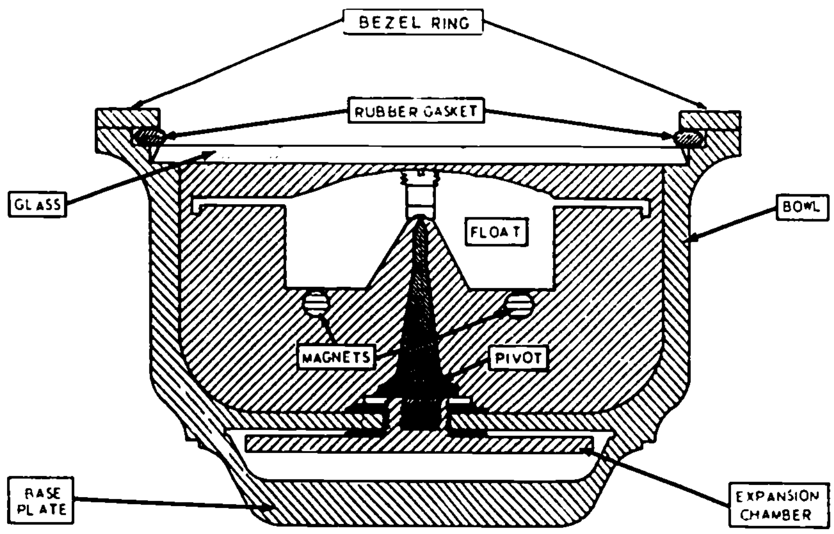

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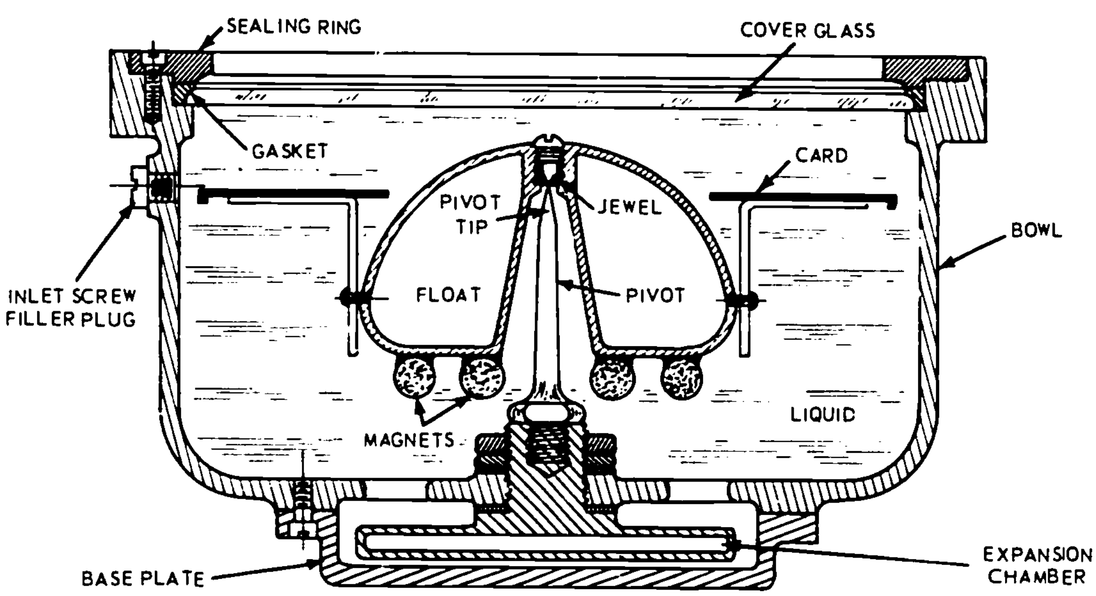
Figure 12-4.—Cross section of a magnetic compass.

to prevent leakage. The pivot which holds the float is secured to the bottom of the bowl, and it has a rather sharp point which fits in a jewel located in the top-middle part of the float. Study illustration 12-5, which shows the pivot tip and the location of the jewel. The pivot tip fits in a cavity in the bottom of the jewel to allow smooth action of the float balanced on the pivot. Observe also in figure 12-5 the inlet screw filler plug and the compass card. In this compass, the expansion chamber is filled with air and is surrounded by the compass liquid; when the liquid expands, it compresses the chamber.

The compass card is secured TO THE TOP of the float. The bar magnets are fastened UNDER THE FLOAT, as shown.



137.286

Figure 12-5.—Nomenclature of a magnetic compass.

The float is a hollow, metal chamber submerged in the liquid, which gives it enough buoyancy to support most of the weight of the magnets. The float assembly of a 7 1/2-inch compass, for example, weighs 3,060 grains in air, but it weighs less than 90 grains when submerged. The float therefore makes the compass more sensitive and more stable.

COMPASS ERROR

Variation and deviation combined constitute magnetic compass error. If you know the true course for a ship, worked out from the chart, you must then know the compass course to steer to make the true course good. This is accomplished by applying compass error, in the shape of variation and deviation, to the true course. On the other hand, if there is a bearing taken by a magnetic compass, variation and deviation must be applied to the compass bearing to obtain the true bearing.

All compass errors, whether caused by variation or deviation, are either easterly or westerly. There are no northerly or southerly errors. Correction for error is made by ADDING easterly error and SUBTRACTING westerly error when correcting compass course to true course, and by SUBTRACTING easterly error and ADDING westerly error when uncorrecting true course to compass course.

Deviation

A compass needle is a magnet, and iron and steel attract magnets. Because ships are made of steel, they affect the action of compass needles. The amount of magnetic deflection of a magnetic compass needle from true north by magnetic material in the ship is called DEVIATION. Deviation is different for different compasses, and also for different parts of a ship.

Although deviation remains a constant amount for any given compass heading, the amount is not the same for all headings. Deviation gradually increases, decreases, increases, and decreases again as the ship goes through an entire swing of 360 degrees. Because the deviation for each heading must be known in order to correct the error, a deviation table is made up for every ship; and this table usually shows the deviation for each 15° of swing. See illustration 12-6.

To find the deviation, swing the ship in 15° increments around to 360° and note the amount the compass points away from each magnetic heading. This is the compass deviation for that particular heading. In using the table, the deviation for the heading nearest the one being checked is selected. If the deviation for a 17° heading is desired, for example, the deviation for 15° (10° W) would be selected.

DEVIATION TABLE

SHIPS HEADING MAGNETIC	DEV.	SHIPS HEADING MAGNETIC	DEV.	SHIPS HEADING MAGNETIC	DEV.
000°	14°W	120°	15°E	240°	4°E
015°	10°W	135°	16°E	255°	1°W
030°	5°W	150°	12°E	270°	7°W
045°	1°W	165°	13°E	285°	12°W
060°	2°E	180°	14°E	300°	15°W
075°	5°E	195°	14°E	315°	19°W
090°	7°E	210°	12°E	330°	19°W
105°	9°E	225°	9°E	345°	17°W
				360°	14°W

69.12

Figure 12.6.—Sample deviation table.

Variation

The amount a compass needle is offset from true north (caused by attraction to the position of magnetic north) is called variation, because it varies at different points on the earth's surface. Even in the same location it usually does not remain constant—it decreases or increases annually at a certain known rate. Deposits of iron ore tend to pull a compass needle away from its true pole (the end of the imaginary axis on which the earth rotates), and in some parts of the world the needle may point as far as 60° from true north.

Because all our maps and charts are drawn to true north, readings of a compass for variation must be corrected before it is used. Magnetic compass variation through all navigable waters, however, has been accurately determined and recorded for use by ships.

DISASSEMBLY

When you receive a defective compass for repairs, give it a careful inspection. You can often determine the trouble with the instrument at this time, before you start disassembly. Look for the following:

• If the compass card is level and there is a large bubble under the glass cover, liquid is leaking out under the cover glass, or there is a leak in or around the expansion chamber.

• If the compass card is tilted and a large bubble is under the glass cover, but there is no leak around the cover, there is probably a leak in the float.

• If there is no bubble under the cover glass but the card is tilted, the magnets have shifted, or the balancing solder has fallen off the float, or the float has jumped off its pivot.

• Put the compass on a level workbench and turn it until the north point on the card is at the lubber's line. With your magnet, deflect the compass card exactly 11° and then quickly remove the magnet. The compass will then swing back; and as the zero mark crosses the lubber's line, start your stopwatch. The zero mark will reach the end of its swing and start back; and as it crosses the lubber's line the second time, stop your stopwatch and read it. The time you read is THE PERIOD OF THE COMPASS, and it should be 10 seconds or less. If it is longer than 10 seconds, the magnets are weak, or the pivot point is in poor condition.

• If the float does not swing freely under the influence of a magnet, the pivot point or the jewel is broken.

The recommended procedure for disassembling a magnetic compass is as follows:

1. Remove the filler plug and drain out a small quantity of the liquid, to prevent spillage in trying to handle a full compass bowl. Then replace the filler plug. Save the liquid you drew out.

2. Mark the lip of the bowl and the edge of the bezel ring, for you must put the bezel ring back in the same position it occupied before removal.

3. Remove all screws from the bezel ring. CAUTION: Loosen each screw a little at a time, in rotation or opposite each other, to prevent tilting of the bezel ring by the rubber gasket and probable breakage of the glass.

4. Lift off the bezel ring and then remove the rubber gasket. See illustration 12-7. CAUTION: Use care to prevent damage to the gasket.

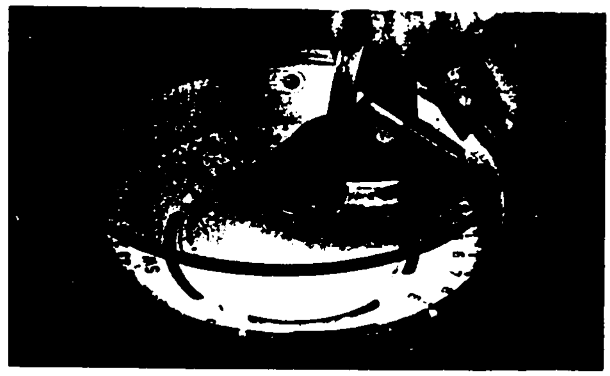
5. With a suction gripper (fig. 12-8), or a pegwood stick, lift the glass. CAUTION: The glass is beveled to a thin edge and chips easily.

6. Test the float for leaks. Push down on one side of the float, as shown in illustration 12-9, hole it down for several seconds, and then release it. If the float stays down, it contains liquid. Repeat this test at three different points around the card.

7. With a piece of wire bent to form two hooks (fig. 12-10), lift the float out.

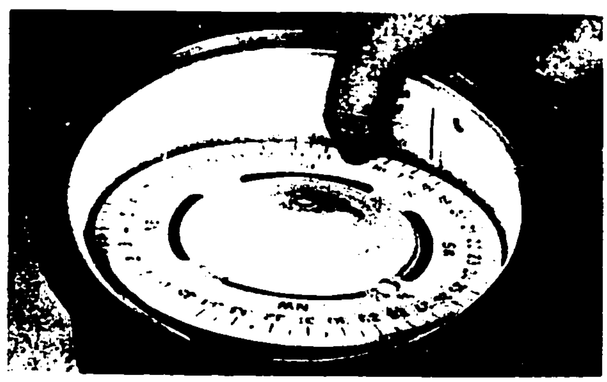
137.287

Figure 12-7.—Removing the rubber gasket.



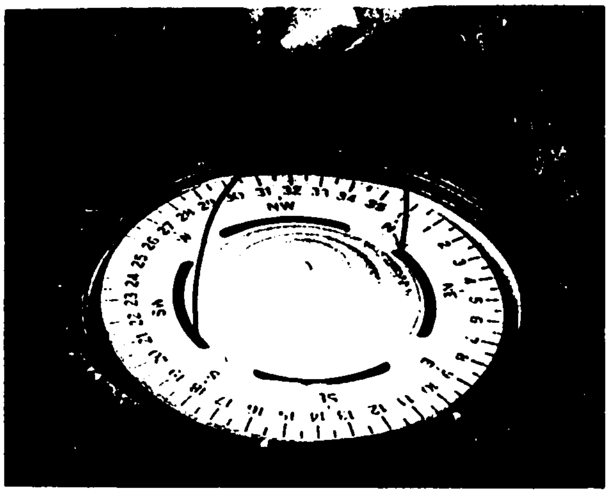
137.288

Figure 12-8.—Removing the cover glass.



137.289

Figure 12-9.—Testing the float for leaks.



137.290
Figure 12-10.—Removing the float assembly.

8. Pour the remainder of the liquid from the bowl and filter it through filter paper or absorbent cotton into a clean bottle for future use.

9. To remove the pivot, fit a socket wrench over its hexagonal base and turn counterclockwise. CAUTION: Be sure the center hole of the wrench is deep enough to provide clearance for the pivot point.

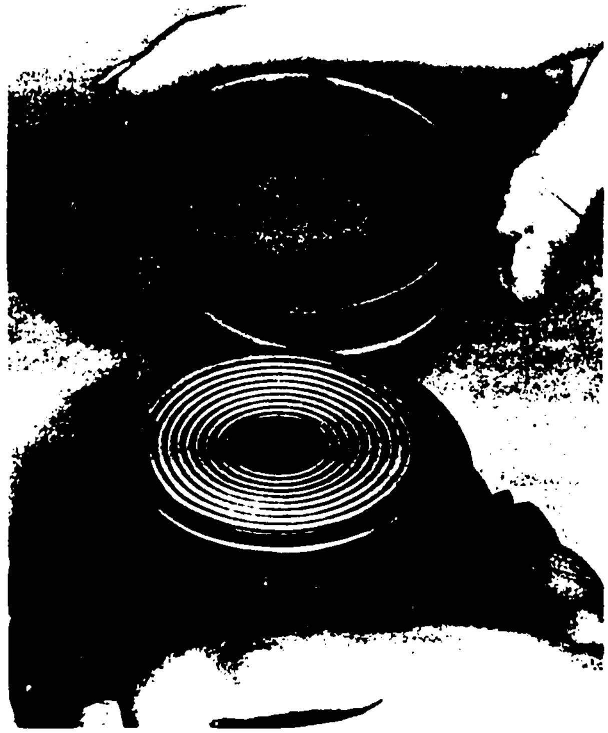
10. Turn the bowl over and, with a punch, make light register marks on the bowl and the base plate, to guide you in reassembling the base plate in its original position.

11. Remove the screws from the base plate and lift it off. See illustration 12-11. This base is made heavy to help keep the compass on an even keel.

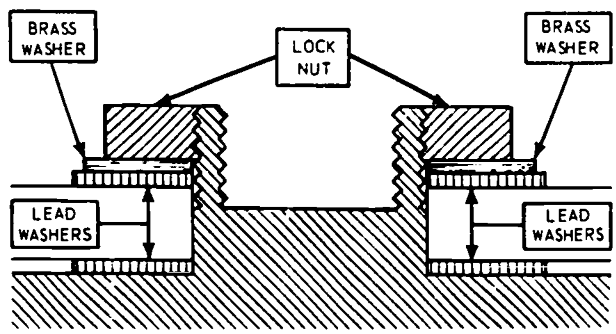
12. Note in illustration 12-11 the bottom of the expansion chamber, and then study figure 12-12 to learn how the chamber is secured through the hole in the bottom of the compass bowl. Beneath the expansion chamber nut is a friction brass washer, and under this washer is a lead washer. Between the chamber and the bottom of the bowl is another lead washer. When these washers are put under pressure, they seal the opening in the bottom of the bowl.

13. Turn the bowl over and remove the expansion chamber lock nut with a socket wrench.

14. Remove the expansion chamber from the bowl and inspect it for leaks or other damage.



137.291
Figure 12-11.—Removing the base plate.



137.292
Figure 12-12.—Expansion chamber secured to bottom of compass bowl.

REPAIR AND ASSEMBLY

Inspection of parts, repair, and reassembly of a magnetic compass are discussed conjointly, step by step, as follows:

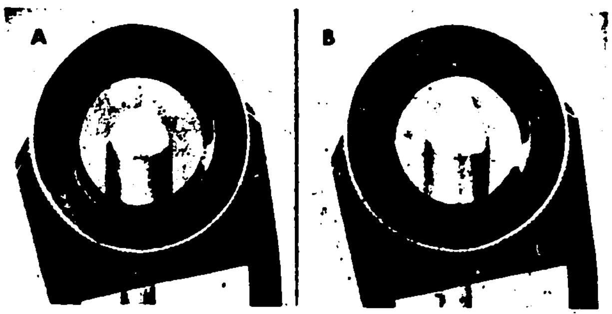
1. If the expansion chamber is in good condition, reassemble it. CAUTION: Do NOT forget the lead washer between the expansion

chamber and the bottom of the bowl. If this washer is not in perfect condition, replace it.

2. Replace the second lead washer, inside the bowl and replace the brass friction washer. If necessary, use a new washer. Start the hexagonal lock nut by hand and tighten it with a socket wrench. NOTE: Use enough tension to make a good seal at the lead washers.

3. Put the base plate back into position; then replace the base plate screws and tighten them. CAUTION: Be sure to line up your two marks you made during disassembly; otherwise, the compass will be out of balance.

4. With a magnifying glass, inspect the pivot point for wear. Study illustration 12-13. The magnified pivot in part A of figure 12-13 is badly worn. Observe the round appearance. The pivot point shown in part B of this illustration has proper shape. NOTE: A badly worn pivot point makes a compass sluggish.

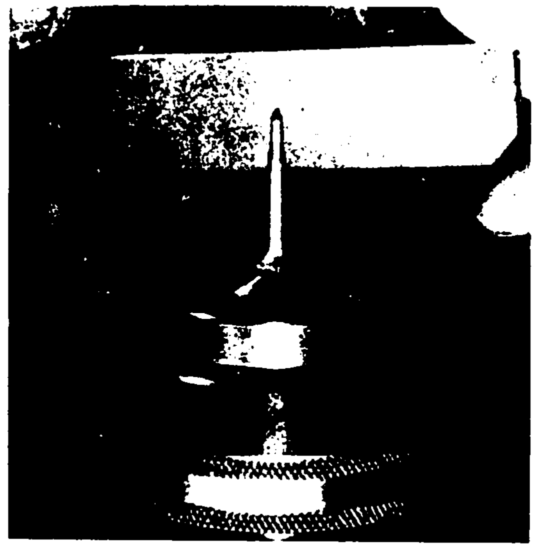


A. Worn pivot point.
B. Good pivot point.

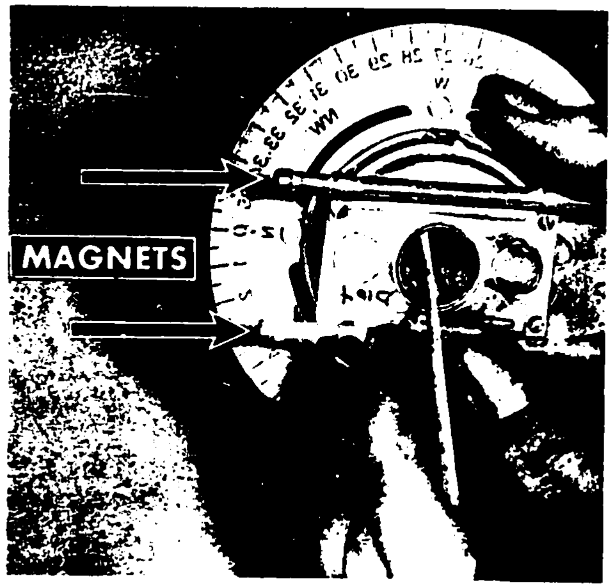
137.293
Figure 12-13.—Pivot points.

5. If the pivot point is worn, put it in a lathe and reshape it with a fine carborundum slip (fig. 12-14). Then polish it with an Arkansas oil stone and inspect again for correctness of shape. The tip of the pivot should have a radius of .005 inch.

6. Remove the screw from the top of the float and use a piece of pegwood with a rounded end to push the jewel and its spacer out of the float. Study illustration 12-15. Then hone a steel needle to a sharp point on an oil stone and rest it on your finger nail (fig. 12-16). If it slides under its own weight, it is NOT sharp enough; if it catches on your thumb nail, it has correct sharpness. Now slide the needle under its own weight over the whole bearing surface of the



137.294
Figure 12-14.—Shaping a worn pivot point.

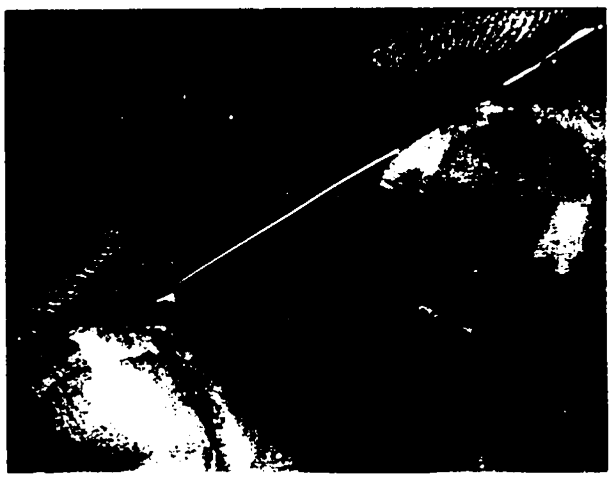


137.295
Figure 12-15.—Removing the jewel from the float.

jewel, as shown in figure 12-17. If the surface of the jewel has a crack or a pit, it will snag the fine point of the needle. NOTE: If the jewel is defective, replace it.

7. Test the float for leaks by submerging it in warm water (120 F). The heat will expand the air inside the float; and if there are leaks in

137.296
Figure 12-16.—Testing a needle for sharpness.

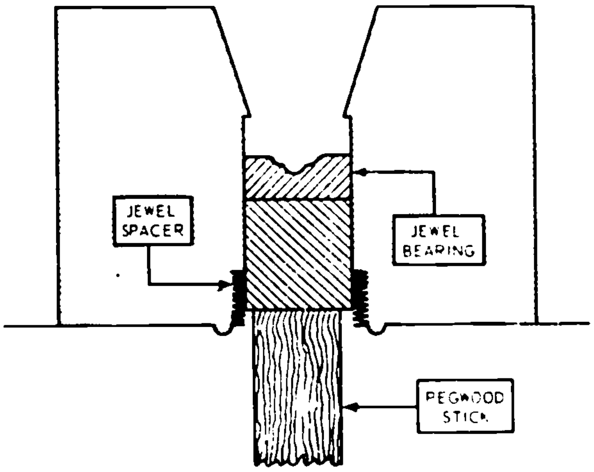


137.297
Figure 12-17.—Testing a pivot jewel with a needle.

the float, air will bubble out through them. Use a pencil to mark the position of a leak.

If the float has a leak, drill a small vent hole in it, drain out the liquid, and dry the float in an oven. Then scrape the float down to base metal at each leak, clean the metal, and solder all leaks. Scrape the area around the vent hole and close the hole with solder.

Put the float back into warm water and recheck for leaks. NOTE: Leaks in the cone section of the float are difficult to close; and if you cannot seal them, replace the float.



137.29?
Figure 12-18.—Replacing pivot jewel and spacer.

8. Use a pegwood stick with a flat end to press the jewel and its spacer back into the float, as illustrated in figure 12-18. Then replace the retaining screw in the top of the card and tighten it. CAUTION: Do NOT use force; too much pressure will crack the jewel.

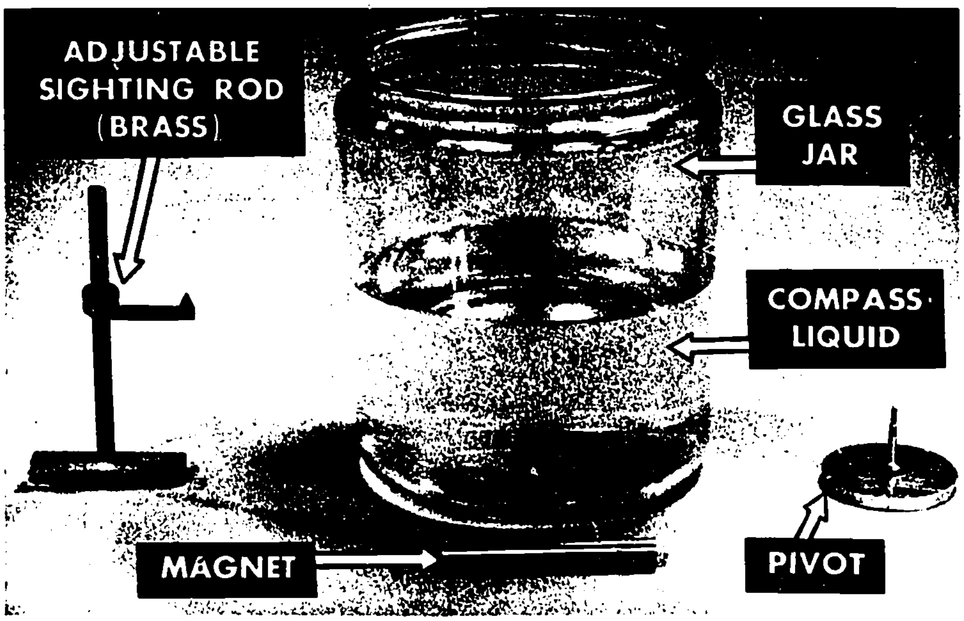
9. When you repair a float or replace a jewel, you generally destroy the balance of the float and must rebalance it. Materials required for making a float balance test are shown in figure 12-19.

10. To get bubbles from under the compass card and out of the cone section of the float, immerse the float edgewise in the compass liquid in the jar, as illustrated in figure 12-20. Then ease the float onto the pivot.

11. Set the point of your sighting rod at the same height as the compass card and spin the float with your magnet. See figure 12-21. As the card spins, compare its level with the sighting rod. If the float is balanced, the card will stay level while it is spinning. If the float is out of balance, you will see a high spot (fig. 12-22.

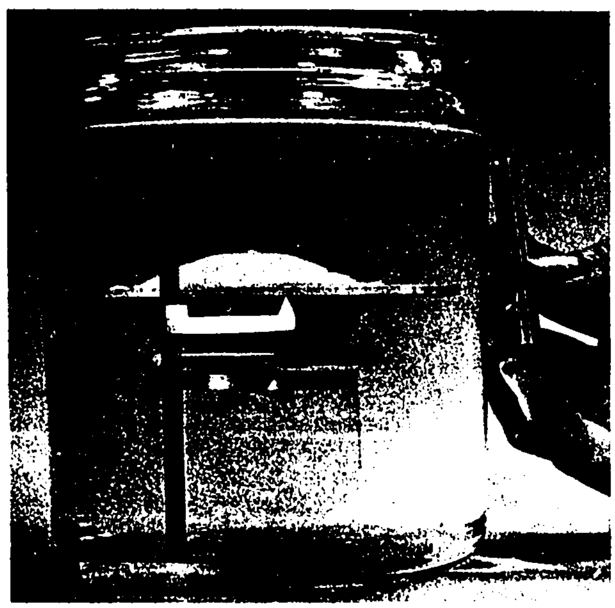
Remove the float and scrape a clean spot on its edge at the high point. Then apply a small amount of solder at the spot shown in figure 12-23. Put the float back on the pivot and retest for balance, and keep adding solder and retesting until you have the float in perfect balance. NOTE: If you apply too much solder, scrape off some of it with a knife.

12. Inspect the seats for the cover glass and the rubber gasket (fig. 12-24). If they are corroded, scrape them by hand or remove the corrosion



137.299
Figure 12-19.—Equipment for testing float balance.

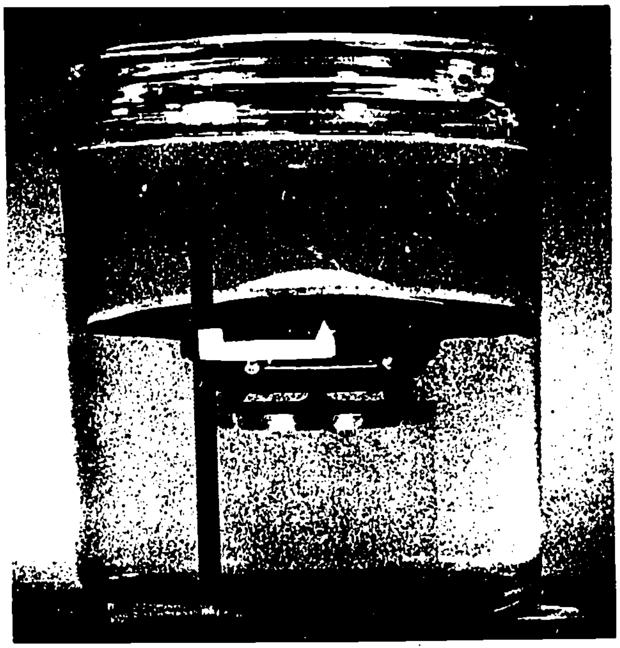
137.300
Figure 12-20.—Mounting the float for a balance test.



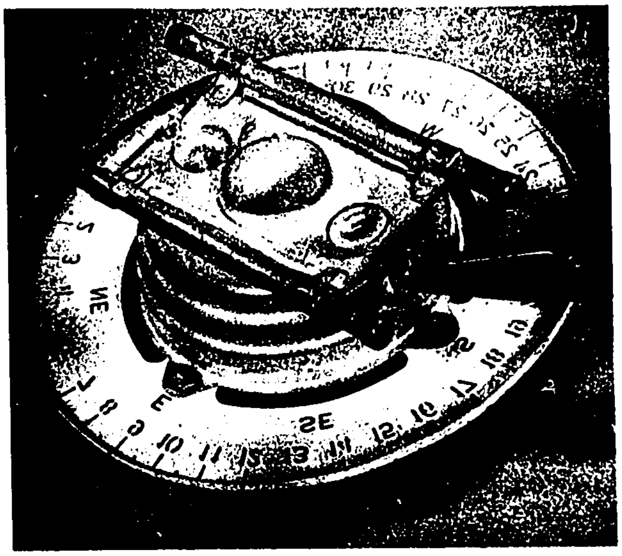
137.301
Figure 12-21.—Making the balance test.

on a lathe. Then clean the surfaces thoroughly with an approved cleaner. NOTE: When in doubt about anything, consult your shop supervisor.

13. Inspect the beveled edge of the glass cover. NOTE: The side which seats against the bowl



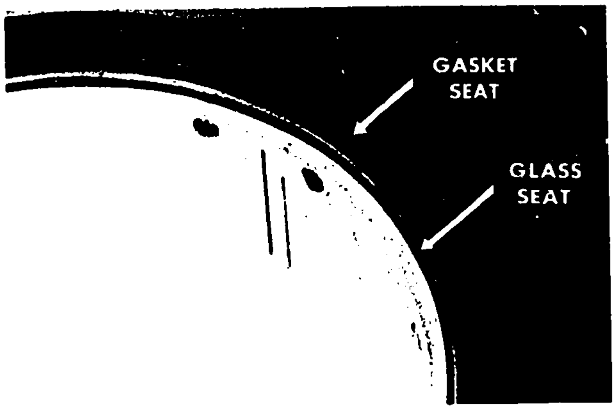
137.302
Figure 12-22.—A float out of balance.



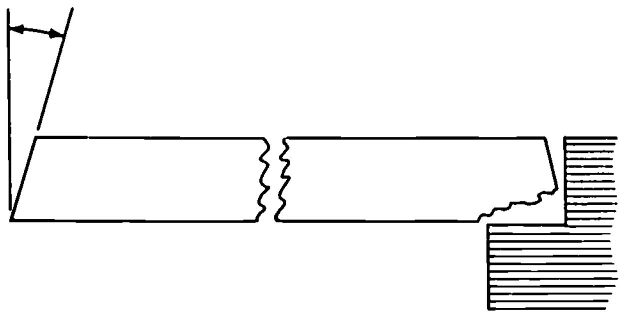
137.303
Figure 12-23.—Applying solder to the float.

has the larger diameter. If you find chips which would extend beyond the seat, as illustrated in figure 12-25, install a new glass cover.

14. Clean the bowl with a soft-bristle brush.



137.304
Figure 12-24.—Cover glass and gasket seats.



137.305
Figure 12-25.—Inspection of cover glass.

15. Fill the expansion chamber with compass liquid. See illustration 12-26.

16. Replace the pivot and tighten it with a socket wrench.

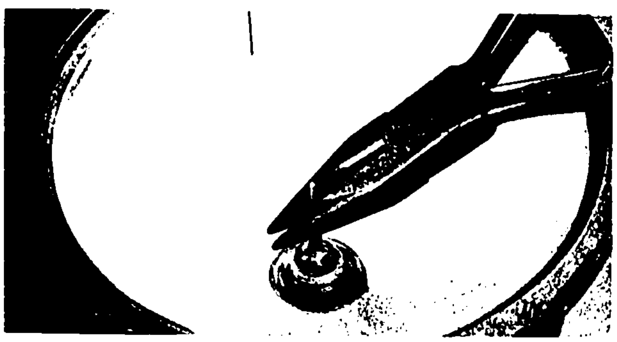
17. At several points, measure the distance from the rim of the bowl to the tip of the pivot. NOTE: The pivot point should be exactly centered in the bowl. If necessary, adjust the point with a pair of pliers in the manner shown in figure 12-27. Be careful, lest you inflict damage to the point.

18. With wire hooks, lower the float onto the pivot.

19. Measure the distance between the edge of the card and the inner rim of the bowl. If it is not the same all the way around, remove the float and readjust the pivot.

20. Remove the float and fill the bowl with compass liquid to a level one half inch below the cover glass seat.

137.306
Figure 12-26.—Filling expansion chamber.



137.307
Figure 12-27.—Adjusting the pivot with pliers.

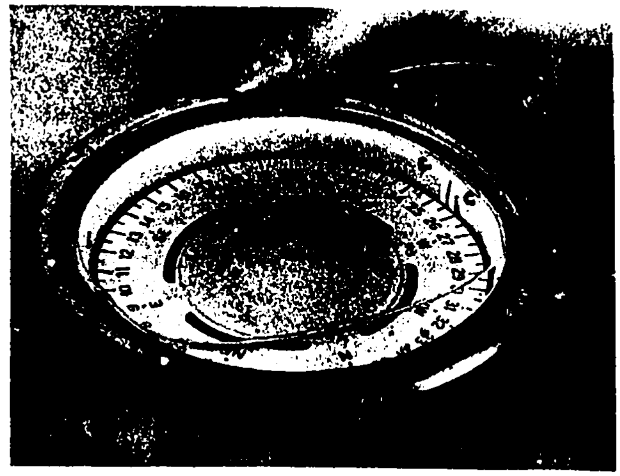
21. Replace the float and, with a pegwood stick sharpened to a chisel point, carefully place the glass in position.

22. Fit the rubber gasket around the edge of the cover glass (fig. 12-28). The ends of the gasket should meet perfectly. If they overlap, trim them to perfect fit; if the gasket is too short, install a new one.

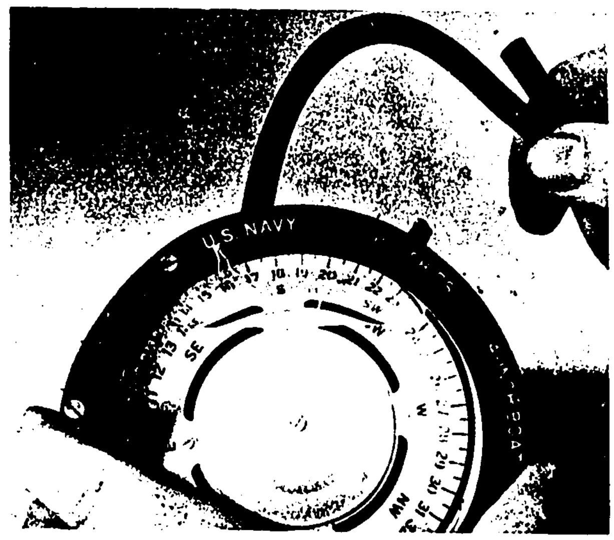
23. Replace the bezel ring, insert the screws, and turn them tight with your fingers. Then use a screwdriver to tighten all screws, one half turn at a time in rotation, until the ring is secure.

TESTING AND ADJUSTING

The procedure for testing and adjusting your reassembled compass is as follows:



137.308
Figure 12-28.—Replacing the rubber gasket.



137.309
Figure 12-29.—Testing for leaks around the bezel ring.

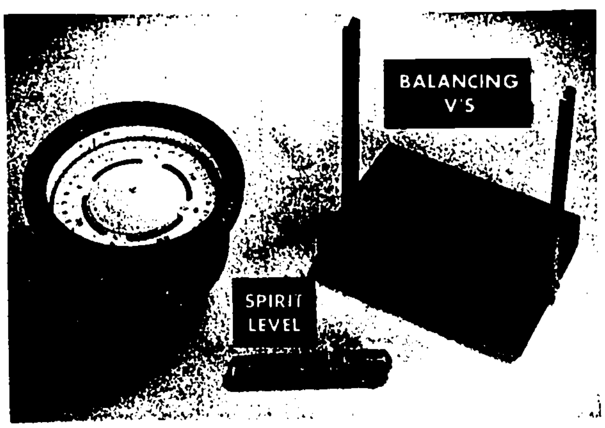
1. To test for leaks around the bezel ring, make a screw to fit the filler hole and drill a small hole through the center of the screw. Insert the screw in the filler hole and fit a piece of rubber tubing over the screw. Suck on the tube and then pinch it off (fig. 12-29). If there are leaks around the ring, bubbles will rise from them.

