The terms training manual (TRAMAN) and nonresident training course (NRTC) are now the terms used to describe Navy nonresident training program materials. Specifically, a TRAMAN includes a rate training manual (RTM), officer text (OT), single subject training manual (SSTM), or modular single or multiple subject training manual (MODULE); and a NRTC includes nonresident career course (NRCC), officer correspondence course (OCC), enlisted correspondence course (ECC) or combination thereof.

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text

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Naval Education And Training Program Management Support Activity

OPTICALMAN 3 & 2

NAVEDTRA 10215

1989 Edition Prepared by
OMC Fred A. Carson

PREFACE

This training manual (TRAMAN) covers the basic theoretical knowledge and mental skills needed by the Opticalman (OM) Third and Second Class. A separate nonresident training course (NRTC) has been developed for OM3 and OM2. The completion of these courses should be combined with the practical experience acquired by on-the-job training.

Completion of the NRTCs provide the usual way of satisfying the requirements for completing this TRAMAN. The assignments in the NRTCs include learning objectives and supporting questions that have been designed to help the student learn the material in the TRAMAN.

This TRAMAN and the associated NRTCs were prepared by the Naval Education and Training Program Management Support Activity, Pensacola, Florida, for the Chief of Naval Education and Training.

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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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CREDITS

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CHAPTER 1

INTRODUCTION TO THE OPTICALMAN RATING

A Navy Opticalman (OM) has a big job. The value of the Navy's ships as combatants depends greatly on the quality and precision of naval optics. As you advance in the Opticalman rating, the condition and quality of naval optics will depend on you. Let's see if you have what it takes to keep the Navy's complex optical instruments in top working condition.

To be an Opticalman, you must have higher than average intelligence and better than average skills with your hands. You will also need good eyesight. You will be required to know (or learn) various types of math, including arithmetic, algebra, geometry, and some simple trigonometry. You will be required to respect your tools. If you do not know how to use your tools properly, you will have to learn. You will need a lot of patience as you will be receiving constant practice in the type of work that involves extreme care and precision. As an Opticalman, you will never be able to get by with careless work. Optical instruments are technical in nature and delicate in alignment and structure. Because of these characteristics, optical instruments are expensive and must be handled with extreme care.

As you advance in the Opticalman rating, you will discover that the world of naval optics is technically complex. No matter how much knowledge you gain about naval optics, there will always be something new for you to learn. If you are going to get ahead as an Opticalman, you must stay alert and try to learn something new every time you get the chance. Your ability as an Opticalman will not be measured in the diversity of equipment you can repair, but in terms of how well and how efficiently you work. There is only one way to make the grade: When you become good at one job, start learning all you can about the next job. Never be satisfied with what you know. Only carefully selected people are permitted to strike for Opticalman. You have passed the screening process. Now, your progress in the Opticalman rating will depend primarily on your efforts.

NAVAL OPTICS

To a physicist or a college professor, optics is a science that deals with light and the way it acts. This type of science is referred to as PHYSICAL OPTICS. You will learn most of what you will need to know about physical optics in chapters 2, 3, and 4 of this rate training manual. As a Navy Opticalman, you will become involved with optics as a science and an art as you deal with the care, maintenance, repair, and overhaul of optical instruments. These responsibilities are referred to as PRACTICAL OPTICS.

What are optical instruments? They are made up of lenses, prisms, and mirrors—or a combination of lenses, prisms, and mirrors—which bend the light. (Sometimes we refer to optical devices, such as lenses, prisms, and mirrors, simply as optics)

Navy optics are made up of three fundamental instruments: the microscope, the telescope, and the periscope To magnify a small object that is close by, you would use a MICROSCOPE. To magnify a larger, more distant object, you would use a TELESCOPE. And, to look at an object from some point where the object would be out of view (such as a submarine), you would use an instrument with mirrors or prisms to bend the line of sight. This instrument is known as a PERISCOPE.

All the instruments that you will work on are either variations or combinations of these three systems. For example, if you attach two telescopes so you can look through one with each eye, you have a pair of BINOCULARS. If you put a reticle in a telescope (so you can point the telescope accurately by sight), and attach the telescope rigidly to a gun barrel, then you have a GUNSIGHT TELESCOPE. If you have two telescopes some distance apart, and point both of them toward a target, you can calculate the range of the target by measuring the distance between the telescopes and the angle between their lines of sight. If the two telescopes and the calculating device are combined into one instrument, you have a RANGE FINDER.

In any military operation, we want to know all we can about the enemy—how many ships are involved, where they are, and how far they are from our ships. In modern warfare, we get much of this information from reconnaissance equipment, but when we actually engage the enemy we are often totally dependent on our optical instruments. We use telescopes and binoculars to detect the enemy and to estimate their strength. We use range finders to measure the range. And, we use sighting telescopes to aim our guns.

THE OPTICALMAN'S JOB

It is the Opticalman's responsibility to keep the ship's optical instruments in top condition. Because Navy optical instruments are delicate, complex, precision instruments, a small error in alignment or a thin film of dust or trace of moisture can sometimes make an instrument ineffective or useless. Yet, these delicate instruments get almost constant use, even in storms. To keep these instruments in top shape, in spite of the hard usage they receive, the Navy depends on the skill of its Opticalmen. For this reason, optical repair is one of the most highly specialized occupations in the Navy today.

There is no room on a combat ship for an optical shop, so most Opticalmen are assigned to repair ships or to repair activities ashore. If an optical instrument on a combatant ship needs repair, it will be sent to a tender or a repair facility that has the necessary space and equipment Repair ships have complete repair facilities, including an optical shop and several Opticalmen. If you are stationed in an optical shop ashore or aboard a ship, overhaul of inoperative instruments will be a part of your job. (Of course, your first job in the optical shop will probably be sweeping or swabbing the deck, or scrubbing paintwork. It will take a lot of hard work and study to put you alongside the best person in the shop. But remember, that person started at the bottom too.)

ASSIGNMENTS, DUTIES, AND TRAINING

When you arrive at your new duty station, you will discover a whole new world, one that consists of working parties, watch standing, and collateral duties. One of the first things you should know about your job as an Opticalman is just how you fit into your new organization and the Navy. If you are assigned to a submarine tender (AS), a destroyer tender (AD), or a repair ship (AR), you will be working in the repair department. Tenders are virtually mobile shipyards providing services and repairs to all of the Navy's ships between shipyard overhauls and during deployments at forward sites where ship repair facilities are not available.

Personnel Qualification Standards (PQS) Program

When you are assigned to your new duty station, qualification will take up a great deal of your time. In 1968 the Navy introduced the Personnel Qualification Standards (PQS) Program to ensure that everyone working on a particular task is equally qualified to a set standard.

Each qualification is a group of knowledges and skills that you must acquire to prepare you for a specific watch station, work station, or team on your ship or station. You will be assigned to a watch station by means of a watch bill, and your duties will usually be for a period of 4 hours A work station is where you will conduct your daily routine.

The PQSs are written in a question-and-answer format and will be used in the evaluation of your readiness to do a specific job The PQSs will also provide a record of your progress and qualifications

Maintenance and Material Management (3-M) Systems

One of the first areas in your shop's PQS program with which you will become thoroughly familiar will be the Maintenance and Material Management (3-M) Systems The main goal of the 3-M Systems is to give commanders tools for ensuring that maintenance is planned in order to keep the material readiness of equipment at peak reliability. The 3-M Systems is further broken down into the Planned Maintenance System (PMS). This system is used for the scheduling and controlling of preventive maintenance on equipment so that the service life of the equipment can be extended and failures at critical times will be prevented. The Maintenance Data System (MDS), another part of the 3-M Systems, is a data collection system that provides type commanders with a report on the fleet's material condition.

An easy way to remember these systems is PMS = does, MDS = reports. You can find more detailed information about the 3-M Systems, along with examples of the forms and reports that you will use and how you should complete them, in OPNAVINST 4790.4 (series).

Watch Station Qualifications

Probably the next set of qualifications you will be required to complete will be watch quals. During a naval ship's active life, there are watches that must be assigned, all day, everyday, and you will probably stand a lot of them. There will be several different types of watches, based upon your ship's needs. In completing each of these watches, you will have a qualification card to complete. In completing watch station qualifications, you will usually be required to demonstrate your watch-standing abilities. You will cover normal procedures, emergency procedures, and instruction procedures, such as tests and checks. Chapter 7 of *Military Requirements for Petty Officers Third Class*, NAVEDTRA 10044 (latest edition), is a mandatory course that will give you a deeper indoctrination into watch qualifications and the general duties you will assume in your future duty stations

Collateral Duties

Finally, there will be quals for the collateral duties to which you will be assigned such as those for supply parts petty officer or shop quality assurance inspector. Collateral duty as supply parts petty officer does not sound exciting, but it is a job that must be done and done correctly Chapter 8 in *Military Requirements for Petty Officer Third Class*, NAVEDTRA 10044 (latest edition), will give you a good idea of the workings of the supply department, how it acquires the repair parts that you need, and how "repairables" are processed for turn-in.

SKILLS AND KNOWLEDGES

At the third or second class level, Opticalmen do not have the responsibility for administering an optical shop. However, an OM3 or OM2 will occasionally be responsible for preparing casualty analysis inspection sheets for instruments and maintaining records and logs in the shop. Opticalmen on active duty at the third class level should therefore observe the work of OMs at the first and second class levels and learn as much from them as possible.

Shop safety is something you should always emphasize and be aware of when you are using tools and operating machines. It is easy to injure yourself. Opticalmen should keep the shop in excellent working condition and hazard-free. Opticalmen should also work individually and collectively in a manner that minimizes personal injury.

As Opticalmen advance and move up the "enlisted ladder," they must acquire greater knowledge and additional skills. An Opticalman can acquire knowledge and skills in a number of ways: attendance at OM A and C schools; attendance at other Navy schools, such as Leadership, Career Counseling, and Instructor Training schools; completion of correspondence courses and college courses; and most important of all, completion of on-the-job training (OJT).

ADVANCEMENT

The benefits of advancement are clear: You get more pay, your job assignments become more interesting and more challenging, and you are regarded with greater respect by officer and enlisted personnel. You also enjoy the knowledge that you are getting ahead in your rating.

But, you are not the only one who profits. The Navy benefits too. Highly trained personnel are essential to the efficient functioning of the Navy. With each advancement, you will find that your value to the Navy increases in two ways: (1) as a specialist in the rating, and (2) as an instructor who can train others to contribute to the efficiency of the entire Navy.

You can find information on how to prepare and qualify for advancement in the *Military Requirements for Petty Officer Third Class*, NAVEDTRA 10044 (latest edition), *Military Requirements for Petty Officer Second Class*, NAVEDTRA 10045 (latest edition), and in the *Bibliography for Advancement Study*, NAVEDTRA 10052 (latest edition), which contains the required and recommended training materials and references for advancement. The information in the *Bibliography for Advancement Study* is issued annually and will provide you with a general idea of what you will need to learn and what the advancement examination questions will cover.

The Navy's advancement system is governed by *The Manual of Advancement*, BUPERS Instruction 1430.16 (series). The basic ideas behind the advancement system have remained stable for many years, but specific portions have changed. These changes are announced in BUPERS Notice 1418, which also provides information about regularly scheduled exam cycles. *The Manual of Advancement* and the latest copy of BUPERS Notice 1418 are available from your educational services officer (ESO).

The normal system for advancement can be divided into two parts:

1. Requirements that you must meet before you can be considered for advancement
2. Factors that determine whether you will be advanced

In general, to be considered for advancement you must

1. have a certain amount of time in paygrade;
2. demonstrate a certain level of knowledge of the material in your rate training manual by successfully completing the appropriate NRCC or by successfully completing an appropriate Navy school;
3. demonstrate ability to perform the Personnel Advancement Requirements (PAR), NAVPERS 1414/4;
4. be recommended by your commanding officer;
5. demonstrate a knowledge of military subjects by passing a locally administered military leadership examination based on the naval standards for advancement; and
6. demonstrate your understanding of the technical aspects of your rating by *passing* a Navywide advancement examination based on the occupational standards applicable to your rating and paygrade.

If you meet all of the requirements satisfactorily, you will become a member of the group from which advancement will be made.

Advancement is not automatic. Just meeting the requirements does not guarantee your advancement. Some factors that determine whether or not you will be advanced are

1. your advancement exam score,
2. your length of time in service,
3. your performance marks, and the
4. number of vacant billets.

If the number of vacancies exceeds the number of QUALIFIED personnel, every candidate will be advanced. More often than not, there are more qualified people than there are vacancies. When this happens, the Navy advances those who are the *best* qualified. To put it simply, each individual is given credit for what he or she has achieved in the areas of performance, knowledge, and seniority. A composite score, known as the final multiple, is reached by use of these three factors. All candidates are then placed on one list, with the person having the highest multiple placed first, and so on, down to the person with the lowest multiple score. Advancement authorizations begin with the persons at the top of the list and end when the number of persons needed to fill the existing vacancies has been reached.