2. With a rubber bulb syringe, finish filling the bowl with liquid; then replace the filler vent plug and secure it.

3. Put the compass in a warm place and let it stand for 24 hours, with the filler hole up. This amount of time allows trapped bubbles to rise and dissolved air to come out of the compass liquid. NOTE: Less time is satisfactory if the air is fairly warm. Remove bubbles by adding more liquid and then replace the plug.

4. Retest the period of the compass. See step 5 under DISASSEMBLY.

5. Test the compass for balance. To do this, you need the material shown in illustration 12-30. Mount the compass bowl on the V's and put the level on the glass. NOTE: Be sure to center the level; otherwise, the level itself may unbalance the compass. See illustration 12-31.



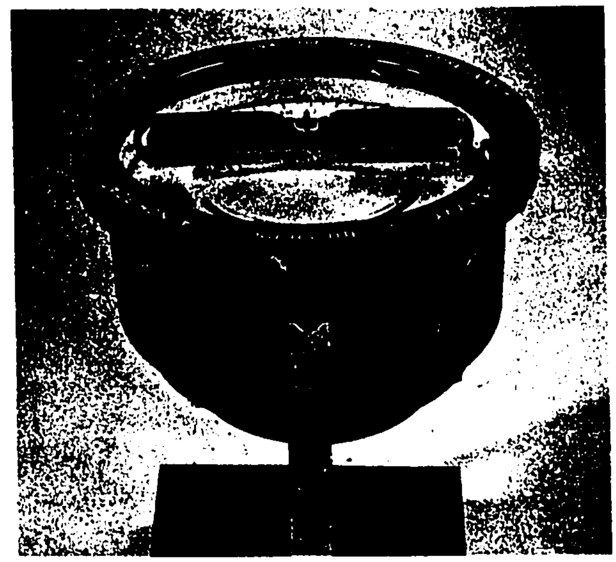
137.310
Figure 12-30.—Equipment for testing compass balance.

If your compass does not balance, file the lugs (projections by which the compass is held) to move the bearing edge over toward the heavy side (fig. 12-32). Make a light cut with your file and test the balance. Repeat this process until the balance is perfect.

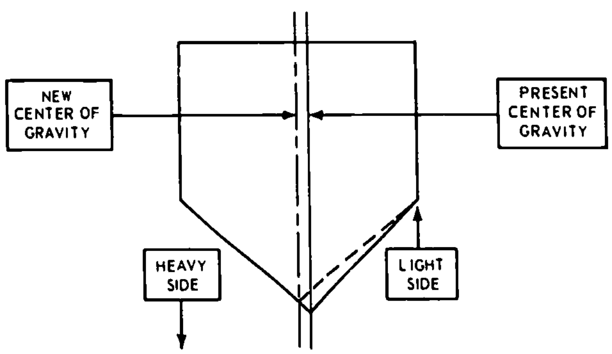
Now mount the compass in its gimbal ring and mount the ring on the V's (fig. 12-33). Test the balance. If necessary, file the lugs (slight amount each time) of the gimbal ring until you have the balance perfect.

AZIMUTH AND BEARING CIRCLES

The meaning of the terms AZIMUTH and TRUE BEARING is the same; namely, the direction of an object from true north (measured clockwise in degrees). In the Navy, however, there is a difference in the use of these two terms—AZIMUTH is used in connection with CELESTIAL BODIES, and TRUE BEARINGS are taken of TERRESTIAL OBJECTS. A Quartermaster, for example, takes a bearing of a lighthouse, but he gets the azimuth of the sun. Relative bearing is the direction of an object relative to the heading of a ship (measured in degrees).



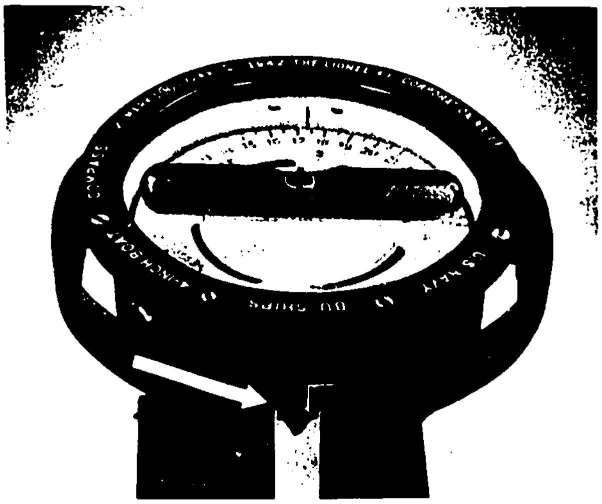
45.23
Figure 12-31.—Testing compass balance.



137.312
Figure 12-32.—Restoring compass balance.

CONSTRUCTION FEATURES

The instrument used for measuring all bearings (true and relative) is the BEARING CIRCLE.



45.23
Figure 12-33.—Final balance test.

which consists of a balanced, non-magnetic ring made to fit snugly over a magnetic compass or a gyro repeater. Study illustration 12-34.

Mounted on the ring of a bearing circle is a pair of sights which enable an observer to line up a ship or terrestial object and read the compass bearing of the object on a compass card. This pair of sights can also be used for measuring the azimuth of the sun.

When piloting his ship within sight of land, a navigator uses his bearing circle to obtain his ship's position—by taking the bearing of a landmark(s) ashore. When his ship is in a formation at sea, an officer of the deck uses a bearing circle and a stadimeter to keep his ship in proper position relative to the guide ship. (A stadimeter is used aboard ship to measure the range of objects of known height.) The navigator and the officer of the deck of a ship keep a bearing circle in almost constant use; for this reason, it must function accurately.

An azimuth circle is exactly like a bearing circle except that it has an additional pair of sights made especially for measuring the azimuth of the sun. Study illustration 12-34. A navigator uses measurements oof the sun's azimuth to check the deviation of his ship's magnetic compass and the accuracy of the gyro compass.

An azimuth circle consists of a balanced, non-magnetic ring which fits over the bowl of a standard 7 1/2-inch Navy compass or compass repeater. To prevent disturbance of the accuracy of magnetic compass on which they are mounted, azimuth and bearing circles must be made of non-magnetic metals. Parts are made of brass or bronze, except screws, which are made of nickel silver. The full assembly is then balanced. Because the compass bowl is mounted on pivots, the azimuth circle must be accurately balanced to prevent tipping of the compass in its mount.

Illustration 12-34 shows two sets of sights (mirrors) mounted on the azimuth circle ring. The set mounted on the 0° and 180° graduations is the same as the set on the bearing circle; the set mounted on the 90° and 270° graduations is the one made especially for measuring the azimuth of the sun. Each set of mirrors (sights) has a small spirit level to indicate when the circle is in a horizontal plane. See illustration 12-35 which gives an enlarged view of the front sight assembly. Observe the open sight and the prism.

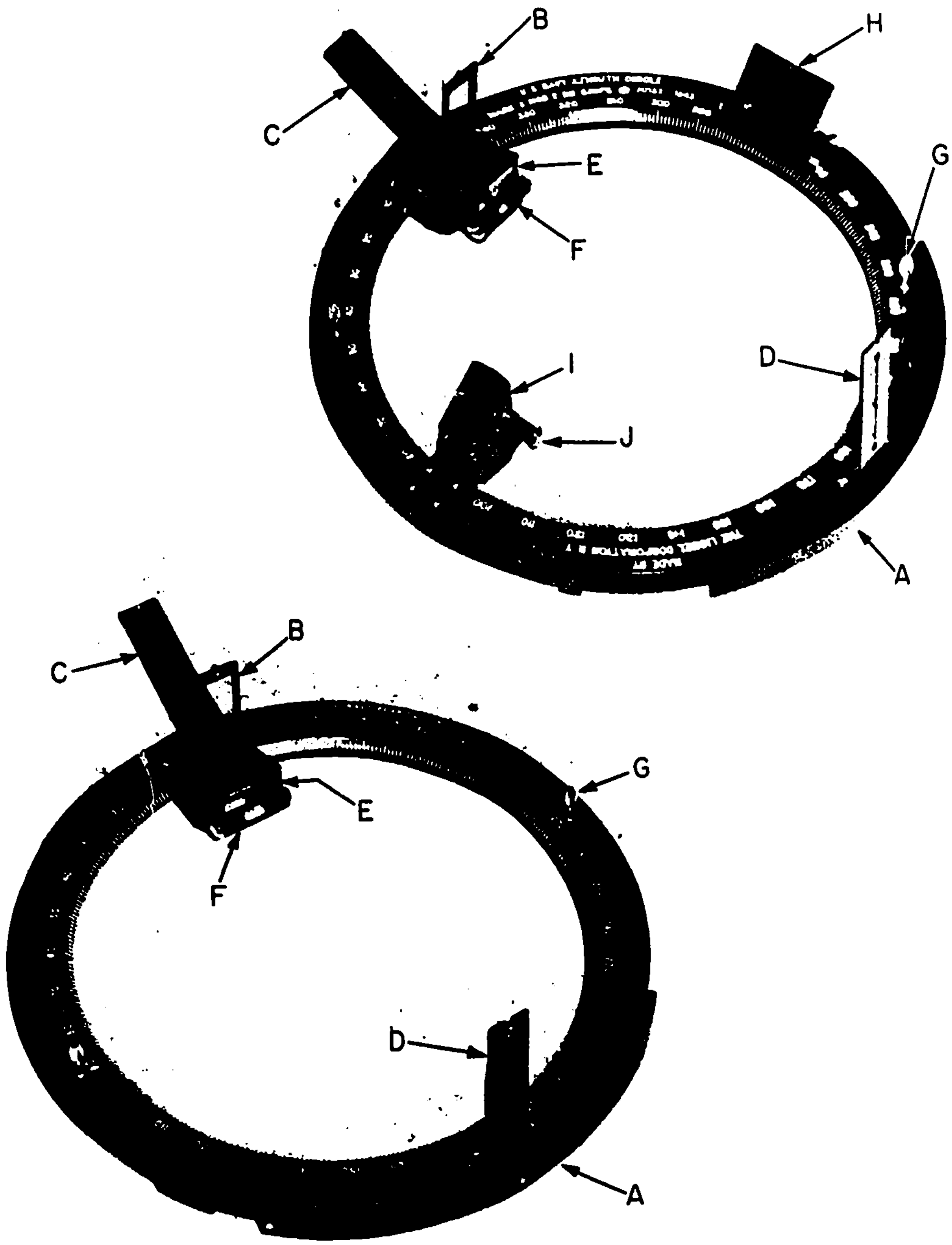
NOTE: If the azimuth circle is out of the horizontal plane when a bearing is taken, the bearing is inaccurate.

A small pentagonal box mounted at 0° on the ring holds all optical elements of the 0° and 180° set of sights. The spirit level is mounted horizontally at the inside edge of the pentagonal box.

Illustration 12-36 shows the path of light rays through the pentagonal prism. As shown, light from the compass card is internally reflected at two different faces of the prism. When you look into the front face, you see a virtual image of part of the compass card. Because the image is reflected twice, it appears erect and normal. A sight wire mounted on the bottom face of the prism housing serves as a reading index of the virtual image of the compass card.

The front sight vane (fig. 12-35), sometimes called the far vane (farthest from your eye), is a rectangular frame with a fine wire stretched down the center of its long dimension. The whole vane (black mirror) moves on a horizontal axis to allow movement down and out of the way when the vane is not in use. The triangular point on the upper edge of the frame is the far point of the open sight.

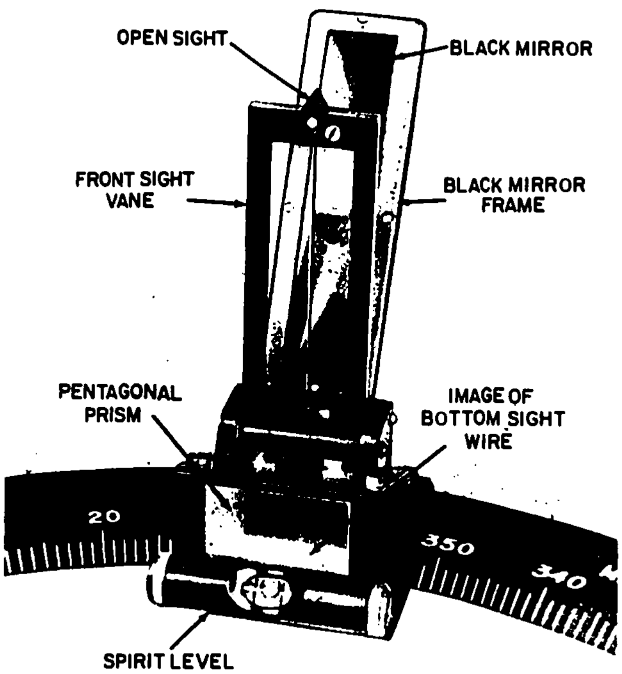
The rear sight vane is mounted on the 180° graduation directly opposite the pentagonal box. As you can see in figure 14-1, this vane is a thin, rectangular plate with a vertical slot down its center. It swings on a horizontal axis to enable the operator to turn it out of the way when not in use. The V-shaped notch in the top edge



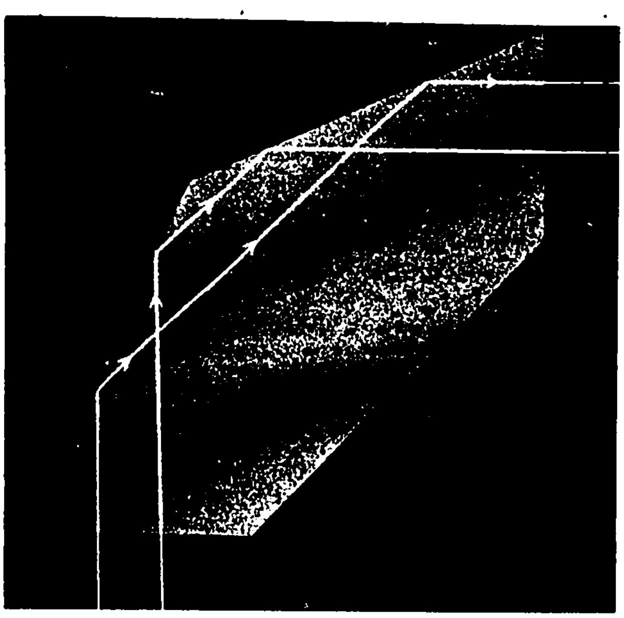
A. Counterweight.
B. Front sight.
C. Black mirror.
D. Rear sight.
E. Penta prism.
F. Penta spirit level.
G. Hand knot.
H. Curved mirror.
I. Right-angled prism assembly.
J. Right-angled spirit level.

65.122

Figure 12-34.—Mark 3, Mod 2, Azimuth circle and Mark 1, Mod 2, bearing circle.



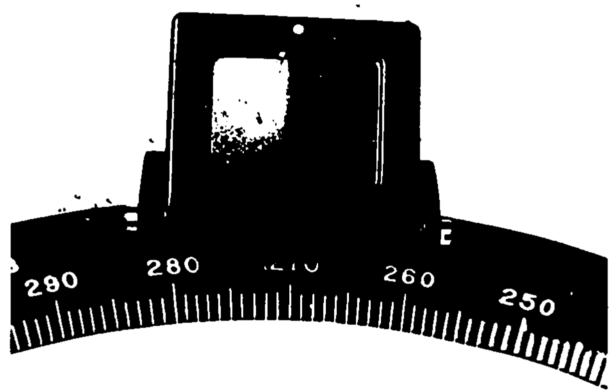
137.313
Figure 12-35.—Enlarged view of the front sight assembly.



137.314
Figure 12-36.—Path of light through the pentagonal prism.

(center) of the frame is the rear half of the open sight.

The cylindrical mirror of the 90° and 270° set of sights is mounted over the 270° graduation on the scale, and it reflects the sun's rays to the right-angled prism. This mirror swings on a horizontal axis to enable its operator to adjust it to the angle required to reflect the sun's rays to the right-angled prism. See illustration 12-37.

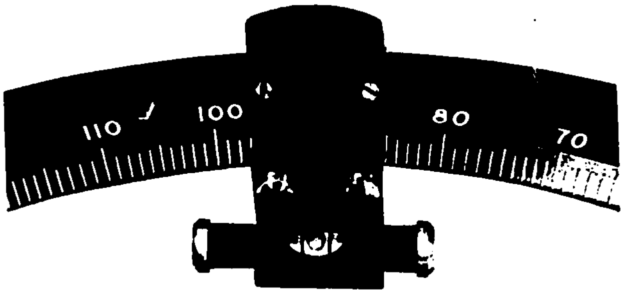


137.315
Figure 12-37.—Front view of the cylindrical mirror.

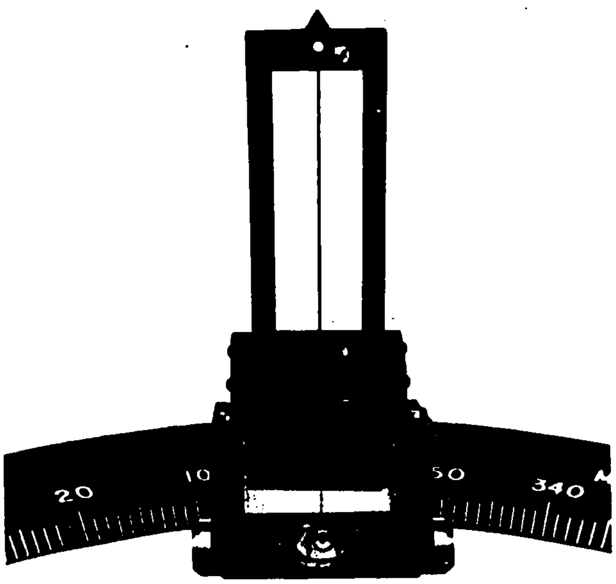
The right-angled prism in the 90° and 270° set of sights is mounted in a metal housing and located at the 90° graduation on the ring of the azimuth circle. A narrow, vertical slit in the face of the housing (fig. 12-38) and in the focal plane of the cylindrical mirror allows entrance of reflected light from the mirror. The prism receives the light, just like a mirror, and reflects it downward to the cylindrical lens mounted under the prism in the prism housing. This lens then focuses the light on the compass card in the form of a bright, narrow band.

OPERATING PRINCIPLES

When a Quartermaster or a navigator desires to take a bearing, he puts a bearing or an azimuth circle on a magnetic compass or ship's course indicator and follows a definite procedure. Suppose, for the sake of illustration, you are piloting a ship within sight of land and spot ashore a lighthouse whose bearing you need. You can get this bearing by using the 0° to 180° set of sights on a bearing or an azimuth circle in the following manner:



137.316
Figure 12-38.—Enlarged view of the right-angled prism housing assembly.



137.317
Figure 12-39.—Front sight assembly in position for taking a bearing.

• Put an azimuth circle on a compass and turn the front and rear sight vanes to the vertical position. Then turn the black mirror down and out of your way. The front sight assembly in illustration 12-39 is in position (black mirror down) for taking a bearing.

• Use the open sight and turn the circle to an approximate bearing on the lighthouse.

• Move your eye down an inch or more and sight through the slit in the rear vane.

• Adjust the circle so that the vertical wire on the front sight vane appears to split the lighthouse.

• Check the spirit level to determine whether the bearing circle and compass are horizontal; if not, level them and sight again.

• Look into the prism and read the number of degrees on the compass card, at the point where the bottom sight wire cuts across the image. This is the COMPASS BEARING of the lighthouse.

• To get the true bearing, correct the compass bearing for variation and deviation.

You can find the relative bearing of the lighthouse by lining up the sights of the azimuth circle as you did to get a true bearing, and by reading at the point on the inner lip of the ring just above the lubber's line the number of degrees on the scale of the azimuth circle.

You can measure the sun's azimuth on the general purpose sights (0° to 180°) on an azimuth or a bearing circle when the sun is partially obscured. The image of the sun is reflected to the observer's eyes from the black mirror (raised for this operation), which fully utilizes available light from the sun and produces a clear, distinct image.

When the sun is too bright to measure its azimuth with the general purpose sights, use the 90° to 270° sights on the azimuth circle, in the following manner:

• Turn the circle until the cylindrical mirror bracket (fig. 12-37) is toward you and adjust its angle until it reflects a band of sunlight to the prism housing.

• Now, turn the circle until the light reflected by the cylindrical mirror enters the slit in the housing (fig. 12-38). When it does, you will see a band of light under the prism housing and superimposed on the graduations of the compass card.

• Check the spirit level to make certain the ring is horizontal.

• Read the compass card at the point where the band of light intersects the scale.

OVERHAUL AND REPAIR

Because the corresponding parts of azimuth and bearing circles are identical, except for the holes in the circle rings for mounting different parts, a common repair procedure is applicable to both types of instruments.

Before you start to repair or overhaul an azimuth or bearing circle, give it a predisassembly inspection to determine whether it should be repaired or surveyed and salvaged. Record all your findings and recommendations on a casualty analysis sheet.

The things for which you should look when you make a predisassembly inspection are:

• GRADUATIONS. Are the graduations clear? Can you read them easily?

• PAINT. Because azimuth and bearing circles generally are exposed to severe weather for long periods of time, their metal parts must be protected by paint. If these parts are worn or chipped, the logical decision is to follow established procedures and repaint them.

• OPTICAL ELEMENTS. Examine the cylindrical mirror, the black mirror, and the two exposed faces of the pentagonal prism for scratches, cracks, pitting, watermarking, or peeling of silver on the cylindrical mirror.

• SIGHT WIRES. Check the vertical sight wire in the front vane sights and the bottom wire at the base of the pentagonal prism for straightness and tautness in their frames. If the wire in the front sight vane is loose, it can be tightened; if it is kinked or broken, replace it with .011-inch brass wire. If the bottom sight wire is loose or broken, replace the wire.

• CIRCLE RING AND PARTS. Inspect the azimuth or bearing circle ring for distortion. It must be a true ring. Check also all parts on the ring.

• SPIRIT LEVELS. Put the ring on a level surface and look at the bubble in the spirit level. If the bubble does not fall exactly between the two lines on the vial, the level is not correctly adjusted.

• HINGE MOTION OF SIGHTS AND MIRRORS. The motion of hinges on sights and mirrors must be smooth and easy but tight enough to hold the sights and mirrors in any desired position.

• SCREWS. Inspect the slots of screws for burrs or deformities.

COLLIMATION

When you complete repairs on an azimuth or bearing circle, give the assembled instrument a careful inspection. Test the ring assembly for flatness and trueness; and if inspection results are satisfactory, collimate the instrument.

Collimation of an azimuth or bearing circle is performed on a collimator which simulates a gyrocompass repeater or a standard ship magnetic compass with the sun at a known azimuth. Study the azimuth and bearing circle collimator shown in figure 12-40. This collimator consists of a dummy stand, representing a gyrocompass repeater, and an artificial sun aligned with the 0° and 180° axis of the stand. Observe the nomenclature in figure 12-40. Study particularly the enlarged view in the circle.

The following discussion on collimation is for both azimuth and bearing circles. Procedures inapplicable for a bearing circle are so designated.

The procedure for aligning the rear sight of an azimuth or bearing circle is as follows:

1. Put the circle assembly on the collimator stand, as shown in illustration 12-40.

2. Turn the circle assembly as necessary to align the 0°, 180°, 90°, and 270° marks, called cardinal points, of the azimuth circle ring with the four cardinal points on the collimator stand, with the 180° mark set to the zero point. The rear sight will then be toward the artificial sun of the collimator.

3. Turn the rear sight to a vertical position and note the shadow of the sight cast by the artificial sun on the collimator stand. Light which passes through the slot should be centered on the 0° to 180° dumb line on the stand. If the light is not aligned at one end or the other, use a shim on one side in order to get alignment.

If the light is not even all along the length, loosen the rear sight bracket screws and shift the rear sight assembly sideways. Turn the sight from the vertical position to the horizontal position and observe the light through the slot. It should still be centered on the dumb line; and if it is out at one end, loosen the rear sight bracket screws and turn the whole rear sight assembly. Then check vertical and horizontal alignment in all positions.

NOTE: If the rear sight dowel pins were assembled and the rear sight assembly needs adjustment, drive out the pins and effect necessary adjustment. Then replace the dowel pins.

To align the front sight, the black mirror, and the bottom sight, proceed as follows:

• Align the 0°, 90°, 180°, and 270° marks on the circle ring with the corresponding points on the collimator stand; that is, at the ends of the dumb lines.

• Look through the rear sight at the face of the penta prism for the reflection of the bottom sight wire and the dumb line on the collimator stand. The reflected dumb line should line up with the front sight wire (with the front sight assembly vertical).

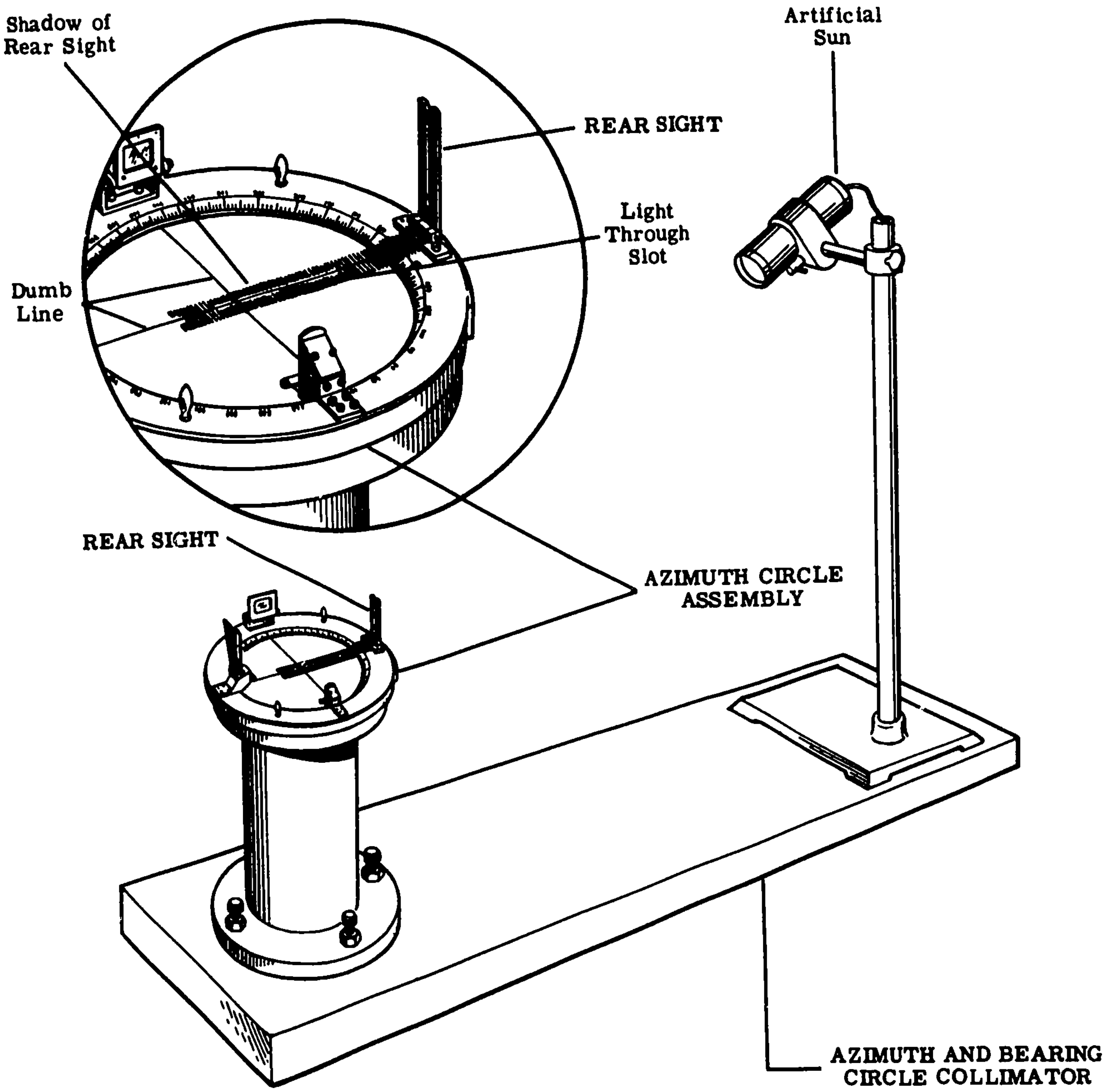


Figure 12-40.—Azimuth and bearing circle collimator.

• Raise both front and rear sights to the vertical position and sight through the front sight at the rear sight. The front sight wire should be exactly centered along the slot in the rear sight. If each sight was properly aligned, the front and rear sight will align with each other.

• Look through the sights and raise the black mirror to reflect the artificial sun. The front sight wire should appear to split the image of the artificial sun for all positions of the mirror which reflects the sun into the sights. If the sun is displaced to one side throughout the travel, disassemble the mirror and place a thin strip of shim paper between the long edge of the mirror and its frame on the opposite side to which the image was displaced. If the image is off at one end of the mirror only, shim the opposite corner across from the direction of displacement.

• Look through the rear sight into the face of the penta prism at the image of the bottom sight wire and the 0° to 180° dumb line on the collimator stand. The bottom sight wire should coincide with the dumb line; and if it does not, shift the bottom sight assembly as required to bring the bottom sight wire into coincidence with the dumb line.

To level the penta spirit level, do the following:

1. Since the collimator stand is level, the bubble in the spirit level should be centered between the leveling lines on the level. To make a SMALL adjustment, loosen the penta level mounting screws and adjust the spirit level assembly as necessary to center the bubble. When a GREATER AMOUNT of adjustment is necessary to center the bubble, remove the spirit level caps and shim the level with cotton wadding and paper liner.

At this point, a MK 1, Mod 3, bearing circle is completely aligned. The next step in collimation for this instrument is "Dowelling the Front and Rear Sights," which is explained later. For a Mk 3, Mod 3, azimuth circle you must collimate the azimuth elements.

The procedure for aligning the cylindrical mirror and the right-angled prism follows:

Turn the azimuth circle assembly to bring the face of the cylindrical mirror toward the artificial sun. The 90° and 270° marks on the azimuth circle ring must be aligned with the 0° and 180° dumb line on the collimator stand. The 90° mark should be set at the 0° end of the dumb line.

The right-angled spirit level bubble should be centered between the two leveling lines on the level. Make small adjustments by loosening the right-angled level mounting screws and shifting the right-angled spirit level assembly. For larger adjustments, remove the two spirit level caps and shim the right-angled spirit level.

This last step completes the collimation procedure for a Mk 3, Mod 3, azimuth circle.

The front sight, mirror, prism and level assembly, and the rear sight assembly must be dowelled to an azimuth or bearing circle ring. To do this, proceed in the following manner:

• If the sights need realignment, the original holes for the dowel pins may be slightly misplaced. When this is the case, use a tapered bottom reamer to enlarge and form a straight tapered hole and install a tapered dowel pin.

• If a new azimuth or bearing circle ring was assembled, use the original holes in the rear sight bracket and the penta prism box. With a .086-inch drill, drill holes 1/8-inch deep in the azimuth or bearing circle. Then assemble the rear and front sight dowel pins.

If you must use a new rear sight bracket or penta prism box, plug the original holes and use an .086-inch drill to make new holes 1/8-inch deep in the ring and assemble the front and rear sight dowel pins.

After you collimate an azimuth or bearing circle, give it a final inspection to make certain everything concerning repair and adjustment of the instrument is satisfactory. Inspect as follows:

• Check the circle for completeness of parts.

• Inspect the general appearance, finish of parts, tightness in the assembly, legibility of engravings, and tightness of screws.

• Examine optical parts for defects and cleanliness.

• Inspect the pivot tension of the front and rear sight vanes, and the black and cylindrical mirror assemblies.

Make final notations (if any) on the casualty analysis sheet for the instrument and put it in the case.

SEXTANT

A sextant is an instrument used for measuring the angle between two objects. The arc on which the scale for reading angles is engraved is approximately one-sixth of a circle; hence the name of the instrument, SEXTANT.

When a ship is at sea and away from visible landmarks, the navigator must use celestial navigation to determine his ship's position. Celestial navigation is possible because the navigator can use a sextant to determine the angle which the sun or another celestial body makes with the visible horizon. He can then determine the position of the particular celestial body at the time he took the sight by referring to the NAUTICAL ALMANAC. If he knows the position of the celestial body at the TIME OF SIGHT and the angle it makes with the horizon, he can (after applying certain correction factors) ascertain the exact position of his ship.

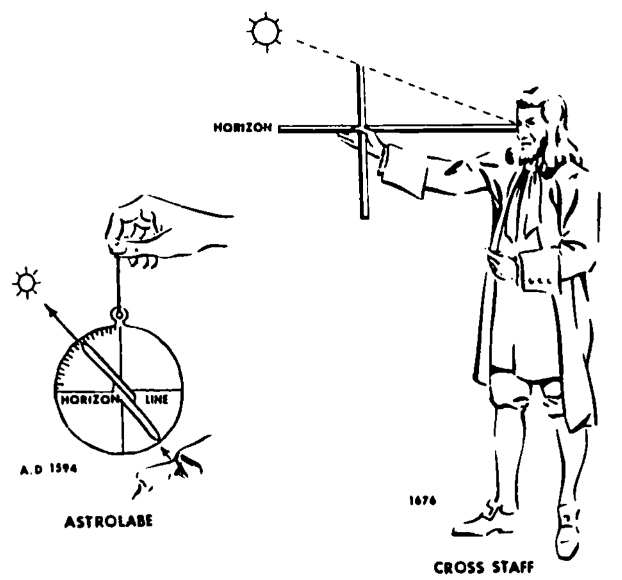
A sextant is well adapted for measuring angles at sea for three reasons:

1. It is small, light, and can be held easily in one hand.

2. It does not need a stable mounting.

3. It measures angles accurately to the nearest tenth of a minute.

Two of the earliest types of sextants are shown in figure 12-41. The ASTROLABE was a round, wooden disk with graduations from 0° to 359 degrees. A movable wooden pointer was fastened to the center of the disk. The instrument was suspended from a plumbline, supposedly to keep the horizon line level. When a navigator desired to measure the altitude of a star with this sextant, he sighted along the pointer to aim at a star and then read the scale on the disk at the end of the pointer.



137.338
Figure 12-41.—Early types of sextants.

The CROSS STAFF had a little more accuracy than an astrolabe but it had one big disadvantage—the navigator had to look in two directions at the same time. A cross staff was made of two wooden boards at right angles to each other, as illustrated, and the vertical board could be moved back and forth along the horizontal board. To take a sight, the navigator sighted from the end of the horizontal board to the celestial body and then moved the vertical board until its tip was on his line of sight. All the while, he had to keep the horizontal board pointed at the horizon. A scale on the horizontal board at the point where the vertical board crossed it gave him the angle formed by the celestial body with the horizon.

Although Sir Isaac Newton was probably the first man to put in writing the idea of the modern sextant, a man by the name of Hadley was perhaps the first man who actually made one (1731). Since that time many improvements have been made to sextants, with the result that those in use today are very accurate.

At this point, study illustration 12-42 particularly the nomenclature and location of parts. Refer to this illustration as you study the construction of the instrument.

The principal parts of a sextant are:

- ARC, OR LIMB. The arc of a sextant is the lower curved part of the frame, with a scale graduated in degrees engraved on it (fig. 12-42). Gear teeth (one tooth to each degree on the scale) are cut in the lower edge of the arc.
- INDEX ARM. The index arm moves on a pivot mounted at the geometric center of the arc, and the index mirror is attached to the upper part of the arm (at the pivot). The index mirror is silvered plate glass and moves with the index arm. Its plane is perpendicular to the plane of the index arm.

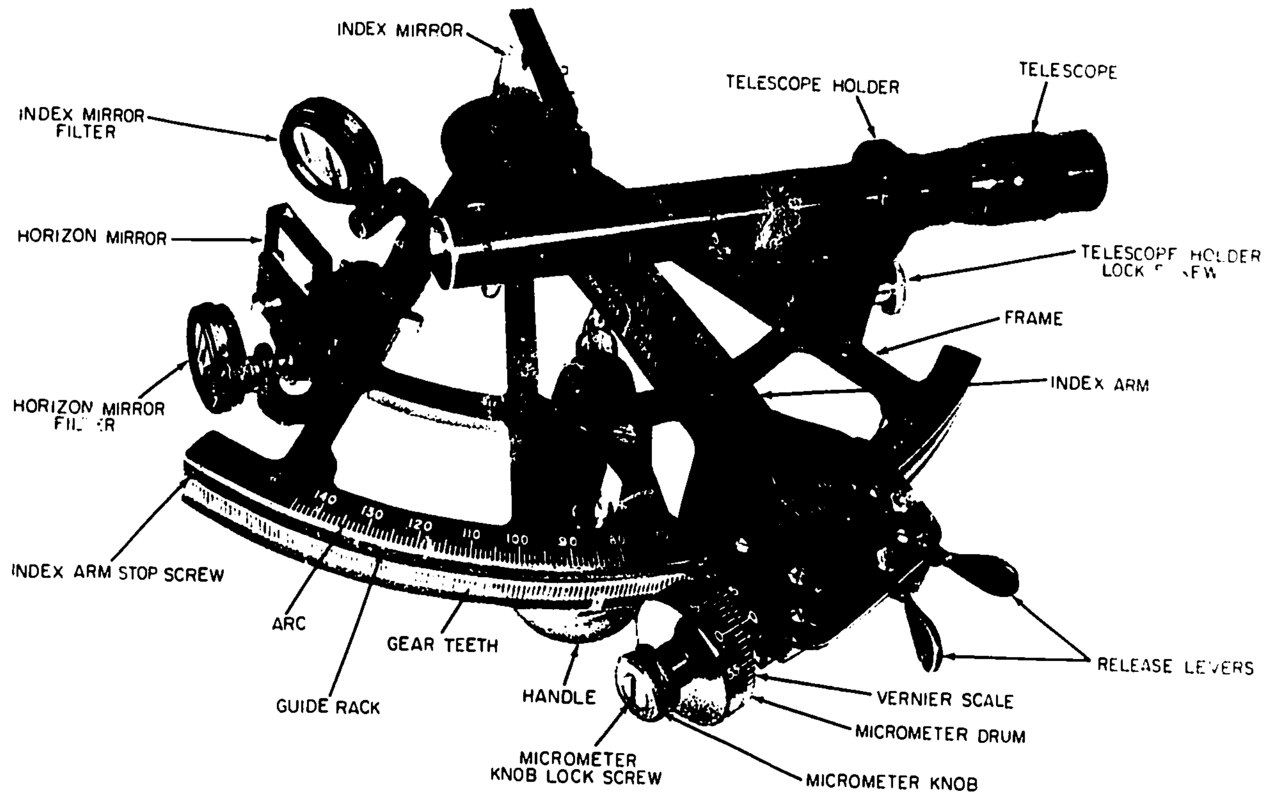
Near the lower end of the index arm is the index mark, where you read the plane of the arc. The endless tangent screw (fig. 12-43), attached to the lower part of the index arm, engages the gear teeth on the arc.