Who, then, is advanced? Basically the persons who are advanced are the ones who have achieved the most in terms of preparing for advancement. They were not content just to qualify; they spent extra efforts in their training. Through training and work experience, they have developed greater skills, learned more, and accepted more responsibility.

While it cannot guarantee that everyone will be advanced, the advancement system does guarantee that everyone will compete equally for the vacancies that exist

CONTENTS OF THIS RATE TRAINING MANUAL

The contents of this rate training manual start with basic optical theory Before you learn to repair optical instruments, you must first learn something about what light is, how it behaves, and why it behaves as it does You may ask yourself, "why is this knowledge so important?" While it is true that you can handle many repair jobs by just memorizing a list of instructions, or by completing OM school, sometimes you may meet a problem that is not covered by the instructions. When there is no one available whom you can ask, you must be able to rely upon the knowledge you have gained concerning OPTICAL THEORY. Then you can figure out the answer for yourself.

After you have learned about light, you will learn how you can combine lenses and prisms to make optical systems. Then you will be ready for the instruments and repair techniques you will be required to use in the optical shop.

In the material at the end of this chapter, you will find some of the references that were used for the text of this rate training manual.

In the appendix, you will find a glossary. The glossary is a list of special technical terms that are used in the study of optics. The glossary contains a definition for each term. All of the terms we will use in this manual are defined in the glossary. The glossary also defines many terms that we will not use in this rate training manual, just in case you run across them in reference books. At the end of this manual is an index. (You already know how to use an index—just look up the topic.) All general topics are listed alphabetically.

This manual assumes that you already know a certain amount of math. But some of what you know you may have learned a long time ago. If you cannot remember this information in a hurry, then you will need a review of math. Navy training courses on mathematics will be helpful. It might be a good idea for you to keep a math course on hand for reference while you are studying the first few chapters of this rate training manual.

Naturally, this rate training manual cannot tell you everything you will need to know concerning the work of an OM. First, it would make this book so big and heavy you could not use it conveniently. Second, some details of Navy optics are confidential, and we cannot put this information in a book that is intended for general distribution. So, we will not be able to tell you where to find every screw on each model and modification of an instrument.

This manual is general and basic. You can acquire additional *specific* information from the following sources:

1. Opticalman A school, where you will receive instruction and practical experience
2. Navy technical publications, such as the *Naval Ships' Technical Manual* (NSTM), ordnance pamphlets (OPs), and NAVSEA publications

When we discuss a particular instrument, we will give the number of the technical manual (TM) or ordnance pamphlet (OP) in which you can find the information you will need. These references were considered to be complete at the time this rate training manual was published, but science, optical art, and Navy optics do not stand still. The Navy will constantly improve its instruments and put new equipment into service. These improvements and new instruments will be covered by the appropriate new technical manuals. You will have to stay alert and study these manuals as they become available. They will keep you up to date in the field of Navy optics.

Some of your work as an Opticalman will require an ability to read and work from mechanical drawings. You will find information on how to read and interpret mechanical drawings in *Blueprint Reading and Sketching*, NAVEDTRA 10077 (latest edition).

In addition to knowing how to read drawings, you must also know how to locate them. The drawings included in the manufacturers' technical manuals for certain equipment may give you the information you need. In many cases, however, you will have to consult the onboard drawings. These are sometimes called the ship's plans or ship's blueprints and are listed in an index called the *Ship's Drawing Index* (SDI).

The SDI lists all drawings that have a NAVSHIPS drawing number. The onboard drawings are identified in the SDI by an asterisk (*).

Drawings are listed in numerical order in the SDI and are filed by numerical sequence in the repair department technical library.

HOW TO STUDY THIS RATE TRAINING MANUAL

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

1. Study the naval standards and the occupational standards for your rating before you study this training manual. Refer to the standards frequently as you study this manual. The information you acquire will help you to meet these standards.
2. Set up a regular study plan. It will probably be easier for you to study at the same time each day. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you begin to study any specific part of this manual, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Thumb through the book. Look at the illustrations and read some of the text here and there as you see things that interest you.

4. Look at this 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. In this manner you will get a clear picture of the scope and content of this book. As you look through this book, ask yourself these questions:

- What do I need to learn about this?
- What do I already know about this?
- Is this information related to information given in other chapters? How?
- How is this information related to the occupational standards?

5. When you have a general idea of what is in this training manual and how it is organized, learn 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. You may find it helpful to make a written outline of the unit as you study, or at least to write down the most important ideas.

7. As you study, relate the information in this 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 a 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 have not. Without looking at the training manual, write down the main ideas that you have gotten from studying this unit. Do not just quote this book. If you cannot present these ideas in your own words, the chances are that you have not really mastered the information.

9. Use nonresident career courses (NRCCs) whenever you can. The NRCCs are based on RTMs or other appropriate texts. As mentioned before, you can complete a mandatory RTM by passing an NRCC based on the RTM. You will probably find it helpful to take other courses as well as those based on mandatory manuals. Taking a 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 this RTM. You are working for advancement to third class right now, but some day you will be working toward higher rates. Anything extra that you can learn now will also help you later.

REFERENCES

Naval Ships' Technical Manual (NSTM), NAVSEA S9086-CS-STM-000, Chapter 083, "Allowances, Issues, Expenditures of Material, and Repair Parts," Naval Sea Systems Command, Washington, DC, 15 May 1981.

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

CHAPTER 2

NATURE OF LIGHT

THEORIES OF LIGHT

Nobody knows exactly what light is. The scientists who study theoretical physics have been trying to determine what light is for centuries. Some of their experiments indicate that light is made up of tiny particles, while other experiments suggest that light must be made of waves.

Most people have always been curious about the world in which they live. Some of them invented theories to help explain the way things work. Regular reflection of light from smooth surfaces was known in the time of Plato, 400 B.C. As early as the second century A.D., the Greeks made observations concerning the refraction of light at the interface of two transparent media of different densities. Alhazen (965-1038) studied the refraction of light and disputed the ancient theory that visual rays emanated from the eye. He demonstrated the behavior of light as it passed from a less dense to a more dense optical medium and recognized that angles of incidence and refraction were related, but he was unable to discover the law that defined their relationship. This relationship was finally discovered 600 years later

Until about 300 years ago, no one had developed a reasonable theory of the nature of light Then Sir Isaac Newton published what he called the corpuscular theory of light. He believed that light was made up of high-speed particles and that any source of light sent out a stream of these particles. He also believed that these particles could travel through a vacuum and penetrate transparent materials such as air, glass, and water. Many people had observed that light seemed to travel in straight lines. Newton's theory of light explained this. If light was made up of flying particles, the particles had to move in a straight line; otherwise, they would violate the law of inertia.

Christian Huygens, who lived about the same time as Newton, had a different idea about light. He developed the wave theory of light. A few years before Huygens published his theory, someone had discovered that if you look at a small object through a certain kind of crystal (Iceland Spar) you can see not one image but two. Huygens could explain the appearance of the two images with his wave theory. Newton's theory could not. Huygens' greatest concern was this: It was easy for him to think of waves passing through water or sound waves passing through air; but, he wondered how it was possible for light waves to travel from the Sun to the Earth through empty space. How were the waves able to travel without there being something to travel in?

To answer that, Huygens invented a new substance, which he called ether. He assumed that ether occupies all space, even the space already occupied by something else. This ether had to be "loose" enough to let the Earth and planets move freely through it. At the same time, in order to carry waves at the speed of light, it had to be a solid many times more rigid than steel. It is easy to see why Huygens' theory was not very popular.

In 1827, Thomas Young and Augustin Fresnel studied the interference of light. They were able, under certain conditions, to make two beams of light cancel each other. You can see how two systems of ocean waves could cancel each other and make smooth water if the crests of one system were superimposed on the troughs of the other.

During his experiments, Young was able to measure the distance between two waves of light. But there was one strong argument against his wave theory; it could not explain why light travels in straight lines. If you have ever seen waves breaking against a breakwater, you have probably noticed that the waves curve around the ends of the breakwater.

Fresnel found that the same thing happens to light. Light waves actually bend around an obstruction, just as ocean waves bend around the end of a breakwater. But since light waves are extremely short, the amount of bending is very small. That is why no one had noticed it before.

Young and Fresnel were able to support Huygens' wave theory, but they could not help him with his ether theory.

In the last half of the nineteenth century, James C. Maxwell and Heinreich R. Hertz performed a number of experiments that seemed to prove that light is wave motion. Maxwell showed, by mathematical calculation, that an alternating current ought to radiate electromagnetic waves. By making certain electrical and magnetic measurements, Maxwell was able to estimate how fast waves should travel. The speed Maxwell calculated for his electromagnetic waves was almost exactly the speed of light.

Hertz set up an electric circuit that oscillated at a high frequency and found that his circuit gave off radiation that acted like light. The radiation could be reflected, refracted, and polarized, just like light. As a result of these and other experiments, wave theory gained further acceptance. It explained all the known facts and did away with the need for a rigid ether. All electromagnetic waves needed for propagation was an ether that was a nonconductor of electricity. So, for a while, physicists thought they had the theory of light solved.

In 1900 Max Planck discovered some new facts that the wave theory could not explain. Planck experimented with the photoelectric effect. He found that under certain conditions light can knock electrons off various substances. When this happens, the energy of the light is transferred to the electrons. Planck measured the energy of these electrons. In order to explain what he found, he had to assume that the energy of light does not flow in a steady stream, like waves, but moves in particles. He called these particles quanta, and his theory is referred to as the quantum theory.

Five years later, Albert Einstein backed up Planck's theory with mathematical equations, showing that quanta have a frequency, like waves

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

In effect, neither the particle theory nor the wave theory is a good theory, because neither explains all of the known facts. What we need is a new theory that will tell us how light can be made of waves and particles at the same time. In the future someone may give us the answer, but it cannot be done now.

But, we do know this: If we study the way light starts from a source, and the effect it has on matter when it stops, the quantum theory gives us the best answer. If we study the way light travels, what we find can best be explained by the wave theory. In this rate training manual we are going to study optical instruments and the way light travels through them, so we will use the wave theory.

Even if we do not know exactly what light is, we can get a good idea of how it acts. We know that light enables us to see and that light is a form of energy. You have seen a demonstration of that if you have ever used an exposure meter. If you turn the meter toward light, the meter hand will deflect, even though there is a spring holding it back. The energy of the light makes the hand move.

SOURCES OF LIGHT

All of our lives we have been aware that the Sun is our greatest source of light. The Sun and all other sources of light, regardless of the amount of light they give off, are considered 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.

The only sources of natural light are the Sun, 93 million miles away, and the stars Even though lightning, volcanic activity, and certain vegetable and insect luminescence are actually natural, they cannot be considered relevant to the study of optics.

From the previous statement, you should easily understand that all light that does not come from the Sun or 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 incandescent bulb, and with today's neon and fluorescent lights we have a wide variety of colors and intensities to choose from.

Any object that we are able to see because of light reflected from its surface is classed as an illuminated body. The Moon, because it reflects light from the Sun, is an illuminated body. The book you are reading now is an illuminated body because it reflects light energy, whether it comes from a natural or an artificial source.

TRANSMISSION OF LIGHT

Have you ever dropped a pebble in still water? (See fig. 2-1.) A falling pebble makes a "dent" in the surface. The surface recovers and rises, then falls and makes another dent. So when you drop a pebble into the water you create a source of oscillation. Energy spreads outward from the source of disturbance in the form of little waves. The waves are circles that get bigger and bigger. If you have ever seen wheat blowing in the wind, you have seen waves traveling across the field just like they do in water. And you have seen that the wheat itself does not go anywhere except up and down; it is only the waves that travel.

Here is a rule to remember: When wave motion is traveling through a medium, the medium is displaced and then returns to its original position. It is only the disturbance in the medium that travels.

MOTION OF LIGHT

A medium (singular for media) is a substance in which waves travel. When light travels from the Sun to the Earth, the medium is mostly empty space. When light travels through an optical instrument, the principal media are air and glass.

A luminous light source acts as an oscillator, just like the water where you dropped the pebble. Oscillating atoms in the glowing filament radiate energy in the form of light waves. And just like waves in the water, these light waves spread out from the source. Here is the big difference: In the water, the disturbance is only at the surface. Since the surface is a plane, the waves move outward in the form of growing circles; but the luminous filament creates a disturbance in three-dimensional space. Since light travels outward in all directions from its source, the waves take the form of growing spheres.

137.4

Figure 2-1.—Creation of waves in a liquid by a dropped pebble.

We cannot show that in figure 2-2 because the page surface is a plane.

In the figure, the circles spreading outward from the electric lamp show where the paper cuts the wave fronts. However, you should be able to picture these spherical wave fronts.