If you turn the tangent screw through one revolution, you advance the index mark one degree. A micrometer drum and vernier are mounted on the shaft of the tangent screw to enable an observer to read an angle accurately to a small part of a degree. Up to and including 90 degrees, the maximum permissible error for declination and inclination readings is plus or minus 30 seconds of arc. Above 90 degrees, the maximum permissible error is plus or minus 35 seconds of arc.

NOTE: DECLINATION readings are taken by going one degree ABOVE the required reading, and then by rotating the micrometer drum to set the index mark at the required reading. INCLINATION readings are taken by starting one degree BELOW the required reading, and then by setting the index mark to the required reading with the micrometer drum.

When you press the two release levers together (fig. 12-42), you disengage the tangent screw from the gear teeth of the arc and obtain freedom of movement of the index arm.

- HORIZON GLASS. The horizon glass (fig. 12-42) is attached to the frame and does NOT move. The half of the glass closest to the



29.268

Figure 12-42.—David White endless tangent screw (ETS) sextant.

frame is silvered so that it will reflect images of celestial bodies to the eye of an observer looking through the sextant telescope. The image is reflected from the index mirror to the horizon mirror.

The outer half of the horizon glass is clear to enable an observer to see the horizon through it. The horizon glass is perpendicular to the plane of the arc; and when the index mark is at 0° on the scale, the horizon glass is parallel to the index mirror.

- TELESCOPE. A sextant telescope enables an observer to see objects (images) more clearly, and it helps him to direct his line of sight to the horizon glass. The telescope has a magnification of 3, and its resolving power must be 18 seconds of arc in the center of the field.
- POLAROID FILTERS. There are two sets of polaroid filters. When an observer looks through the clear part of the horizon glass, he should use the filters with circular frames to reduce glare from the horizon. He should use the shades with square frames to eliminate or reduce glare produced by the reflected image.

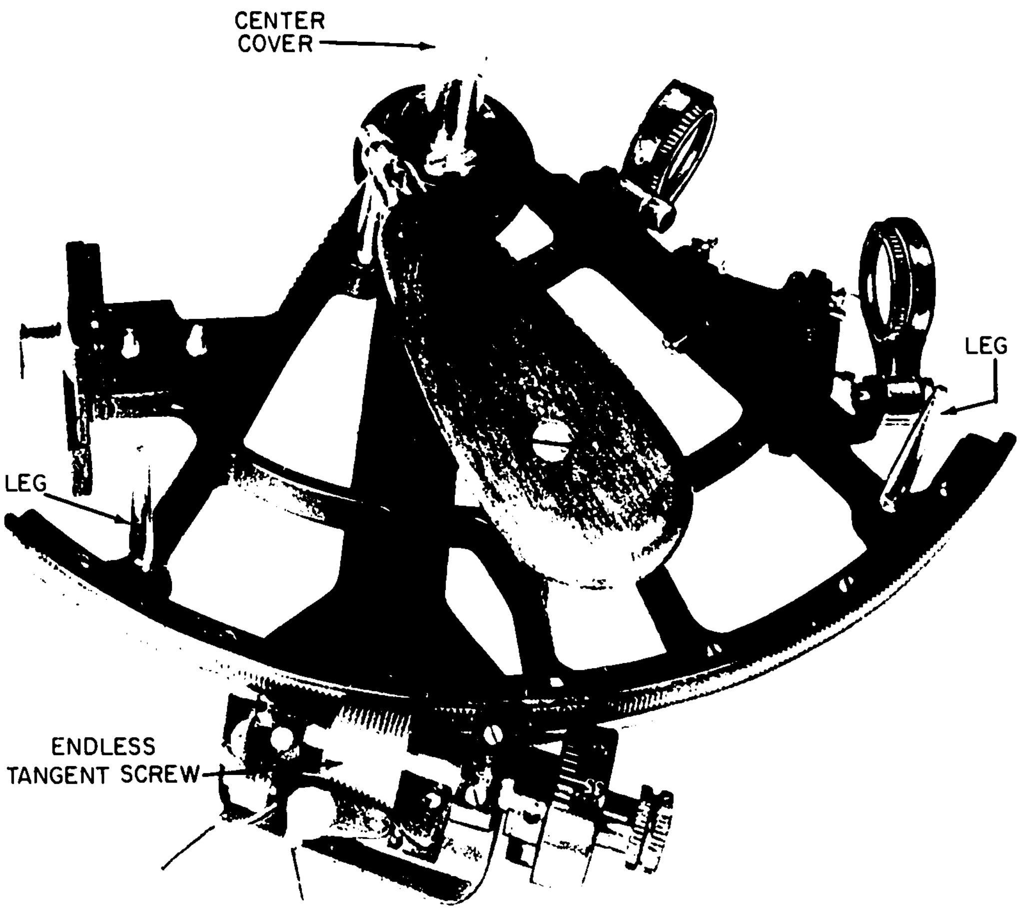
OPERATION

A sextant consists basically of two optical systems, one rotatable and one fixed, and a sextant must have both to perform satisfactorily. If you understand how these optical systems function, you will have little difficulty in understanding the principle of operation of a sextant.

The components of the fixed optical system of a David White or Pioneer sextant are: (1) a horizon mirror, and (2) a telescope. Study part X of illustration 12-44. You already learned in this chapter the function of these components.

The rotatable optical system of a sextant is composed of the index arm and the index mirror, which is mounted on the index arm. See part X of figure 12-44. The index arm rotates around a center point (top), and it indicates on the sextant arc scale (by means of an index mark) the angle in degrees a celestial body makes with the visible horizon.

Study part Y of illustration 12-44, which is a schematic diagram of a sextant. Compare this



137.339

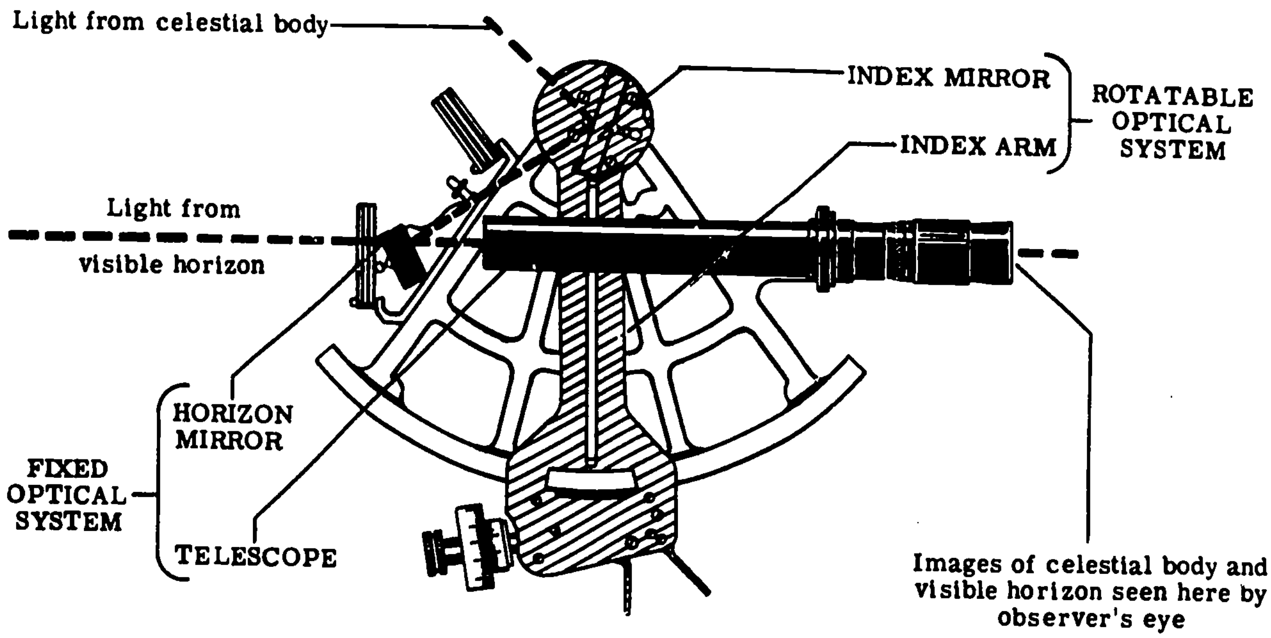
Figure 12-43.—Bottom view of a David White sextant.

part with part X. The letter C represents a celestial body whose angular altitude you must know. Your eye is at point 0, which would be next to the eyepiece of the telescope shown in part X. Line OD is your direct line of sight to the horizon. This means that angle COD is the one you must determine, because it represents the angle of the celestial body above the horizon.

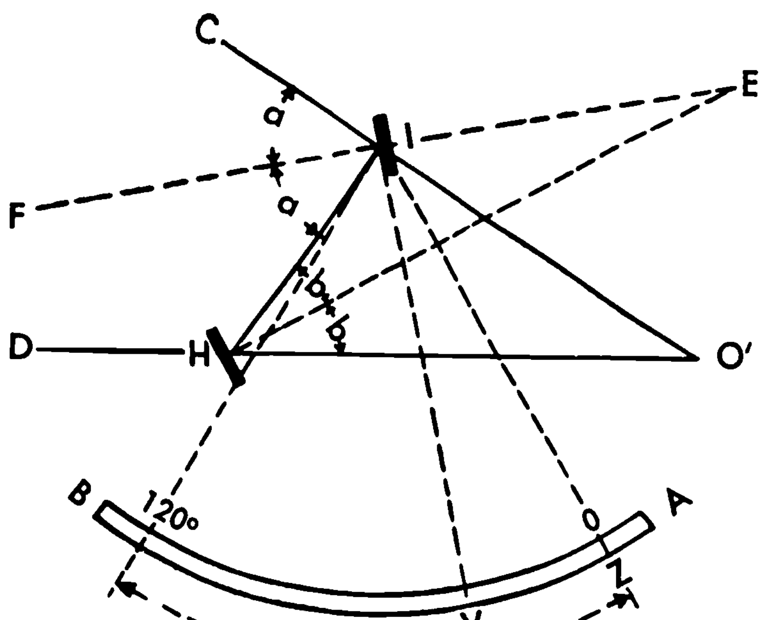
The horizon glass is represented by H, and I is the index mirror, attached to index arm IV. When you swing the index arm along arc AB, you change the angle of the index mirror. When you move the arm to the point where the reflected image of the celestial body appears to lie on the horizon, rays from the body travel from C to I, from I to H, and from H to O. As you can see, these rays enter your eye along the same line of sight as rays from the horizon. Your next step, therefore, is to read the angle on the graduated scale at point V.

Because one degree on the arc is marked as two degrees on the scale, when angle VIZ is 15° the pointer at V shows exactly 30° on the scale. If the sextant is to give a true reading, angle COD must therefore be twice angle VIZ. How can you prove that it is of this size ?

Line FE in the diagram is the normal to the index mirror and HE is the normal to the horizon glass. Angle CIF is therefore the angle of incidence on the index mirror, and FIH is the angle of reflection. Because both of these angles are equal, as you learned in chapter 3, we can designate both as a; and since the angles of incidence and reflection the horizon glass are also equal, we can call both of them angle b.



X



Y

Figure 12-44.—Schematic drawing of the principle of operation of a sextant. 137.340

Line IZ goes from the geometrical center of the arc to the zero mark on the scale, and the horizon glass is always parallel to this line. Since line HE is perpendicular to the horizon glass, it is also perpendicular to line IZ. Line IV lies along the reflecting surface of the index mirror, so it is also perpendicular to the normal (FE).

A theorem in plane geometry states that: "If the two arms of an angle are respectively perpendicular to the two arms of another angle, the two angles are equal." Angles VIZ and IEH are therefore equal. A principle of operation of a sextant also states that: "The angle between the first and last directions of a ray of light that has suffered two reflections in the same plane is equal to twice the angle that the two reflecting surfaces make with each other." The reflecting surfaces in this case are the index mirror and the silvered section of the horizon mirror.

It follows in reverse order, then, that if the celestial body you have under observation is 60° above the visible horizon, the angle which the index mirror and the silvered section of the horizon mirror must make with each other to bring the celestial body tangent to the visible horizon is 30 degrees. This is just half the angular height of the celestial body.

The scale on the arc of a sextant is graduated in degrees. From this scale, therefore, you can read with accuracy ONLY TO the nearest degree. Look at the index mark and read the number of degrees on the arc. Then use the micrometer to get a more accurate reading.

The micrometer drum has a scale with sixty divisions, and each division represents one minute of arc. To increase further the accuracy of the reading, use the vernier scale located alongside the micrometer drum. This scale has ten divisions and enables you to determine the angle being measured to one-tenth of a minute, or to the nearest six seconds or arc.

To read a sextant, therefore, you read degrees on the arc at the index mark. Then you add the number of minutes read on the micrometer drum, and also the number of tenths of a minute you read on the vernier scale.

Study illustration 12-45, which gives two sample sextant readings. In part A of this illustration, the reading on the arc is 13 plus (at the index mark), the 0 mark on the vernier scale is between 16 and 17, and the first mark on the vernier which coincides with a mark on the drum is 7 on the vernier scale; so the reading is 13°16.7'. The reading in part B of figure 12-45 is 55°25.2'.

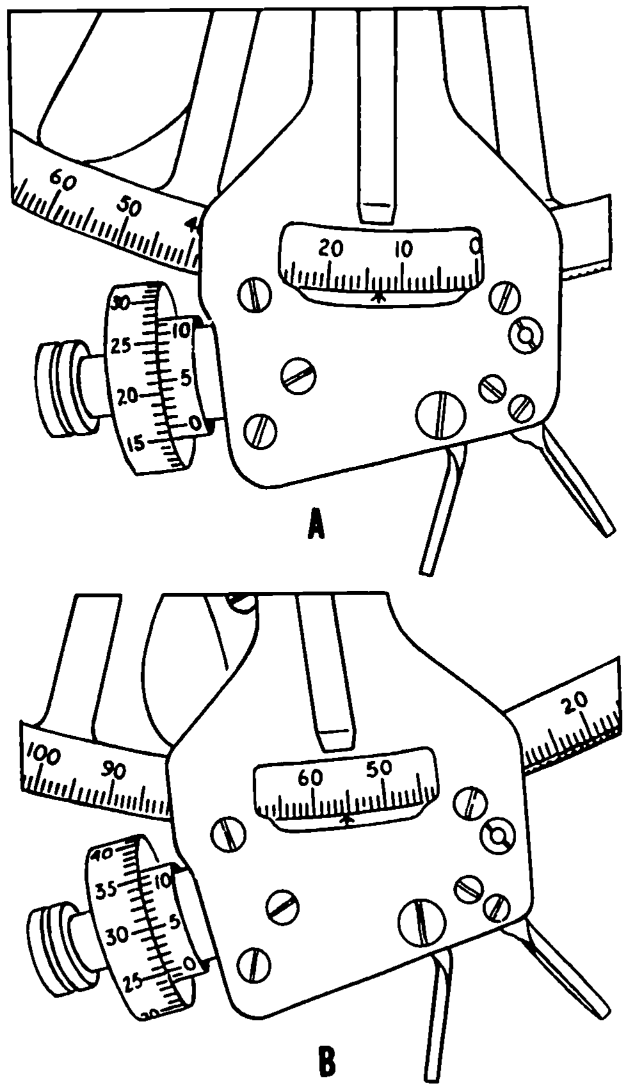


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Figure 12-45.—Examples of sextant readings.

DISASSEMBLY

A preliminary decision must always be made concerning the feasibility of repair of an instrument. This is the purpose of a predisassembly inspection, to determine whether the instrument should be repaired or surveyed and salvaged; and if repair is the decision, the extent of disassembly required.

Some of the things to check when giving a sextant a predisassembly inspection include:

- Condition of silver on mirrors.
- Corrosion, and failure of protective finishes.

• Evidence of unauthorized tampering and disassembly.

• Appearance, finish, and condition of parts in the sextant assembly. Examine scale markings for legibility.

• Cleanliness and physical condition of the telescope assembly. If mounted, remove the telescope from its sliding bracket before you make this test.

NOTE: Be certain the diopter scale reference mark is at the top when you mount the sextant telescope in the sliding bracket.

• Action of the diopter focusing ring. It should be smooth over the entire diopter scale range, but it should be fairly tight.

• Polaroid filter assemblies. There should be no cracks or chips, cloudiness, or dark spots caused by dirt or moisture between the individual glasses of each filter.

NOTE: Polaroid filters must have a protective coating on their edges.

• Rack teeth. Check with an eye loupe for wear, bends, and chipping. Clean the rack teeth, the endless tangent worm and worm gear thread, and the guide slot with a suction line or a nylon brush.

The actual disassembly of the sextant should not be undertaken without using NavShips Manual 250-624-12 as a technical guide. This manual gives step by step procedures for disassembly, overhaul, reassembly and Collimation of the sextant.

OVERHAUL AND REPAIR

All overhaul and repair steps should be accomplished exactly as prescribed in the NavShips Technical Manual. If a problem arises that you are in doubt about, seek the advice of your shop supervisor.

During the predisassembly inspection of the sextant you made recommendations concerning some parts on the casualty analysis sheet for the instrument. After disassembly, inspect all disassembled parts and make a decision concerning their usability. If they are still good, clean them in the approved manner and protect them until needed. Put parts which can be repaired in a special tray; discard parts which have no further usefulness.

A sextant's accuracy is dependent upon accurate engagement of the endless tangent worm in the sextant rack teeth. Nicks or burrs on the rack teeth, or high spots on the worm gear thread, will cause large errors in readings.

The technical manual for sextants lists and illustrates several special tools that are required for work on sextants. Always use these tools as they are designed to perform a definite function that will help you to accomplish your job in an efficient manner and help prevent damage to parts during repair operations.

REASSEMBLY AND COLLIMATION

After repairs have been made and the sextant has been assembled in the approved manner, give it a precollimation inspection. Ensure that all repairs have been accomplished and there are no defects that would prevent you from accurately collimating the sextant.

The collimation procedure outlined in the technical manual must be followed in precise detail in order for the sextant to meet performance standards of the instrument. During collimation, handle the sextant very carefully, as rough treatment will often cause a misalignment that will prevent proper collimation. The sextant is a delicate instrument and should always be given careful treatment. Make it a habit to observe these rules:

• Handle the sextant carefully. Don't let it get bumped or jolted.

• When you aren't actually using it or repairing it, keep it in its box.

• Never leave a sextant where it's exposed to moisture, or to the direct rays of the sun.

• Before you pick up a sextant box, be CERTAIN that the locking levers are secured over the sextant handle, the telescope, and the screw drivers, and that the lid of the box is closed and the catch securely fastened.

STADIMETER

A stadimeter is an instrument used to measure the range of objects of known height. Aboard ship, the officer of the deck uses a stadimeter to maintain his position in a formation by sighting on the guide ship for range. The height scale is calibrated in feet for objects from 50 to 200 feet in height. The range scale is calibrated in yards for readings from 200 to 10,000 yards and infinity.

Refer to illustrations 12-46 and 12-47 as you study the construction of a Fiske stadimeter, the principal parts of which are:

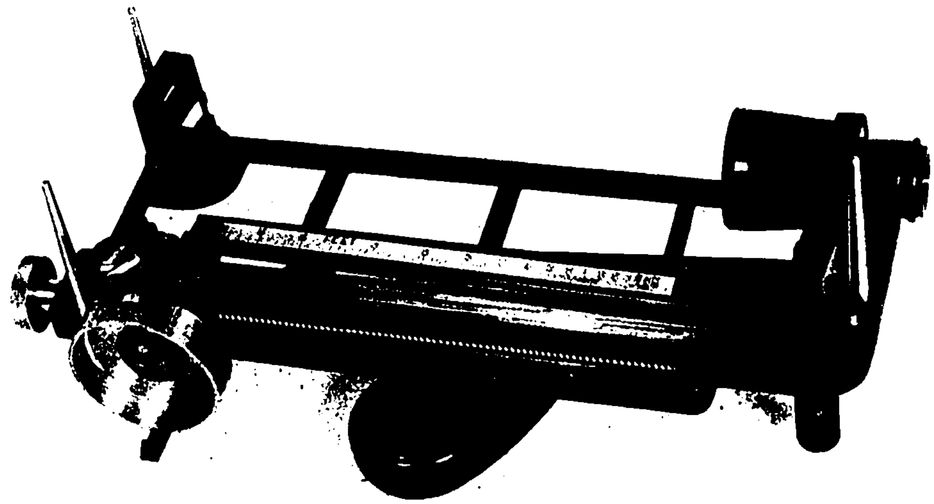

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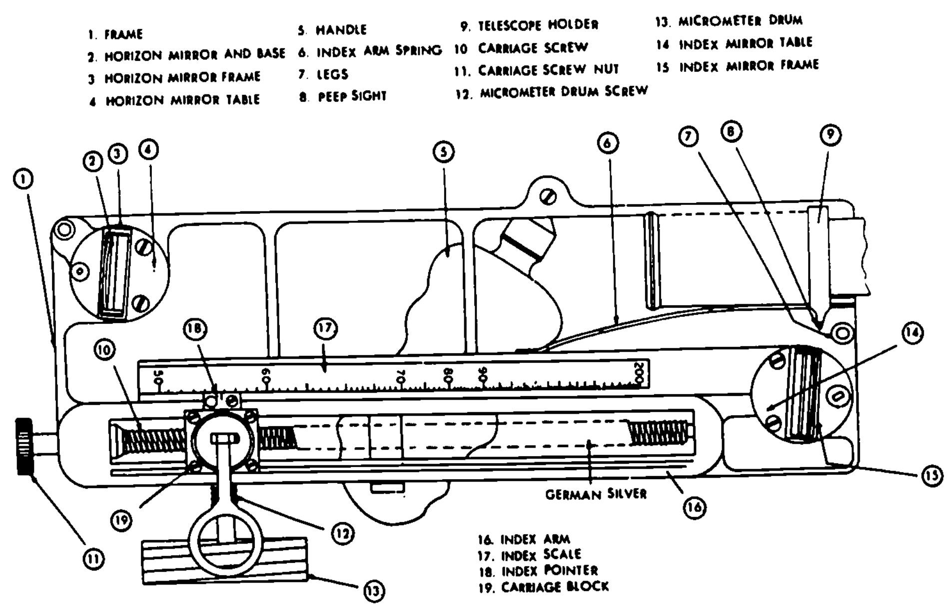
Figure 12-46.—The Fisk stadimeter.



137.364

Figure 12-47.—Construction of a Fisk stadimeter.

• FRAME. The frame is the rectangular base on which all other parts of the instrument are mounted.

• INDEX ARM. This arm carries the height scale; and it swings on a pivot at one corner of the frame.

• INDEX MIRROR TABLE. The index mirror table is an adjustable platform mounted on the index arm (directly over the pivot) to carry the index mirror and its frame.

• HORIZON MIRROR TABLE. This table is an adjustable platform which supports the horizon mirror and its frame.

• CARRIAGE SCREW. The carriage screw moves the carriage block back and forth on the frame, and it is used to set the carriage index mark to the proper height on the height scale.

• MICROMETER DRUM AND SCREW. The micrometer drum shows in yards the range of an object. For any given position on the height scale, the position of the drum controls the angle of the index arm and the index mirror.

• CARRIAGE BLOCK. The carriage block carries the micrometer drum and screw (on a track) along the length of the frame.

• INDEX MIRROR. The index mirror receives rays of light from the target and reflects them to the horizon mirror.

• HORIZON MIRROR. This mirror, as in a sextant, enables an observer to see two images of the target, a direct image and an image reflected from the index mirror. Unlike the horizon glass of a sextant, however, the horizon mirror of a stadimeter has no clear glass on one side. It is merely a half-sized mirror in half of the mirror frame.

• TELESCOPE. The telescope of a Fiske stadimeter is a low-power Galilean telescope which directs the line of sight toward the horizon mirror and gives a magnified image of the target.

• MAGNIFYING GLASS. The magnifying glass is mounted on a bracket above the micrometer drum to give the observer a magnified image of the range scale. The bracket is adjustable, to allow movement of the glass up and down for focusing on the scale.

PRINCIPLE OF OPERATION

Like the sextant, the stadimeter has a fixed horizon glass and a movable index mirror. And like the sextant, it uses the principle of double reflection to measure an angle. Figure 12-48 shows how it works.

Like the sextant, the stadimeter brings two lines of sight into coincidence. And the angle between the two mirrors is always half the angle between the lines of sight.

But the stadimeter goes one step beyond the sextant. Instead of giving the result in degrees, the stadimeter reads in distances. Actually, it's a form of rangefinder. You're already familiar with the range-finder principle. Figure 12-49 will remind you how it works.

The drawing shows two ships; the line BC represents a range finder on the ship to starboard. (It's not to scale, of course.) ABC is a right triangle. You can measure the distance BC, and the range finder itself measures the angle BCA. When you know one of the acute angles and one of the arms of a right triangle,

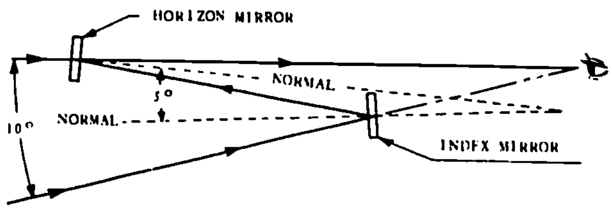


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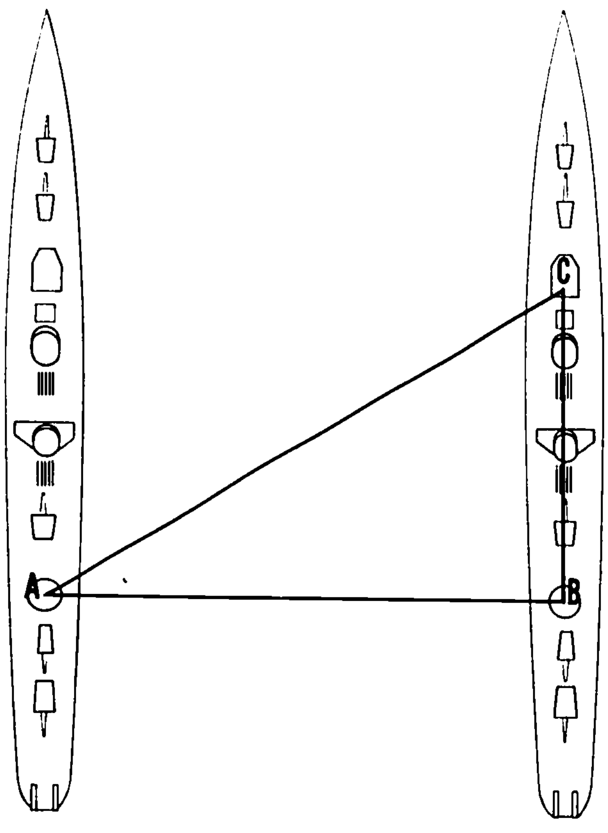
Figure 12-48.—Optical principle of the stadimeter.



137.532
Figure 12-49.—The rangefinder principle.

you can solve the whole triangle. The range finder solves the triangle automatically. It's calibrated so that when you make coincidence, you can read the range AB directly from the dial.

Figure 2-3 shows how the stadimeter uses the same principle.

The man using the stadimeter is at point A, on the starboard ship. If he knows BC (the height of the other ship), he can set his stadimeter for that value. Then, when he makes coincidence, his stadimeter will measure the angle BAC, solve the triangle, and show the range BA on its micrometer drum.

It works the other way, too. If you know the range, you can set the micrometer drum for that distance. When you make coincidence, you can read the height of the other ship on the height scale.

If you're on your toes, maybe you've noticed this: if the man at point A in figure 12-50 is standing on the main deck, then the triangle won't be a right triangle. But don't let that worry you. Since the angle BAC is always quite small, it doesn't matter whether you have a right triangle or not. The errors from this source are so slight they won't show up on the stadimeter. You'll get the same range, whether you take your reading from the lowest porthole or the top of the mast.

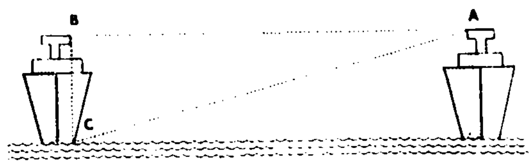


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Figure 12-50.—Rangefinder principle applied to a stadimeter.

As a range finder, the stadimeter is pretty limited. First of all, you have to know the height of the target. Second, the results are only approximate, especially at long ranges. In the Battle of Santiago, in 1898, the American naval gunners actually used stadimeters to find the range of the enemy ships. But in modern gunnery, the stadimeter has no battle use. Range finders are much more accurate.

Then why doesn't the officer of the deck use a range finder, instead of a stadimeter? Because the stadimeter is handy: it's light and portable, and quick, and for this purpose it's accurate enough.

Here's a summary of the abilities and limitations of the stadimeter: If you know the height of an object, you can measure its range; if you know the range, you can measure its height. But this is true only when the height is somewhere between 50 and 200 feet, and the range somewhere between 200 and 10,000 yards. At ranges up to about 2,000 yards, the stadimeter is accurate within plus or minus 2 percent, if you use it carefully. Beyond 2,000 yards, its accuracy decreases.

When the Officer of the Deck wishes to know the distance from his ship to another ship whose foretruck is 120 feet above the waterline, he would use the stadimeter in the following manner:

- Hold the stadimeter in your right hand, by its handle.
- Screw the telescope into its mount.
- By turning the carriage screw, set the index mark on the carriage block to exactly 120 feet on the height scale.
- Bring the instrument up to your eye, holding the frame in a vertical plane. Sight through the telescope, toward the target. Focus the telescope. Now you'll see a direct image of the target through the empty half of the horizon mirror frame, and a reflected image in the horizon mirror.
- By turning the micrometer drum, you can move the reflected image up and down. Turn the drum until the foretruck in the reflected image is opposite the waterline in the direct image. Now you're "on the range."
- Sight through the magnifying glass, and read the range on the drum. If the index mark falls between two graduations on the drum, estimate the range as accurately as you can.

OVERHAUL AND REPAIR

NAVSHIPS technical manual No. 250-624-6 gives all step-by-step procedures for the overhaul, repair collimation of stadimeters. The repairman should use this comprehensive manual when effecting any repairs or adjustments to the stadimeter.

As with all optical instruments, when you start to work on a stadimeter, prepare a casualty analysis sheet for the instrument and make a predisassembly inspection to determine whether it should be repaired or surveyed. Record your findings on the inspection sheet.

During the predisassembly inspection of a stadimeter, look for:

- Excessive play of the drum screw in the carriage.
- Too much play of the carriage to the frame.
- Excessive play in the center assemblies.
- Condition of lubricants.
- Excessive errors resulting from the condition of the scale arm.
- Condition of silver on the mirrors.
- Corrosion and/or failure of protective finishes.
- Evidence of unauthorized tampering and disassembly.

TELESCOPIC ALIDADE

The telescopic alidade is a portable navigation instrument used by personnel aboard ship to accurately measure the bearing of distant objects. When in use, a telescopic alidade is placed over the ship's magnetic compass or gyro repeater and the observer sees the object being sighted combined with the indicated bearing of the compass cord.

The alidades to be discussed in this section are shown in figure 12-51. The Mark 4 Mod 0 alidade is currently in use aboard some ships in the Navy, but it is being replaced by the more modern Mark 6 Mod 1 or Mark 7 Mod 0. Only limited repairs should be made to the Mark 4 alidade and when the cost of repair exceeds 50 percent of replacement cost or repair parts are not available, the Mark 4 alidade should be recommended for survey and replaced with a Mark 6 or Mark 7.

CHARACTERISTICS

The complete optical system of the basic telescopic alidade, as illustrated in figure 12-52, consists of a 4-power main telescope system for viewing distant targets and an auxiliary optical system for sighting a portion of the compass card simultaneously with the object being sighted through the main telescope.

Mark 4

The basic optical system shown in figure 12-52 is identical to the Mark 4 Mod 0 alidade. It is essentially a terrestrial telescope with a vertical line reticle for sighting purposes rigidly mounted on a bearing circle assembly.

Within the body of the main telescope there is incorporated, the auxiliary optical system consisting of a penta prism (fig. 12-52C), a small objective lens (fig. 12-52D), and a rhomboid prism (fig. 12-52E).

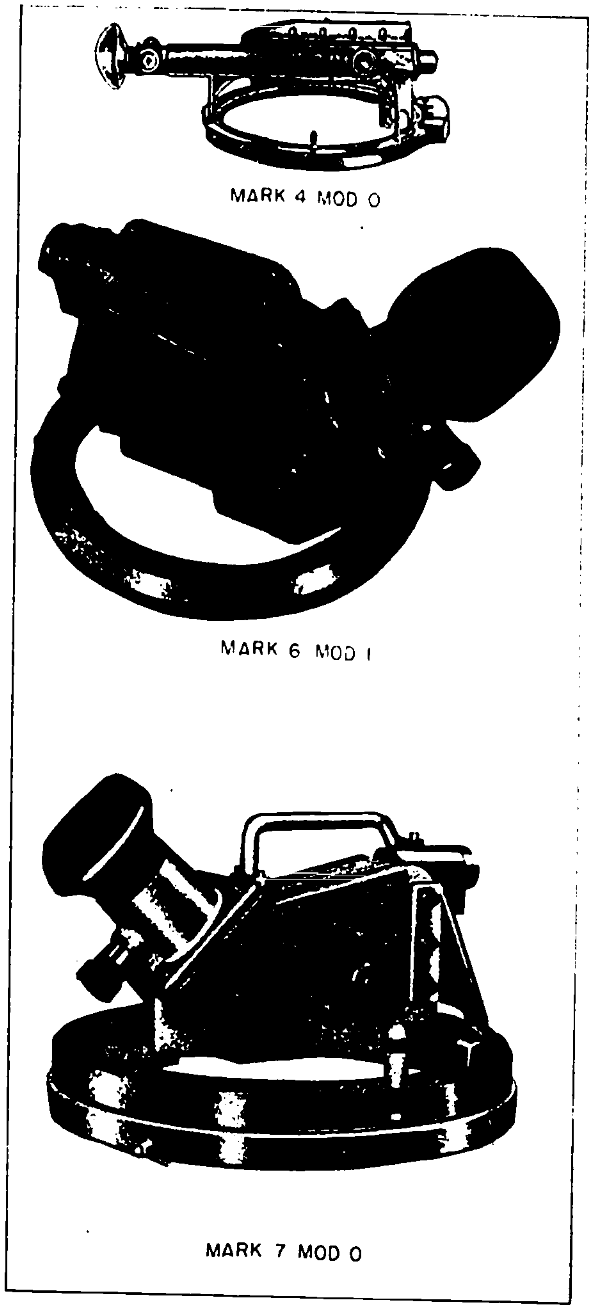

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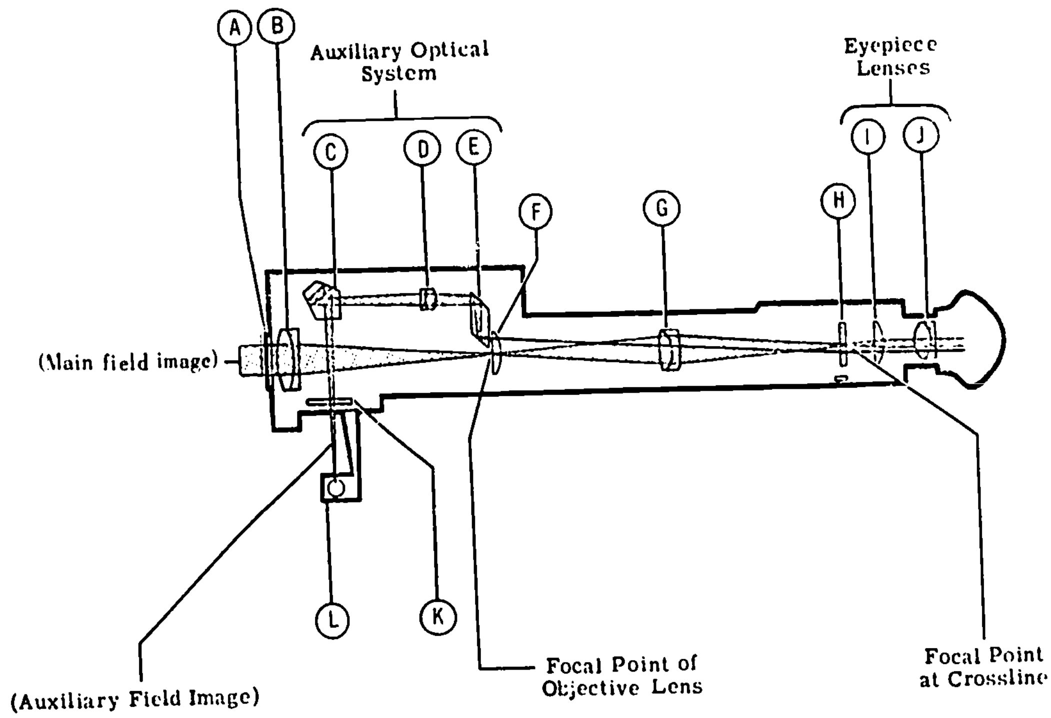
Figure 12-51.—Mark 4, 6, and 7 Telescopic alidades.



A - OBJECTIVE FILTER
B - OBJECTIVE LENS
C - AUXILIARY PENTA PRISM
D - AUXILIARY OBJECTIVE LENS
E - AUXILIARY RHOMBOID PRISM
F - RHOMBOID COLLECTIVE LENS
G - ERECTOR LENS
H - CROSSLINE PLATE (Reticle)
I - EYEPIECE COLLECTIVE LENS
J - EYE LENS
K - AUXILIARY WINDOW
L - SPIRIT LEVEL

137.534

Figure 12-52.—Telescopic alidade—cross section view.

The purpose of the auxiliary system is to project the image of the compass card and level bubble into the main telescope system. This auxiliary field image is introduced into the main optical system from the auxiliary rhomboid prism, which covers about half of the rhomboid collective lens. You see the object being sighted, the instrument's crossline, a portion of the compass card and the level bubble, directly below it, at the same time when you look through the eye end of the telescopic alidade. The bearing of the object is read on the compass card as indicated by the portion of the crossline in the auxiliary field. Refer to figure 12-53.

Each air-glass optical surface in an optical system will reflect five percent of the light incident upon it. The accumulative effect of this is a serious loss of light intensity and contrast in the final image. The loss of contrast is from the glare caused by the reflected and diffused light finding its way into the eyepiece by multiple reflectic in the instrument. An antireflection coa ng of magnesium fluoride (.000004 inch thick) will reduce reflection losses to about one percent at a surface which greatly increases the image brightness and contrast.

The objective, erector, eyepiece collective and eye lenses are coated. This results in a light transmission of approximately 70%. The rhomboid collective lens and the crossline plate are not coated because any defects in the coating would be plainly visible; these optics are in focus in the field of view. The auxiliary optical parts are not coated since the auxiliary system

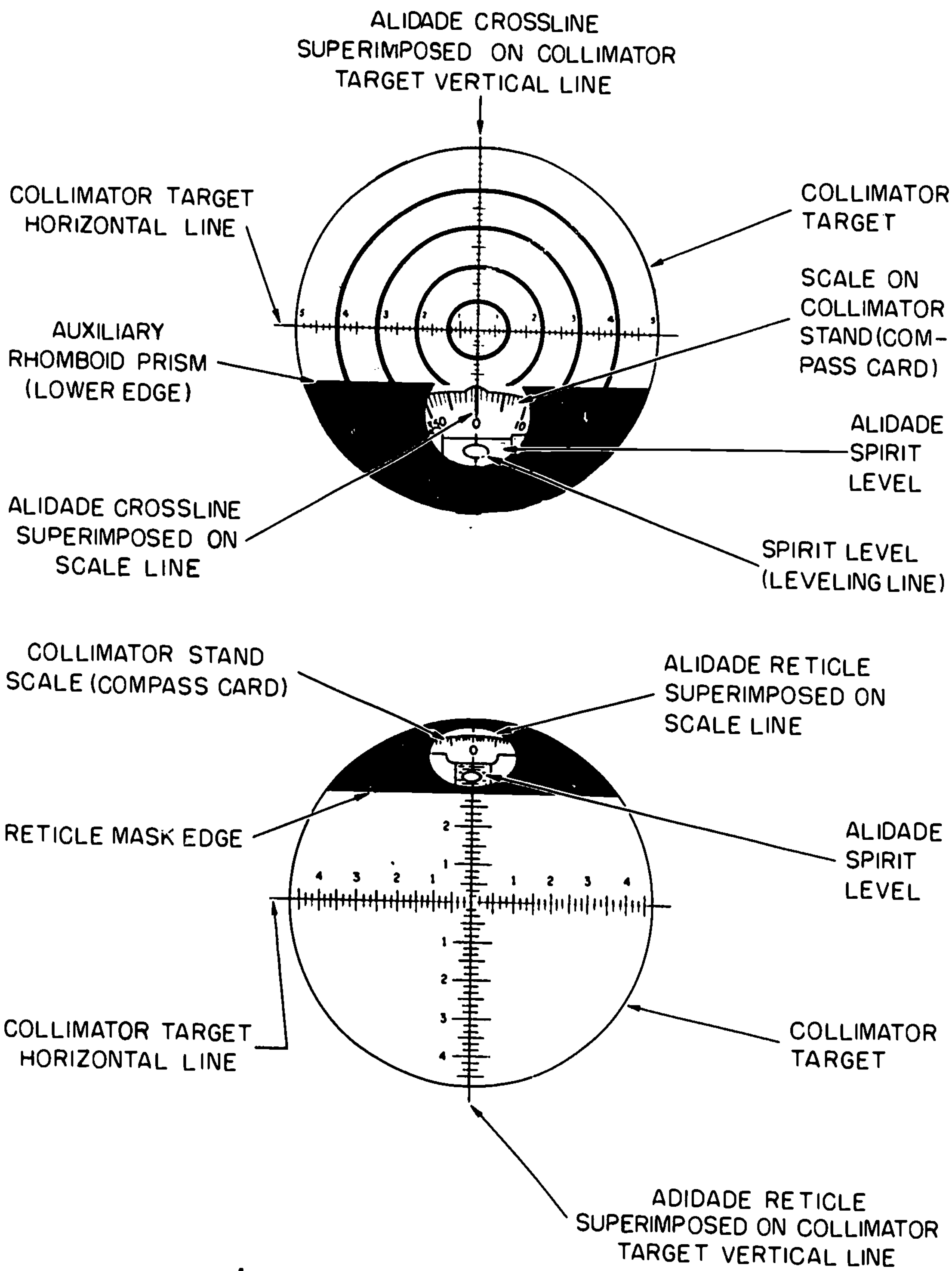


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Figure 12-53.—Collimator target viewed through a telescopic alidade.

is required only to give an image of the compass card which can be illuminated as bright as is necessary by the compass illuminator lamp.

One of the principal design features of the Mk 4 telescopic alidade is the attempt to make the telescope waterproof and moistureproof by adding rubber gaskets to the seats of the eye lens and the objective lens, a rubber seal over the objective mount and a scaling ring on the eyepiece. Where wax was used for sealing in earlier marks and mods, rubber gaskets are used in this alidade. The telescope body was redesigned so that it is one piece instead of three, thereby eliminating joints where moisture could enter the interior; the eyepiece mount moves in and out of the end of the body instead of having a separate adapter (as in the other alidades). Instead of the conventional focusing ring engaging a key on the eye lens mount, focusing is accomplished by turning a pinion, which engages a rack cut on the eyepiece lens mount. Instead of being in a fixed plane, the crossline plate is mounted in its own mount and is capable of being positioned in or out in relation to the eyepiece. The whole auxiliary telescope system is mounted on a plate, permitting it to be made up as a subassembly before being placed into the telescope body. To absorb any moisture that does get into the interior, a container of desiccant (silica gel) is placed within the telescope body. The body cover is made watertight by a rubber gasket between it and the telescope body.

Mark 6 and Mark 7

The Mark 6 and Mark 7 alidades shown in figure 12-51 are identical to each other in optical design. They differ from each other only in mechanical features of the bearing ring assemblies. The Mark 6 alidade attaches to a 6-inch magnetic compass or ship's course indicator and the Mark 7 alidade is equipped with an adaptor for mounting on the 7 1/2-inch Navy Number 1 magnetic compass or the 7 1/2-inch ship's course indicators.

The optical design of the Mk 6 and 7 alidade, as shown in figure 12-54, is similar to the basic design discussed previously. It has a terrestrial telescope for viewing distant objects and an auxiliary optical system for simultaneous viewing of the compass card and spirit level.

There are some differences in the individual optical elements of the Mk 4 and Mk 6 and 7 alidade, so compare figures 12-52 and 12-54 as you study the following description of the Mk 6 and 7 alidade.

The main optical system of the Mark 6 and 7 (fig. 12-54), telescopic alidade is a terrestrial telescope which consists of an objective lens (piece 8), polarizing filters (2-piece 6), a compensator lens (piece 7), an Amici prism (piece 4), a reticle, and the eyepiece elements. The objective lens receives light from a distant object and forms an image which is subsequently magnified by the eyepiece optical elements. The two polarizing filters may be rotated in or out of the line of sight as situations require. Placed in the path of light, they reduce light intensity and glare. One polarizing filter may be independently rotated to vary the intensity of light received from the distant object. The compensator lens is also mounted in the filter assembly, but it is only positioned in the line of sight when the polarizing filters have been rotated to the down position. The compensator lens is used to converge the light path and maintain the required focus when the polarizing filters are rotated out of the line of sight. The light from the compensator lens or polarizing filters is then focused through a fixed stop aperture onto the eyepiece side of the Amici prism. The Amici prism inverts and reverts the image and deviates the line of sight through a 45-degree angle. The recticle wire is superimposed on the image and the eyepiece elements, which consist of a field lens (piece 1), center lens (piece 2), and eye lens (piece 3) produce an enlarged virtual image of the distant object at the eyepoint of the alidade.

The auxiliary optical system consists of a sealing window (piece 9), front surface mirror (piece 13), an outer objective lens (piece 12), an inner objective lens (piece 11), erector lenses (2-piece 10), and an auxiliary optical system prism (piece 5). The image of the compass or indicator card and level vial is transmitted through the window and reflected into the auxiliary optical system by the front surface mirror. The inner and outer objective lenses converge the image from the front surface mirror, through a stop in the erector lens cell, into the auxiliary optical system prism. The erector lens inverts the image of the inner and outer objective lens, while the auxiliary optical system prism re-inverts the image in the plane of the mask, and reticle wire. The reticle wire is superimposed on the compass card and the bubble in the level vial (piece 14), and an image is formed at the eyepoint of the alidade.

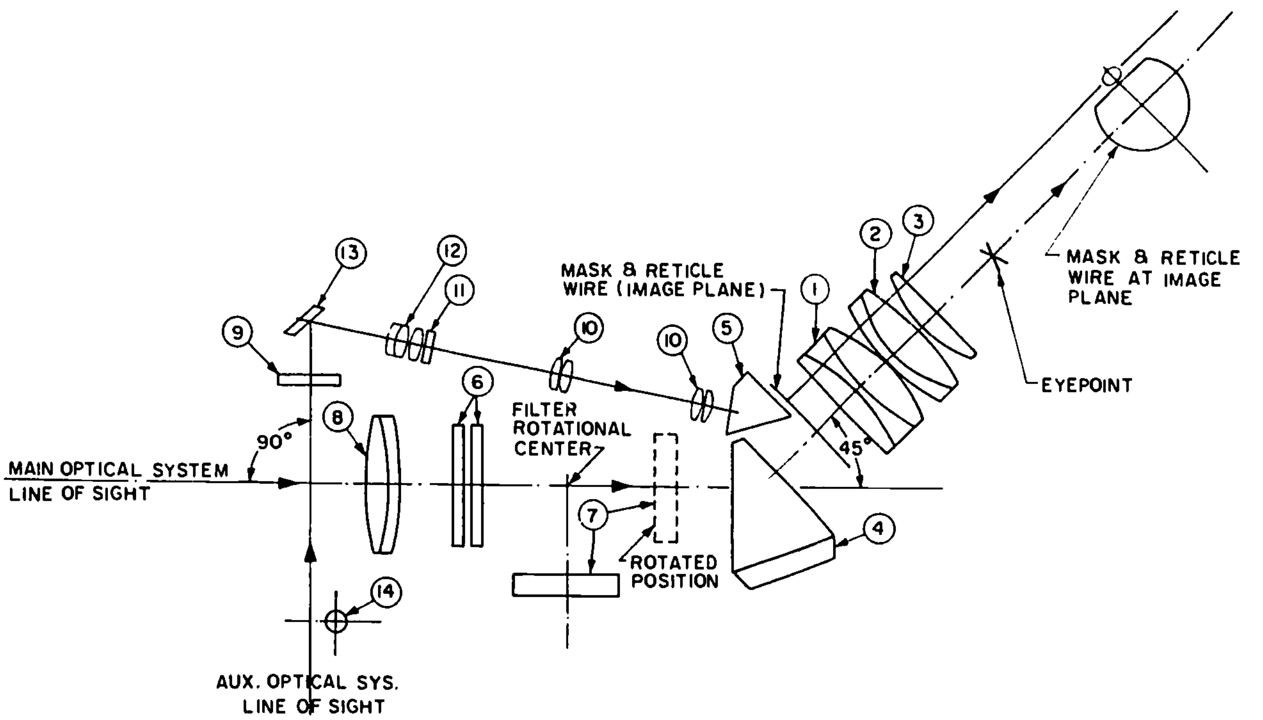

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Figure 12-54.—General optical arrangement Mk 6 and 7 alidade.

The complete image formed at the eyepoint of the alidade consists of the distant object with reticle wire superimposed, as viewed through the main optical system, and the image of the compass card, bubble in the level vial, and the reticle wire superimposed, transmitted through the auxiliary optical system.

To accommodate for the visual variations between different observers, the alidade has a focusing assembly. The focusing assembly includes a focusing knob, focusing shaft, focusing plate, diopter scale, and a stuffing box. When the focusing knob is rotated, the focusing shaft alters the position of the focusing lens mount. By this movement the observer may adjust the eye lenses to his desired focus. The diopter scale on the focusing knob may be aligned with the white line on the stuffing box to obtain a diopter setting.

The filter assembly provides a means of controlling the light intensity and glare within the alidade. The control is a two concentric knob device with the larger knob inserting the filters or compensator, and the smaller knob adjusting the density of the filters.

OPERATING PRINCIPLES

The telescopic alidade is a precision optical instrument and extreme care should always be used when handling it. Rough treatment or severe shock can cause misalignment of the optics and serious damage to the external controls and bearing rings.

There is little difference in operating the Mk 4 and the Mk 6 and 7 alidade, except for mounting. Since the Mk 4 and Mk 6 alidades each have only one mounting ring, the discussion on operation will cover the Mk 7, illustrated in figure 12-51, which has two adapter rings.

The Mk 7 alidade comes equipped with a Type A adapter ring for mounting on the 7 1/2-inch Number 1 magnetic compass, and a Type B adapter ring that fits on most 7 1/2-inch ship's course indicators. The appropriate adapter ring is first mounted and locked in place and the telescopic alidade, with its permanently fixed bearing ring is then mounted on the adapter ring. While looking into the eyepiece, the operator will then rotate the focusing knob until he sees a clear image of the vertical reticle wire. When glare presents a problem, the operator should then position the polarizing filters into the optical system in a manner that allows for the clearest view.

After the alidade is mounted and adjusted for viewing, the operator should rotate the alidade into the general direction of the target. While sighting through the eyepiece, adjust the rotational position of the alidade until the target image is centered on the reticle wire. As soon as the reticle bisects the target, direct your vision to the upper third of the eyepiece and read the bearing represented by the compass card division indicated by the reticle wire. While reading the compass card division, check the position of the level bubble. The most accurate bearings are obtained when the alidade is level.

REPAIR

Complete repair procedures and parts lists, for the Mk 4 telescope alidade, are given in the NAVSHIPS 250-624-5 technical manual. The Mk 6 and Mk 7 alidade are thoroughly covered in NAVSHIPS 324-0488 and NAVSHIPS 0924-001-6000 technical manuals. The technical manual that applies should always be used as a guide when actually working on a telescopic alidade.

Here listed are some of the major points of repair that an opticalman should examine.

- Inspect the alidade thoroughly to be certain all parts and assemblies are present.
- Examine the housing for dents and cracks.
- Check the focusing and filter assemblies for bent or broken parts. These assemblies should operate easily.
- Inspect for dirt and moisture on the interior optical parts; their presence will indicate improper internal pressure in the housing.
- The diopter scale must be clearly defined and easily readable.
- The exterior finish of the alidade must be intact to maintain protection against corrosion.

No dirt, smears, scratches, digs, chips, fractures, fungus growth or cement separations should be visible inside the alidade as viewed through the objective lens. With the use of the method called "shadowing," it is possible to locate these defects in the lenses. Shadowing is the technique of looking obliquely into the eyepiece or objective end of an instrument to obtain a reflection from a particular surface in the optical system. Seen in this way, the surfaces of the lenses appear dark grey and any defects show up as white particles. If salt spray marks appear on the exterior glass surfaces, they should be removed by rinsing in fresh water before any other glass cleaning is attempted.

Collimation

Collimation of a telescopic alidade is a step-by-step procedure of interdependent adjustments. The main optical system and also the auxiliary optical system must be collimated to the mechanical axis of the bearing circle. The first step is mechanical alignment of the bearing circle with the axis of the collimator. The second step is alignment of the main optical system with the collimator. The third step is alignment of the auxiliary optical system with the main optical system.

The collimator generally used for collimating a telescopic alidade is a Mk 4, Mod 0, instrument, illustrated and discussed in chapter 8 (fig. 8-4). The collimation procedure discussed in this section is for a Mk 6, or 7, telescopic alidade.

- Bearing Axis: The alidade requires a collimator adapter which simulates the bezel ring of the compass, and, in addition, contains a scale with graduations properly located and oriented to simulate the compass card. A setting fixture is also necessary to set the adapter so that the center of the bezel ring and the center mark of the scale are capable of being aligned along the line of sight of the collimator telescope.
- Main Optical Prism Adjustment: The main system Amici prism is bonded to a metal mount held by three screws to the prism mount plate. Sufficient clearance is allowed for a small adjustment in height, distance along axis, and rotation in a vertical plane defined by the optical axis, of the mounted prism. There is no provision for rotation, or tilt, of the prism in any other plane. After adjustment, screws must be taken up tightly.
- Auxiliary Objective Adjustment: In the adjustment of the auxiliary system, it has been found advisable to set the erector assembly approximately midway of its travel, and to adjust by moving the auxiliary objective cell in or out. This operation is best performed after the filter assembly has been removed, providing access to the back end of the auxiliary objective cell. The set screw holding the auxiliary optical cell is below the forward nameplate screw, in the

same threaded hole. Care should be taken to back off this set screw before attempting to remove the cell, and to take it up tightly after completion of the adjustment.

• Auxiliary Mirror Adjustment: The auxiliary optical system mirror, bonded to its threaded mount, can be adjusted to change the height of the card and level vial images, to change the lateral positioning of these images, and to tilt or correct tilt introduced by other elements. All three of these adjustments are functions of the rotational and longitudinal position of the threaded mount in the housing casting wall, and, therefore they are not independent adjustments. Care should be taken to make sure all three factors are satisfactory before locking the mount in position with its setscrew. Final adjustment should not be made until the auxiliary optical system prism has been adjusted and locked.

• Auxiliary Prism Adjustment: The auxiliary optical system prism is bonded to a metal mount and fastened to the prism mount plate in a manner similar to that used with the main optical system prism. Adjustments are the same. Any rotation of image or sidewise displacement must be corrected by small rotational adjustments of the auxiliary mirror mount.

• Fixed Polarizing Filter Adjustment: Removal or replacement of the fixed polarizing filter requires attention to its orientation in the mount. Since it is required to reduce glare from the water surface, its index lines should be vertical, or perpendicular to the filter shaft, when it is locked into position in the filter mount. This should be checked after tightening the retaining ring, as the final movement of the retainer ring may have caused the filter to rotate.

CHAPTER 13

BINOCULARS

The optical instruments you have previously studied and the binoculars you will study in this chapter are all designed to do one thing, that is, to control the direction of light rays so that we can see more effectively when looking through an instrument.

From our previous studies we know that, under normal conditions a light ray will travel in a straight line and we are able to change its direction of travel by reflecting it from a smooth surface or by sending it through a transparent glass, in which case, the ray will be refracted into another direction of travel.

When we observe an object through a binocular we are controlling the light rays from the object and aiding our vision in two ways.

1. By enlarging the image of the viewed object, formed in our eyes, making it appear larger and closer.
2. By increasing our ability to judge the distance and dimensional properties of the object.

The enlarged image is caused by magnification and the ability to judge distance and size is called stereoscopic vision which you studied in chapter 5.

In order to understand stereoscopic vision more clearly refer now to figure 13-1 and let A and B represent the two eyes of an observer viewing an object at point P. The two images of P will be formed slightly different on the two retinas and the observer will subconsciously appreciate this fact and rotate his eyes in order to combine both images. The eyes then form a convergence angle and as the distance (R) of the object increases, the convergence angle (W) becomes smaller, until it reaches the limit of stereoscopic vision. Under normal viewing conditions the limiting angle has been found to be about 30 seconds of arc and the distance about 500 yards.

If our eyes could be moved farther apart our range of stereoscopic vision would be increased. This of course is impossible but the same effect can be accomplished by artificial means such as the mirrors shown in figure 13-2. In effect this would increase the interpupillary distance of the eyes.

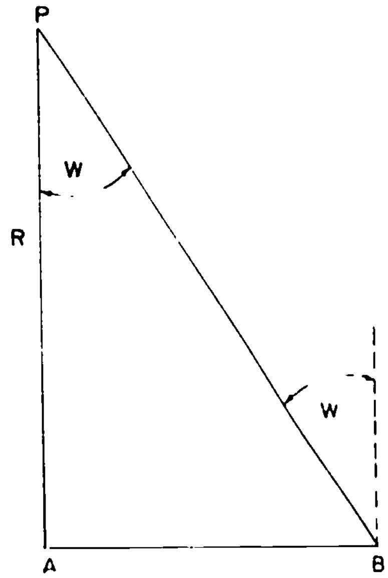

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Figure 13-1.—Angle of convergence with both eyes on object.

If the object is also viewed under magnification a further increase in stereoscopic range is obtained and we will have the optical principle used to design the prismatic binocular system shown in figure 13-3.

HAND-HELD BINOCULARS

There is no simple positive method to quickly identify all the various types of hand-held

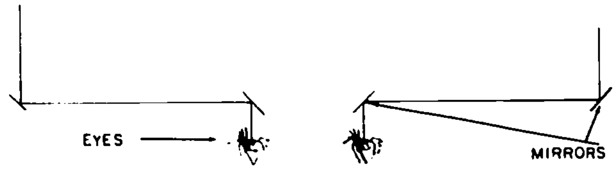

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Figure 13-2.—Stereoscopic increase with mirrors.

binoculars used in the Navy. A brief description of the Mk 28 and the Mk 45 is given here, so that the reader will comprehend some of the major variations in different types of binoculars.

Refer now to figure 13-4 which illustrates the standard Navy Mark 28 binocular.

The number, 7 x 50, used to describe the type of binocular treated in this manual, represents the following information. The 7x is the power of the binocular; and the number 50 is the free aperture (usable diameter) of the objective lens in its mount, measured in millimeters. This code system is commonly used for all binoculars. For example, a 9 x 63 binocular magnifies an object 9 times and the free aperture of its objective lenses is 63 millimeters.

By definition, a binocular pertains to both eyes. It consists of two complete optical systems—the left telescope and the right telescope, which are hinged together.

The hinge action provides adjustment of the eyepieces to the spacing of a user's eyes (interpupillary distance).

FEATURES

Prismatic binoculars considered in this chapter are manufactured in accordance with Navy specifications. The bodies are made of aluminum, as are all other mechanical parts, with the exception of gaskets and some of the hinge parts.

The optical systems in both bodies of a binocular are identical, and the optical axes of the two systems must be parallel and LOOK at the same point on a distant object. This is necessary to prevent eyestrain.

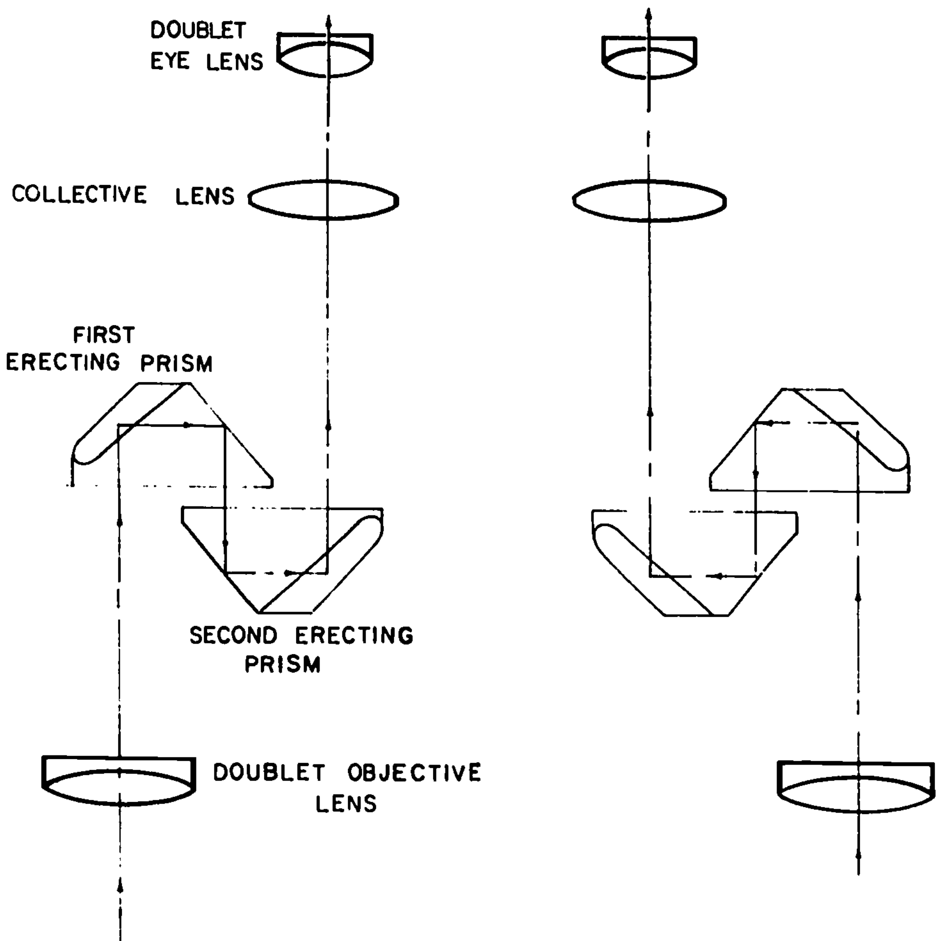

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Figure 13-3.—Prismatic binocular.

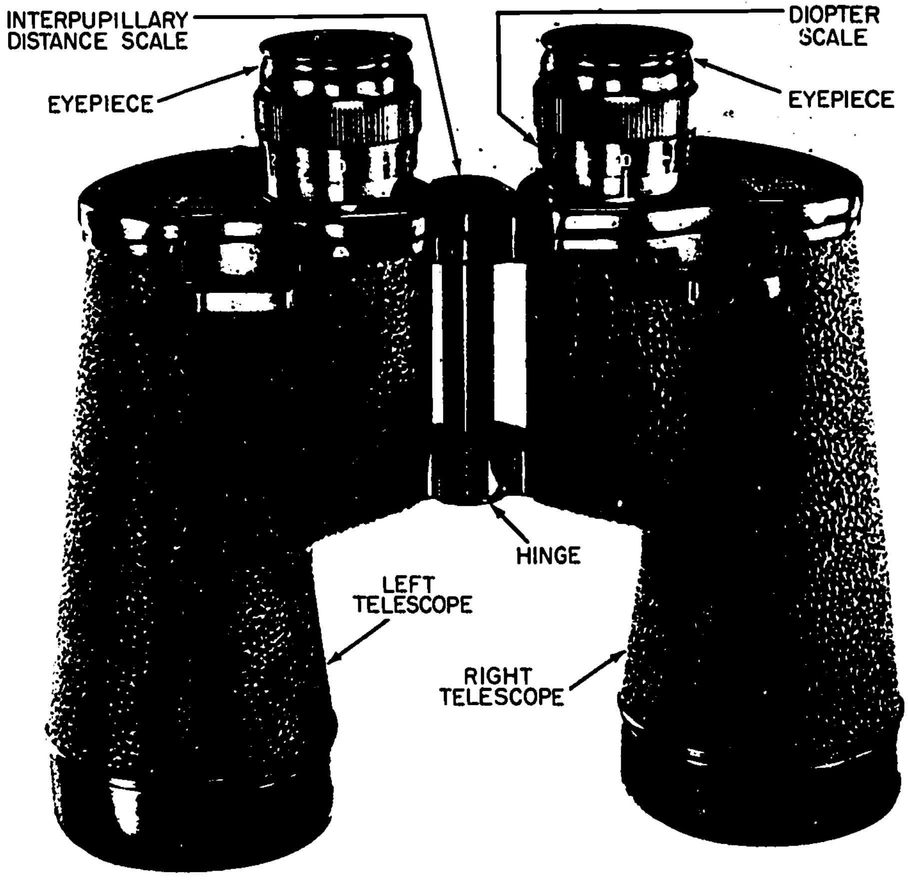


Figure 13-4.—Mark 28, Mod 0 binocular.

Study figure 13-5 as we discuss the optical elements used in hand-held binoculars.

At one end of each telescope there is a large cemented doublet lens, called the objective lens, which collects the light from the "object" being viewed. Its size (free aperture) determines the amount of light it can gather (and not, as one might suppose, how wide a view can be seen). For example, the extra large objective lenses of so-called "night glasses" make dim objects appear in greater detail.

The objective lens receives the light reflected from a distant object and forms a real image within the telescope at the focal plane of the objective. This image is in turn viewed by the eyepiece, and would be inverted and reversed if a pair of porro prisms or some other erecting system were not placed in the path of the light coming from the objective lens.

Two porro prisms, mounted at right angles to form a cluster, are used in each telescope between the objective lens and the eyepiece. The prism clusters serve three important purposes in the binocular.

- They reverse and invert the image, formed by the objective lens, to the right-side-up or true position.
- They increase the stereoscopic effect, which gives better depth perception, this, by reason of the fact that their placement permits a greater distance between the left and right objective lenses than would be allowed by the user's interpupillary distance.
- They also decrease the physical distance, the length of the body, between the objective lens and the eyepiece by "folding up" the light path. This can be proven by measuring the distance the light travels (the light path) from

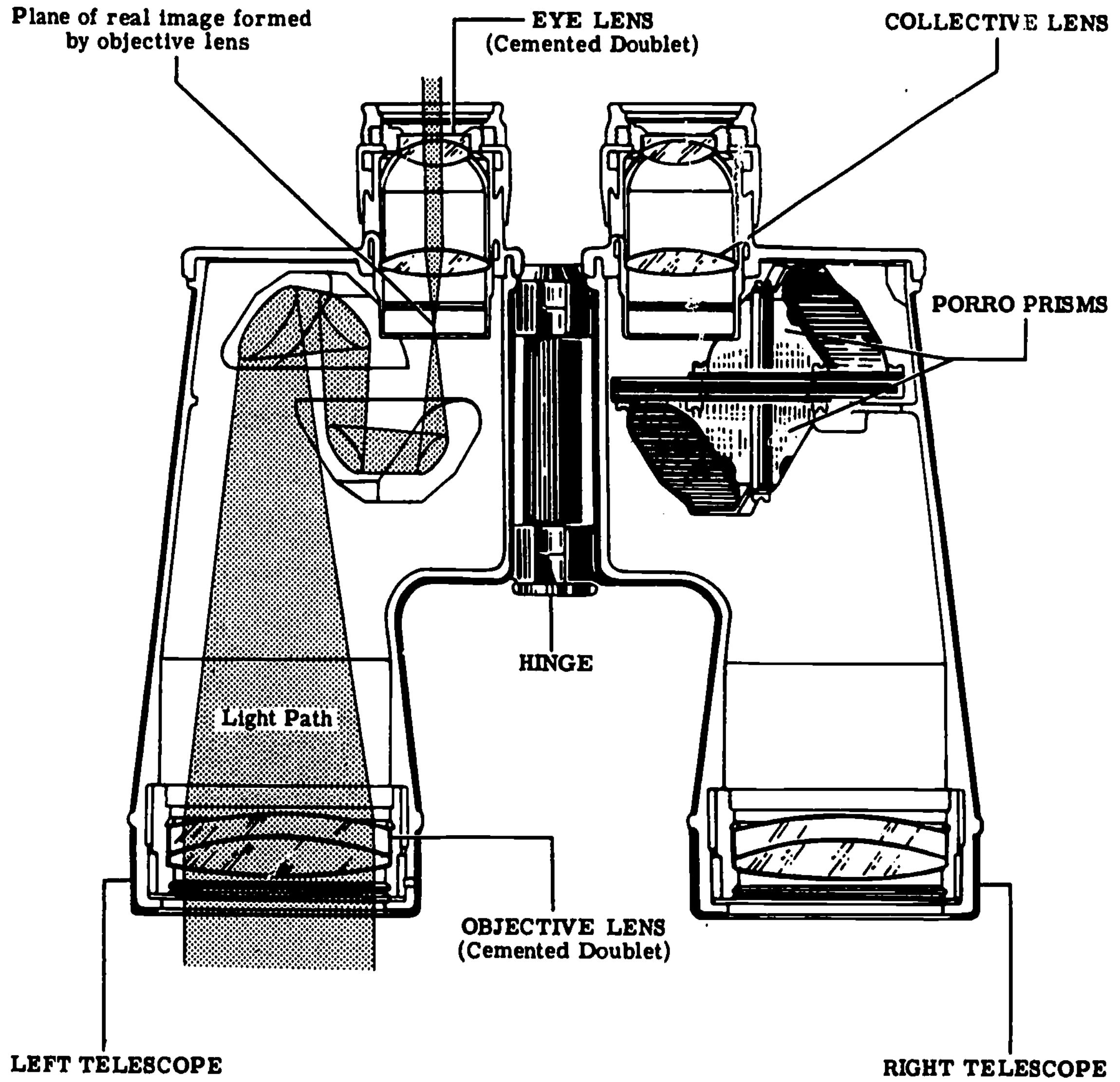
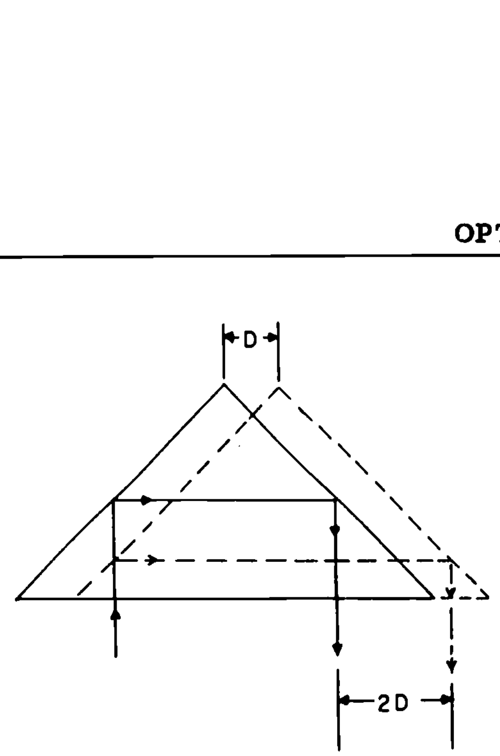


Figure 13-5.—Cross section of a binocular system.

the objective lens, back and forth through the prisms, and then to the eyepiece. Then measure the direct length between the objective lens and the eyepiece in figure 13-5.

The last-mentioned function makes possible the short bodies characteristic of prismatic binoculars compared with the long tube of a telescope. If prisms were not used, an erector lens would have to be provided which would require still more space (along the length of the body) to form its image.

Mounting the prisms in the main body is of considerable importance. In the first place, their faces must be kept perpendicular to the optical axis. Second, because rotation of one prism with respect to the other causes a rotation of the image through twice as large an angle, it is important that they be positioned rigidly with respect to each other. Third, a lateral displacement (D) of a porro prism causes a shift in the beam of 2D, as is shown in figure 13-6. When this occurs, the beam from an object on the axis of the objective, reaches



D= SLIGHT SHIFT IN PORRO PRISM.

2D= THE RESULTANT DISPLACEMENT ON THE EMERGENT BEAM.

137.539

Figure 13-6.—Porro prism displacement.

the eyepiece well removed from the axis, and is thus deviated, arriving at the eye at an angle. If this deviation is large the instrument is unusable, while if it is small it will cause considerable discomfort to the user, without his being aware of the cause. To eliminate this difficulty, considerable care is taken in the mounting of the prisms.