Take another look at figure 2-2. Pick any point on any of the wave fronts in the picture. Which way is the light moving at that point? The answer is this: The light is moving directly away from the light source. The lines in figure 2-3 show the direction in which the wave fronts are moving. They are the radii of the spheres formed by the wave fronts. You could draw as many of them as you like, but usually two or three will be enough to show where the light is going. In diagrams of optical instruments, and in this manual, these lines are called light rays.

So, when you see light rays in a diagram you will know they are just radii drawn from a light source—imaginary lines to show which way the light is traveling. Single rays of light do not exist. But, since of the most important thing we want to know about any optical instrument is how light travels through it, we will discuss light rays, instead of waves.

If you look at figure 2-3, you will see that the wave fronts near the source are more curved than those farther away. This causes the radii of the sphere to spread or diverge. As the wave front moves outward, however, it gradually becomes less curved and eventually appears to be almost straight, as shown in figure 2-4

After traveling a distance of 2,000 yards from their light source, radii are considered to be parallel to each other and perpendicular to the wave front

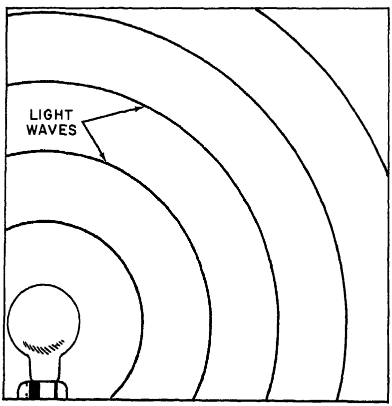

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Figure 2-2.—Light waves created by a light.

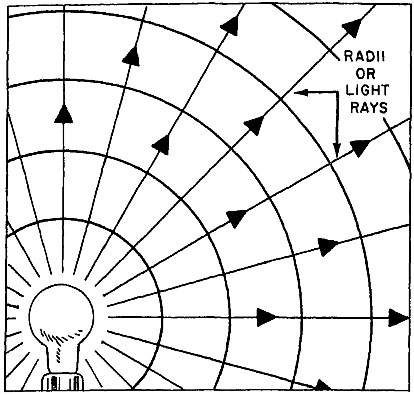

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Figure 2-3.—Direction of travel of light waves

INTENSITY OF LIGHT

The unit used to measure the intensity of a light source is called candlepower, or lumen If a luminous source gives 10 times as much illumination as a standard candle, it has the intensity of 10 candlepower

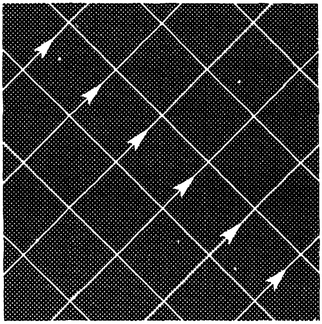
Because of the difficulty in getting exact measurements with a standard such as a candle, the National Bureau of Standards maintains a group of incandescent electric lights that meet the conditions for measurement standards.

The intensity of light falling on a nonluminous surface is measured in footcandles

The surface of an object located at a distance of 1 foot from a 1 candlepower source is illuminated by 1 footcandle.

Suppose the object is 2 feet from a light source of 1 candlepower. Then what is its illumination? Look at figure 2-5.

You can see that after the light has traveled 2 feet from the source, it covers four times the



137.10

Figure 2-4.—Waves and radii from a distant light.

area it covered after traveling 1 foot. The illumination is, at this point, only one-fourth of a footcandle. At 3 feet it is one-ninth of a footcandle. So, you see now that illumination is inversely proportional to the square of the distance between the source and the object. The formula for determining the strength of illumination is

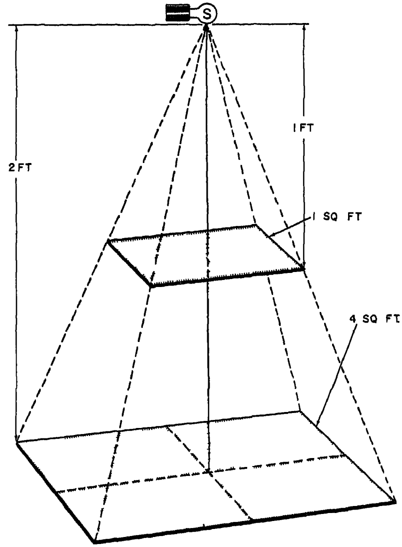
$$\text{Footcandles} = \frac{\text{Source candlepower}}{(\text{Source to object distance})^2}$$

SPEED OF LIGHT

In a vacuum, light travels at about 186,000 miles per second In a denser medium, such as glass, water, or diamond, it travels more slowly. The speed of light is an important measurement in the study of optics It is only because light travels more slowly in glass than in air that a glass lens can bend rays of light to a focus.

For a long time people thought that light traveled instantaneously, at an infinite speed. It was assumed that when any major event happened among the distant stars, the event could be seen instantly at all other points in the universe.

Galileo Galilei once tried to measure the speed of light, but without success Galileo stationed himself on one hilltop with one lamp, and an assistant on another hilltop with a similar lamp. Galileo would first uncover his lamp for an instant, sending a short flash of light to his assistant. As soon as the assistant saw Galileo's light he uncovered his light, sending a flash back



137.12

Figure 2-5.—The inverse square law of light.

to Galileo, who noted the elapsed time. After numerous repetitions of this experiment, at greater and greater distances between the observers, Galileo came to the conclusion that they could not uncover their lamps fast enough, because the total distance was only a couple of miles. In the one-fourth of a second it takes to react, light can travel about 40,000 miles The light was too fast for Galileo

Eight years later, in 1675, the Danish astronomer Olas Roemer found the first definite proof that light does not travel at an infinite speed. Roemer was studying one of the moons of Jupiter. Since the Earth, Jupiter, and Jupiter's moons all revolve in approximately the same plane, Roemer found that the moon he was studying was eclipsed by Jupiter each time it revolved around the planet. Roemer tried to measure the time the moon took to make one revolution, by measuring the time between eclipses. He found that while the Earth was moving closer to Jupiter, the time between eclipses got shorter and that when the Earth was moving away, the time between eclipses got longer.

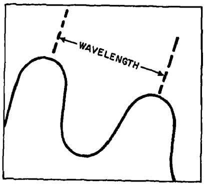
Roemer concluded from his measurements that light takes about 20 minutes to travel a distance equal to the diameter of the Earth's orbit. In Roemer's time the best guess for this distance was about 172,000,000 miles. If Roemer had finished the calculation, he would have computed a velocity of about 130,000 miles per second.

The most notable measurement of the speed of light was made by A. A. Michelson, using a rapidly revolving mirror. In Michelson's system, light was reflected from the revolving mirror to a distant stationary mirror. By the time the light got back, the revolving mirror had turned a short distance. The returning light then struck the mirror in a new position and was reflected at a different angle. The faster the mirror turned, the more the angle changed. By measuring this angle, the speed of the mirror, and the total distance traveled by the light, Michelson calculated the velocity of light.

The latest measurements of the velocity of light are based on interference. The results are even more accurate than those given by the revolving mirror.

Physicists can now measure the speed of light with great precision. Their calculations vary between 186,276 and 186,410 miles per second, according to the method used. For all practical purposes, we can assume that the speed of light in air or vacuum is 186,000 miles per second. In denser media, it is a little slower. Here is an example of how media slows yellow light.

Quartz	110,000 mps
Carbon	114,000 mps
Ethyl alcohol	137,000 mps
Water	140,000 mps
Diamond	77,000 mps



137.14

Figure 2-6.—Measurement of a wavelength.

Wavelength and Frequency

The action of waves on the surface of a liquid has explained the wave motion of light. But, 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 2-6. The best way to measure wavelength is by the frequency—the number of waves that pass a point in 1 second. To determine frequency, put a stake in water and count the number of waves that pass the stake per second (fig. 2-7).

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 a formula that shows the relationship between speed, frequency, and wavelength.

The formula is $c = f\lambda$

where c = speed of light in a vacuum

f = frequency of waves

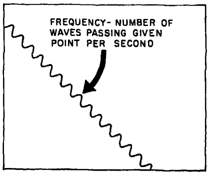
λ = wavelength (Greek letter lambda)

By applying the formula to the problem, you get

$$3 = 6\lambda$$

$$\lambda = 3/6 = 0.5$$

Light waves, in contrast with waves on water, are much too short to be measured in inches or millimeters. (A millimeter is about one twenty-fifth 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 shorter wavelength of light, a



137.15

Figure 2-7.—Determination of wave frequency.

smaller unit than a micron must be used. This unit is the millimicron, which represents one-thousandth of a micron and is abbreviated mμ.

Another important unit is the angstrom (AU), which is one-tenth 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 is used. It is one-thousandth of an angstrom (fig. 2-8).

In referring to the electromagnetic spectrum, we are talking about the whole range of electromagnetic radiations. In their basic nature,

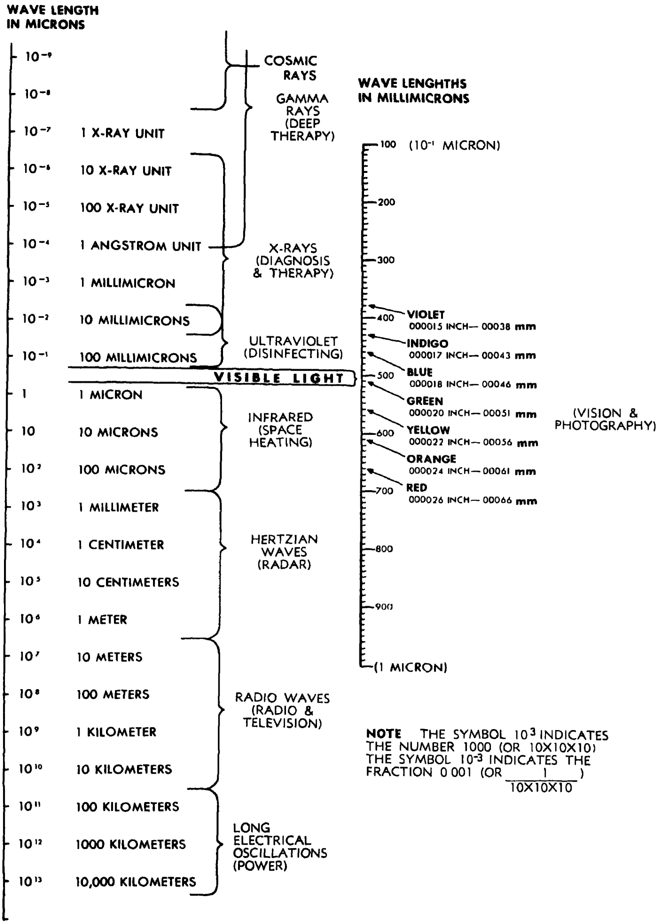


Figure 2-8.—Electromagnetic spectrum.

there is no difference between light waves and other kinds of electromagnetic waves. In a vacuum they all travel at the same speed—about 186,000 miles per second—but there is a great difference in wavelength and frequency between the various kinds of radiation. As shown in figure 2-8, visible light represents only a small range of wavelengths, from about 400 to 700 millimicrons.

Notice that in figure 2-8 each spectrum color has its own small range of wavelengths. For example, if light of around 660 mμ reaches your eyes, you see red. Light around 460 mμ will begin to appear blue; so the red waves are much longer than the blue waves.

Light with a wavelength of 300 mμ and shorter is sometimes called ultraviolet light; but, if we define light as visible radiation, then ultraviolet is not light. Ultraviolet radiation causes sunburn. All shortwave radiation can cause some physical damage if you are overexposed to it. A prolonged or repeated dose of strong X rays can cause irreparable damage to your body.

Gamma rays are the deadly shortwave radiation given off by atomic particles. Notice that infrared light rays are between 1μ and 100μ in the electromagnetic spectrum and are sometimes called heat rays. We cannot see infrared, but if we could, things would look a lot different. Surveillance photographs are often taken with infrared cameras because infrared radiation can penetrate haze and smoke more readily than visible light.

Infrared has several important military uses. It is sometimes used for signaling between ships at night. A "Nancy" receiver is used to detect the infrared signals.

Intelligence-gathering teams use infrared photography to take advantage of the fact that things look different on infrared photographs. A camouflaged object may blend into its surroundings and be almost indistinguishable. However, since it does not reflect the same amount of radiation as its surroundings, an infrared photo will make the camouflaged object stand out clearly.

In Vietnam the "snooperscope" was used to see in the dark. The snooperscope has a powerful infrared spotlight. When the infrared radiation strikes an object and is reflected back, the snooperscope receiving unit changes the reflection of the object to visible wavelengths. So, with a snooperscope, you can watch the enemy at night without being observed. The "sniperscope" uses the same principle, except that it is attached to a rifle and is used to aim the weapon.