The image, formed by the objective lens (inverted and reversed by the prisms) is seen magnified through the eyepiece. The eyepiece, consisting of a collective lens and doublet eye lens, is used just as an ordinary magnifying glass is used to look at newspaper print except that the "object" being viewed in the binocular is the real image formed by the objective lens.

To adjust for any difference in vision that might exist between the right and left eye, and to focus the image so that it is seen sharply and clearly, the eyepieces may be moved in or out. By this means, the distant object can conveniently be seen alternately with the unaided eye or through the binocular.

The scale on each eyepiece, known as the diopter scale (fig. 13-4), is provided to permit a person regularly using the binocular to set the eyepieces to compensate for any visual correction required by his own eyes which does not change unless his eyes should change. The binoculars once adjusted are ready for immediate use by that person with no delay for focusing.

There is no simple positive method to quickly identify all the various types of hand-held binoculars used in the Navy. A brief description of the Mk 28 and the Mk 45 is given here, so that the reader will comprehend some of the major variations in different types of binoculars. During actual overhaul or repair work the Opticalman should use NAVSHIPS Technical Manual 250-624-2. This comprehensive manual was prepared for the information and guidance of all personnel in the Naval Establishment engaged in the servicing, repair, and testing of hand-held binoculars.

Mark 28

The Mark 28 binocular (fig. 13-4) is the basic design for all 7x50 hand-held binoculars.

The hinge (fig. 13-7) joins the two optical systems and provides a means for interpupillary adjustment. The design of the hinge is such that it gives smooth action, with sufficient tension to maintain proper spacing between the systems, without play or looseness.

The tapered hinge axle (fig. 13-7) is held firmly in the hinge lugs of the left body and rides freely in the matching taper of the hinge tube, which is set permanently in the hinge lugs of the right body. Hinge tension is controlled by the lower axle screw. When this screw is tightened, the left body hinge lugs are SQUEEZED against the right body hinge lugs. Since the right body lugs are held rigid by the hinge tube, friction developed between the faces of the outer and inner hinge lugs gives hinge tension. The .010-inch cellulose acetate hinge washers between each pair of upper and lower hinge lugs receive the wear resulting from hinge motion. These washers fit firmly in their positions against the hinge lugs and provide friction for hinge tension.

The porro prisms in the system (fig. 13-8) are firmly mounted on a prism plate and set on lugs that are cast in the telescope body.

The objective lens is mounted in an eccentric mount (fig. 13-9) that slips directly into a machined recess in the objective end of the body casting.

Mark 45

The Mark 45 is the most waterproof of all the binoculars. Designed for underwater

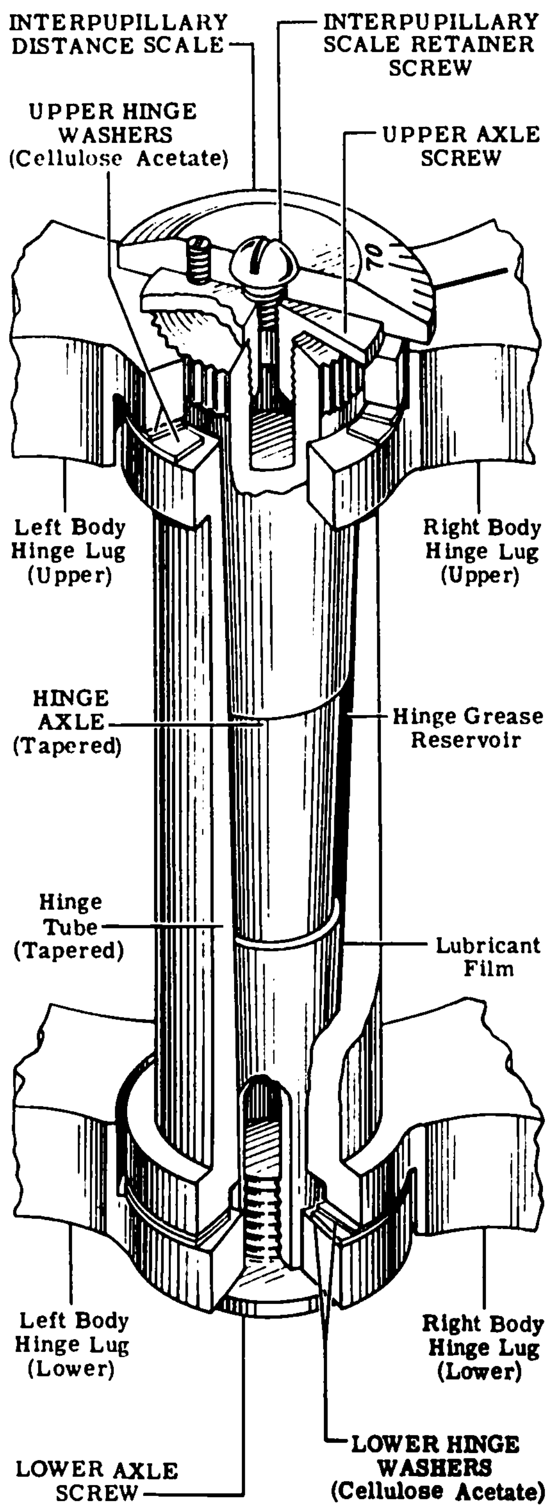


Figure 13-7.—Hinge mechanism (Mks 28, 32, and 39 binoculars).

service to withstand water pressure where the other binoculars will not, it is used on board submarines and by demolition teams.

This binocular has an entirely different design of hinge. It is illustrated in figure 13-10. The straight hinge axle fits tightly in the straight hinge tube; the axle is splined to the top of the tube. The hinge tube is held in the left body (inner) hinge lugs. A split hinge expanding bearing is threaded onto a modified buttress-type thread on each end of the axle. The right body lugs swing on the expanding bearings. When a hinge expanding bearing is tightened against the hinge bearing thrust washer, which is placed between the bearing and the bottom of the threaded axle shoulder, the thrust forces the bearing up on the sloping sides of the buttress threads causing it to expand (it is split) and develop friction with the right body hinge lug. The hinge tension is adjusted by tightening the hinge expanding bearings. The ends of axle and the bearings are notched. Hinge locks (see fig. 13-9) fit these notches and keep the bearings from loosening on the axle. Lubrication is forced into the hinge through a grease fitting. Lubrication holes carry the lubricant up through the center of the axle to the top bearing.

Thus we see that in the case of the Mk 28 design of axle, hinge tension is developed by squeezing the binocular right and left body hinge lugs together. In the case of the Mk 45 design of axle, hinge tension is developed by forcing the expanding bearings against the right body hinge lugs.

The prism cluster of the Mk 45 binoculars are held suspended from the eyepiece cover assembly by three posts. As shown in figure 13-11, when the cover and eyepiece assemblies are removed from the binocular body, the prism cluster remains attached to the underside of the cover. The prism cluster is then separated from the cover assembly after removing the prism plate screws as shown in figure 13-11.

The objective mount of the Mk 45 binocular fits into an objective adapter that is threaded into the body casting. See figure 13-11. This arrangement allows the repairman to replace a damaged objective adapter, whereas damage to the objective end of a Mk 28 binocular often means the complete binocular body must be replaced.

DISASSEMBLY

Each binocular is given a predisassembly inspection to determine faulty operation or

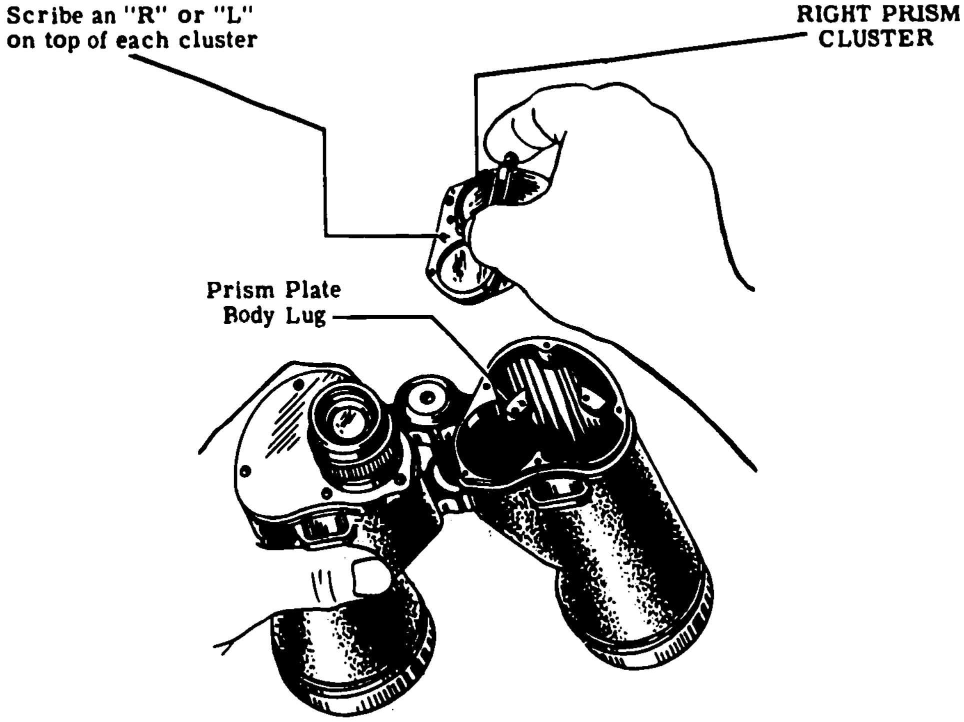


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Figure 13-8.—Prism cluster mounting in body.

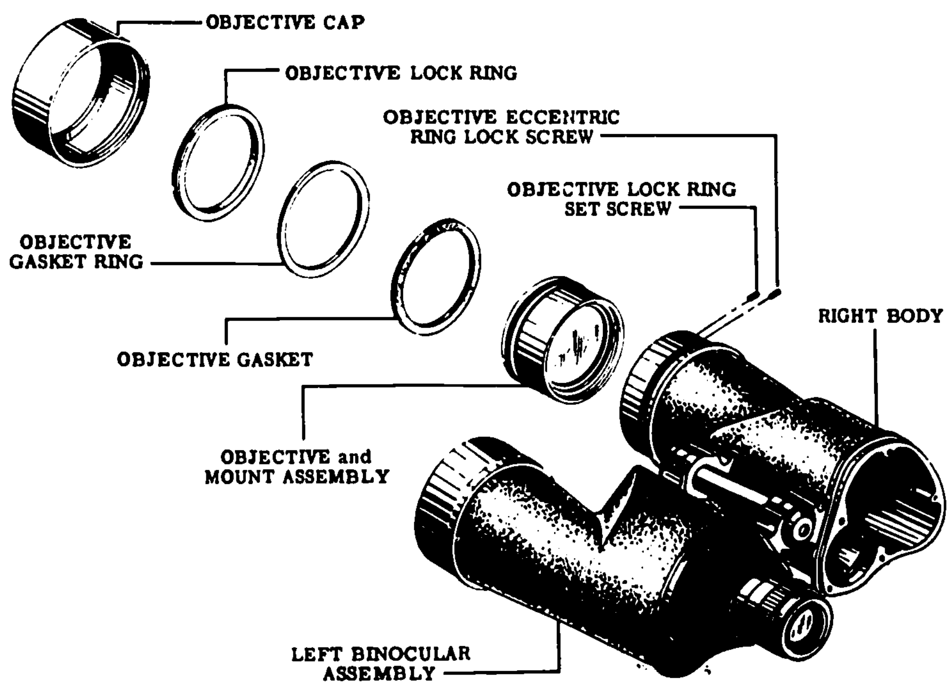

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Figure 13-9.—Binocular objective and mount assembly Mk 28.

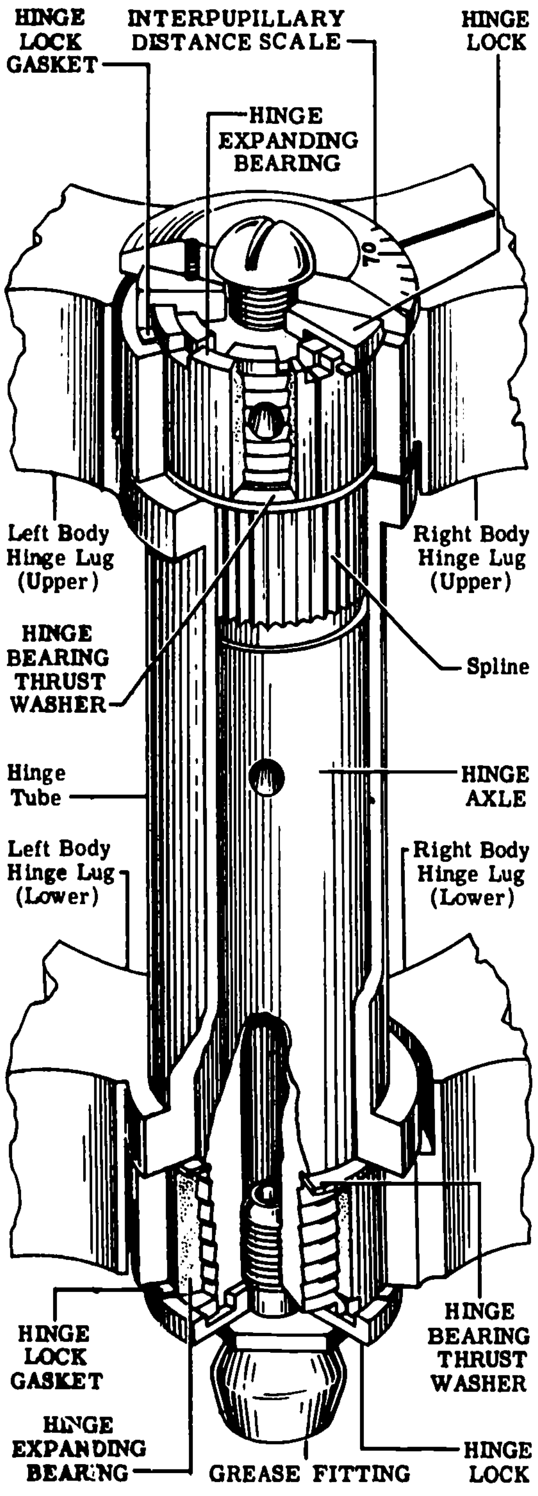

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Figure 13-10.—Mk 45 hinge mechanism.

appearance, and hence, whether it is worth repairing and, if so, the extent to which it is to be disassembled. As determined by this inspection, the defective right or left half binocular assemblies will be broken down into their subassemblies and then into their component parts.

This is an economy measure to select for overhaul only those binoculars that justify repair and to prevent the needless expenditure of time and effort in disassembling and reassembling those portions of a binocular that are in good working order. Unless it is defective, nothing is gained in overhauling this optical instrument, which is a "non-wearing" type instrument as compared to a "wearing" or "running" type, as in the case of a chronometer. In fact, trouble may result from disturbing the elements and, hence, the adjustments. The rule here is, "Leave well enough alone."

Look for the same things you would in any optical instrument: mechanical damage to the housing; lost motion or binding of moving parts (the hinge axle and the diopter scales); damaged, or dirty, or damp optics. Set the diopter scales to the proper correction for your eyes, and then look toward a distant object. If it's in focus, the scales are set correctly. If the binocular has a reticle, check it for parallax (preferably with the aid of an auxiliary telescope).

To check the interpupillary distance scale, you'll need a rule graduated in millimeters. Adjust the binoculars so that the scale reads 64 mm. Put your rule across the centers of both eyepieces, and measure from the edge of one lens to a corresponding point on the other. The distance should be exactly 64 mm.

The lines of sight of both barrels must be parallel with the axis of the hinge, within an angle of two to three minutes. The only way to make an accurate alignment test is with a collimator. (Directions later.) But when an observer reports that a pair of binoculars causes eyestrain or a headache, you can be fairly sure they're out of collimation. If the barrels are badly out of line your eyes won't be able to fuse the two images, and you'll see a double image of distant objects.

Check each barrel separately for lean. A collimator gives the most accurate test, but you can make a rough check in the field. Sight through the eyepiece with one eye, and look at the target itself with the other. Pick a target with definite horizontal and vertical lines, such as a group of buildings. The lines of the image should be parallel with those of the target.

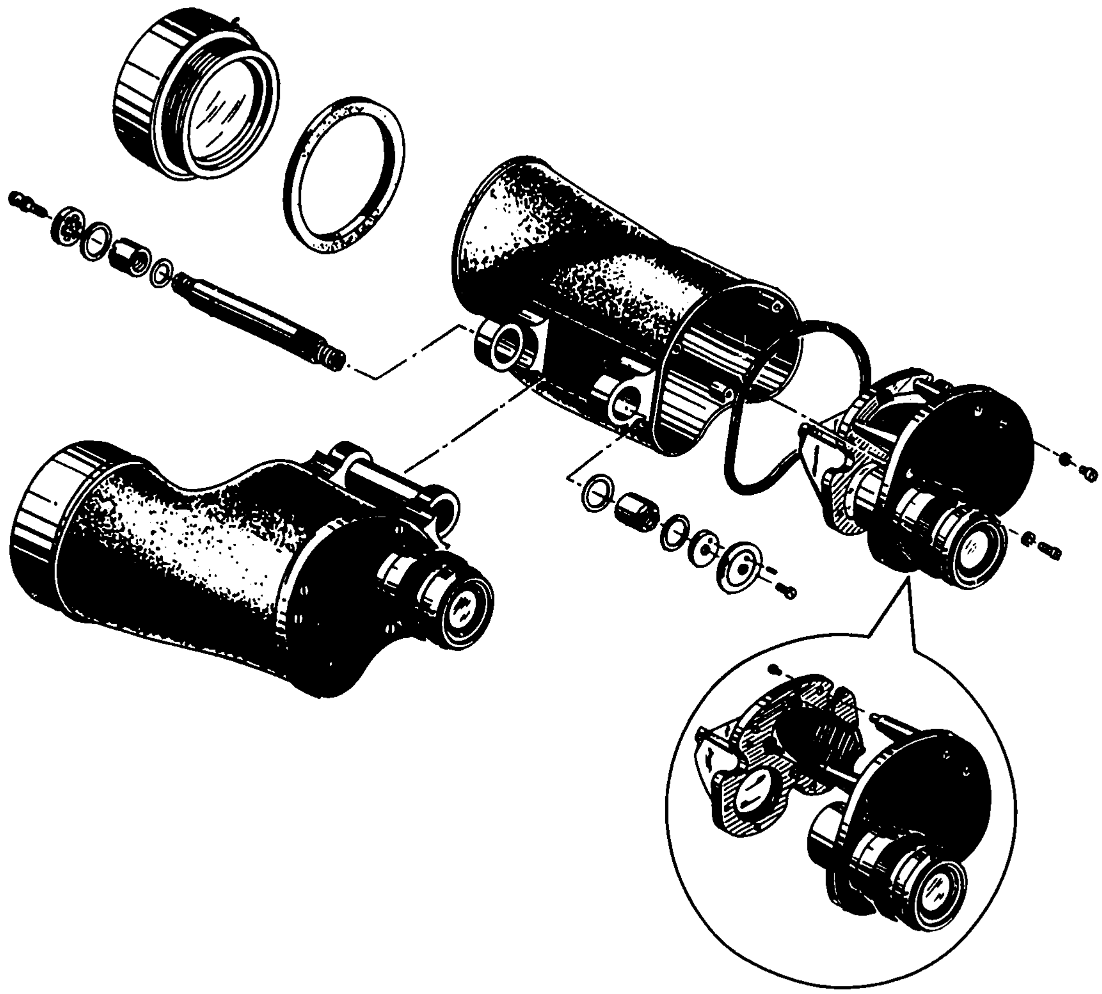

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Figure 13-11.—Mk 45, 7 x 50 binocular assembly—exploded view.

If they aren't, one or more of the porro prisms is out of adjustment.

Any defective subassemblies, as revealed by the inspection, will be removed from the major assembly. The subassemblies will then be broken down only for enough to permit the necessary repairs and replacement of parts to correct the indicated trouble. In many cases, such as dirty optics, disassembly of the subassembly will not be required since these elements can be cleaned in their mounts.

REASSEMBLY

The manual for OVERHAUL, REPAIR AND HANDLING OF 7 x 50 BINOCULARS, NAVSHIPS 250-624-2 is used as a technical guide for all repair procedures. The Opticalman should also be thoroughly familiar with the general procedures for repair and testing that are covered in NAVIGATIONAL INSTRUMENTS CONTROL MANUAL, NAVSHIPS 250-624-12.

When binoculars come in for repair, you must be particularly careful in performing each step of your work so that the instruments, when they finally leave the repair shop, will do the job they were designed to do out in the Fleet; that is, to allow personnel to see distant objects clearly and without eyestrain. To accomplish this, there are certain requirements, which must be fulfilled in the repair operation. These requirements are brought to your attention so you will see the reasons for observing them.

The repairman is charged with the responsibility of preparing a complete set of serviceable parts for efficient reassembly. Following an inspection to determine defects, the parts are repaired or replaced in accordance with the "Parts Inspection Standards" as referenced in the Control Manual index.

Replacement parts are to be obtained from stock. The Federal Stock Catalog is used as a source for stock numbers and also to indicate subassemblies or matched parts which must be replaced as units. All mechanical parts are cleaned. Matched optical parts are checked on special testing fixtures to facilitate compliance with the optical requirements. The complete set of inspected and approved parts of the binocular is then returned to the individual parts tray.

Considerable work will be saved if the binocular parts are reassembled to the same instrument from which they were disassembled, and in the same system (right or left) out of which they came.

There are matched and fitted parts that must remain together. The manufacturers "sweated it out" for you, so don't make unnecessary work for yourself and others by mixing up these parts.

The matching of each objective lens to its individual mount is necessary to make sure that the images formed by the two objective lenses focus at the same distance along the length of the body. If this is not done, the eyepieces will project unevenly from the body since they must focus on the images formed by each of the objective lenses. With uneven eyepieces, the user could not look straight into both eyepieces with his eyes against the eyepiece caps which is a necessary condition for best performance.

The prisms of each prism cluster must be matched to each other to eliminate the inherent error in individual prisms to deviate a beam of light, being reflected by it, from a normal optical axis. The size of the prisms also influences the position of the image formed by the objective lens, causing the same difficulty as stated for the condition of unmatched objective lenses and mounts. The prisms are matched in pairs to provide clusters that have allowable errors of deviation and path length.

Even if the lenses and prisms are perfect, in order to obtain the highest degree of clarity in vision, cleanliness of the optical surfaces is of the utmost importance in a binocular. Polished surfaces must be free from any objectionable scratches, stains and other defects visible in the field of vision, or optical performance will be impaired. A tiny speck of dust or lint, if in or near the plane of the real image, can obscure a far-away point that an observer may be trying to distinguish. There must be no dirt, dust or any foreign particles in the interior of the binocular which in time might gather on the optics and weaken or block the image of a viewed object. Particles of dirt, dust or grease make the binoculars more susceptible to fogging by condensation of vapor.

To maintain the cleanliness and functional efficiency of optics, they have to be handled properly. "Handling Glass Optics" in the Control Manual includes details on this subject; however, a few words of caution should be mentioned here. Recent scientific studies have shown that a fingerprint on an optic is more objectionable than even a scratch! Fingerprints not only leave a film on an optical surface that cuts down light transmission but the film has a tendency to etch and permanently injure the optical quality. Do not touch the polished surfaces of optics; clean off accidental fingerprints immediately.

Rough or careless handling will scratch the optical surfaces. Scratches will diffuse light and reduce the clarity of the image.

When optical surfaces are coated with an anti-reflection coating, scratches and abrasions will rub it off and defeat its purpose. The coating is only four millionths of an inch in thickness and it is softer than glass; therefore, great care is necessary to avoid damage.

At disassembly, all optical parts should be wrapped in lens tissue to protect them from accidental damage.

Throughout the phases of the overhaul procedure, the binoculars will be handled as assemblies, subassemblies and parts. Precautions must be taken at all times to prevent damage.

An example of this is the treatment of the binocular assembly after reassembly has been completed. The binoculars will most likely be stood on their objective end while awaiting test and adjustment. If they are set down hard, there is the danger of bending the relatively thin wall of the objective end of the body which will damage the internal thread for the objective lock ring. Damage at this point would probably require some disassembly and reassembly which would be costly and wasteful.

Following step-by-step instructions from the repair manual the parts for the left or right body are reassembled. Each optical element is examined and cleaned as required just before it is reassembled to insure maximum cleanliness, thereby permitting best performance of the binocular. The prism clusters are checked individually for squareness and freedom from strain. The binocular is closed but not waterproofed until after collimation.

COLLIMATION

The first adjustment you must make in order to bring a binocular up to performance requirements is setting the diopter scales on each eyepiece. They must read 0 diopters plus or minus 1/4 diopter on their scales to get sharp focus of a distant object.

To check the position of the eyepieces, set both eyepieces to 0 diopters and check with a straightedge across the top of both eyepiece caps to determine whether they are even. They should be even within 1/16 inch.

When a binocular is thoroughly overhauled and properly assembled, collimation with a Mk 5 collimator is not difficult. The TAIL-OF-ARC method of collimating is recommended. The step-by-step procedure for using this method is as follows:

1. Turn the binocular upside down and so mount it on the collimator fixture that the left body (now on your right) swings freely (fig. 13-12).

2. Look through an auxiliary telescope (with the rhombold prism attachment in place) and the swinging body of the binocular. Two images of the collimator crossline should be visible, and one image should be more magnified than the other.

3. With the two adjusting screws on the collimator fixture, superimpose the two crosslines at 58 mm interpupillary distance. Study figure 13-13.

4. Move the swinging barrel down to 74 mm interpupillary distance and observe the position of the larger crossline, as shown in figure 13-14. Then sketch on graph paper the two crosslines as they appear in the field of view, and construct an equilateral triangle, as explained in the next step. NOTE: ALWAYS figure the displacement of the larger crossline on the scale of the smaller crossline.

5. Use point A in figure 13-15 as the vertex of a compass and the distance from A to B as a

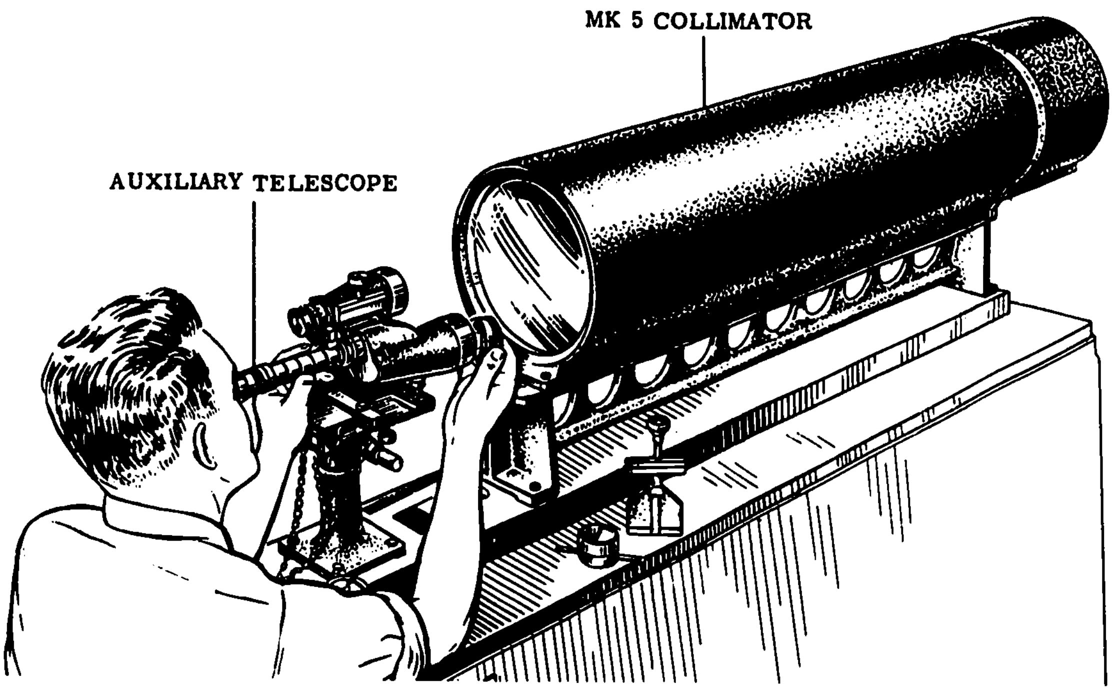

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Figure 13-12.—Mark 5 binocular collimator.

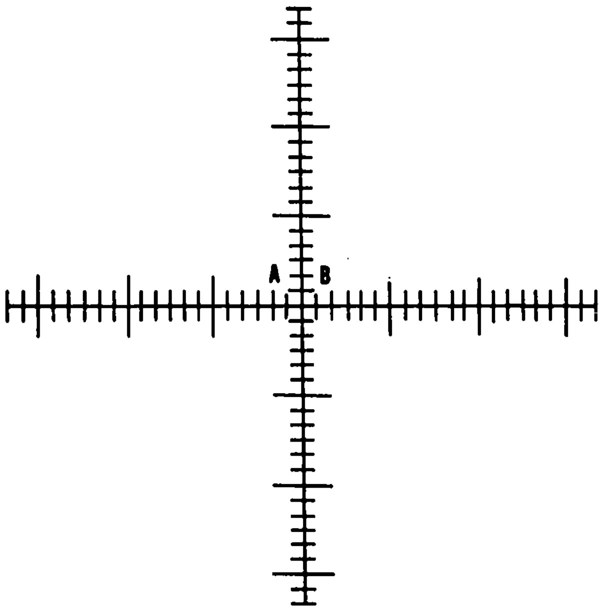

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Figure 13-13.—Binocular crosslines superimposed at 58 mm interpupillary distance.

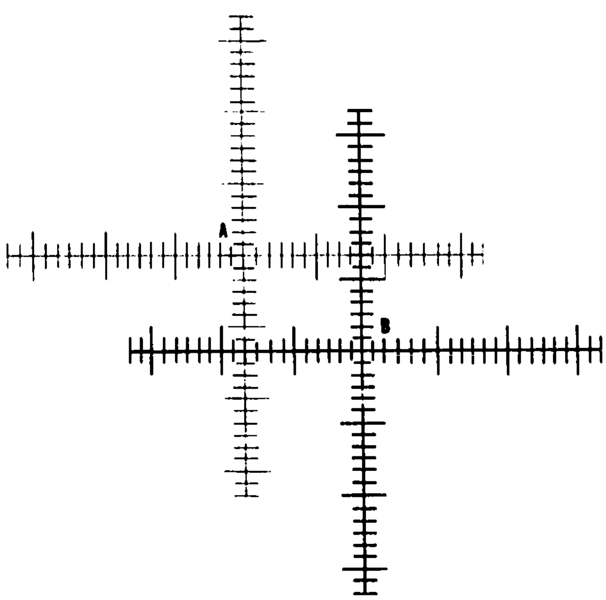

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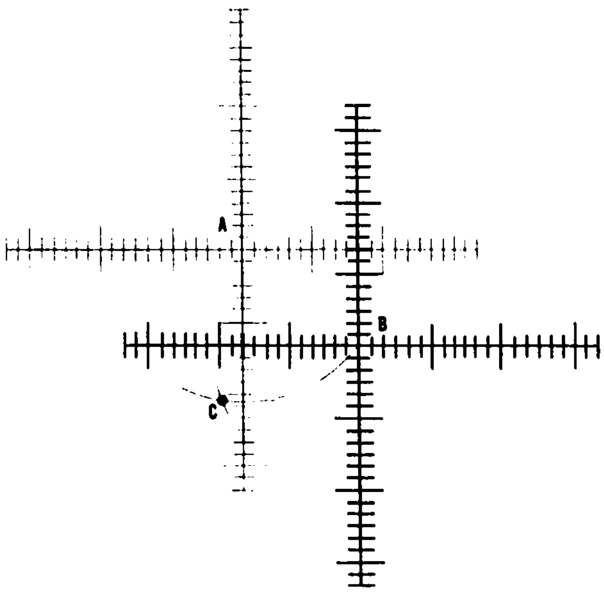
Figure 13-14.—Position of binocular crosslines (A & B) when the interpupillary distance is at 74 mm.

radius and draw an arc CLOCKWISE from B. NOTE: Point A is the intersection point of the



137.492
Figure 13-15.—Locating the mechanical axis of a binocular.

smaller crossline and B is the point of intersection of the larger crossline. Next, use point B as the vertex of your compass (with the same radius) and draw another arc which crosses the first arc. This is represented by C in figure 13-15, and C is the mechanical axis of the binocular. The distance from one letter to the other is the same, and the triangle formed by connecting points A, B, and C, is therefore equilateral.

NOTE: ALWAYS draw the FIRST arc clockwise from point B.

6. Observe the vertical and horizontal displacement of point C.

7. Look through the auxiliary telescope and the swinging body of the binocular and mentally transfer the triangle to your field of view. Then manipulate the objective eccentric rings until the point of intersection of the larger crossline is at point C.

8. Repeat steps 4 through 7 until the crosslines remain superimposed at all settings when the swinging barrel is moved from 58 mm to 74 mm interpupillary distance.

9. Exercise care to prevent throwing the objective mount out of collimation and lock the objective mount setscrew and the objective lock ring.

10. Leave the mechanical adjustments to the collimator fixture intact and look through the

stationary body with the auxiliary telescope. Then manipulate the objective eccentric rings until the crosslines are superimposed.

11. With the objective ring setscrew, lock the objective eccentric rings in place. CAUTION: Do NOT throw the barrel out of collimation.

12. Replace the objective gaskets, the objective gasket rings, and the objective lock rings.

13. Check both bodies again to make certain the instrument was not thrown out of collimation. Then replace the objective lock ring setscrews.

14. Put a drop of sealing compound over the objective ring and the objective lock ring setscrews. Then replace the objective caps.

15. Give the instrument another check to be sure it is still collimated.

Binoculars must meet specific tolerances and performance requirements before they are returned to service, as follows:

- The optical axis of the two telescopes must be parallel within: (a) 2 minutes' step (vertical alignment of the two axes); (b) 4 minutes' divergence (spreading apart of the two axes); and (c) 2 minutes' convergence (coming together of the two axes). CAUTION: Failure of the axis to stay within these tolerances causes eyestrain, sometimes severe and accompanied by nausea.
- When both eyepieces are set to the same diopter reading, they should be even within 1/16 inch. Deviation from this tolerance causes eyestrain.
- The images of a distant, vertical, straight line formed in the two telescopes must be parallel to each other within 1 degree. This is a very liberal tolerance. Failure of the images to stay within this tolerance results in eyestrain.
- Hinge tension of a binocular is most important. At 70°F, plus or minus 5°, the unsupported side must support a load of 1.80 to 3 pounds at a distance of five inches from the center of the hinge (9 inch pounds minimum and 15 inch pounds maximum). Part of the weight is to the unsupported side of the binocular. If the hinge is TOO tight, it will NOT permit adjustment over the interpupillary distance range. If the hinge is TOO loose, it will not maintain any interpupillary setting.
- Interpupillary scale readings must be accurate within 1 millimeter. Deviation from this tolerance causes eyestrain.
- The diopter scales must be set to give readings accurate within 1/4 diopter. If this tolerance is not maintained, a blurred image and eyestrain result.
- Loss of image fidelity results when optical elements in a binocular are improperly mounted. The image is distorted. Tests of two characteristics of optical performance (central astigmatism and central resolution) provide an overall check on both design and service defects. NOTE: Most defects are eliminated by design of the instrument.

Objects in the center of the FIELD OF VIEW that subtend an angle of 4 seconds of arc must be clearly resolved. In terms of the test to be made, equal-width lines equally spaced .018 inches on centers must be clearly visible as separate and distinct when viewed at 77 feet. Failure to stay within this tolerance results in BLURRED and/or DISTORTED images and eyestrain.

- Each telescope of a binocular must transmit at least 75 percent of the white light being viewed, and the transmission of the two barrels may not differ by more than 3 percent. Give the binocular a functional test and inspect the optics for proper coating. Loss of light, image brightness, and glare, result when this tolerance is not maintained.
- When submerged in water, a binocular must withstand a pressure of 3 pounds per square inch; otherwise, moisture will collect in the instrument during service. This means that sealing of the instrument must be thorough.
- To test a binocular's resistance to shock, drop it from a height of six feet into a box containing six inches of sand and then recheck alignment on the collimator. If the binocular cannot withstand this test, it will be knocked out of collimation during normal usage.

SHIP-MOUNTED BINOCULAR

The ship-mounted binocular is used by the quartermaster or signalman in conjunction with visual signaling operations on many ships. The Navy uses both the Mark 3 Mod 1 and the Mark 3 Mod 2 ship-mounted binocular. Except as noted herein, the only difference in the two Mods is that the Mod 1 binocular is secured to a C-shaped bracket on the elevating carriage by a means of a dove-tailed plate, whereas the Mod 2 binocular housing is fitted with trunnions which are secured to a U-shaped yoke on the elevating carriage. The procedures for disassembly and reassembly are the same for both the Mod 1 and Mod 2.