The wavelengths for radar are adjacent to the infrared "band" and are a little longer. We know that these wavelengths travel at the same speed as light because they have been sent to the Moon and reflected back in 2.6 seconds. The distance to the Moon is about 240,000 miles (in round numbers). Therefore, $2 \times 240{,}000$ miles $\div$ 2.6 seconds = 184,615, the speed of radar in miles per second.

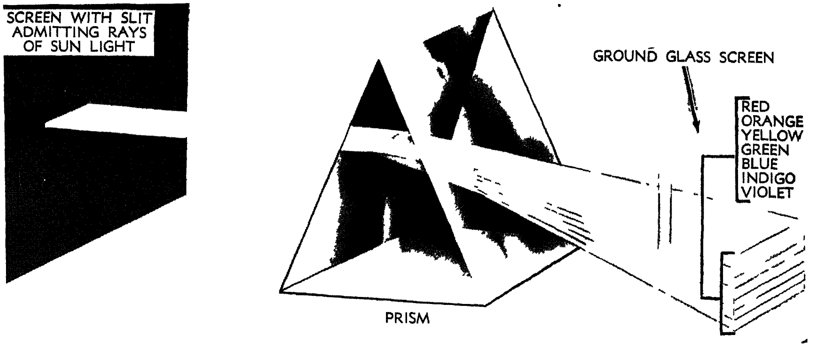
The radiation that reaches us from the Sun consists of visible light, plus most of the infrared and the longer part of the ultraviolet. Solar radiation includes some of the shorter waves, but most of them are scattered or absorbed by the Earth's atmosphere before they reach the surface of the Earth.

Color of Light

Since sunlight includes the whole range of wavelengths between 400 mμ and 700 mμ, it contains a mixture of all visible colors. You can prove this for yourself. When the sun is shining, put a prism on a table in a room with one window. Cover the window with dark paper Then cut a slit about one 1 inch long and one-sixteenth of an inch wide in the paper to admit a small quantity of light. Hold the prism close to the slit to ensure that sunlight passes through the slit onto one of the long faces of the prism At the same time, hold a piece of ground glass screen or a sheet of 6- to 8-inch white paper on the other side of the prism. When the sunlight passes through the prism, wavelengths of various colors will refract at different angles toward the base of the prism You will see the whole range of spectrum colors produced. This breaking up of white light into colors is called dispersion (fig. 2-9) Notice that the red light, with a longer wavelength, is bent less than violet, which has a shorter wavelength.

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

When you look through a piece of yellow glass, you see yellow. The glass is transmitting yellow light and absorbing other colors. Usually, a piece of yellow glass will absorb violet, blue, and some green. It will transmit yellow, orange, and red. But when yellow, orange, red, and a



137.19

Figure 2-9.—Dispersion of light into a spectrum by a prism.

little green all enter your eye at once, the color you see is yellow.

This selective absorption is the principle of the color filter you will find in many optical instruments Suppose you are using a rangefinder on a hazy day. The image you see will be blurred by the haze. Slip a yellow filter into the line of sight, and the image becomes sharper. Here is how it works A thin haze will let most of the light go through, but it scatters some of the blue and violet light in all directions Haze is visible mostly because of this scattered blue and violet light. Now look through a yellow filter, which absorbs blue and violet, and the haze becomes invisible (Not entirely invisible, of course, but enough to help.)

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 is therefore not always what you expect.

To fully understand the ability to see an object, you must understand what light is and how it reacts with matter. To be sure you understand, review the 15 items listed below:

1. Light is a form of energy.
2. Experiments show that light has the nature of particles and is dispersed in waves.
3. Luminous objects are a source of light.
4. Nonluminous objects reflect light from another source.
5. Visible objects reflect light that enters our eyes.
6. Light travels in straight lines as rays of light.
7. Only the energy of a wave travels.
8. The intensity of light is measured in candlepower (or lumens).
9. Wavelength is the distance between two successive waves.
10. Frequency is the number of waves passing a fixed point in 1 second.
11. Visible light is a relatively small range of the electromagnetic spectrum.
12. The speed of all electromagnetic waves is the same, even in a vacuum
13. The speed in more dense media is less and varies with the wavelength.
14. White light is made up of a mixture of wavelengths between about 400 and 700 mμ.
15. When an object reflects some of the wavelengths of light, but absorbs others, it gives a sensation of color.

BEHAVIOR OF LIGHT

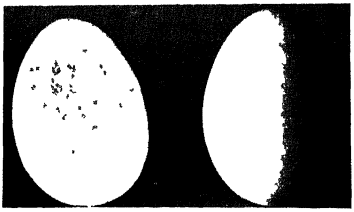
How do you know what you are looking at? Stop reading for a minute and look around you. You will see a hundred things you can recognize and name. How can you tell them apart? Is it because of the different sizes and shapes? Yes, but how can you tell the shape and size of an object by just looking at it? How do you know where one object stops and the next one begins?

You know that you see these things by the light that they reflect. If two objects appear differently to you, it is because they reflect light in a different way.

Color is one difference. If two objects reflect a different color you will not have any trouble telling them apart. Intensity of the reflected light is another difference. Suppose you have two pieces of paper, and both of them are reflecting red light and absorbing all the other colors. If one of the pieces of paper is reflecting 80 percent of the red light that falls on it and the other piece of paper is reflecting 40 percent of the light, you can tell them apart at a glance.

So you can judge the size and shape of an object when the light it reflects is different in color or intensity from the light reflected by other things around it. Take a look at figure 2-10. It is a picture of two objects. One is an egg and the other is a piece of cardboard cut to the same outline. Both are the same color—white. But you do not have to look twice to tell which is the egg and which is the cardboard. All parts of the cardboard reflect light equally, because all of the rays that fall on it strike at the same angle. But for the egg the reflection pattern is different.

Rays of light strike the shell at different angles on different parts of the shell. The amount of light reflected from any surface depends partly on the angle the surface makes with the incident light. Even though the egg and the cardboard have the same outline, you can see the difference in shape by observing the variations in intensity of the reflected light.



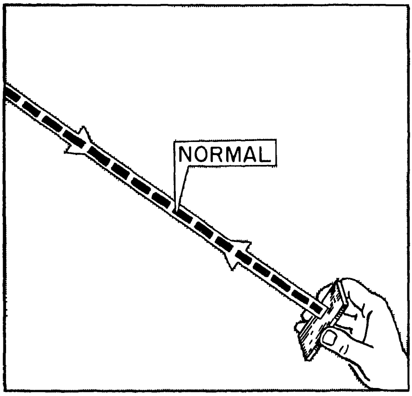
137.24

Figure 2-10.—Visual determination of difference between objects.

There are two other ways to tell the egg from the cardboard. Did you notice that the shadows are different shapes? That is one way to tell the difference. Now take a close look at the egg. Light striking at certain angles shows the roughness of the shell. The shell and most other surfaces have texture. They show minute differences in color or shape all over the surface.

For convenience, we can divide objects into three different classes, depending on how light acts when it strikes them. Most objects are opaque. All the light that strikes an opaque object is either reflected or absorbed. None of it goes through the object. A translucent object will reflect some of the light striking it and absorb some of it. But a translucent object will also let some of the light go through it. A piece of tissue paper makes a good example. Hold a sheet of tissue paper up to a strong light. A lot of the light will come through, but you cannot see a clear image of the light's source when you look through the paper. Light rays are well scattered when they pass through a translucent object. A transparent object, such as a sheet of glass, will reflect a little of the light that strikes it and absorb a little of the light. But, most of the rays will go through the sheet of glass. You can see objects clearly through a clean piece of glass, because the light passes through without scattering

We are using the terms opaque, translucent, and transparent because they are convenient. No medium, except empty space, is perfectly



137.25

Figure 2-11.—Reflection of a beam of light back on its normal or perpendicular.

transparent. Air seems to be transparent when you look through it for a short distance. From an airplane, objects at a great distance appear hazy, even on a very "clear" day. The sky appears blue because part of the sunlight that passes through the air is scattered in all directions. When you look at the sky you are really seeing scattered sunlight.

We think of glass as transparent because we usually see it in thin sheets. But how do you think things would look through a pane of glass 10 feet thick? To get a rough idea, imagine holding a pane of window glass up to the light and looking through the edge of it. You can imagine how much light would be transmitted by a pane of window glass a foot thick. The glass would not be very transparent. Conversely, no medium is perfectly opaque. You can see through anything if it is thin enough. Even heavy metals like silver and gold can be plated on glass so thinly that you can see through them. If you make the film just a little bit thicker it will be translucent, or between translucent and opaque. These are relative terms, which we use for convenience.

You will find all three of these classes of material in optical systems. Lenses and prisms are transparent. Any light they absorb will be wasted and will decrease the brightness of the image. So, people who make optical glass make it as clear as possible. Good optical glass is much more transparent than window glass.

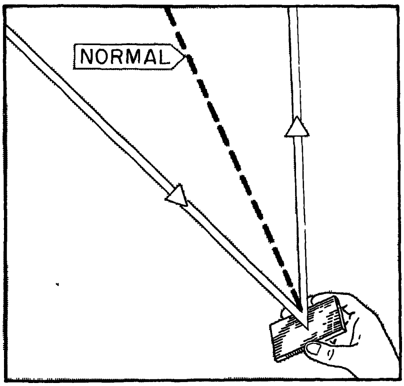


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Figure 2-12.—Reflection of beams of light at different angles.

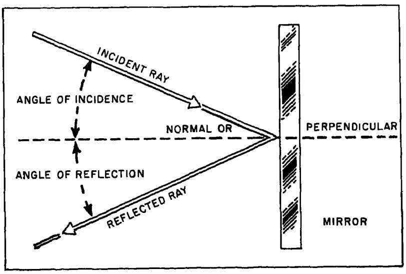
The tubes that hold the lenses and prisms in an optical system are opaque so that no light can get into the system unless it comes in through the front lens. The tubes are painted black inside so that they will absorb instead of reflect any light that strikes them. Translucent objects are rare in optical systems. The only examples of translucent objects are the ground glass screens used in some types of cameras, collimators, and polariscopes.

Reflection

You know from experience that a mirror reflects light. If you experiment with a plane mirror, in a darkened room with a window to 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 perpendicularly to a beam of light, you can reflect the beam back along the same path by which it entered the room, as shown in figure 2-11.

Then, if you shift the mirror to an angle from its perpendicular position, the reflected beam will shift at an angle from the incoming beam twice as great as the angle by which you shifted the mirror. Look at figure 2-12. If you hold the mirror at an angle of 45° to the incoming beam, the reflected beam is projected at an angle of 90° to the incoming beam. Basically, the incoming beam struck the mirror at an angle of 45° and left the mirror at another angle of 45°.

If we put that in technical terms, we have the law of reflection. Look at figure 2-13 for an explanation of the terms



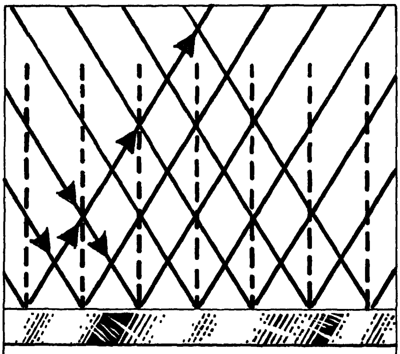
101.30
Figure 2-13.—Terms used for explaining reflected light.

The ray that strikes the mirror is called the incident ray, and the ray that bounces off is called the reflected ray. The imaginary line perpendicular to the mirror surface at the point where the ray strikes is called the normal. The angle between the incident ray and the normal is the angle of incidence. The angle between the reflected ray and the normal is the angle of reflection.

The first half of the law says: The angle of incidence is equal to the angle of reflection. The other half of the law says: The incident ray, the reflected ray, and the normal all lie in the same plane. You will find plenty of use for this law later on, so you should memorize it. You should also experiment with a mirror until you are sure you understand this law thoroughly.

When light strikes a smooth polished surface, like the mirror in figure 2-14, the reflection will be regular.

Parallel rays will all strike at the same angle and will be reflected at the same angle. They will still be parallel after the reflection. But, suppose the surface is rough, as shown in figure 2-15. The only way you can tell what light will do is to apply the law of reflection separately to each ray. Figure 2-15 applies the law of reflection to each of the rays in the picture. For each ray, the angle of incidence is equal to the angle of reflection. But, because the surface is rough the angle of incidence will be different for each ray. The reflected light is scattered in all directions



DOTTED LINES—NORMAL

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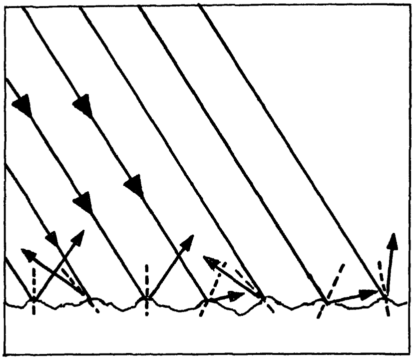
Figure 2-14.—Regular reflection.



DOTTED LINES—NORMAL

137.31

Figure 2-15.—Diffuse reflection.