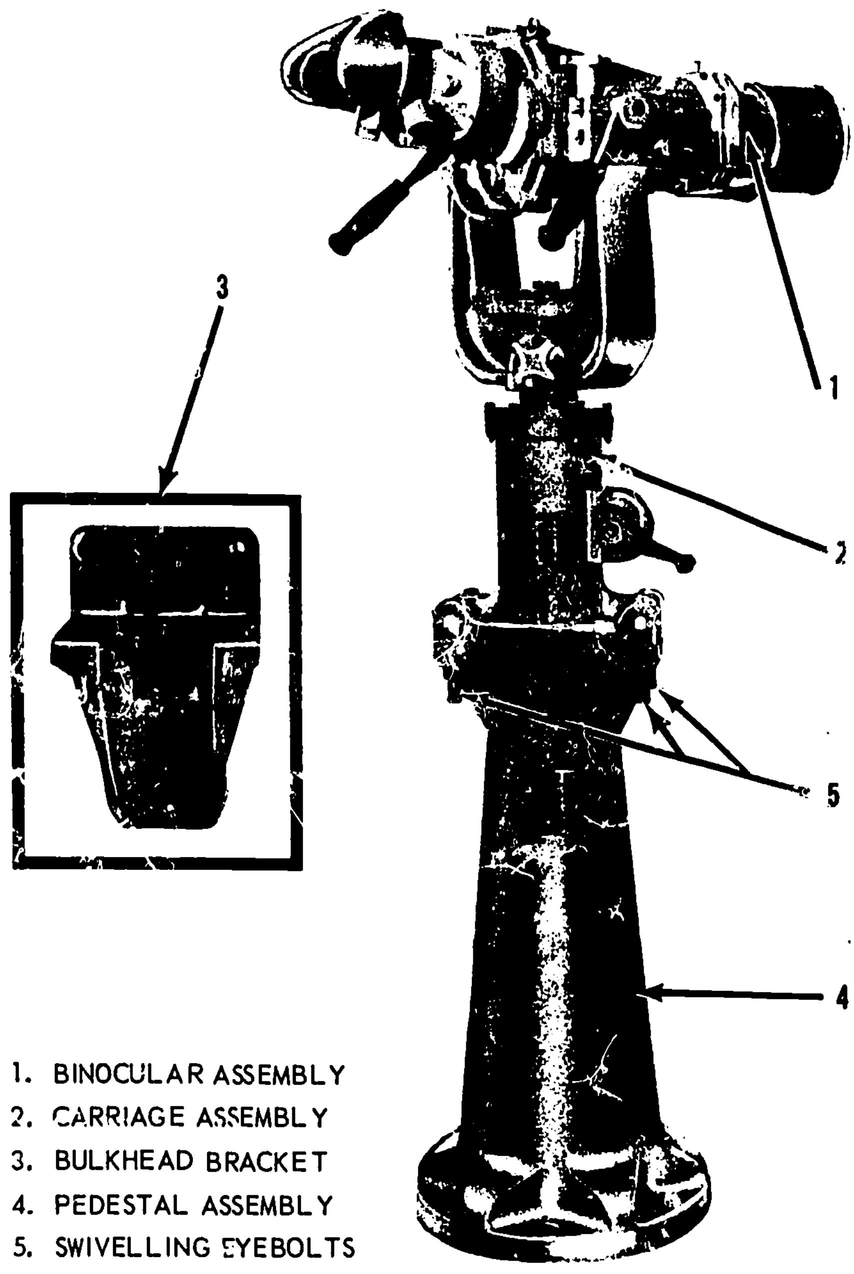


Figure 13-16.—Ship binocular.

In the next few pages we will discuss the Mark 3 Mod 2 (fig. 13-16). Information is provided on the means of mounting the binocular assembly and the construction of the binocular assembly itself. Step-by-step procedures are given for the disassembly, reassembly, and charging of the binocular.

CHARACTERISTICS

The design characteristics of the Mark 3 Mod 2 binocular are:

Magnification . . . . 20 power
Clear aperture of objective 120 mm
True field of view . . . . . . 3° 30'

Eye distance (at zero diopters)	22.5 mm
Apparent field (approx.)	70°
Exit pupil	6 mm
Interpupiliary distance	56-74 mm
Maximum elevation of line of sight	60°
Maximum depression of line of sight	-10°
Overall binocular length (sunshade extended)	20.375 inches
Overall binocular width	22.5 inches
Height above bulkhead bracket or pedestal:	
Extended (eyepiece LOS)	35.375 inches
Retracted (eyepiece LOS)	27.375 inches

The binocular assembly contains the optics required to obtain the desired magnification and provision is made to install an illuminated reticle if required. An illuminated reticle is not provided for binoculars used aboard ship. Eyeguards are provided to exclude stray light from the observer's eyes when sighting through the eyepieces. Two focusing knobs located on each eyepiece enable the eyepieces to be individually adjusted to accommodate eyes of unequal vision. Each focusing knob is provided with a diopter scale which is graduated from -3 to +1 diopters in 1/2-diopter increments.

An interocular knob, located below the right eyepiece, is adjustable from 56 to 74 millimeters, and provides adjustment of the interpupillary distance of the eyepieces. To control the brightness of the field of view, an INCREASE DENSITY control knob is provided on the front of the binocular just below the left eyepiece. By turning this knob left or right you can control the brightness. Inlet and outlet connections are provided to evacuate and fill the binocular assembly with dry nitrogen.

The ship binocular consists of four main assemblies: the binocular, carriage, pedestal, and bulkhead bracket. The pedestal and bulkhead bracket assemblies are used to either deck mount or bulkhead mount the binocular assembly. The binocular and carriage assemblies are secured together and are employed on both types of mountings. A gray canvas cover protects the binocular assembly from the weather.

Carriage

An azimuth scale and an elevation scale are mounted on the carriage assembly; these permit the binocular assembly to be positioned in azimuth and elevation. The elevation scale is graduated in 1-degree increments from -10° to +60°. There are also locking devices that will hold the binocular assembly in any desired position. For vertical adjustments a handcrank on the carriage assembly permits vertical movement through a maximum range of 8 inches.

Bulkhead Bracket

The bulkhead bracket assembly is used to mount the ship binocular on any vertical surface which allows the binocular assembly to be rotated 360° in azimuth and elevated through a range of 8 inches without any obstructions. The bulkhead bracket assembly is slotted at each side to accept swivelling eyebolts of the carriage assembly. (See fig. 13-16.)

Pedestal

The pedestal assembly (fig. 13-16) may be used where deck mounting of the ship binocular is desired. The carriage assembly is inserted through the large hole of the pedestal assembly; slotted holes at the top of the pedestal accept the swivelling bolts of the carriage assembly.

Binocular

The general arrangement of the optics contained in one of the two identical barrels in the binocular assembly is illustrated in figure 13-17. The objective lenses form a normal inverted image of the object entering the binocular assembly; the image travels through either a compensator lens or a polarizing filter as required by the viewer. The two porro prisms invert the image to an erect position (as viewed through the eyepieces). The objective lenses in the ship binocular are air-spaced doublets which have a spacer ring between them. The eyepiece consists of three lenses: the triplet field lens, doublet center lens, and the singlet eye lens.

Each barrel contains one adjustable and one fixed polarizing filter to control the intensity of light entering the binocular assembly. The INCREASE DENSITY control rotates the adjustable

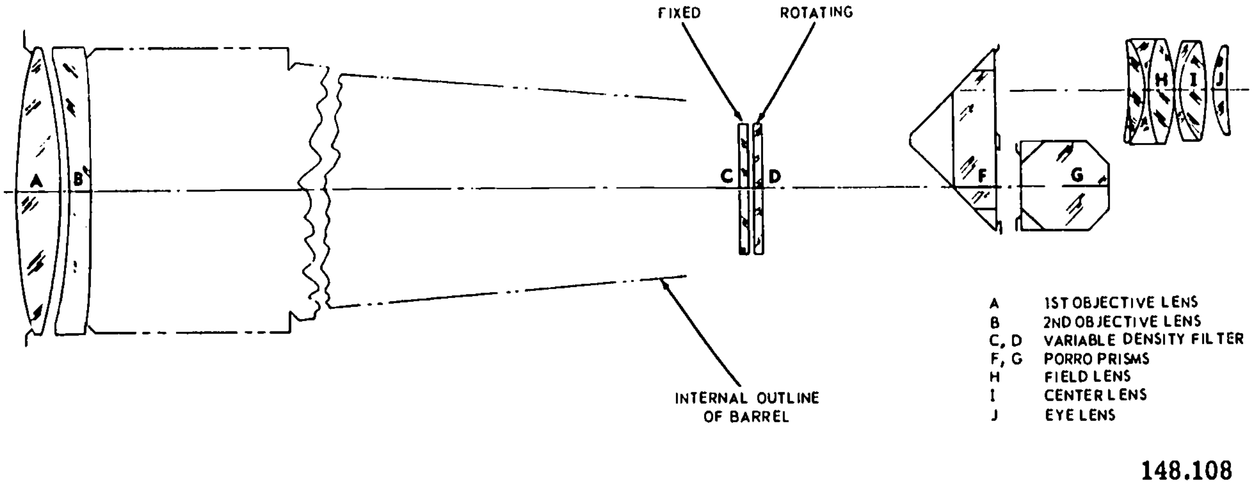


Figure 13-17.—Arrangement of optics.

polarizing filter to obtain the desired light intensity. With the INCREASE DENSITY control set to the OUT position, the control rod contacts the filter stop, which swings the fixed polarizing filter out of position so that the compensators will be inserted in the binocular assembly line of sight. The detent locks either the fixed filters or the compensators in the line of sight.

The eyepieces are of the internal focus type. The eye lens is mounted and sealed in the lens housing assembly; the center lens and the field lens are mounted in a lens mount which may be positioned axially for focusing. When the diopter knob is rotated through a range of +1 to -3 diopters, a cam control will adjust the lens mount to produce the proper correction for the individual observer.

On the top of the light filter assembly housing is the headrest; it slides onto the headrest support shaft to provide fore and aft adjustment and is locked into position by a locking nut. A hinge assembly is also provided to allow upward and downward movement of the headrest.

A handwheel is provided for locking the binocular in azimuth. Rotation of the handwheel clockwise will cause locking action by forcing the brakeshoe against the undercut portion of the elevation shaft.

MAINTENANCE

This section discusses preventive maintenance and corrective maintenance for ship binocular. The amount of preventive maintenance that ship personnel carry out will determine how much corrective maintenance you will have to do when the ship binocular is brought to the optical shop for repair.

Preventive maintenance of the ship binocular includes routine inspection and cleaning procedures which are performed under shipboard conditions. Preventive maintenance procedures should be performed without exposing the internal elements of the ship binocular to atmospheric conditions.

The ship binocular should be inspected by qualified personnel to ensure its operational capability. Perform the following inspection tests at least every six months:

- Check that the binocular assembly is capable of being elevated from a -10° position through a +60° position without binding.
- Ensure that the carriage assembly yoke has smooth rotation through 360° in azimuth.
- See that the three locking devices—headrest, binocular elevation, and azimuth, function smoothly and lock securely.
- Check that all controls operate smoothly but offer enough resistance to indicate a snug fit between their respective shafts and packing rings.
- Be sure that all external optical surfaces are clean.
- Check that the rubber visors slide snugly along the objective mount and examine all rubber components for any signs of deterioration.
- Check all external fastenings for tightness. After a period of excessive vibration or when shock conditions have been experienced, recheck the fastenings.

The objective and eyepiece lenses may be cleaned using lens paper or a soft, lint-free cloth which may be moistened with alcohol to remove grease. Unnecessary cleaning should be avoided. Wipe metal surfaces to remove accumulation of salt or dirt. To remove grease and oil from the rubber components, wash them with a mild soap and water solution. Note: Rubber will deteriorate if not kept dry.

Two types of fogging (external and internal) may be encountered when using the ship binocular. External fogging is a temporary condition that will disappear as the lens surface becomes warmer. To immediately remedy this condition, wipe the eyepiece and objective lenses with lens paper. Internal fogging indicates that a seal has been impaired at some point, allowing water vapor to enter the binocular. If internal fogging occurs, the binocular will have to be taken to the optical shop for repairs and recharging with dry nitrogen. (The procedure for recharging will be given later in this chapter.)

The overhaul of the ship binocular will be performed ONLY in an optical repair shop where adequate facilities and equipment for overhaul, repair, and collimation are available. The ship binocular should be overhauled only when necessary due to a malfunction of moving parts, separation of cemented lenses, a break in a seal allowing water vapor or dirt to enter the binocular assembly, or destruction or misalignment of optical parts.

If a seal has been broken, it will be necessary to disassemble the binocular to the extent required to clean and dry all optical and mechanical parts. Inspection and replacement of all packing rings, and gaskets as necessary, should be accomplished during the overhaul procedures. Immediately following the reassembly procedures, the binocular assembly should be charged with dry nitrogen.

The following checklist may be used to determine the extent of repairs necessary to return a damaged ship binocular to satisfactory operating condition:

- Inspect the exterior of the binocular assembly for physical damage.
- Ensure that the interocular handle operates smoothly without binding or excessive looseness.
- Check for proper operation of the INCREASE DENSITY control.
- View a distant object (approximately 1/2 mile) and adjust focus control of eyepiece to ensure proper definition for each eye. If proper definitions cannot be obtained, either an adjustment of the diopter controls is necessary or the optics of the binocular assembly are defective.
- Check that the elevation, azimuth, height mechanism, and locks operate smoothly.
- Check for internal gas pressure.

Disassembly

In order for the reader to become familiar with format used in most NAVSHIPS Technical Manuals, the disassembly procedure and the illustration for the ship-mounted binoculars is listed in the same step-by-step form.

Before disassembling any component from the binocular assembly, open the OUTLET screw (top of right barrel) to release the internal pressure if parts within the binocular seal are to be removed.

Disassemble the binocular assembly as follows (refer to fig. 13-18):

1. To disassemble the objective lens assembly remove ring (56) and the preformed packing (62) from the objective lens housing.
2. Unscrew ring (57) and remove spacer (58) from the crown objective lens, and remove crown lens (59) and wrap in lens paper and store in a safe place.
3. Remove spacer (60) and objective flint lens (61) from housing and also wrap flint lens in lens paper and store in a safe place.

NOTE

> If both objective lenses from both barrels are removed at the same time, it is advisable to keep the lenses and other components of the left and right lens mounting arrangements separated and identified so that they may be replaced properly.

4. Next remove the optics housing from the light filter housing. First remove retaining ring (73) that secures the light filter assembly to the optics housing.
5. Next detach spring (84) from the detent arm.
6. Now remove the light filter assembly from the optics housing.
7. Remove screws to detach retaining plate from filter housing.
8. Remove washers (78 and 81), polarizing filters (79), and compensating filters (82) from housing.

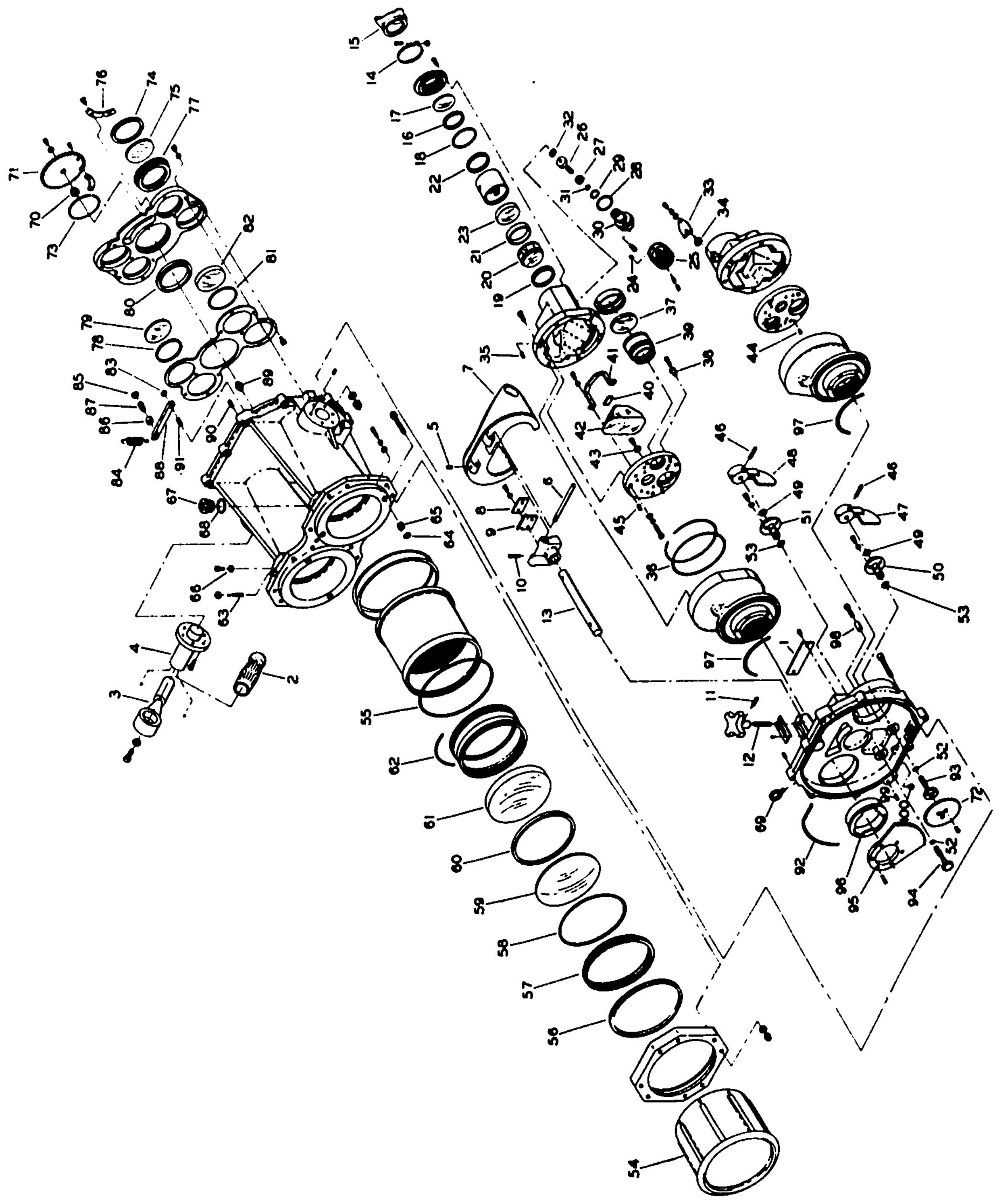


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Figure 13-18.—Binocular assembly.

9. Remove screws to detach clamp (76), and gear assembly (70 and 71) from filter housing.

10. Remove retaining rings (74), and polarizing filters (75) from filter housing.

11. Now separate the prism housing from the light filter housing. First remove screws securing sector gears (95) and sleeve bearing (96) allowing separation of the two prism housings from the light filter housing.

12. To disassemble the INCREASE DENSITY control (47) and the interocular knob assemblies (48) follow the order of index numbers in figure 13-18.

13. Refer to figure 13-18 and remove the appropriate screws to separate the prism housing from the eyepiece housing.

14. Now disassemble the prism and plate assemblies by removing the appropriate screws to separate the prism and plate assembly from the housing.

15. Remove items (37 through 39) from prism plate.

16. Loosen screws and remove retaining strap (41) and clamp pad (40).

17. Remove prisms (42) from support plate. Wrap prisms in lens paper and store in safe place.

18. Now disassemble the left and right eyepiece housing assemblies. Loosen setscrew and remove diopter knob (25).

19. Next loosen screws and remove bearing sleeve (30) and items (27 through 29, 31, and 32).

20. Disassemble items (16 through 25) following the order of index numbers shown in figure 13-18.

Disassembly of the ship binocular is now completed. The next step is to repair or replace parts that are worn or damaged.

Reassembly

Reassembly procedures are essentially the reverse of disassembly. Old packing should be replaced and parts which were sealed with glyptal should be carefully cleaned before resealing with fresh compound.

Match-marks noted or made at disassembly will assist in proper orientation and mating of parts. Extreme care should be exercised to prevent oil or moisture from contacting parts to be mounted inside the binocular assembly.

To reassemble the binocular assembly, do the following:

1. Apply a bead of Navy approved sealing compound, approximately 3/32 inch in diameter, to junction of outside diameter of crown objective lens (59) and housing.

2. Assemble spacer (58) and ring (57) in cell housing. Ring shall be installed to ensure metal to glass contact between items 58 and 59.

3. Apply a thin film of Navy approved high vacuum grease to all preformed packing.

4. Apply a thin film of adhesive to the housing shoulder and eyepiece lens (17).

5. Press fit filter housing shaft (89), grooved pin (90), and shouldered pin (91) into optics housing assembly.

6. Stake shoulder pin (87) to detent arm (88).

7. Press fit bearing sleeve (70) into spur gear (71).

8. Press two straight pins (44 and 45) into right-hand support plate.

9. Apply approved cement to items 40 and 41.

10. Press fit two straight headless pins (99) into binocular housing to a height of 3/16 inch.

11. Press knob stop cushion (100) into binocular housing.

12. Align hole of interocular knob (48) with hole of gear shaft (94) and insert a dummy pin. Check that end play of gear shaft is between 0.002 and 0.005 inch. If it is not, shim with flat washer (49) to obtain desired end play. Remove dummy pin and press in groove pin (46).

13. Align hole of filter knob (47) with hole of adjustment shaft (93) and insert a dummy pin. Check that adjustment shaft end play is between 0.002 and 0.005 inch. If it is not, shim with flat washer (49) to obtain required end play.

14. When assembling focusing mechanism insert assembly consisting of bearing sleeve (30), diopter shaft, and cam control (32) into diopter shaft bore of housing (with eyepiece lens assembly, 19 through 22, secured in the housing). With the flange of the bearing sleeve (30) held securely against the eyepiece lens housing, measure end play of shaft (between shaft assembly, cam control, and eyepiece lens housing, 18 through 22). End play should be between 0.001 and 0.005 inch. Disassemble and shim between bearing sleeve and diopter shaft with flat washer (27) to obtain desired end play.

15. To set diopter knob to correct mounting position with respect to its diopter scale and the reference mark on the eyepiece casting, it will be necessary to establish the zero diopter position for each eyepiece.

Insert a test reticle in place of item 37 into housing (39). The test reticle should have markings on the side closest to the objective end of the binocular. Assemble the prism plate assembly to the eyepiece housing. Set an auxiliary telescope which has been focused to suit the viewing eye of the observer against the binocular eyepiece. Rotate the diopter shaft until the image on the test reticle is in sharp focus. Position the diopter knob (25) on the diopter shaft so that the zero marking on the knob coincides with the reference mark on the casting. Secure the knob with the setscrews. Remove the test reticle and insert the optical window (37).

16. With the eyepiece assembly correctly set and using an auxiliary telescope adjusted to the viewer's eye, the objective cell assembly can be brought into focus. Screw the objective cell in or out to bring a distant object in focus (a collimator with an infinity target may be used). Secure the objective cell with ring (56).

COLLIMATION

Two collimating telescopes are aligned on a surface plate with their axis parallel, as in figure 13-19. Two reticle collimating telescopes are aligned opposite the collimator to establish a true reference line of sight. The reticle image of each collimator is superimposed upon that of its opposite collimating telescope. The binocular is inserted and secured (with each eyepiece focused at infinity) as shown in figure 13-20.

Each collimator employs a reticle with a rectangle. This graphically indicates the tolerance limits within which the optical and mechanical axis of the line of sight must fall. The image of the collimator is viewed through the collimating telescopes. If the vertical and horizontal crosshairs of the reticle image intersect within the limits circumscribed by the rectangle of the collimating telescope, the binocular is aligned both optically and mechanically.

If the intersection of the reticle image falls beyond the limits of the rectangle, the binocular is out of adjustment.

To bring the binocular into collimation, two eccentric buttons (65, fig. 13-18) are provided in each objective of the optics housing and must be turned in conjunction with each other to enable horizontal and vertical adjustment of the objective barrels. When adjusting the objective barrels, loosen the square flanged ring securing the objective lens assembly. Retighten the flanged ring after collimation is completed.

NOTE: On the Mod 1 binocular, a double-eccentric ring and lens mount must be rotated with respect to each other to bring the reticled image to its optimum position within the rectangle. Turning the eccentric ring moves the objective lens mount perpendicular to the optical axis of the binocular. Turning the objective mount turns the lens on its mechanic‑l axis and, therefore, rotates the optical center of the lens.

SEALING AND CHARGING

The ship binocular shall be dried and recharged with dry nitrogen whenever internal fogging occurs or a seal has been broken. Proceed with the following steps:

1. Remove OUTLET screw and washer from right barrel of the binocular.

2. Back off large INLET screw of gas inlet valve (67, fig. 13-17) to allow the entrance of dry nitrogen into the binocular.

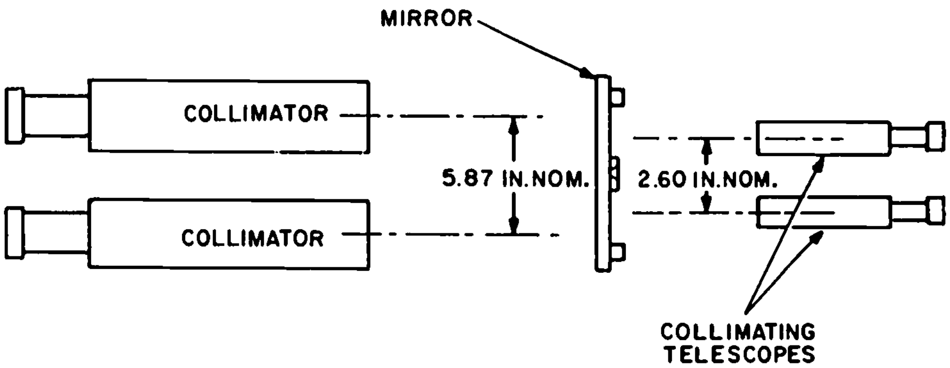

Figure 13-19.—Collimation adjustments.

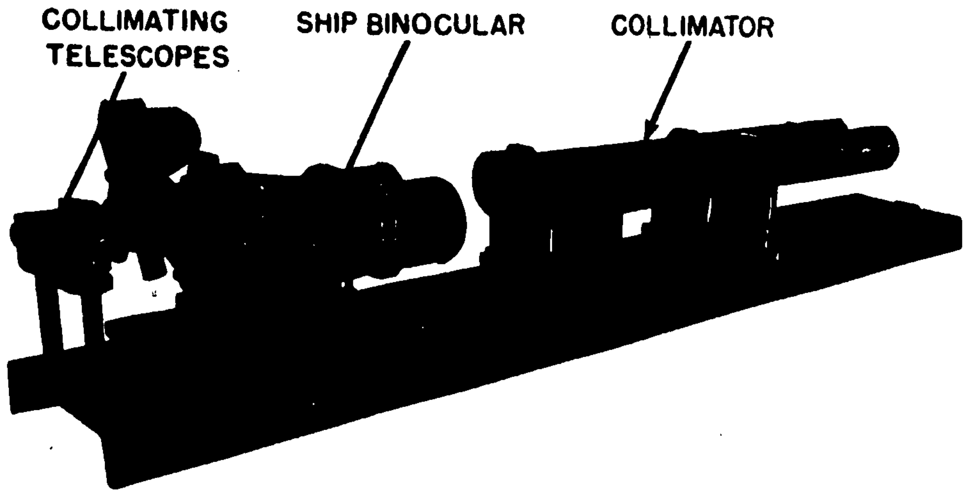

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Figure 13-20.—Collimation setup.

3. Remove the inlet plug and insert an adapter connected to the nitrogen source.

4. Introduce and circulate dry nitrogen through the binocular until all air has been discharged. Replace the OUTLET screw and washers in the right barrel of the binocular.

5. Charge the binocular to a pressure of 5 psi. NOTE: Do not put more than 5 psi in the ship binocular.

6. Tighten large INLET screw and remove adapter. Replace inlet plug in the valve assembly.

7. After a period of no less than 24 hours, check with a pressure gage to determine if there has been any significant gas leakage. Any loss in internal pressure requires a recheck of the binocular seal to determine the source of the gas leakage.

8. After correcting the cause of gas leakage, if any, recycle the binocular (steps 1-7), then bleed off the gas to obtain an internal gage pressure of 2 psi. Retighten the OUTLET screw and replace the INLET plug.

CHAPTER 14
SUBMARINE PERISCOPES

Optically, the submarine periscope is no more complicated than a large gunsight. But because the periscope has several functions instead of just one, and because its designer has had to solve a number of special problems, the mechanical systems are intricate.

The earliest submarines were built without provision for periscopes and therefore, when submerged, were forced to grope their way blindly.

In 1854, Marie Davey, a Frenchman, designed a sight tube for a submarine. The tube contained two mirrors, one above the other, at a 45° angle and facing in opposite directions. These mirrors, while providing some degree of sight to the submerged ship, were faulty at best; in 1872, prisms were substituted for mirrors.

Before the War Between the States, the submarine had not had a place among the ships of naval warfare. An American, Thomas H. Doughty, USN, was the inventor of the original periscope. Doughty's invention was not the result of study and research but grew out of necessity. During the campaign of the Red River, while he was serving aboard the monitor Osage, Confederate cavalry on the banks of the river kept up a steady series of surprise attacks upon the Union ships, which had no way of seeing over the banks. This led Doughty to seek some new method of watching the shores. He took a piece of lead pipe, fitted it with mirrors at either end, and ran it up through the turret. This makeshift periscope provided sight for the crew of the Osage.

The earliest periscope, other than a collapsible one designed late in the nineteenth century by Simon Lake and known as an omniscope or skalomniscope, was a fixed tube. Soon, however, provision was made to allow the tube to be raised and turned by hand. This was fairly satisfactory when the boat was traveling at a low rate of speed, but with increased speed the pressure was apt to bend the tube and throw the image out of line. Improved design resulted in a double tube, the outer one to resist pressure and the inner one to house the lens systems.

DESIGN DESIGNATION

To ensure a uniform method of definitions on submarines, a standard system of nomenclature is used in all correspondence, specifications, and plans relating to such instruments.

The periscope nearest the bow is called the No. 1 periscope. This is normally the observation periscope. The next periscope aft of the No. 1 periscope is called the No. 2 periscope. This is normally the attack periscope. In some newer type submarines, the periscopes are mounted side by side instead of fore and aft. In these submarines, the starboard periscope is No. 1, normally the attack periscope, and the port periscope is No. 2, normally the observation periscope.

The term "ALTIPERISCOPE" is applied to instruments having the combined qualities of altiscopes and periscopes; they are also sometimes called altiscope-periscopes and alti-azimuth instruments. With the altiperiscope, the upper prism is movable on a horizontal axis, so that by turning it, the observer can raise or lower his line of sight.

The term "UNIFOCAL" designates an instrument with only one magnification; a BIFOCAL instrument offers a choice of two magnifications. Most of the periscopes in use today are of the bifocal type.

The NIGHT PERISCOPE is especially designed for use in dim light; it has high light transmission and a large exit pupil.

An ATTACK PERISCOPE is designed to allow the submarine to get as close as possible to the enemy without being seen. The diameter of its head section—the part that rises above the surface—is reduced to an absolute minimum.

The term "AZIMUTH CIRCLE," as applied to a periscope, refers to the graduated ring mounted below the packing gland in the conning tower. This is true except for periscopes which incorporate the electrical and electronic (E and E) adapter; on this type of periscope the azimuth circle is on the E and E adapter. The azimuth circle is used for taking bearings through the periscope.

Submarine periscopes are under the technical cognizance of the NavShipsSysCom. They have no Mark numbers. Instead, each separate design, or modification of a design, is assigned a DESIGN DESIGNATION made up of the following symbols:

- A serial number for each design, or modification; these numbers are assigned by BuShips.
- A letter indicating the manufacturer, using this code:
  - K—Kollmorgen.
  - S—Sperry.
- A letter showing the type of instrument:
  - A—bifocal altiperiscope.
  - H—high-power altiperiscope.
  - N—night periscope.
- A number showing the length of the optical system, in feet (to the nearest foot).
- The letter T may be used to show that the optics have been treated (by filming) to increase their light transmission.
- If the outside diameter of the upper head section is less than two inches, this diameter, in inches, is added to the design designation, separated from the preceding symbols by a diagonal mark.
- If the instrument is an altiperiscope, and if its field of view can be raised enough to include the zenith, the letters HA (meaning high angle) are added to the design designation.

Here is a typical design designation:

91KA40T/1.414HA

Decoded, that means:

91 K A 40 T 1.414 HA

91	Serial number of the design
K	The manufacturer, Kollmorgen
A	Type of instrument: bifocal altiperiscope
40	Length of the optical system, in feet
T	Coated optics
1.414	Outside diameter, in inches, of the upper head section
HA	High angle

Each individual instrument is assigned a registry number (the same as a serial number on other instruments). You will find the registry number cut or stamped on each periscope at its eyepiece end, and on all of its detachable fittings, such as the training handles. On the eyepiece box of each periscope you will find a nameplate, which shows the design designation, the registry number, and some of the optical characteristics, such as magnification and field of view.

THEORY AND DESIGN

Basically the periscope is a tube, with reflecting elements at the top and bottom, to raise the observer's line of sight. But the actual design is not that simple. The periscope designer must solve several special problems that are not encountered in the design of other optical instruments. He must make a compromise between conflicting requirements. Here are some of the problems:

First of all, the periscope has to be relatively long, as you can see in figure 14-1. It must be long enough to rise above the surface while the submarine is still far enough below to be invisible to surface craft. Optical lengths of periscopes in service run to 40 feet or more.

Another important requirement is that the upper head section—the part that sticks out of the water—must be as slender as possible, to escape detection by the enemy, and to create a minimum wake. The wake of the periscope, if seen by the enemy, would not only reveal the submarine's presence, but also would indicate its course.

When the periscope is not in use, it is lowered, for protection, into a well (fig. 14-1). But when the submarine is maneuvering into attack position, it will use its periscope, fully elevated, while underway submerged. During that time, the periscope will be dragged through the water at high speeds. The periscope, in spite of its slender construction, must be rigid enough to resist the bending effect of the water pressure that results from its own drag. The optical system must be so designed that the bending effect will not distort or displace the target image.

Another requirement is that the periscope must be able to scan the whole horizon; it must be provided with some means for sweeping through 360 degrees in azimuth. With a modern

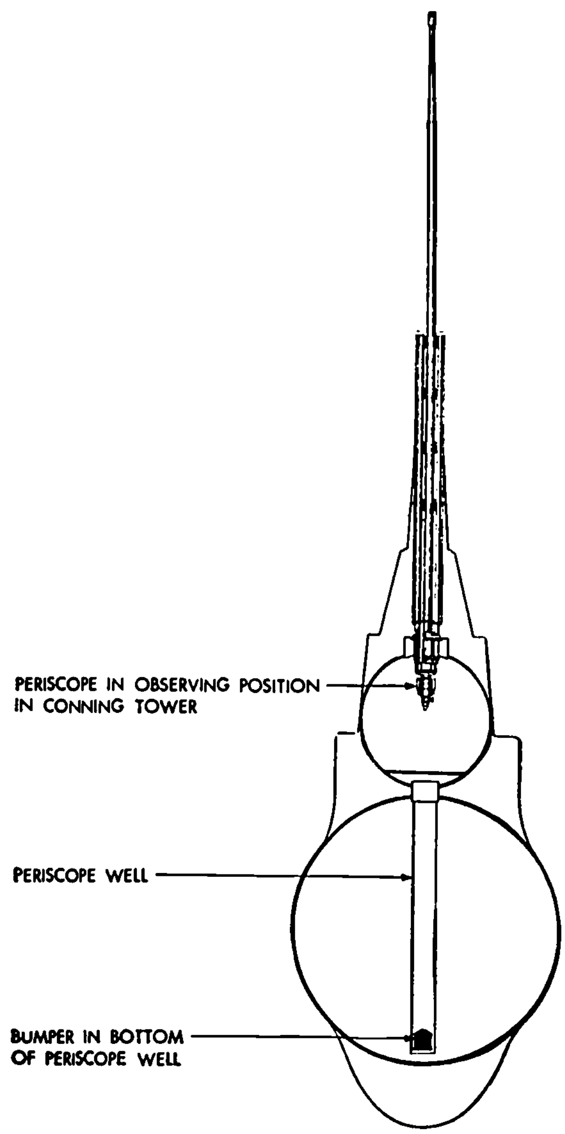

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Figure 14-1.—Vertical section through a submarine, with periscope elevated.

periscope, the submarine captain sweeps the horizon by rotating the entire instrument.

It would obviously be impractical to make the periscope an integral part of the hull. And because the periscope must be raised and lowered and rotated, it cannot be welded to the hull; it must pass through an opening in the hull. The design and packing of that opening create another serious problem. The packing must admit no water into the submarine, even under tremendous pressures. Yet the packing must be so designed that the periscope can be freely raised, lowered, and rotated within it.

The periscope itself must be completely waterproof. Since the submarine is so dependent on its periscope, there must be positive assurance that the internal optical surfaces will not fog up. This is done by keeping a pressure of 7 1/2 psi of nitrogen in the periscope at a suitable dewpoint. The head window and its bezel, and the joint by which the head is secured to the upper part of the tube, are in direct contact with the sea. And yet the leakage through them must be zero.

The problems we have listed so far have been strictly mechanical. But there are optical problems too. The optical system must present to the observer a normal, erect image, bright enough to be useful. The field of view must be reasonably wide, so the observer can find his target quickly.

The problem of image orientation is not hard. All you need are two prisms—one at the top of the tube and one at the bottom—facing in opposite directions.

Field of view is a harder problem. In one design the tube is 40 feet long; light enters it through a head window a trifle more than an inch wide. If there were no optical system in the tube except the two prisms, the field of view would be about one-tenth of one degree. But the optical system is so designed that the true field of the image will be around 30°.

Remember that all the light that forms the image must come through that small head window. So we must keep to a minimum not only the amount of glass in the system, but also the number of elements.

Another problem is incorporating some range measuring device into the periscope system itself. This is normally incorporated into the attack periscopes as a stadimeter. The stadimeter is the more important of the periscope's two ranging devices. The less important one being the telemeter, which is covered later in this chapter.

The periscope stadimeter uses the same principle as the hand-held stadimeter covered in Chapter 12. It gives a double image, and has a built-in calculator. However, it contains no mirrors; it uses an entirely different system to give you a double image. You know that when the target and the eyepiece of a telescope are fixed, the image will move if you move the objective at a right angle to the axis. The periscope stadimeter uses this principle to displace the two parts of a double image. The objective lens of the lower main telescope is SPLIT VERTICALLY into two halves, with a small space between them.

To use the stadimeter, you first set the actual target height on the dial. Then, as you turn the ranging knob, half the lower main objective rises (relative to the target image), and the other half is lowered. As a result, you will see a double image of the target, and the farther you turn the ranging knob, the farther the two images will separate. When you bring the top of one image into line with the bottom of the other, you can read the range on the stadimeter dial.

OPTICAL DESIGN

We will consider first the principal optical problem: securing a true field of useful width in spite of the small head window and the long narrow tube. The periscope designer solves the problem by combining simple optical systems such as the astronomical telescope.

As astronomical telescope produces an inverted image. It has only two principal elements—an objective and an eyepiece; this is a valuable feature for use in a periscope, since we are trying to hold the number of elements to a minimum. We need not worry about the inverted image if we use two astronomical telescopes in series. The first will invert the image; the second will reinvert it.

In any telescope, the magnifying power is equal to the focal length of the objective divided by the focal length of the eyepiece; and the magnifying power is equal to the apparent field divided by the true field. For example, suppose that an object, when viewed by the naked eye, subtends an angle of 5°. The same object, when viewed through a telescope, appears to subtend an angle of 30°. You know at once that the magnifying power of the telescope is 6 X.

Our problem is to take a fairly wide true field and reduce it to a narrow apparent field, so that the image will travel as far as possible down the periscope tube. You have probably looked through the wrong end of a telescope at some time or other. You remember that the objects you saw looked very small and far off (and consequently the true field of view was much larger than the apparent field).

The main optical system of the submarine periscope consists of two astronomical telescopes. We call them the UPPER MAIN TELESCOPE and the LOWER MAIN TELESCOPE. The upper main telescope is backwards—its eyepiece is at the top of the tube. Suppose we want a true field of 30°. And suppose that our upper main telescope has a magnifying power of 15 X—the focal length of its objective is 15 times that of its eyepiece. Since the upper telescope is backwards, its actual magnifying power will be 1/15 X, and its apparent field will be 1/15 the true field. Thus our 30° true field will be reduced to only 2° as it leaves the upper telescope, and that narrow beam can pass down the periscope tube for a considerable distance.

We defined the objective as the lens nearest the target. If we apply that definition to the upper main telescope of the periscope, then it is not really backwards. It is a normal telescope with a short-focus objective and a relatively long-focus eyepiece. But we are accustomed to working with telescopes whose magnifying power is more than one. We are used to the idea that the short-focus lens is the eyepiece, and the long-focus lens is the objective. The men who work with periscopes hold on to that idea—they call the upper lens of the upper telescope the eyepiece, even though there is no eye within 40 feet of it. We will go along with them. Keep that in mind so you will not be confused.

The lower main telescope is in the normal position—its objective is toward the target, and the focal length of its objective is greater than that of its eyepiece. Its magnifying power, therefore, is greater than one. In the example given, we assumed that the upper main telescope had a magnifying power of 1/15 X. Now, if we give the lower telescope a magnifying power of 15 X, the magnifying power of the two together will be:

$$1/15 \times 15 = 1$$

The upper telescope reduced the true field of 30° to an apparent field of 2°. The lower telescope, with a magnifying power of 15 X, will bring the field back to an apparent field of 30°, equal to the true field of the instrument.

In figure 14-2 you can follow the path of light rays through the periscope we have described. Part A shows the action of the two telescopes alone; in part B we have added the two prisms, to bend the line of sight twice through 90°. In the figure, the broken line represents the optical axis. The two solid lines show the path of

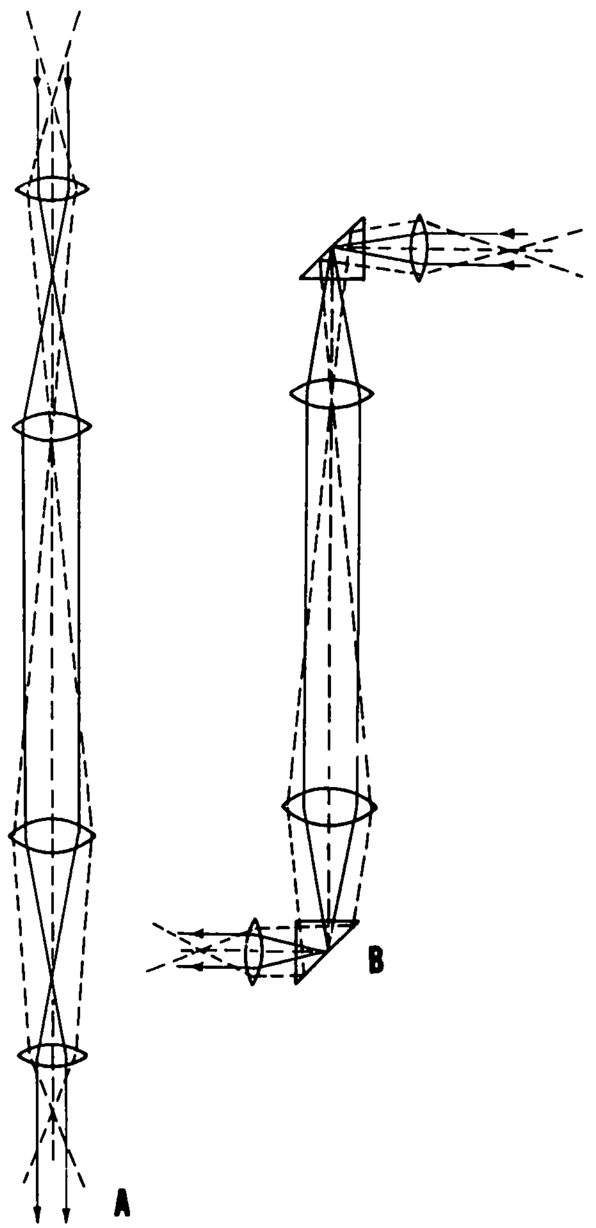

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Figure 14-2.—Path of rays through a periscope.

two rays from the center of the field; as they strike the first lens, they are parallel to the axis. The two dotted lines represent two diagonal rays, one from each extreme edge of the field. The angle between them is the true field of the instrument.

To illustrate the path of rays through an instrument, we can choose the rays that are most convenient for our purpose. We will use the two diagonal rays that cross in front of the upper eyepiece because those two happen to pass through the center of the upper objective. Since they pass through the objective without bending, the angle between them is the angle at which the light diverges as it leaves the upper telescope. These two rays limit the distance between the two telescopes—the objective of the lower main telescope must be close enough to the upper system so that these two rays will fall on it.

As you can see in figure 14-2, there are two real images within this periscope. In part B of figure 14-2, we have put two real images at the reflecting surfaces of the prisms, simply because that makes it easier to follow the rays. You will not find this situation in an actual periscope, since any tiny flaw in the reflecting surfaces would show up as a part of the final image.

The sample periscope design we have described has a magnification of one. Since the magnifying power of the periscope is equal to the product of the separate magnifying power of its two telescopes, you can see that there are two ways to enlarge the image; we can decrease the reduction of the upper telescope, or we can increase the magnifying power of the lower telescope. We might decrease the reduction of the upper telescope from 1/15 to 1/7.5. Then the magnifying power of the whole system would be:

$$1/7.5 \times 15 = 2$$

Or, we could increase the magnifying power of the second telescope to 30 X. Then:

$$1/15 \times 30 = 2$$

The first method would require that we shorten the tube, since the rays from the first telescope would then diverge at an angle of 4°, rather than 2°. The second method would decrease the illumination of the system, since it would reduce the diameter of the exit pupil. Which method we would actually use would depend, of course, on what we wanted our design to accomplish.

It is obvious that the design of any periscope is limited by several factors:

Length of the tube.
Diameter of the tube.
Magnifying power required.

Diameter of exit pupil.
Angle of true field.

In the longer periscopes such as the type 2 you will find two additional astronomical telescopes. We refer to them, respectively, as the UPPER AUXILIARY TELESCOPE and the LOWER AUXILIARY TELESCOPE. The two auxiliary telescopes are mounted above the main telescopes. Usually each of them has a magnification of one; their only function is to lengthen the system and to carry the image down through the narrow, tapered section at the top of the tube.

In all periscopes in service you will find a Galilean telescope at the very top of the optical system—above the upper auxiliary telescope. Since it is relatively short, it does not lengthen the tube too much. The Galilean telescope provides the periscope with its CHANGE-OF-POWER mechanism. Since it forms an erect image, it can be thrown in or out of the system without changing the orientation of the target image.

In practice, the submarine captain always uses the highest magnification of the periscope for measuring the range and bearing of his target, to aim his torpedoes. He will use the low power only for observation. Since the two lenses of the Galilean telescope are moved on or off the axis by a fairly long change-of-power control system, we cannot be sure they will always come to rest in exactly the same place on the axis. But in measuring target bearing, we must have maximum accuracy. We must, therefore, design the periscope to give low power with the Galilean telescope IN, and high power with the Galilean telescope OUT. We can do that by mounting the Galilean telescope backwards, like the upper main telescope. Its short-focus divergent lens will be toward the target; its long-focus convergent lens will be toward the observer.

Let us see how that actually works. In one typical periscope design, the high power is 6 X; the lower power is 1.5 X. The Galilean telescope has a reducing power of 4 (or a magnifying power of 1/4 X). With the Galilean telescope OUT, of course, the power of the periscope is

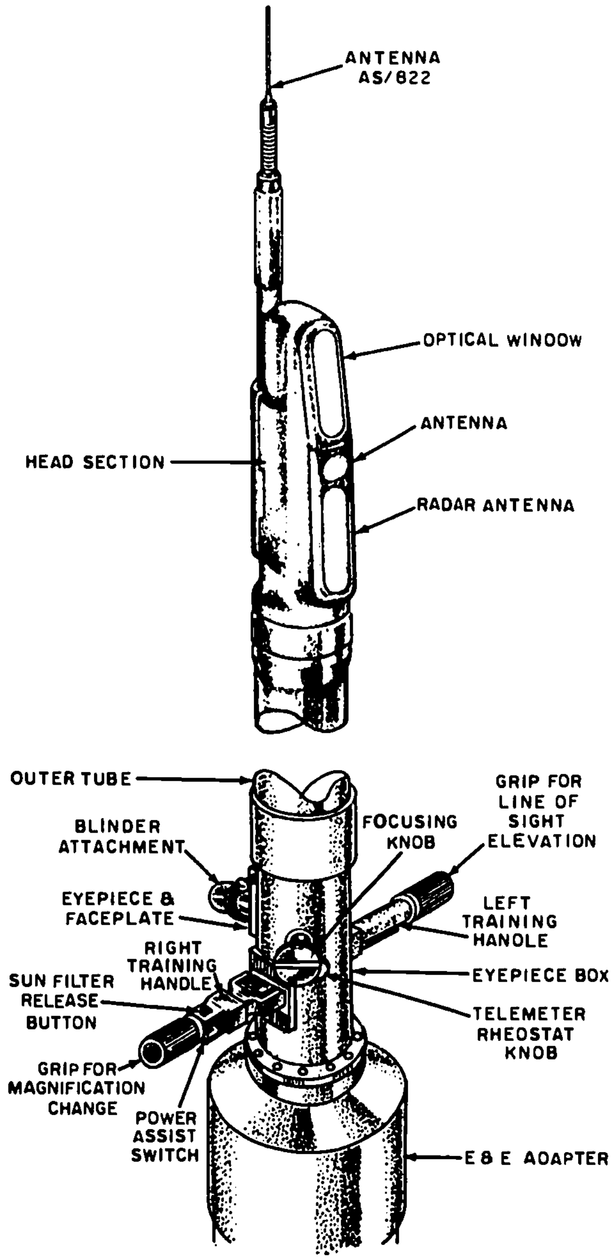

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Figure 14-3.—8-B periscope.

6 X. With the Galilean telescope IN, the power of the periscope is:

$$1/4 \times 6 = 1.5 \text{ X}$$

TYPE 8B PERISCOPE

The submarine periscope system 8B is a general purpose instrument consisting of a

365

type 8B periscope, (fig. 14-3), an Electrical and Electronic (E and E) Adapter, and several externally mounted control or connection boxes.

The type 8B periscope is a night service instrument of 36-foot optical length and 7 1/2-inch outer diameter, exclusive of the eyepiece and faceplate assembly, handles, and other controls on the eyepiece box. All electrical connections to the periscope are made through the E and E adapter.

The optical system in the 8B periscope contains a tilting head prism that is capable of elevating the line of sight 60° above the horizontal, and 10° below the horizontal. A sun filter located in the head section may be moved in or out of the optical path while the periscope is in high power. At night the telemeter may be red-illuminated for better observation. There are also attachments provided for mounting a camera adapter to the eyepiece box for taking photos while the submarine is submerged.

The 8B periscope also contains a means of de-fogging and de-icing the head window of the periscope by use of a heated head window.

The men on submarines at times have to stand watch at the periscope when the submarine is submerged. To make this job a little easier the periscope system incorporates a training torquer, which is operated from the right training handle and is used to aid in training the periscope. This is done by use of a motor, which when turned on will help turn the periscope. After about 15 minutes on watch, having to turn the periscope by hand would wear the man out. With the power torquer to assist him, this will not happen. The power torquer is to be used as an assist to help turn the periscope and is not to be used alone. If used correctly, it will be like using power steering in a car.

The external casing of the periscope system consists of four main sections: the outer head, the outer tube, the eyepiece box, and the E and E adapter. The joints between the outer head and the outer tube and between the outer tube and eyepiece box, consist of an "O" ring, a bronze coupling, two setscrews, and a gasket seal. The outer tube itself is made out of corrosion-resisting steel.

The internal framework of the system consists of three main parts: the head skeleton, the body skeleton, and the eyepiece components. All of the internal optics are supported and positioned by this framework. The shafts and linkages from the eyepiece box, which are used to operate the mechanisms, are also supported by the internal framework.

The optical system of the 8B periscope consists of three main components: the head assembly, optical relays, and the eyepiece and faceplate assembly. The head assembly contains a tilting prism, which is operated by rotating shafts and gearing from the left training handle. A 2-speed and a 36-speed synchro are also incorporated, for precision measurement of the relative elevation of the line of sight.

For low-power operation, movement of the right training handle mechanically causes two lenses (Galilean cubes) to rotate into position just below the head prism. These lenses act as a reverse telescope to decrease the periscope magnification.

When the periscope is in the high power operating position, further movement of the right training handle causes a sun filter to rotate into place. The focusing knob on the side of the eyepiece box, shown in figure 14-3, mechanically moves the focusing erector lens near the base of the tube. This knob provides for the +1.5 to -3.0 diopter focus range for the observer, and also provides for camera focus. There is also a sextant switch located on the left training handle, for taking sextant readings while submerged. A more detailed coverage of the submarine periscope can be found in the OM 1 and C training manual, and the NavShips Technical Manuals.

REMOVAL AND INSTALLATION

The illustrations and text in the following section will depict a Type 2 attack periscope; however, the general procedures discussed will apply to all types of submarine periscopes.

To remove a periscope from a submarine and transport it to the optical shop of a tender, follow these steps:

- Removing a periscope from a submarine can be done only in a sheltered harbor, since rolling of either ship is likely to seriously damage the periscope. The submarine should be moored alongside the tender on the side from which it will be easiest to move the periscope into the optical shop. If there is a cover plate over the steady bearing of the submarine (at the top of the periscope opening), remove the plate.

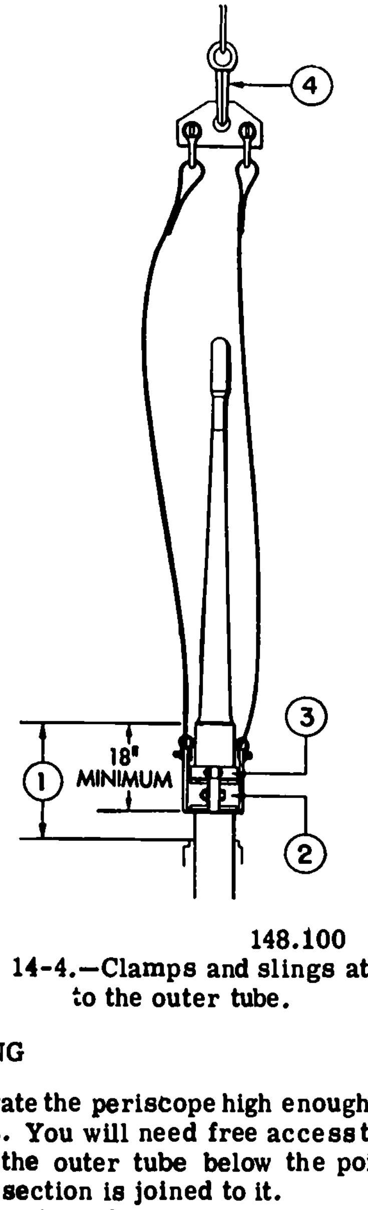

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Figure 14-4.—Clamps and slings attached to the outer tube.

CLAMPING

• Elevate the periscope high enough to attach the slings. You will need free access to at least 2 feet of the outer tube below the point where the taper section is joined to it.

• Bolt a forged steel hoisting clamp around the outer tube, at least 12 inches below the joint between the outer tube and the taper section. (The hoisting clamp is marked No. 2 in fig. 14-4.) The hoisting clamp should be lined with emery cloth with its smooth side next to the outer tube of the periscope. Since the friction between the clamp and the outer tube must support the weight of the periscope, do not try to use a clamp that fits poorly. And never use a clamp containing setscrews. Bolt one or two safety clamps (No. 3 in fig. 14-4) to the outer tube above the hoisting clamp. The safety clamps will keep the periscope from slipping downward within the hoisting clamp.

• The slings must be long enough to clear the periscope head, and they must be attached to a spreader bar of sufficient width to keep them from fouling the head. Put the hook of the lifting crane in the hook opening of the spreader bar, as in figure 14-4.

• Raise the periscope to observing position, and transfer its weight to the lifting crane.

EXTERNAL FITTINGS

• Now remove all parts of the periscope that project beyond the diameter of the outer tube. Figure 14-5 shows these parts. First, remove the two training handles by removing the four hinge bracket bolts.

• Remove the focusing knob assembly by taking out four lockscrews.

• Remove the color filter assembly by pulling outward on the two spring-actuated plunger knobs.

• Remove the stadimeter housing.

• Remove the eyepiece attachments, which are secured to anchor screw pins projecting from the eyepiece box.

• Now check to be sure the lifting crane is holding the weight of the periscope. Slack off the hoisting yoke.

• Remove the lockscrews from the cover ring, and unscrew the cover ring with a spanner wrench. Then remove the hoisting yoke body, the phosphor bronze locating collar, the lower ball bearing race, the ball bearings and retainer, and the upper ball bearing race. (These parts are identified in fig. 14-5.) Be especially careful to protect all these parts from dirt and grit.

• Remove the split ring and the ring cover.

• Slack off the hull stuffing box gland.

• The periscope must be hoisted vertically; before hoisting, check to be sure that the crane boom is directly above the periscope. Attach a hinged clamp with handles to the outer tube above the deck opening of the submarine. While the crane is hoisting the periscope, use the handles of the clamp to rotate the periscope back and forth, to be sure it is not binding. If there is any tendency toward binding, stop hoisting at once, and do not start again until you have found the trouble and corrected it.

• Hoist the periscope clear of the submarine and transport it in a vertical position to the upper deck of the tender. To place the periscope

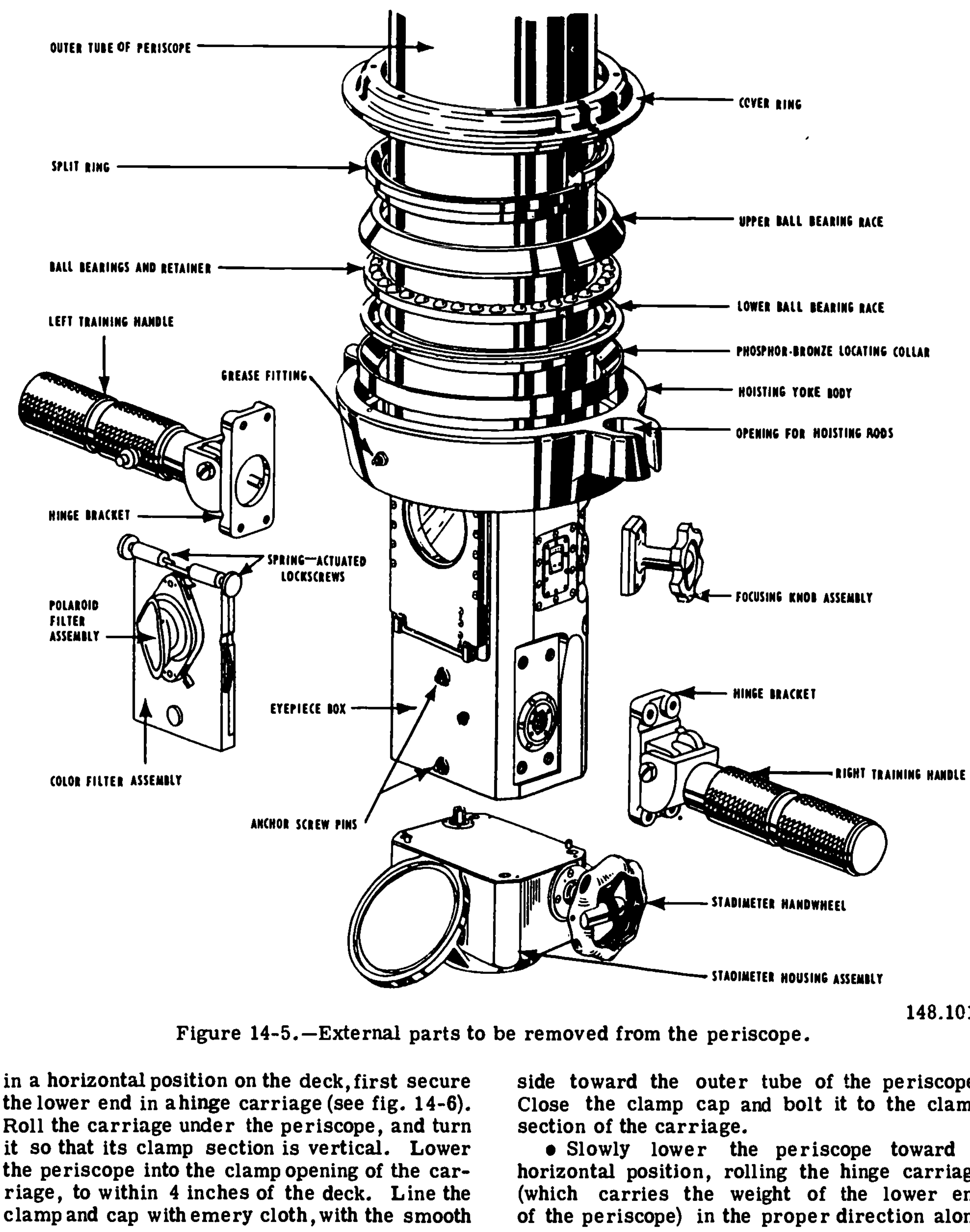

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Figure 14-5.—External parts to be removed from the periscope.

in a horizontal position on the deck, first secure the lower end in a hinge carriage (see fig. 14-6). Roll the carriage under the periscope, and turn it so that its clamp section is vertical. Lower the periscope into the clamp opening of the carriage, to within 4 inches of the deck. Line the clamp and cap with emery cloth, with the smooth side toward the outer tube of the periscope. Close the clamp cap and bolt it to the clamp section of the carriage.

• Slowly lower the periscope toward a horizontal position, rolling the hinge carriage (which carries the weight of the lower end of the periscope) in the proper direction along

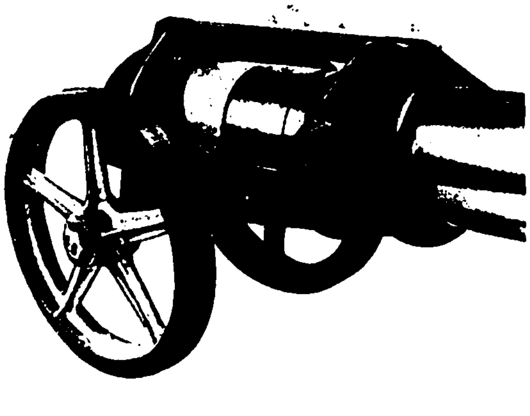

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Figure 14-6.—Hinge carriage at horizontal position.

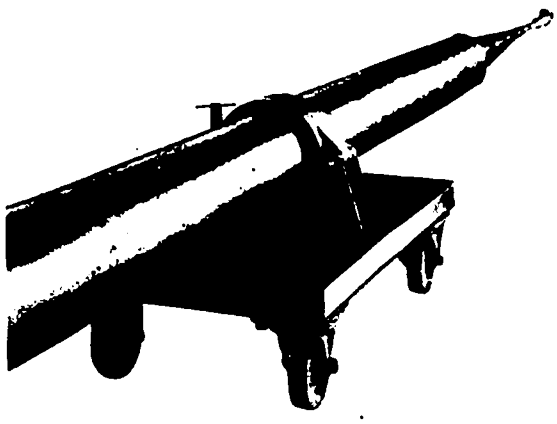

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Figure 14-7.—Upper part of periscope in clamp carriage.

the deck. Figure 14-6 shows the hinge carriage, and the lower end of the periscope, in horizontal position.

- When the periscope is nearly horizontal move the clamp carriage into position under it, with the upper half of the clamp hinge open. Lower the periscope into the clamp; close upper half of the clamp, and secure it with the swinging wing nut. (See fig. 14-7.)
- Remove the hoisting clamp and safety clamps from the periscope.
- Bolt a spreader bar onto the outer tube of the periscope, between the two carriages.
- Roll the periscope, on its two carriages, to the in-board transfer opening of the upper deck.
- Put the hook of the chain fall of the overhead track in the hook opening of the horizontal lifting spreader bar. Transfer the weight of the periscope to the chain hoist, and remove the two carriages.
- Lower the periscope to the overhead chain hoists of the main deck. Transfer the weight of the periscope to the chain hoists of the main deck, attaching a hook in the shackle at each end of the horizontal lifting spreader bar, as in figure 14-8.
- Roll the periscope into the optical shop, and lower it onto the separated channel optical benches. Remove the spreader bar and lifting clamps.

PACKING

After the overhaul and collimation are completed, install the periscope in the submarine by following these steps:

- Remove the packing gland and the packing assembly (see figs. 14-9 and 14-10) from the hull casting of the submarine. Ordinarily, you will use Garlock chevron packing, as shown in figure 14-9. It consists of an upper metal packing ring, a ring of Garlock chevron packing, a lantern ring, two more rings of chevron packing, a lower metal packing ring, a filler ring, and the metal packing gland. Assemble the Garlock chevron packing assembly loosely on a work bench or table, and measure the distance from the upper surface of the upper packing ring to the inner shoulder face of the packing gland. Now, in the hull casting of the submarine, measure the distance from the lower face of the lower guide bearing to the lower face of the extension ring. This second measurement should be 1/16- to 3/32-inch longer than the first, to provide the clearance shown in figure 14-9. If there is insufficient clearance, replace the filler ring with a shorter one, or cut it down on a lathe.
- Transport the periscope from the optical shop to the submarine by reversing the procedure used to move it to the optical shop.
- Lower the base of the periscope a short distance into the top bearing of the submarine. Apply grease freely to the outer tube of the periscope as it enters the guide bearings.
- Attach a hinged clamp and handles to the outer tube of the periscope. Rotate the periscope back and forth while lowering it, to check for binding.

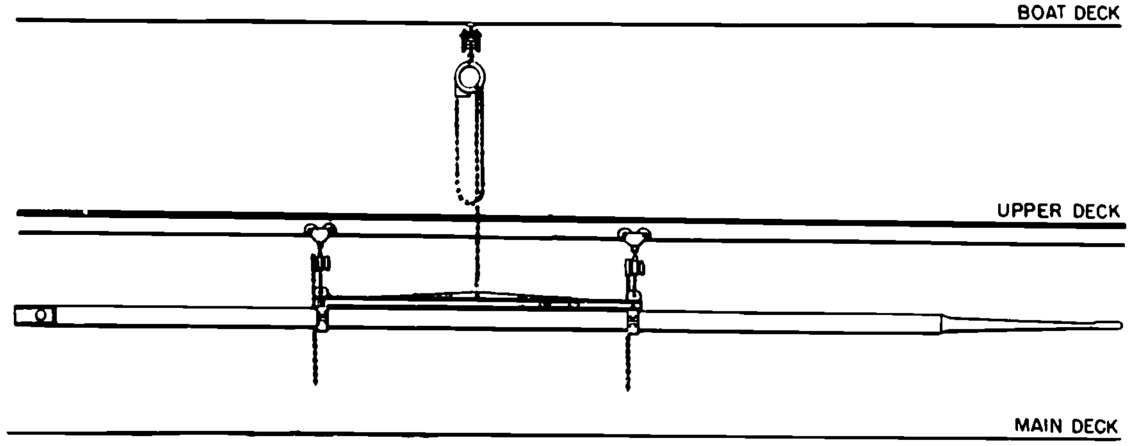

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Figure 14-8.—Periscope transferred to overhead chain hoist of main deck.

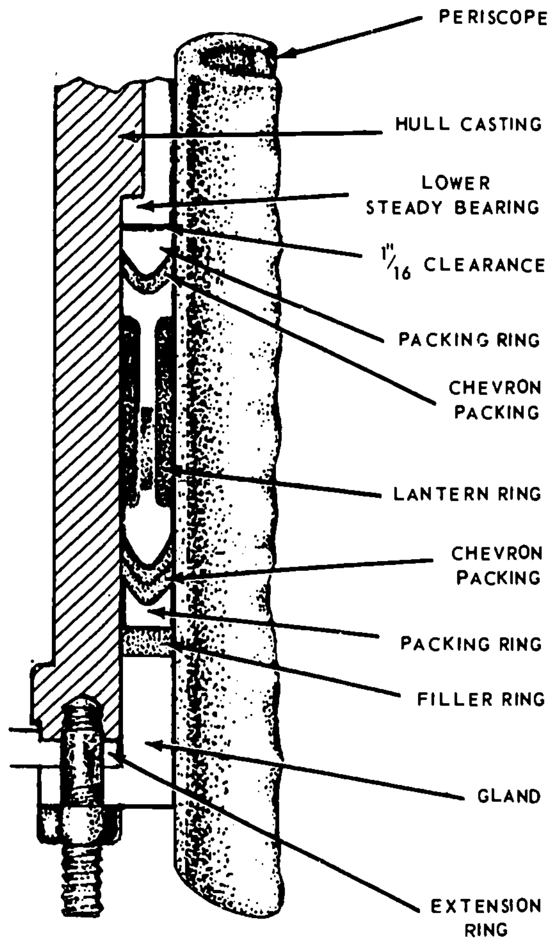

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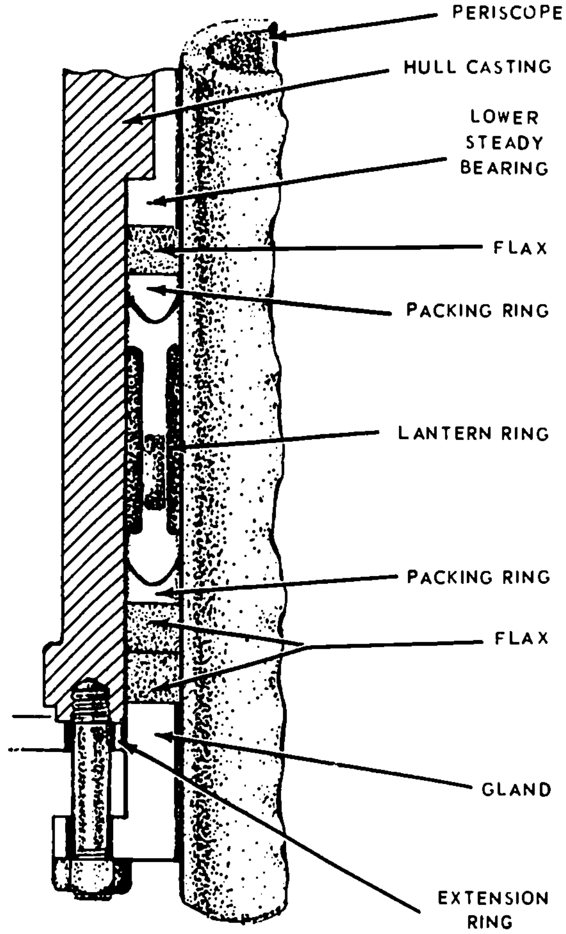
Figure 14-9.—Garlock chevron packing.



148.106
Figure 14-10.—Emergency flax packing.

• When the periscope has been lowered to the observing position, replace the hull packing assembly. In reassembly pack the cavity around the lantern ring with grease and bring the packing gland hard against its shoulder. Now with a 0.006-inch feeler gage, check the clearance between the outer tube of the periscope and the inner circumference of the packing gland. The clearance should be uniform all the way around.

• After the packing is placed in the hull gland assemble the azimuth circle and auxiliary circle attachment to the extension ring. Train the periscope on the forward and after bench marks of the submarine, to be sure the azimuth circle reads correctly on the lubber's line.

• Reassemble the hoisting yoke, and fill it with mineral grease, Grade II medium.

• Now, while raising and lowering the periscope, fill the lantern ring cavity, through the external grease fitting of the hull casting, with mineral grease, Grade II medium.

• Assemble all the external parts of the eyepiece box, following the disassembly steps in reverse.

• Train the periscope several times through 360°, and watch the azimuth circle. If the periscope grinds against it, the circle has been improperly mounted. Remount it in the proper position. While training the periscope, listen for grinding in the guide bearings. If you hear grinding, it probably means that chips of metal have fallen into the bearings during assembly. To correct this, the periscope must be withdrawn, the outer tube scratches smoothed down, and the guide bearings cleaned and repacked.

• Check the periscope training handles, the altiscope, and the power shift, to be sure they are all functioning properly. Check the stadimeter in the observing position, to be sure there is no double image at the infinity reading. Check the focusing adjustment; the range of diopter setting should be from -3 to +1 1/2 diopters.

• When the periscope is in satisfactory condition, report to the submarine officer and ask him to inspect it for approval.

At this point we will discuss packing leakage. When leakage occurs through the Garlock packing, you will be expected to fix it. The usual cause of leakage through the chevron packing is distortion of the packing ring, which opens up a crack between the packing and the periscope. Usually the leakage can be stopped by removing the packing and replacing it. Should leakage continue after the hull gland has been packed according to specifications, use the following check list to locate the problem area.

- Support bearing and hull gland alignment.
- Eccentricity in packing gland.
- Eccentricity in lantern or packing ring.
- Proper size of hull gland.
- Concentricity and size of periscope outer tube.

When necessary an emergency flax packing can be used when assembled as shown in figure 14-10. This will stop the leak, but has the disadvantage of making the periscope harder to train. Cut the flax packing rings with square ends, and measure them to fit the inner circumference of the hull casting, rather than the outer circumference of the periscope. As you bring up the packing gland, be sure to check for uniform clearance with a feeler gage. This is especially important with flax packing, since the gland is not brought all the way up against the extension ring.

STORAGE

A modern submarine periscope, in spite of its size (up to 50 feet in length) and weight (up to 2,000 pounds) is a fragile instrument. When moving it from one place to another, be constantly alert to protect it from bending, vibration, or shock. Periscopes are shipped and stored in sturdy boxes, and are secured by clamps. These clamps prevent endwise movement within the box.

When you remove a periscope from its box, be sure to put the clamps back in the box so they can be used again. When returning a periscope to its box for reshipment, be sure that all the clamps are in place. See that all accessories are either mounted on the periscope itself, or carefully secured inside the box.

When moving a periscope in its box, always hoist or support the box at more than one point—preferably at the quarter points—to prevent needless stresses on the periscope tube. If a periscope is shipped by rail, the box should be securely chocked in the car. For highway shipping a reach truck should be used if available. The box should be so loaded on the truck that the overhanging end contains the upper, lighter end of the periscope. The nameplate of the shipping box should always be at the heavy end.

EXTERNAL MAINTENANCE

The following pages of this chapter will describe some of the maintenance procedures you will use most often on submarine periscopes. Because detailed information on the periscopes is classified and the external fittings are so numerous only a brief discussion on external fittings can be presented in this manual.