We see most things by irregular reflection When light strikes a sheet of paper, for example, the rays are scattered in all directions Here is an experiment you should try Put a sheet of white paper on a table and illuminate it with a reading lamp or an overhead bulb. The paper looks equally bright over all of its surface This is because each part of the paper scatters light in all directions. If you walk around the table, you will see that the paper appears equally bright from all angles and that the reflection from the surface of the paper is irregular Now replace the paper with a mirror. You will see that the light is reflected brightly in one area of the mirror, while the rest of the surface of the mirror is fairly dark If you walk around the table now to a position where you can see a reflection of the lamp, and to other positions where you cannot, the reflection of the mirror will be regular

There are a couple of other terms you may run across when reading other books on optics. Regular reflection is sometimes called specular reflection, and irregular reflection is sometimes called diffuse reflection.

Refraction of Light

You have probably noticed that a pool of clear water is deeper than it appears, especially if your line of vision makes a small angle at the surface.

Also, when a straight stick enters the water at an angle, the stick appears to bend at the surface of the water. How do you explain these illusions? It is easy. When a ray of light passes from the water into the air, the ray bends. Also, when a ray passes from the air into water, it bends at the surface of the water. This bending of light, when it goes from one medium to another, is called refraction.

Figure 2-16 shows what happens when a beam of light goes through a sheet of glass. The beams of light in this picture are made up of bundles of parallel rays. The beam that strikes the glass at a right angle is not refracted. The beam that strikes the glass surface at a smaller angle is bent downward, toward the normal, as it goes through the surface of the glass. As long as the beam stays in the glass, and as long as the glass is of uniform density, the beam will travel in a straight line. But when it leaves the glass it will be refracted again. This time it will bend away from the normal.

To understand why the light is refracted, you should briefly forget about beams and rays, and think about wave fronts. Rays, as you remember, are just imaginary lines that show which way the waves are moving and are at right angles to the wave fronts. Figure 2-16 shows the wave fronts in a beam of light striking a glass plate at an angle.

Look at where the wave has just started to enter the glass. As each point on the wave strikes the glass it slows down, because light travels more slowly in glass than in air. The first points on the wave to enter the glass will slow down first, while the other points on the wave still move at their original speed. As other points on the wave enter the glass, they will slow down too, resulting in a slowdown of the entire portion of the wave inside the glass. The slowdown causes the wave to change its direction of motion inside the glass. Since the direction of the wave front changes inside the glass, the direction of the wave's light ray also changes inside the glass.

As long as the light stays in the glass it will travel in the same straight line, but when the light leaves the glass it will change direction again. The first points on each wave to leave the glass will pick up speed before the others. So, the wave fronts will change their angle again. That, of

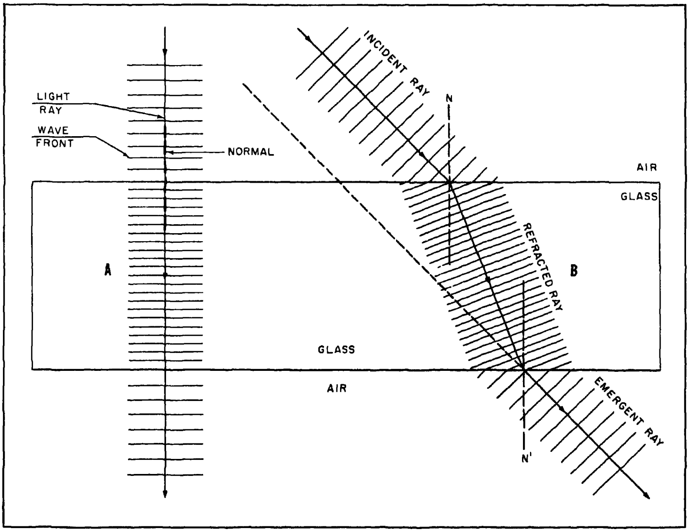


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Figure 2-16.—Refraction of light beams by a sheet of glass.

course, changes the direction of the light ray.

When a ray of light goes through a plate of glass with parallel faces, the ray that comes out will be parallel to the one that goes in. The glass displaces the ray to one side, but it does not change its direction. Figure 2-17 shows what happens.

The ray that strikes the denser medium (glass, water, and so forth) is called the incident ray. While the ray is traveling in that medium it is called the refracted ray. When the ray leaves the denser medium it is called the emergent ray. Recall that the normal is an imaginary line at a right angle to the surface. The angle between the incident ray and the normal is the angle of incidence. The angle between the refracted ray and the normal is the angle of refraction. (Notice that both angles are measured from the normal and not from the surface of the medium.)

The law of refraction says: Light bends toward the normal when it enters a medium denser than the one in which it is traveling. Light bends away from the normal when it enters a medium less dense than the one in which it is traveling. If you memorize the law, you will find it useful later on, and it will help you trace the path of light through optical systems.

You have learned that light is refracted at the surface of two different media because of the difference of the speeds of light in each medium. The greater the change in speed, the more the light rays bend. Before you can trace the path of light through an optical instrument, you will have to calculate the amount of bending (angle of refraction) at several surfaces. To do that you will need to know two things—the angle of incidence and the speed of light in the lens or prism you are studying. But instead of the speed of light, you will use the index of refraction, because it is less complicated. The index of refraction of a medium is the velocity of light in space divided by the velocity of light in the medium. As an example, we will find the index of refraction of water. If we divide the speed of light in space (186,400) by the speed of light in water (139,800), the answer will be 1.333.

$$\frac{186{,}400}{139{,}800} = 1.333$$

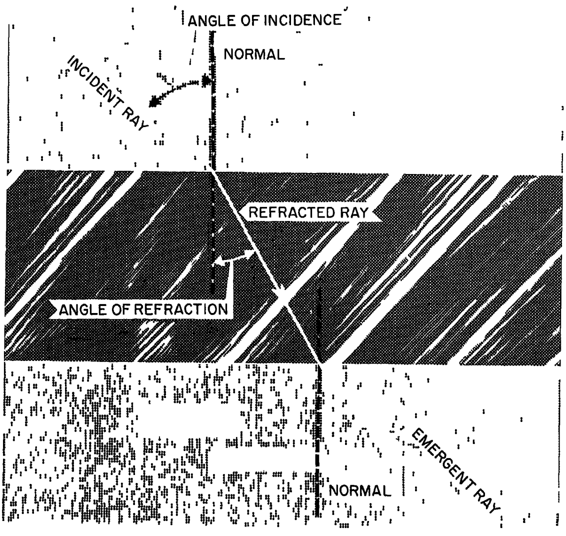

Figure 2-17.—Terms used for describing refraction.

We have used almost exact velocities for this problem and have computed a figure of 1.333 for the index of refraction of water. The table below lists the index of refraction for some common media. Remember that the speed of light varies with its wavelength, so the index of refraction depends on wavelength too. (This table is for light of 589 mμ wavelength.)

Vacuum	1.000000
Air	1.000292
Water	1.333
Ordinary crown glass	1.516
Boro-silicate crown glass	1.524
Canada balsam	1.530
Light flint glass	1.571
Medium flint glass	1.627
Dense flint glass	1.754
Extra dense flint glass	1.963

For most purposes, you can use 1.000 for the index of refraction of air.

How can you calculate an angle of refraction? Here is an example. Suppose a ray of light strikes a plate of glass at a certain angle. You know the angle of incidence and the index of refraction of the glass and want to find the angle of refraction. To find the angle of refraction, use the equation for Snell's law ($n \quad \mathrm{Sin}\ \theta = n' \cdot \mathrm{Sin}\ \theta'$). It is not as difficult as it looks. In optical formulas, the letter *n* means index of refraction. In this formula, *n* is the index of refraction of the first medium, and *n′* (prime) is the index of refraction of the second medium. Sin is the abbreviation for sine, which is a trigonometric function expressing the ratio of the side opposite a given angle to the hypotenuse. The Greek letter theta (θ) usually refers to an angle. 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.

Now, we will use Snell's law in an actual problem. Figure 2-18 shows the problem.

Here we have a ray of light striking a plate of glass at an angle of 45°. The index of refraction of the glass is 1.500. What is the angle of refraction? Apply the formula: The index of refraction of the first medium (air, 1.000) times the sine of the angle of incidence (Sin, 45°) is

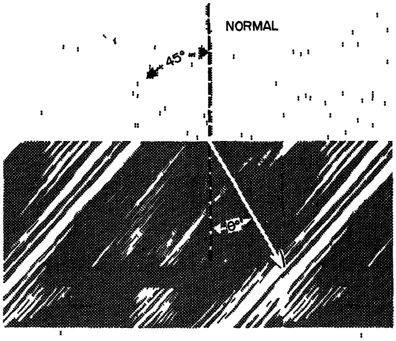

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Figure 2-18.—A problem in refraction.

equal to the index of refraction of the second medium (glass, 1.500) times the sine of the angle of refraction. When you write that as an equation it will look like this: $1.000 \times \mathrm{Sin}\ 45° = 1.500 \times \mathrm{Sin}\ \theta'$ Now look up the value of sine 45° in a table of trigonometric functions. You will find that sine 45° is 0 707. Substitute, and solve for sine θ':

$$\mathrm{Sin}\ \theta' = \frac{1.000 \times 0.707}{1.500'} = 0.471$$

Now look in the table and find the angle whose sine is 0.471. The answer is 28°0.20′. That is the angle of refraction.

Look back at figure 2-18 and reverse the direction of the light ray. Its angle of incidence at the surface of the glass is 28°0.20′. Now, what is the angle of refraction? Use the same equation. Remember that now the first medium is glass and the second is air. Substitute the known values: $1.500 \times \mathrm{Sin}\ 28°30' = 1.000 \times \mathrm{Sin}\ \theta'$. Solve the problem for sine θ'. The sine of θ' equals 0.707. Look up 0.707 in the table and you find that the angle of refraction is 45°. But, 45° was the angle of incidence when the ray was going in the other direction. What does that mean? It means the ray will retrace its path exactly if you reverse the direction of it.

Here is an important rule to remember: If you reverse the direction of a light ray at any point in an optical system, the ray will retrace its path back through the system. This is true regardless of the number of lenses, prisms, and mirrors in the system. This is called the law of reversibility.

Combined Reflection and Refraction

When the surface of glass is smooth, it will reflect a part of any light that strikes it. Most of the light striking the glass will be refracted. The surface will reflect about 5 percent of the light—or more if the angle of incidence is large. (Remember that the angle of incidence is measured from the normal.)

Figure 2-19 shows a ray of light passing through a plate of glass. Most of the light entering the glass is refracted, with about 5 percent reflected. When the refracted ray strikes the lower surface, most of the ray will leave the glass. But about 5 percent will be reflected back into the plate. This is called internal reflection. The internally reflected ray will be refracted at the upper surface and will emerge parallel to the reflection from the incident ray.

Figure 2-20 shows reflections from both surfaces of a glass plate. See if you can determine which of the two images is caused by reflection.

If you have several plates of glass in a stack, with thin layers of air between them, you will see twice as many reflections as there are pieces of glass. You will sometimes find a situation like that in optical instruments. If there are five lenses in a system, you will have ten surfaces. Each surface will reflect a part of the light. The image you see when you look through the instrument is formed only by the light that passes through

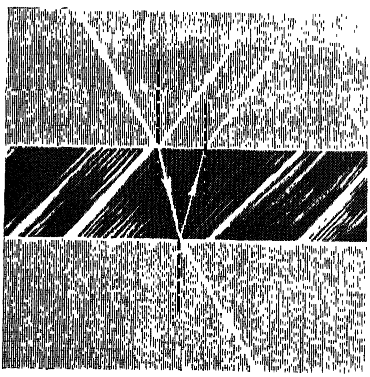

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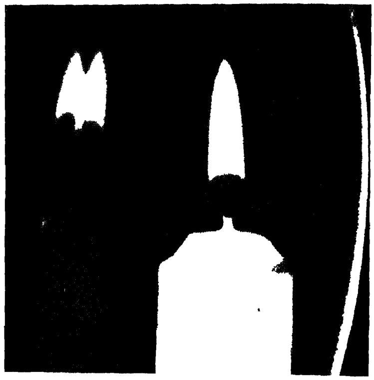
Figure 2-19.—Reflection and refraction combined.



137.36
Figure 2-20.—Reflection from the surfaces of a glass plate.

the lenses. So the reflected light is wasted. Complex instruments, like the submarine periscope, may have more than two dozen surfaces, each reflecting a part of the light. If we do not stop these reflections, the instrument will waste more light than it uses. What is done to correct this? The lenses and prisms are treated by a special process that prevents reflections This process is called coating, or filming

Since good optical glass is transparent, how can you see it? Why is it visible? A smooth piece of glass is visible mostly because of reflection from its surface. If you are looking through a clean plate of glass and cannot see its edges, the glass will appear to be invisible except for the surface reflection.

Other (nonoptical) glass objects are visible partly by refraction. You will be able to see a part of the background through the glass, but the glass will bend the rays from the background before they reach your eyes. Each ray will bend at a different angle, depending on the angle at which the ray strikes the surface of the glass, causing the background to appear distorted.

Look at the glass rod in figure 2-21. The rod is in a beaker of air, and behind the beaker is a sheet of white paper. (We are going to make the rod "disappear.") Why is the rod visible? The rod is visible partly because of reflection and partly because of refraction. Light from the white paper is refracted as it passes through the rod, so that the background is distorted and the rod seems to

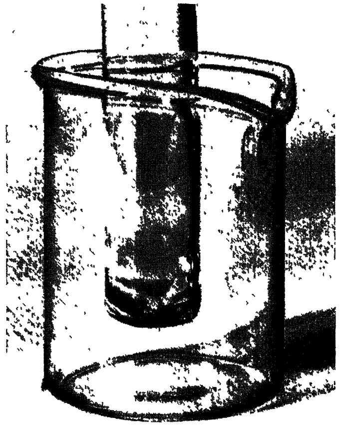


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Figure 2-21.—Visibility resulting from combined reflection and refraction.

vary in brightness. But, reflection can take place only at a surface between two media with different indexes of refraction. Since the rod in figure 2-21 is in air, the difference between the two media is fairly large and the rod is quite visible. The same thing is true of refraction. You can prove that by using Snell's law. If the two media have the same index of refraction, the angle of refraction will be equal to the angle of incidence, and there will not be any refraction.

In figure 2-22 the end of the rod is immersed in water. Now the difference in index of refraction between the two media is much smaller, due to the curved surface of the water in the beaker. This curved surface causes a varied amount of refraction, so the rod in the water appears larger. There is less reflection and refraction. The part of the rod that is underwater is less visible than the rest of the rod, but it is still visible.

Suppose we put the end of the rod in a solution that has the same index of refraction as the glass (fig. 2-23). Now the glass rod is surrounded by another medium with the same index of refraction. Because there is no reflection or refraction, the end of the rod is invisible.

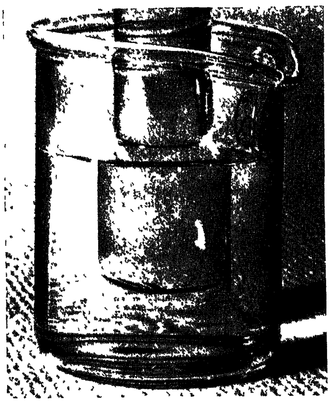

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Figure 2-22.—Effect of visibility by the reduction of reflection and refraction.

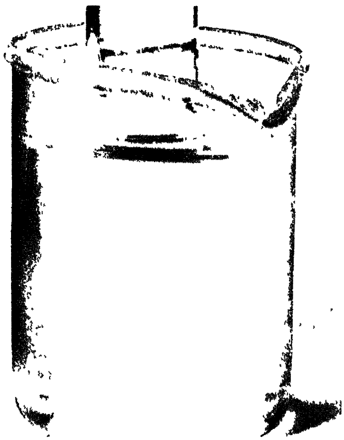

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Figure 2-23.—Elimination of visibility by eliminating reflection and refraction.

Total Internal Reflection

You have seen that when a ray of light passes from one medium to another of lower density (as from glass or water into the air), a part of the light is internally reflected. When the angle of incidence is small, the surface will reflect only a small part of the light; but if you increase the angle of incidence, you will increase the percentage of internal reflection.

Figure 2-24 shows several rays of light radiating from a theoretical underwater light source. The surface of the water will reflect about 5 percent of the ray that strikes it along the normal, but the ray will emerge unrefracted. The next ray shown in the picture has an angle of incidence of about 30°; the surface will reflect about 10 percent of that ray. (The drawing does not show the reflected ray.) The rest of the rays will be refracted and will bend away from the normal.

Look at the next ray. The surface will reflect nearly half of that ray back into the water. But, look at what happens to the refracted ray. It bends so far away from the normal that it travels along the surface of the water. The angle of refraction is 90°. When the angle of refraction is 90° the angle of incidence is called the critical angle. What happens when the angle of incidence is greater than the critical angle? The ray will be entirely reflected and none of the ray will pass through the surface. For all rays striking the surface at an angle greater than the critical angle, there is total internal reflection. Remember that the critical angle can only be shown when light is traveling from a more dense medium to a less dense medium.

The following is a table showing the critical angles of various media when the adjacent medium is air:

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

We will now calculate the critical angle of water. The second medium is air. Remember, when the angle of incidence is equal to the critical angle, the angle of refraction is 90°. According to Snell's law, the index of refraction of the first medium (water, 1.333) times the sine of the angle of incidence (critical angle) is equal to the index of refraction of the second medium (air, 1.000) times the sine of the angle of refraction (Sin, 90°). Or,

$$1.333 \times \operatorname{Sin} \theta = 1.000 \times \operatorname{Sin} 90°$$

Look up sine 90° in the table of functions. Substitute and solve the equation for sine θ (Sin 90° = 1.000).

$$\operatorname{Sin} \theta = \frac{1.000 \times 1.000}{1.333} = 0.75018$$

Now look up 0.750 in the tables and you will find that $\theta = 48°36'$. That is exactly the value given in the table of critical angles.

Now we are going to see if we can prove mathematically that total internal reflection always occurs at angles greater than the critical

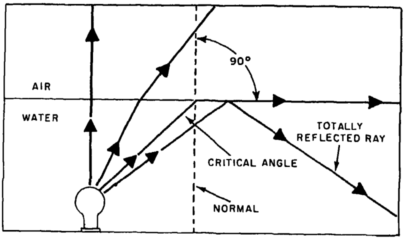

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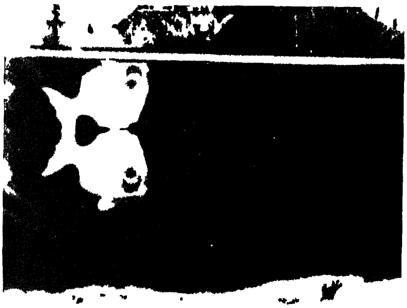
Figure 2-24.—Angles of light rays from an underwater source.



137.41
Figure 2-25.—Total internal reflection at the surface of water.

angle. Assume the angle of incidence at the surface of the water is 50°—just a little greater than the critical angle. Using Snell's law, calculate the angle of refraction.

$$N \cdot \sin\theta = N' \cdot \sin\theta'$$

Substitute $1.333 \times \sin 50° = 1.000 \times \sin\theta'$

Look up the sine of 50°. Substitute and solve the equation.

$$\sin\theta' = \frac{1.333 \times 0.766}{1.000} = 1.022$$

When you look at the table of sines, you will find that no angle has a sine greater than 1.000. There is no angle of refraction, therefore, there is no refraction. All of the light is reflected.

Figure 2-25 shows total internal reflection at the surface of the water. Rays of light from the goldfish, are striking the upper surface of the water at greater than the critical angle and are being reflected back into the water. Since the reflected rays are striking the end of the aquarium at less than the critical angle, they are passing through, and you can see an image of the fish reflected by the upper surface of the water. Figure 2-26 is a diagram showing the path of the reflected rays.

Atmospheric Refraction

For most purposes, we can assume that air has exactly the same index of refraction as empty space. But, that is not exactly true. There is enough difference to make the Sun's rays bend when they enter the Earth's atmosphere at an angle (fig. 2-27).

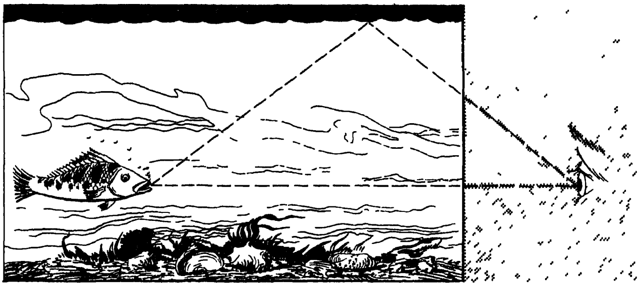


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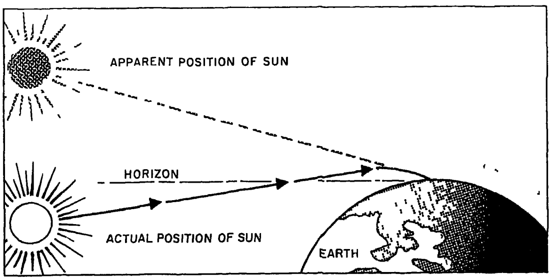
Figure 2-26.—Effect of total internal reflection on light rays.



137.44

Figure 2-27.—Visibility of the Sun below the horizon as a result of refracted light.

Of course the atmosphere has no definite upper surface—the decrease in density of the air is very gradual. The rays of sunlight do not bend at a sharp angle. Since they are entering a medium in which the index of refraction changes gradually, the rays curve gradually.

Atmospheric refraction makes the day about 4 minutes longer than it would be if the Earth had no air. You can still see the Sun for a short while after it has actually set, because the air bends the Sun's rays downward.

How much the Sun's rays bend depends on the angle at which they enter the atmosphere. The rays bend most when they are nearly horizontal. As the angle of incidence decreases, the angle of refraction decreases; and when the Sun's rays enter the atmosphere along the normal, there is no refraction. You may have noticed that the Sun looks a little flat when it is near the horizon. That is because rays from the bottom of the Sun's disc enter the atmosphere at a greater angle than those from the upper part of the disc. As a result, they bend more. That makes the apparent angle between the top and bottom of the Sun smaller and the Sun appears flat.

Maybe you have noticed that the setting Sun or the rising full Moon looks bigger when it is near the horizon than it does when it is higher in the sky. That is an optical illusion—it has nothing to do with refraction. The apparent magnification of the Sun and Moon when they are on the horizon is entirely imaginary. If you doubt it, try this; get a pair of binoculars with a mil scale, and measure the diameter of the rising Moon in mils. Then, wait a couple of hours, and repeat the measurement. The Moon may look smaller to the naked eye, but the reading on the mil scale will be the same.

MIRAGES.—Thirsty travelers in the desert often see beautiful lakes that are not really there. They are not hallucinations. Mirages can actually be photographed. You have probably seen one yourself, even when you were not thirsty.

Where can you find a mirage? Look for one on a black asphalt highway, on any clear hot summer day. When the highway rises in front of you and then flattens out so that its surface forms a small angle with your line of sight, you will see reflections of the sky. The reflections look like puddles of water in the road. If the conditions are just right, you may even see an approaching car reflected in a mirage.

What causes a mirage? The answer is refraction. When the Sun's rays are shining brightly on sand, or on a highway, the rays make the surface hot These hot surfaces heat the air just above them, while the air at higher levels remains comparatively cool. Since cool air is denser than hot air, the index of refraction is fairly low at the surface and gradually becomes greater as you go higher

Figure 2-28 shows the path of light rays in a mirage. The ray that travels in the cool air does not bend The ray that travels downward toward the warmer air curves upward It is easier to understand a mirage if you think of wave fronts that are at right angles to the curved ray The air's index of refraction is greater at higher levels, which causes the upper/part of the wave front to slow down more than the lower part Since the upper part of the wave is "dragging" in denser

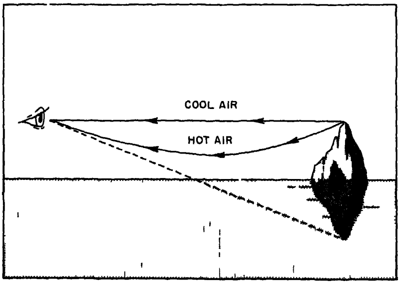


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Figure 2-28.—Path of light rays in a mirage.

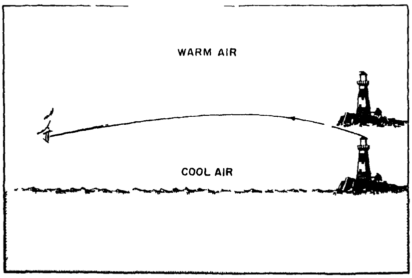

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Figure 2-29.—Path of light rays from a looming object.

air, the wave front will constantly change its angle. And, since the ray is always perpendicular to the wave front, the ray will curve.

LOOMING.—Looming is the exact opposite of a mirage. Ships, lighthouses, and islands occasionally loom; that is, they appear to hang in the sky above their actual location. On certain bodies of water, such as the Chesapeake Bay and the Gulf of California, looming is very common. Figure 2-29 shows the path of the light rays.

If the water is a good bit colder than the air, the air will be cooled at the water surface. The index of refraction will decrease as you go higher, and the rays of light will bend downward.

HEAT WAVES.—Another thing you are likely to see on a hot highway is a shimmering of the air. This happens when the air is unevenly heated. The convection currents of the hot air will rise. The air in these rising currents will be of varying density. The rays that pass through this rising air will be refracted at various changing angles, causing the shimmering and distortion we sometimes call heat waves.