The repairs required to keep the external fittings of a submarine periscope such as handles, stadimeter, or eyepiece in good operating condition can be accomplished without breaking the hermetic seal or removing the periscope from the submarine.

When it is found that an external fitting is in need of repair the fitting is removed from the periscope and brought to the optical shop where all of the special tools and fixtures required for repair are readily available. During the overhaul of all periscope fittings the NavShips maintenance technical manual that is applicable should be used as a guide.

When you are removing the external fittings from a periscope be sure to pull straight out on the fitting without cocking or twisting it. Otherwise the mechanical linkage or electrical connectors will be damaged.

Maintenance of the installed periscope is limited almost entirely to elimination or prevention of fogged optical surfaces.

Internal fogging is far more serious than external fogging, and of course it is much easier to prevent than to correct. Prevention requires only that all seals be airtight, and that the instrument be kept fully charged with very dry nitrogen. Fogging of an optical surface occurs when the optical element is at a temperature below the dew point of the air in contact with it. We can prevent fogging inside the periscope by keeping the dew point of the charging gas extremely low.

The drying and charging gas for submarine periscopes is NITROGEN, prepared in accordance with Navy specifications. The specifications require that the nitrogen be delivered in cylinders charged to 1,800 pounds per square inch. The nitrogen must be entirely free from acid, dust, and objectionable impurities, and it must be at least 99.5 percent pure. CAUTION: DO NOT USE A CYLINDER AFTER ITS PRESSURE HAS FALLEN BELOW 400 psi. (When pressure in a cylinder is below 400 psi, oil and dirt in the bottom of the cylinder will be discharged into the periscope.)

DEWPOINT TEST

The dewpoint of a gas is tested by letting the gas flow against a cold surface and gradually reducing the temperature of the surface until moisture condenses on it. When condensation begins, the temperature of the surface is equal to the dewpoint of the gas.

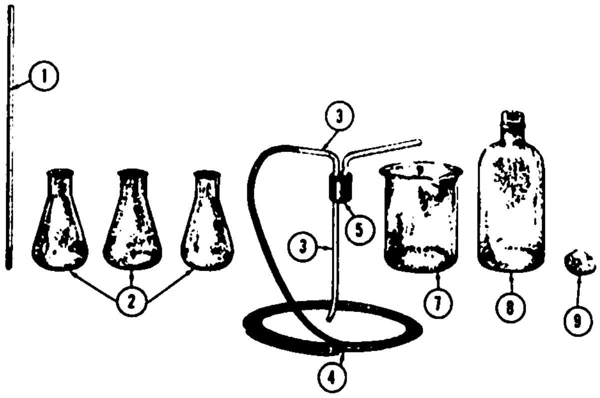


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Figure 14-11.—Dewpoint testing equipment.

Figure 14-11 shows the equipment required for a dewpoint test. The numbers in the figure correspond to those listed here:

1. A centrigrade thermometer, with a range from minus 100°C to plus 50°C.
2. Three 200-ml pyrex Erlenmeyer flasks, each silvered on the bottom and part of the side. If the silver is outside, it must be copper plated and coated with acetone-resisting enamel. If the silver is inside, it must be coated with clear lacquer.
3. Two pieces of glass tubing (total about 12 inches), bent to form an inlet and outlet tube is shown in the figure.
4. Four feet of rubber tubing.
5. A two-hole rubber stopper to fit the Erlenmeyer flasks, and hold the inlet and outlet tubes.
6. Half a pound of dry ice. (Not shown.)
7. A one-liter pyrex beaker, big enough to contain one of the Erlenmeyer flasks immersed in 2 inches of cooling mixture.
8. Half a liter of acetone.
9. Soft apiezon wax, for sealing the fittings.

To make a dewpoint test, follow these steps:

- Heat the Erlenmeyer flasks on a hotplate to drive out all moisture.
- Assemble one of the flasks with the rubber stopper, the inlet and outlet tubes, and the rubber tubing. The inlet tube should almost touch the bottom of the flask. (Leave the two other flasks on the hotplate to keep them warm and dry.)

• Connect the rubber tubing to the outlet connection of the periscope. Use the soft apiezon wax to seal all the connections: one at each end of the rubber tubing, two at the top of the rubber stopper, one between the stopper and the flask.

• Open the periscope outlet valve very slightly, to permit an extremely light flow of gas through the apparatus. To detect a light flow of gas, hold the outlet tube of the flask close to your lips. A feather-like touch can be felt on moistened lips. If the flow of gas can be felt on dry lips, the flow is too strong.

• Pour the half-liter of acetone into the beaker.

• Immerse the Erlenmeyer flask in the acetone, to about an inch above the silvered sides. Try to keep the flask from touching the bottom of the beaker.

• Put the thermometer into the acetone, and hold it or clamp it so that its tip is about 1/4 inch from the bottom of the beaker. (If the thermometer touches the sides or bottom of the beaker, it will give a false reading.)

• Slowly add powdered dry ice to the acetone, stirring constantly. Carefully watch the silvered surface of the flask, under the end of the inlet tube. When the surface begins to cloud, quickly read the thermometer. Record the temperature.

• Repeat the test twice more, using the two other warm, dry Erlenmeyer flasks. The highest of the three thermometer readings is the dewpoint of the charging gas.

The dewpoint test is the best way to check a periscope for moisture before fogging occurs. All submarine periscopes should have a routine dewpoint test at 6 month intervals even when there is no indication of fogging.

Should the dewpoint test show that an excessive amount of moisture is present in the periscope or when a hermetic seal has been broken, the periscope must be recharged with dry nitrogen. The process used to ensure that the charging gas meets the requirements is known as CYCLING.

CYCLING EQUIPMENT

Figure 14-12 shows some of the equipment needed for cycling a periscope. The numbers in the figure correspond to those listed here, except as noted:

1. A vacuum gage (Stokes-Flcsdorf Manometer).

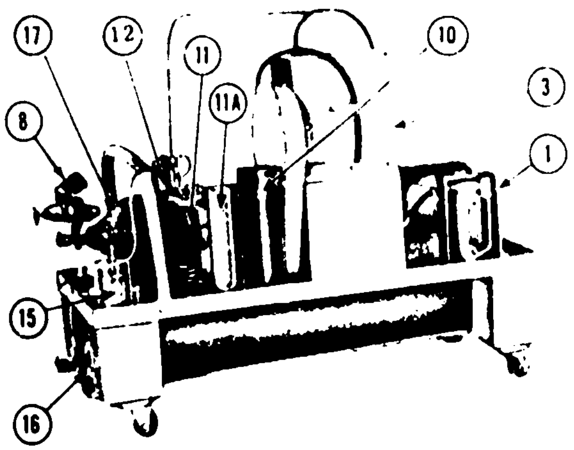

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Figure 14-12.—Cycling equipment.

2. Vacuum gage fitting for the inlet connection of the periscope. (Not shown.)
3. Cenco Hyvac pump.
4. Cenco Hyvac pump fitting for the outlet connection of the periscope. (Not shown.)
5. A pressure gage, with a range from zero to 150 psi. (Not shown.)
6. A Mk 3 instrument dryer, adapted for use with the periscope (as in fig. 14-13).
7. Freshly baked silica gel. (Not shown.)
8. Reducing valve for the nitrogen cylinder.
9. Soft apiezon wax. (Not shown.)
10. Pyrex thermos jar, with an inside diameter of 2 3/4 inches, and an inside depth of 12 inches. The thermos jar should be surrounded with half-inch cork insulation, and secured in a metal container. The joint between the insulation and the flask should be sealed with wax.
11. Fifteen feet of 3/8-inch copper tubing, coiled to 2 1/2 inches outside diameter, and inserted in the flask.

11A. Wire screen.

12. A Cuno air filter, in the line between the nitrogen tank and the copper coil.
13. Half a liter of acetone. (Not shown.)
14. Three pounds of dry ice. (Not shown.)
15. Snow Man dry ice machine.
16. Cylinder of CO_2.
17. Nitrogen cylinder.

The above list includes all the equipment for BOTH methods of drying. If using the cold trap method, you will not need items 6 and 7. If using the silica-gel dryer, you will not need items 10, 11, 13, 14, 15 and 16.

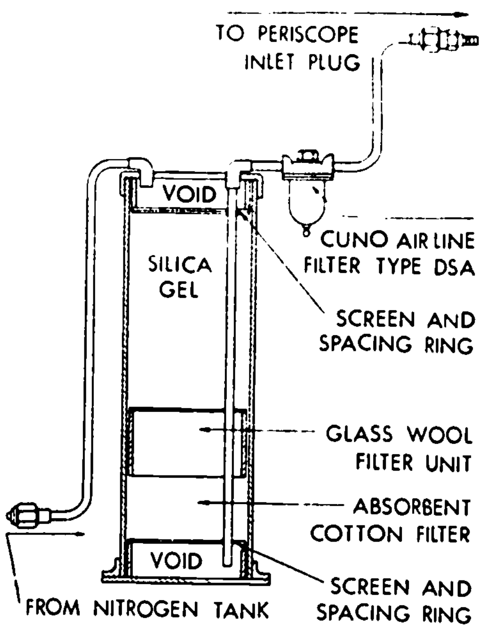

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Figure 14-13.—Mk 3 instrument dryer, adapted for periscope use.

Remember: DO NOT use the silica-gel dryer unless the cold trap method is impracticable.

DRYING EQUIPMENT

Gas pressure within the periscope must be maintained at 7 1/2 pounds per square inch (psi) at 70°F, to prevent all possibility of "breathing" when the pressure changes. (Pressure will vary from 7.1 psi at 60°F to 7.9 psi at 80°F. The pressure will vary even more at extreme temperatures.) The gas used for charging the instrument must be so dry that no condensation can occur at any temperature that the periscope may conceivably encounter in service.

In drying or charging a periscope, the gas from the cylinder must pass through a special drying device before it enters the periscope. Either of two drying devices can be used. The most reliable of these is the COLD TRAP. It consists of a coil of tubing immersed in a bath of acetone and dry ice. The temperature of the cooling mixture will be around -70°C or less. Any moisture in the drying gas will condense on the inside walls of the copper tubing, until the dewpoint of the gas is reduced to the temperature of the coil. The gas that emerges from the cold trap is extremely dry.

If neither dry ice nor the means of making it is available, use a SILICA-GEL DRYER. Figure 14-13 shows a Mk 3 instrument dryer modified for use with the submarine periscope. Note the filter units inside the cylinder, and the Cuno Filter in the outlet line.

Since the indicator crystals are not sufficiently reliable to show the condition of the silica gel, the gel must be baked immediately before each use, regardless of the color of the indicator crystals. Use a covered pan or kettle; bake for 2 hours at a temperature of 500°F.

Silica gel tends to be dusty, the purpose of the filters in the dryer and its outlet line is to keep the dust from entering the periscope. Even so, some dust may pass through. This is extremely objectionable, since dusting off one of the internal surfaces of a periscope is a major operation. So whenever it is possible use the cold trap rather than the silica-gel dryer.

CYCLING PROCEDURE

If inspection of the periscope has shown that cycling and recharging are necessary, follow these steps:

1. Carefully measure the temperature in the conning tower of the submarine and the temperature of the outside air. If either is below 50°F, remove the periscope and take it to the optical shop for cycling.

2. If conditions are satisfactory for cycling aboard the submarine, elevate the periscope from its well—high enough to give easy access to its inlet/outlet connection. Be sure all required equipment is aboard the submarine. Do not try to run in long vacuum or pressure lines from outside.

3. Turn the stadimeter handwheel to the observing position, so as to ensure easy reassembly. Remove the four bolts from the stadimeter housing and lift off the stadimeter assembly, working carefully so as not to bend the transmission shaft. (The stadimeter will be found on attack scopes only.)

4. Remove all the other external projection fittings from the eyepiece box, including the training handles, the focusing knob, and the color filter attachment. This will give access to all the packing glands, so you can test them for leakage.

5. Remove the outlet plug of the periscope, and release the internal gas pressure, if any, by opening the air outlet valve. When all the pressure is released, close the outlet valve.

6. Remove the inlet plug, and secure the hose fitting in the inlet connection.

7. Insert the zero to 150 psi gage in the air outlet fitting and use an offset screwdriver to open the outlet valve, as in figure 14-13.

8. Connect the nitrogen cylinder, through the reducing valve and the dryer, to the inlet connection of the periscope. If you are using the cold trap dryer, pour half a liter of acetone into the flask, and stir 3 pounds of powdered dry ice into the acetone. Run gas slowly through the dryer and charging lines for about a minute before making the connection to the periscope.

9. Close the reducing valve on the nitrogen cylinder. Open the main valve, and set the reducing valve for a pressure of 10 psi. Then open the inlet valve of the periscope.

10. Slowly build up the pressure. Remember that strong gas currents in the periscope may deposit dust on the optical surfaces, and a sudden increase in pressure may throw the optical system out of line. Raise the pressure in 4-pound steps, holding each value for about 5 minutes before increasing it. The pressure should build up to 100 psi (50 psi for scopes sealed with "0" rings) in about 2 hours.

11. When the gage in the outlet connection shows a pressure of 100 psi, close the inlet valve of the periscope. Close off the nitrogen pressure at the cylinder, and remove the charging line fitting from the periscope inlet connection.

12. Now check the periscope for leaks. If possible submerge the entire lower end, including the whole eyepiece box, in a container of water. If that is not possible, coat all connections and packing glands with heavy soapsuds, and watch for bubbles. At the periscope head, soap the edge of the window, the bezel frame screwheads, the gasket, the connection between the head and the taper section, and the bolts that secure that connection. If there is any sign of leakage, eliminate the leak before drawing a vacuum. A leak through a packing gland can sometimes be stopped by tightening the gland. If necessary, release the gas pressure (slowly, over a period of 2 hours), replace the faulty packing or gasket, and repeat the pressure test.

13. When you are satisfied that the periscope is gastight, close the air outlet valve and remove the pressure gage from the outlet connection.

14. Open the outlet valve slightly, to release the pressure slowly and gradually over a period of 2 hours. When all pressure has been released, close the outlet valve.

15. Connect the mercury manometer fitting to the inlet connection.

16. Connect the evacuating fitting to the air outlet connection. Keep all leads short, with as few joints as possible, to reduce the possibility of leakage.

17. Start the Cenco Hyvac pump, and then open the outlet valve. Do not leave the pump unattended while it is drawing the vacuum. If the pump should stop, or show signs of stopping, quickly grab the hose, kink it, and close the air outlet valve to prevent the periscope vacuum from drawing air back through the pump. The air that is drawn back will carry oil and oil vapor from the pump into the periscope and deposit it on the optical surfaces. It takes a major overhaul to repair this damage.

18. When the pump is operating properly open the inlet valve, so the manometer can indicate the vacuum in the periscope. Keep pumping until the manometer shows a pressure of 4 mm or less (2 mm, if it is possible to pump it down that low). Then close the outlet valve, and secure the pump.

19. Hold the vacuum for 3 hours, and then read the manometer. Any rise in pressure shows that drying is incomplete, and so will require more pumping.

NOTE: if you continue pumping, start the pump and let it run a few seconds BEFORE opening the outlet valve.

20. When the periscope will hold a vacuum, close both the inlet and outlet valves, and disconnect the pump and manometer.

21. Now the periscope is ready for charging. Run nitrogen through the dryer and connecting lines for a few seconds, then connect the line to the input fitting of the periscope. If a cold trap dryer is being used, add more dry ice to the acetone, to bring the mixture up to the top of the coil.

22. Insert the pressure gage in the air outlet connection, and open the outlet valve.

23. Slowly open the inlet valve, and gradually build up the pressure to 10 psi. Then close the inlet valve, and shut off the nitrogen pressure at the cylinder. Disconnect the nitrogen inlet fitting, and replace the inlet plug.

24. Close the outlet valve, and remove the pressure gage. Connect the dewpoint test apparatus to the outlet fitting, and a dewpoint test. If the dewpoint is higher than minus 50°C,

you must repeat the cycling procedure from the beginning.

25. If the dewpoint is satisfactory, bleed the pressure VERY SLOWLY, through the outlet valve, to 7 1/2 psi. If the periscope has a built-in gage, this is easy. If it does not have a built-in gage, bleed a small amount of gas, close the outlet valve, insert the gage in the outlet connection, open the valve, and read the gage. Then close the valve, remove the gage, and continue bleeding, with frequent pressure checks, to 7 1/2 psi.

26. The cycling procedure is now complete. Secure all the cycling equipment. Replace the outlet plug, and all the external fittings of the periscope.

CHAPTER 15
NIGHT VISION SIGHTS

In previous chapters we have discussed light and the effect optical instruments have on it. We have seen how light losses occur when light passes through an optical instrument. In this chapter, we shall discuss instruments that not only do not have an overall light loss but actually intensify the brightness of an image as it passes through the instrument. These instruments are collectively called night vision sights.

Night vision sights are Army-developed devices which provide night observation capabilities. Night vision sights are being used extensively by naval forces in combat areas and are being installed on surface combatant ships and submarines. Eventually, most ships of the Navy will have night vision capabilities. The sights are used for observation, surveillance, and the aiming of weapons during night operations.

As an Opticalman, you will be required to maintain and repair these sights.

To do so, you must know how these sights function and what checks to make when they do not function properly. This chapter will provide information on how the sights function, basic characteristics of the sights, safety precautions to be observed while repairing the sights, and basic repair procedures common to the sights. When repair of a particular instrument is required, always consult the appropriate technical manual or ordnance pamphlet.

CHARACTERISTICS OF NIGHT VISION SIGHTS

Night vision sights fall into two basic categories, tripod mounted and hand held. Basic characteristics of each model are included in table 15-1.

The night vision sights AN/TVS-2 (fig. 15-1), AN/TVS-2A, and AN/TVS-4 (fig. 15-2) are tripod mounted sights. They are medium range, seven power, battery operated, electro-optical instruments. These sights are used for observation, surveillance, and as navigational aids. The sights AN/TVS-2 and AN/TVS-2A may also be weapon mounted for fire control.

The night vision sights AN/PVS-1 (fig. 15-3), AN/PVS-2 (fig. 15-4), and AN/PVS-2A are four power, battery operated, electro-optical instruments. These hand held sights are used for observation, surveillance, navigation, and may be weapon mounted.

The main advantage of these night vision sights over other types of night vision devices such as searchlights and infrared sights, is that instead of requiring an artificial light source, they use natural light radiations of a very low level to produce a useful, visible image. Since the sights do not project or require a visible or infrared light, they reduce the possibility of enemy detection. This passive quality is also their main disadvantage because the natural

Table 15-1.—Basic Characteristics of Night Vision Sights

Model	Type	Power	Weight	Length	Diameter
AN/PVS-1	Hand Held	4X	6.0 lb	18.5"	3.5"
AN/PVS-2, 2A	Hand Held	4X	5.75 lb	17.5"	3.2"
AN/TVS-2	Tripod Mounted	7X	15.0 lb	23.5"	6.5"
AN/TVS-4, 4A	Tripod Mounted	7X	38.0 lb	29.0"	8.3"

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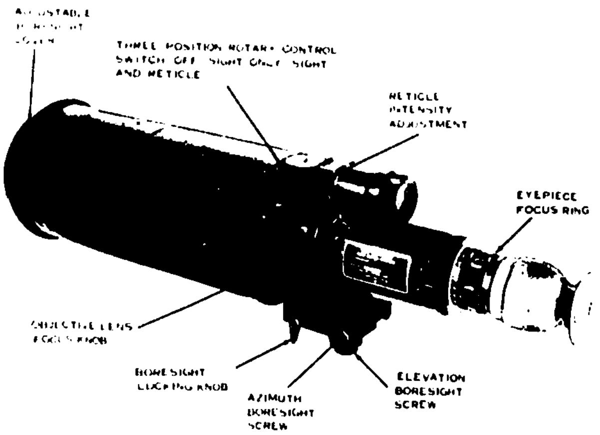

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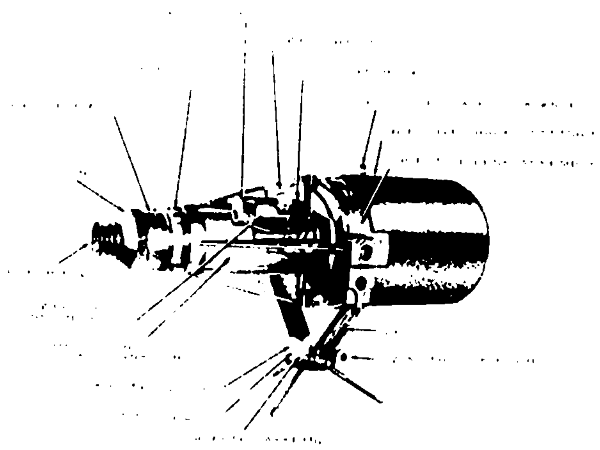
Figure 15-1.—Night Vision Sight, AN/TVS-2.



137.544
Figure 15-2.—Night Vision Sight, AN/TVS-4.

illumination on which they depend can vary widely in intensity. For example, the range of a particular scope under moonlight conditions might be 2000 meters but under overcast skies the same scope might have a range of 200 meters or less.

OPTICAL SYSTEM

The optical system of the night vision sight consists of three major assemblies, the objective lens assembly, the image intensifier assembly, and the eyepiece assembly. We shall use the AN/TVS-4, figure 15-2, as a typical sight for discussion purposes. The objective

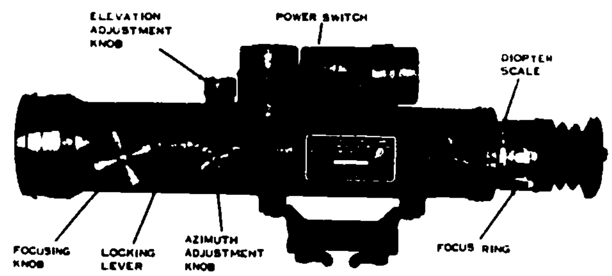


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Figure 15-3.—Night Vision Sight, AN/PVS-1.

lens assembly, figure 15-5, collects the entering light rays and focuses them on the first stage cathode of the image intensifier tube assembly. The image intensifier, figure 15-6, brightens the image, inverts and reverts it, and presents it to the eyepiece assembly. The eyepiece assembly, figure 15-7, magnifies the image and presents it to the eye.

Objective Lens Assembly

Basic differences exist in the objective assemblies of different models of the night vision sight. The hand held units, AN/PVS series, figures 15-3 and 15-4, have small, straight line objective assemblies to reduce weight and size. The tripod mounted units, AN/TVS series, figures 15-1 and 15-2, have large objectives for greater light gathering ability and greater magnification. The AN/TVS-4, figure 15-2, has a unique objective assembly in that the light entering the objective is reflected twice before striking the image intensifier tube (fig. 15-5). This double reflection of the light path serves to reduce the overall length of the telescope, while retaining the long focal length and large entrance pupil of the objective assembly.

Image Intensifier Tube Assembly

The component of the night vision sight which makes possible passive night vision capability is a cascade type image intensifier tube (fig. 15-6). The image intensifier tube assembly is located inside the main housing between the

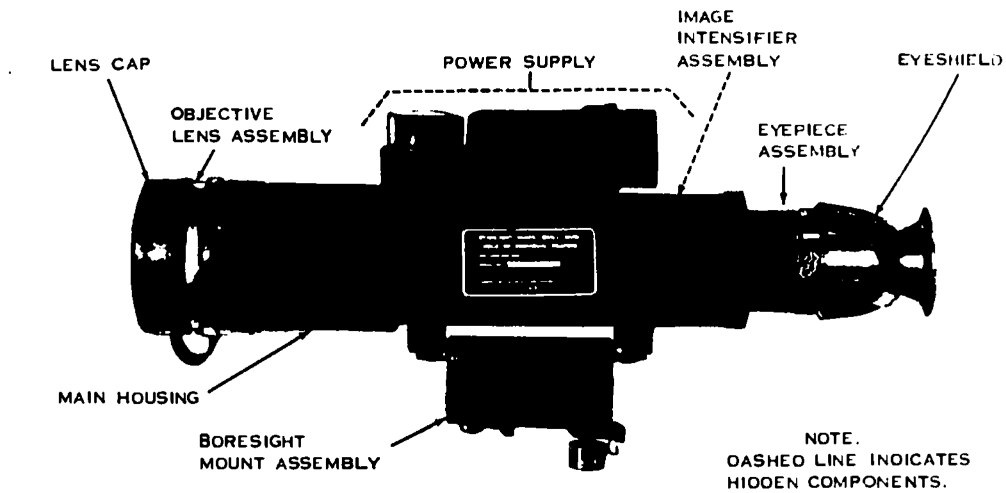

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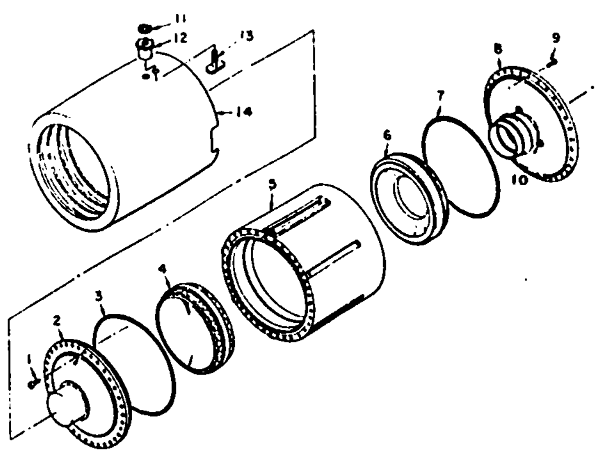
Figure 15-4.—Night Vision Sight, AN/PVS-2.



1. CAP SCREW
2. 1ST CELL ASSEMBLY
3. O-RING
4. 2ND CELL ASSEMBLY
5. OBJECTIVE HOUSING ASSEMBLY
6. PRIMARY MIRROR ASSEMBLY
7. O-RING
8. 4TH ANO 5TH LENS CELL
9. CAP SCREW
10. VALVE ASSEMBLY
11. RETAINING RING
12. KNOB
13. SHADE CLAMP
14. OBJECTIVE SHADE ASSEMBLY

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Figure 15-5.—Objective Lens Assembly, Exploded View.

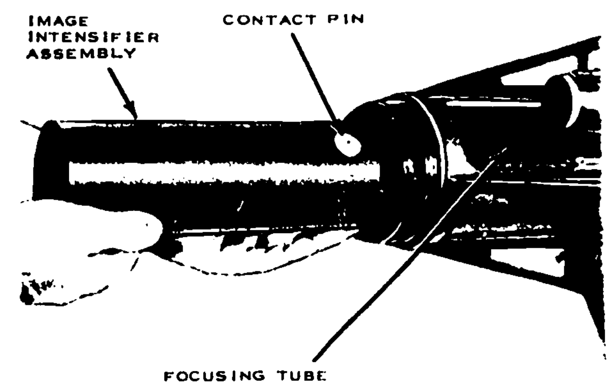

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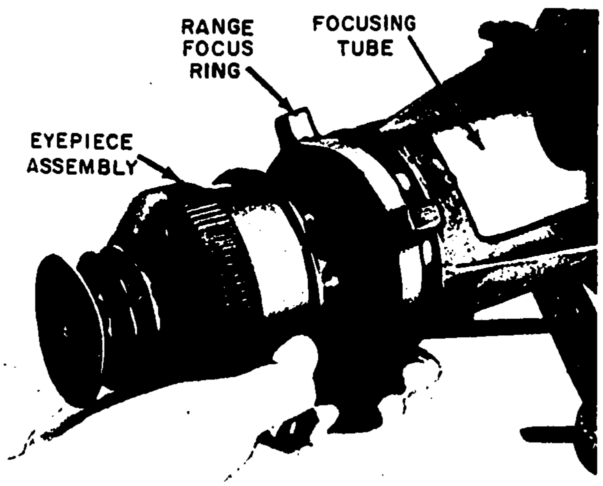
Figure 15-6.—Image Intensifier Tube Assembly.

objective lens assembly and the eyepiece assembly. The image intensifier tube assembly contains the three stage image intensifier encapsulated in RTV-11 silicone rubber.

The image intensifier tube functions as follows:

Ambient light passes through the photoemissive surface of the first stage cathode (see figure 15-8). As the light energy strikes the cathode, electrons are emitted. These electrons are then accelerated and focused to strike the phosphor surface of the first stage screen. The electrons, upon striking the phosphor



STEP 1. UNTHREAD EYEPIECE ASSEMBLY FROM FOCUSING TUBE IN COUNTER-CLOCKWISE DIRECTION.

STEP 2. UNTHREAD RANGE FOCUS RING FROM FOCUSING TUBE IN COUNTER-CLOCKWISE DIRECTION.

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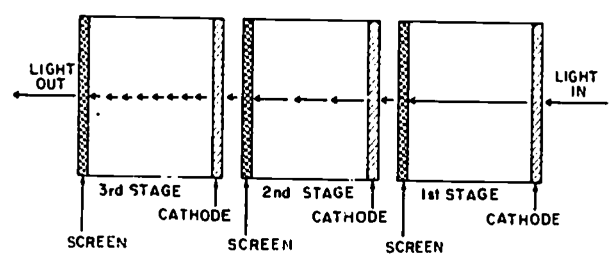
Figure 15-7.—Removal of Eyepiece Assembly and Range Focus Ring.



NOTE: 45,000 VDC POTENTIAL EXISTS BETWEEN THE CATHODE AND SCREEN OF EACH STAGE.

137.548

Figure 15-8.—Image Intensifier Tube, Functional Diagram.

screen, are re-radiated as visible light but, the total amount of light has been greatly increased during the process. This process continues through two successive stages until the light level becomes great enough to be seen by the observer through the eyepiece. The overall light gain provided by the three intensification stages results in an image, presented to the eye, which is approximately 50,000 times brighter than the image entering the objective lens.

SAFETY PRECAUTIONS

Prior to performing any maintenance or repair to any of the night vision sights, a few simple but absolutely necessary safety precautions must be learned and observed. Should you violate any of these safety precautions, it is very possible you will suffer physical damage.

The image intensifier tube will normally have a residual high voltage charge of approximately 45,000 volts d-c. This charge must be removed to eliminate the hazard of electrical shock when the image intensifier tube is removed from its housing.

The phosphor screens, figure 15-8, of the image intensifier tube contain toxic material. If the image intensifier tube should be broken, use extreme caution to avoid inhalation of the phosphor material and to prevent it from coming into contact with the mouth or any open skin wound.

The eyepiece assembly and the objective assembly will normally have an internal pressure of 5 pounds of nitrogen. This pressure must be released prior to disassembly should that become necessary.

Finally, to avoid damaging the night vision sight, do not energize the sight in a lighted area. As the image intensifier tube is extremely sensitive to light, tube damage will result if the sight is energized in too bright an area.

PREMAINTENANCE INSPECTIONS

When a night vision sight is submitted for repair, certain premaintenance inspections must be performed in order to determine the extent of repairs necessary. These checks consist of mechanical and optical inspections of the sight to determine their physical condition, along with electrical inspections to determine the condition of the electrical system.

OPTICAL AND MECHANICAL

Visually check all external surfaces to determine if there are any obviously damaged components that require repair or replacement. Operate the eyepiece assembly and the range focus assembly to determine that they rotate smoothly without binding. In order to make the necessary optical checks, be sure the objective cover is in place. Observing the proper procedures set forth in the operators manual, energize the sight. Then, visually check the image for clarity and brightness.

Using a suitable collimator such as the Mark 5 Binocular Collimator, check image quality at infinity and eyepiece focus at zero diopters. The range focus must be adjustable between infinity and 50 meters. This adjustment may be checked by using a suitable target for the infinity target and some convenient object for the 50 meter target.

ELECTRICAL

An electrical continuity check must be performed to determine the condition of the electrical system. To make the continuity check, remove the battery. Discharge any residual charge of the electrical circuit that may be present by shorting the battery terminal to ground. Connect a resistance measuring device such as an ohmmeter or multimeter between the battery terminal and ground. With the switch in the OFF position, the meter should register infinite resistance. When the switch is turned to the ON position, the meter should register low resistance. If these conditions do not exist, che.k each component of the electrical system to determine which is defective.

MAINTENANCE

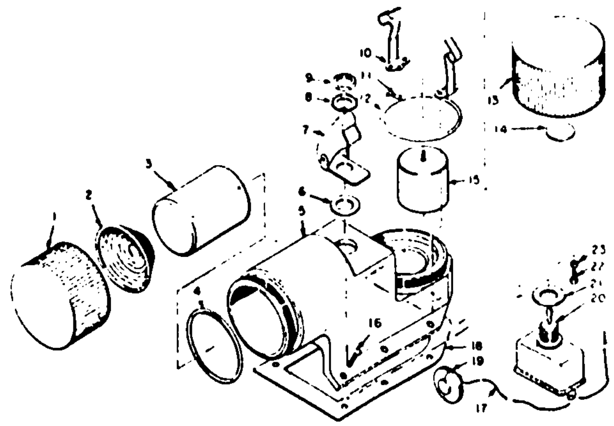
Maintenance of the night vision sights consists primarily of replacing or repairing major assemblies as required. Consult the appropriate technical manual or ordnance phamplet prior to starting any repairs.

The disassembly and reassembly of various models of the night vision sights is basically similar. General procedures will be discussed and major differences pointed out.

The following procedure is to be used as a guideline and is not to be considered as the only correct method.

DISASSEMBLY OF ELECTRICAL SYSTEM

Remove the battery cap and battery from the power supply assembly, figure 15-9. Again, as a safety precaution, short the battery terminal to ground to eliminate any possibility of electrical shock. Remove the oscillator cap. Disconnect the oscillator contact and remove it from the housing. Now remove the oscillator.



1 BATTERY CAP
2 BATTERY SPRING
3 BATTERY
4 O-RING (PACKING)
5 POWER SUPPLY HOUSING
6 BUSHING SEAL
7 SWITCH GUARD
8 LOCKWASHER
9 NUT
10 GROUND CLIPS
11 CONNECTOR
12 O-RING (PACKING)
13 OSCILLATOR CAP
14 INSULATOR
15 OSCILLATOR
16 SEALING SCREW
17 WIRE
18 GASKET
19 TERMINAL
20 SWITCH
21 BUSHING SEAL
22 SCREW
23 LOCKWASHER

137.551

Figure 15-9.—Power Supply Assembly, Exploded View.

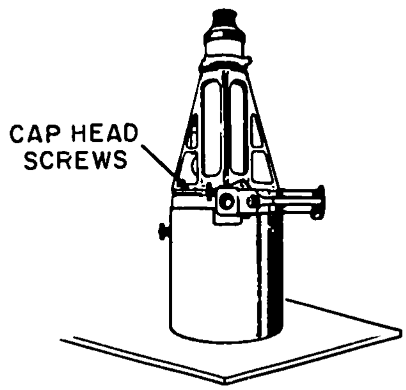
Note: The oscillator must always be removed prior to removing the image intensifier tube assembly to prevent damaging the image intensifier tube contact pin. The power switch may now be removed if premaintenance inspections require it.

REMOVAL OF OBJECTIVE LENS ASSEMBLY

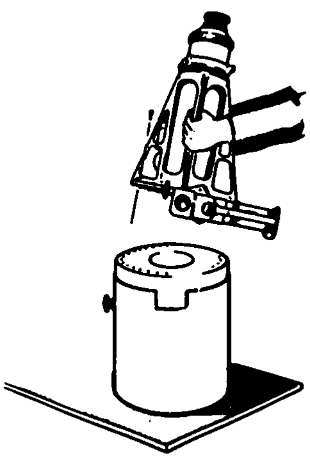
Removal of the objective lens assembly on the AN/PVS series requires that three set screws be removed before the objective lens assembly is unscrewed from the main housing. The objective lens assembly of the AN/TVS-4 is removed by placing the entire sight on the objective end, figure 15-10. The main housing may be removed from the objective lens assembly in this position.

REMOVAL OF EYEPIECE ASSEMBLY

The eyepiece assembly of the AN/PVS series may be removed after removing the retaining



STEP 1. REMOVE CAP HEAD SCREWS (18) FROM AROUND IMAGE TUB HOUSING



STEP 2. GRASP IMAGE TUBE HOUSING IN BOTH HANDS AND RAISE AWAY FROM OBJECTIVE LENS ASSEMBLY

137.552

Figure 15-10.—Removal of Objective Lens Assembly.

ring. On the AN/TVS-4, the eyepiece assembly must be unscrewed from the focusing tube housing, figure 15-7. The range focusing ring may then be removed.

REMOVAL OF IMAGE INTENSIFIER TUBE ASSEMBLY

At this point, the image intensifier tube assembly may be removed from the main housing (fig. 15-6). Again, the image intensifier tube will have a residual electrical charge which must be removed to eliminate the hazard of electrical shock. To accomplish this, carefully touch the oscillator contact pin on the image intensifier tube to the main housing until the charge is removed; carefully touch the ground contact ring to the main housing until the charge is removed. Remove the contact spring from the end of the image intensifier tube. Avoid contaminating the ends of the image intensifier tube.

Note: The screws in the AN/PVS series sights are sealed with a sealing compound which must be dissolved with a suitable solvent such as ketone before attempting to remove the screws. Reseal the screws with Loctite sealant or an equivalent.

REASSEMBLY

Reassembly of the sights is basically the reverse of the disassembly procedure, with the exception of the contact spring. The contact spring is to be installed in the main housing with the fingers facing out and the space in the ring centered in the slot in the main housing flange.

Note: When installing the image intensifier tube assembly, be sure the alignment pin slips into the slot in the main housing flange.

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