The twinkling of stars has the same basic cause as shimmering on a highway. Convection currents are constantly changing the density of the air, and the stars' rays are refracted at changing angles.

RAINBOWS.—You can see a rainbow only under very special conditions. First of all, to see a rainbow you must be looking toward a point where the air holds millions of drops of water. The water can be in the form of a mist or falling rain. To see a rainbow, you must have the Sun shining behind you, and it must be fairly low in the sky. (You will never see a natural rainbow at noon, unless you are looking down from an airplane.) If all of these conditions exist, you will be able to see a rainbow.

What causes a rainbow? Look at figure 2-30. Of course it takes millions of drops of water to make a rainbow. In a rainbow, you can see six distinct colors, but for simplicity, the diagram shows only three drops and three colors. The rays are striking at many points on the surface of each drop, but the rays that strike at the points shown in the diagram are the only rays you will see. A ray is refracted as it enters the drop and is then reflected from the back surface by total internal

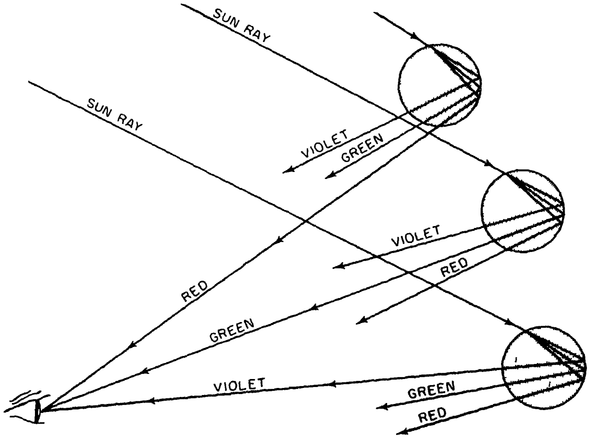

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Figure 2-30.—Theory of the rainbow.

reflection. The ray is refracted again when it leaves the drop, just as in a prism; the index of refraction is different for different colors. The emerging ray is dispersed into a spectrum. The Sun's rays are parallel, so all the violet rays are parallel because they are all refracted at the same angle. All of the green and red rays are parallel. But, as you can see in the diagram, only the red rays will reach your eyes from the upper drop. You will see only the green rays from the middle drop and only the violet rays from the lower drop.

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CHAPTER 3

MIRRORS AND PRISMS

This chapter is devoted primarily to descriptions of plane mirrors and prisms and the effect they have on light transmission. But, before we discuss mirrors and prisms in depth, you should be familiar with two basic concepts—the methods of measurement used in optics and image description.

MEASUREMENTS IN OPTICS

An opticalman usually works with at least four systems of measurement: the English system, the metric system, the degree system, and the mil system. You are familiar with the English system and its basic unit, the foot. The foot can be converted into larger or smaller units by multiplying or dividing. The English system is often complicated and cumbersome, and is not entirely satisfactory for optical mesurement. The lack of simple relationships between units make it very difficult to carry out computations. For this reason, other systems of measurement are sometimes more desirable

METRIC SYSTEM

Shortly after the French revolution, near the end of the eighteenth century, the National Assembly of France decided to appoint a commission to develop a more logical measuring system than those that were in use. The product of that commission was the metric system, which has been adopted by most industrialized countries, except the United States. The United States has begun a slow conversion to the metric system.

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

Length = meter (m)

Mass = kilograms (k)

Temperature = Kelvin (K)

Time = second (s)

Electrical 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. 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 is 0 67 meter long and you need to know the length in decimeters. All that you need to do is multiply 0.67 meter by 10 and you will find the object is 6.7 decimeters in length. If you want to find the length in centimeters, multiply by 100, and you will get 67 cm. To find the length in millimeters, multiply by 1,000 and you will get 670 mm.

Suppose you are using the English system and need to make a conversion from yards to feet. Assume that you have an object that is 0.67 yard long. You simply multiply by 3 to get the answer in feet and by 36 to get the answer in inches.

What, then, is the difference between using the English system as compared to the metric system of measurement? In the English system there are several conversion factors, whereas in the metric system you simply move the decimal point to make a conversion.

The unit of length in the metric system is a meter, which is equal to 39.37 inches. A meter can be divided into 100 equal parts called centimeters, and each centimeter can be divided into ten parts called millimeters. 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	=	0 03937	inch
10 millimeters	= 1 centimeter	=	0.3937	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	=	0.6214	miles

The names of multiples in the metric system are formed by adding the Greek prefixes: deka (ten), hecto (hundred), kilo (thousand), and mega (million). Submultiples of the system are formed by adding the Latin prefixes: deci (tenth), centi (hundredth), milli (thousandth), and micro (millionth).

For a quick approximate conversion from inches to metric system units, or vice versa, refer to a metric unit-inch conversion table. This table should be available in your optical shop. For more exact conversions of large units, here is a table you can use:

From	To	Multiply	
Millimeters	Inches	Millimeters by	0 03937
Inches	Millimeters	Inches by	25.4
Meters	Inches	Meters by	39 37
Meters	Yards	Meters by	1 0936
Inches	Meters	Inches by	0 0254
Yards	Meters	Yards by	0 9144
Kilometers	Miles	Kilometers by	0 6214
Miles	Kilometers	Miles by	1 609

The unit of volume in the metric system is a liter, which is the volume of a cube 1/10 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 a gram, which is the weight of 1 milliliter of distilled water at 4 °C. For all practical purposes a gram may be considered as the weight of 1 cubic centimeter of water.

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

Standard abbreviations for the principal metric units are as follows:

Meter	m
Centimeter	cm
Millimeter	mm
Liter	l
Milliliter	ml
Cubic centimeter	cm^3
Gram	g
Kilogram	kg
Milligram	mg

DEGREE SYSTEM

The degree system is a means of measuring and designating angles or arcs. A degree is 1/360 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 away 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. Remember, for very small angles, the sine and tangent are practically the same.

IMAGE DESCRIPTION

Now we have an exercise for your imagination. Imagine an extra large serving of strawberry shortcake. The cake is covered with thick rich cream and crushed strawberries. The juice is flowing in red streams down the side of the cake. Concentrate now. Do you have the picture?

Stop drooling and figure out what happened. When you imagined strawberry shortcake, you formed a picture, or an *image*, in your mind. Imagination is a process of forming a mental image. If you have a good imagination, your mental image of the strawberry shortcake was accurate and detailed. The English words *image* and *imagine* both come from a Latin word meaning "imitate." So, an image is an imitation.

Following are some examples of images. Every time you look into a mirror to comb your hair, you are looking at an image of yourself. It is not actually you inside the mirror, but it is a good imitation of you. If you have a snapshot of your family or a friend, you have an image. When you took the picture, the lenses of your camera formed an image on the film. When the film was developed, the image became permanent. Every time you go to the movies you are viewing a series of images—thousands of them. The projector lens forms images of the movie film and transmits the images on the screen. The movie film is a record of images that were made by the lens of the movie camera at the time the picture was filmed.

When you look at *anything*, the lens will form an image of that object on the back of each eye. We will discuss this in more detail a little further on in this manual.

You can form your own images You will need a light source (an electric bulb will do). The image will be easier to see if the bulb is the only source of light in the room. Take an ordinary magnifying glass and point the optical axis (the straight line through the center of a lens is the optical axis) of the lens toward the bulb. Hold a sheet of white paper on the opposite side of the lens at a right angle to the optical axis. Move the lens back and forth along its optical axis until you focus the image of the bulb on the paper.

The image of the bulb is a *real image*. How do you know this? What is the test of a real image? If you can hold a piece of paper or a sheet of ground glass where the image is formed, and *see* the image on the paper or glass, it is a real image. If you can see the image, but cannot form it on paper or ground glass, it is a *virtual image*. When you look at an object, a real image is formed. The camera in figure 3-1 forms an image on the focusing screen or film.

Those are real images, but what about the image you see in a mirror? Where would you put a piece of paper or ground glass to catch that image? Children and other small animals will sometimes peek behind a mirror to look for the image, but you and I know better. There is nothing behind the mirror. A plain mirror forms a virtual image.

When you look in a mirror, you do not see yourself as others see you. This is because your image is backwards. Hold this page up to a mirror. It is not easy to read because the image is backwards. The optical term for backward is *reverted*. But, the image is *erect*, which is the optical term for right-side-up.

Look at figure 3-1 again and you will see that the camera lens forms an *inverted* or upside-down image. The camera image is *normal* and is not reverted. You should be careful here. You have learned that the normal is an imaginary line at a right angle to an optical surface, but when you are talking about images, normal has another

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

meaning. Figure 3-2 shows the four possible image positions.

When you describe an image, any image, there are at least three things you can say about it: (1) whether it is real or virtual, (2) whether it is erect or inverted, (3) whether it is normal or reverted, and (4) whether it is enlarged, diminished or same size.

How would you describe your image in the mirror? It is virtual, erect, reverted, and same size (VERSS).

Sometimes on optical schematics you will see the image attitude described as VEE, VER, RIN, and so on. This is a kind of shorthand that is used for image description.

Look at the image formed by the convergent lens of the camera in figure 3-1. It is real, inverted, and normal (RIN). How do we know the image is normal? If you stand on your head and look at the focusing screen, the image appears like the object itself. Because the object is a sailor, it is a little difficult to see in the picture. But, if the object were a printed page, you would be able to see at a glance that the image is normal, even though it is upside-down.

As shown in the picture, the above is true when you are looking at the back of the focusing screen. But, suppose you cut a hole through the camera bellows and view the other side of the focusing screen. The image would then be reverted. So, to be able to determine whether any image is normal or reverted, we will first have to decide which side of the image we are going to look at.

Here is a rule pertaining to images: To describe the position of an image, look into the optical element that forms the image. To make a comparison of *that* image with the object itself, stand on the object's side of the optical element, and look at the object from that position. Look at figure 3-1 again. Here you see the image as it appears when you are looking toward the lens that forms it. You can see the sailor as he appears when you stand between him and the lens. So, if you want to describe the image position on the camera's focusing screen, you can compare the object and image just as you see them in the picture.

How would you describe the image on a movie screen? You can see the image on the screen, so of course it is real. Since the movie projector has a convergent lens, the image is inverted and normal. But, the image is normal only if you are looking toward the lens. In a movie theatre you are looking away from the lens. This is because the projector is behind you. So, from where you sit, the image is inverted and reverted. The pictures you see on the screen look normal and erect. That means the pictures on the movie film, as seen from the projector lens, are running through the projector upside down and backwards.

Think about these ideas for a while. Do not go on until you understand them.

IMAGE TRANSMISSION

Image transmission, by use of a mirror or a prism, is in fact light reflection and refraction put into practical use. Mirrors and prisms are mounted so that they will send light from an object to whatever point we desire. Remember, mirrors and prisms do not produce images. That work is done by lenses and is discussed in chapter 4. Prisms merely alter the path of light and the attitude of objects as viewed through these optical elements.

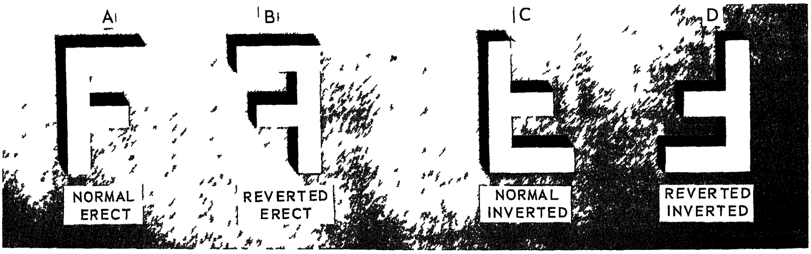

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Figure 3-2.—Various image attitudes of the letter F.

PLANE MIRRORS

In a dark room, if you look at a tiny point of light in a mirror, the point of light appears to be located behind the mirror and on the other side of the room from where it really is. In figure 3-3 you can see the reflected ray. Because the source of the light is behind you, your line of sight is extended, in your mind, in a direct line through and behind the mirror. The *apparent* position of the point of light 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.

If you can see the reflection of the point of light in the mirror, regardless of your location in the room, the apparent position will be unchanged. Observe the line of sight of eye "B" in figure 3-3. The point 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.

Figure 3-4 gives us another illustration of the same principle. Here you see the letter *F* reflected

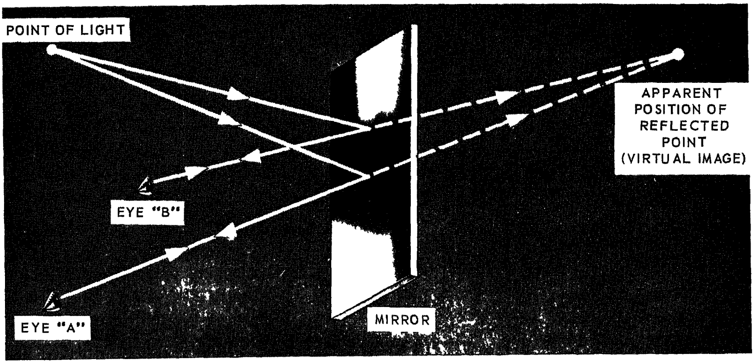

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Figure 3-3.—Apparent positions of a point of light reflected by a plane mirror.

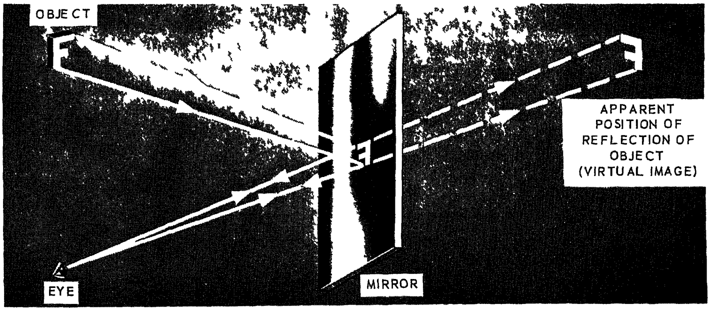

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Figure 3-4.—Apparent position of an object reflected by a plane mirror.

in a mirror. Rays from each point on the letter *F* obey the law of reflection when they strike the mirror's surface. The virtual image is formed behind the mirror. The image is erect and reverted. Notice that the image appears to be exactly the same distance behind the mirror as the object is in front of the mirror. Look at figure 3-3 once more, and you will see that each point on the image lies on the normal drawn from the mirror to the corresponding point on the object. Each point on the image is the same distance from the mirror's surface as the corresponding point on the object.

A single mirror is sometimes used to reflect light and images, such as an adjustable mirror on a car. If the object cannot be reflected adequately with a single mirror, a second mirror can be placed to reflect light from the first mirror and retransmit it. Figure 3-5 shows how mirrors can be arranged so they will change the line of sight. The two mirrors are placed so that they form a 90-degree angle. Light from the object (F) strikes the reflecting surface of the first mirror and is reflected to the second mirror. The second

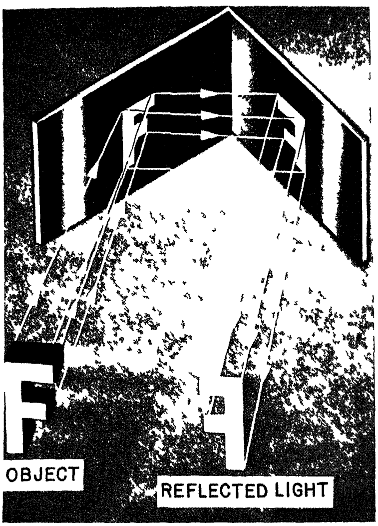

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Figure 3-5.—Attitude of an object produced by two plane mirrors placed at right angles.

mirror then reflects the image parallel to tl original image. The light reflected by the tw mirrors is reflected a total of 180 degrees. Als since the two mirrors are mounted so that you a looking at the back of the object (F), the imag attitude is unchanged in relation to the object. you were to stand between the mirrors ar object F, the object would appear as ꟻ, which exactly what is seen as a result of the tw reflections of the mirrors.

PRISMS

The image forming and transmitting parts c any optical instrument are lenses or prisms c mirrors, or some combination of these thr elements. The other parts are there just for yo convenience. They hold the optics in the proper place, keep unwanted light out of tl instrument, and give you a means of pointing an adjusting the optical system.

Prisms come in many different forms. In th section we are going to do two things. We wi discuss some of the forms and give you exampl of what they are used for.

In an optical system, a prism can serve tw purposes: (1) When light enters one face of prism, and strikes another face at an angle great than the critical angle, the light will be reflecte You can use a prism just like a mirror. It can b used to turn the line of sight (LOS) through a angle or to reverse the image. (2) When two fac of a prism form a sharp angle, and light ente one of these faces and goes out through the othe the prism will bend the light. You can use a pris to bend (deviate) the line of sight

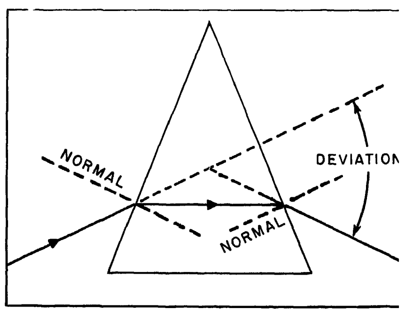

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Figure 3-6.—Refraction in a prism.

Prisms are generally made from borosilicate crown glass. This is because of its high resistance to abrasion and damage caused by atmospheric elements. Occasionally prisms are used for both refraction and reflection in optical instruments. The surfaces of a prism are not easily disturbed, and a prism 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. To see how light is refracted by a prism, look at figure 3-6. Notice 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. This is a measure of the amount of change in direction of a light ray caused by a prism.

WEDGES

Prisms with the 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 and optical alignment 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 on the angle between the entrance and emergence faces and the index of refraction of the glass

Some wedges used in fire control and optical alignment instruments appear to be disks or plates of glass with parallel surfaces. This is 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 that passes through them. Some instruments that use wedges are therefore designed to create a definite amount of initial deviation of a ray of light when it leaves the wedge. This deviation is used to correct for errors in the path of light occurring in an optical system.

By rotating a wedge, it is possible to change the path of light passing through it. (See fig. 3-7.) The solid path of light represents the deviation of light in the original position. The dotted path is the result of rotating the wedge 180 degrees. 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. This is shown in figure 3-8, view A.

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*. Figure 3-8, view B, shows how light is refracted by wedges in three different positions

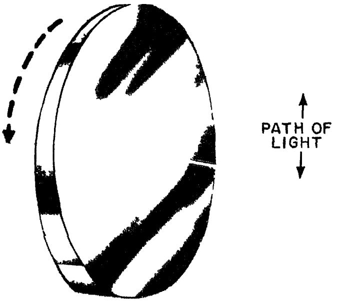

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Figure 3-7.—Direction of light changed by a rotating wedge.

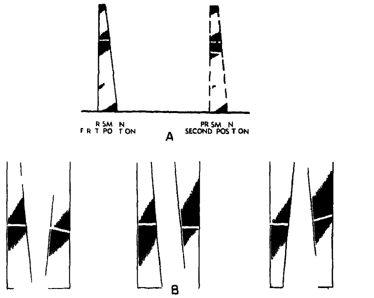

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Figure 3-8.—Path of light changed by pairs of prisms rotating in opposite directions.

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 1 meter from the prism. Study figure 3-9. A prism of 1 diopter bends light so that when the refracted ray reaches a distance of 1 meter beyond the prism it has deviated its path 1 cm from the incident ray. Another example: if a prism has a power of 2 diopters, the deviation of the refracted light will be 2 cm at 1 meter beyond the prism.

REFLECTING PRISMS

Reflecting prisms act just like mirrors. Even though prisms are more expensive than mirrors, the military uses prisms extensively. Here are a few reasons why the military uses reflecting prisms:

1. Silvered mirrors eventually peel or tarnish. Most prisms function using internal reflection on a glass-air surface, and there is no silver to turn dark or peel off.
2. Silver reflects about 95 percent of the light that falls on it and absorbs the other 5 percent. But, a surface that works by total internal reflection does not absorb any light—it reflects all of the light. Light passes through more glass in a prism than it does in a mirror, but the absorption in good optical glass is fairly small. A reflecting prism will absorb less light than a mirror would use for the same purpose. By using prisms instead of mirrors, we get a brighter image.
3. You can mount a prism more rigidly than a mirror. A prism is also much thicker and is less likely to break.
4. Sometimes you will want to bend or deviate the line of sight several times in a single instrument, such as in binoculars, to reduce the physical size of the instrument. You will need two reflecting surfaces, mounted at an angle, that do not vary more than a few seconds. It is possible to accurately mount two mirrors, but it is also easy to knock them out of adjustment. You will not have that problem if you have both reflecting surfaces in a single prism. Once the manufacturer has ground the two faces to the proper angle, they will never change. There is no way they can get out of adjustment.

Right-Angle Prism

You are already familiar with the right-angle prism. You know that light enters through one face, is reflected from the diagonal face, and leaves through a third face. You can use a right-angle prism to turn the line of sight through 90 degrees. At the same time, it will revert the image if the incident rays are horizontal. (If the incident rays are vertical, the prism will invert the image.) Try it yourself, and see how it works. For your object, use the page of a book. (That makes it easy to tell whether or not the image is reverted.) Hold the page vertical and at eye level. Hold a right-angle prism at the proper angle and look at the print reflected in it. The letters are right side up But, because the image is reverted, you cannot read the lines from left to right.

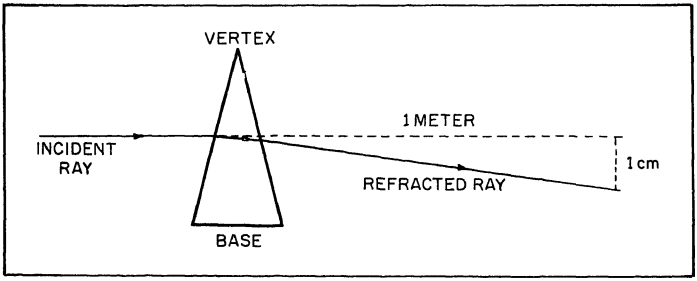

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Figure 3-9.—Prism diopter.

Now put the book flat on the table in front of you, and turn the bottom of the page toward you. Hold a right-angle prism above the page. With your line of sight parallel to the table, look into the prism. The letters are now in the right order from left to right, but they are upside down. The image is inverted.

Figure 3-10, view A, shows another way to use a right-angle prism. The light enters at a right angle to the diagonal face. The light is reflected from one of the short faces to the other where it is reflected again. It leaves the prism through the diagonal face and remains at a right angle to it. When we use a right-angle prism this way, we call it a porro prism.

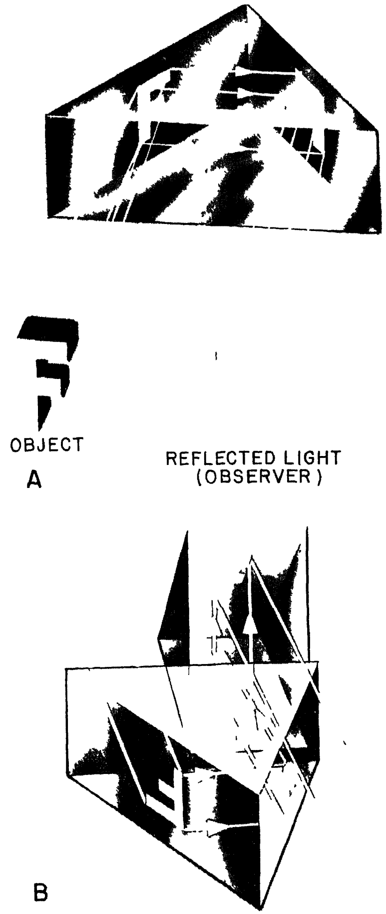

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Figure 3-10.—Object viewed through single porro prism and porro prism cluster.

Porro Prism

Of course it does not look exactly like the porro prism you will find in optical instruments. To keep them simple, we have not tried to make our diagrams look exactly like the prisms they represent. When the manufacturer makes a prism for use in an optical instrument, he will usually round off some of the sharp corners so they will not chip easily; and he will rarely bother to polish the faces that will not be used.

A porro prism bends the line of sight through 180 degrees. What does it do to the image? Compare the object with the image in figure 3-10. The image is obviously erect. Is it normal or reverted? That depends on how you look at it.

In figure 3-10, view A, you see the back of the object and the front of the image. If that is the way you look at it, then the image is reverted. But, if you want to follow the rule we gave you earlier—judge the object by looking toward it from the mirror; judge the image by looking toward the mirror—then the image is not reverted. That idea is important, so do not skip over it. Get a good firm hold on it before you read on

Now look at figure 3-10. Turn the page sideways so that the right-hand margin is toward you. Compare the object and the image. Whether the object is normal or reverted still depends on how you look at it. But, it is *inverted* no matter how you look at it. Take your time with that idea.

Porro prisms are never used singly. They are mounted in pairs as shown in figure 3-10, view B. This arrangement is known as 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. The reflecting surfaces do not require silvering. This is because the angle at which light strikes them is greater than the critical angle of the material from which the prism is made.

Figure 3-11 shows still another way to use a right-angle prism. (Because the right-angle end has been ground off, it does not look like a right-angle prism.) Light strikes one of the short faces at a 45-degree angle and is refracted down to the diagonal face. From there it is reflected to the other short face, where it is refracted again. It then emerges parallel to the incident light. A right-angle prism used this way (whether or not the top is ground off) is a dove prism.

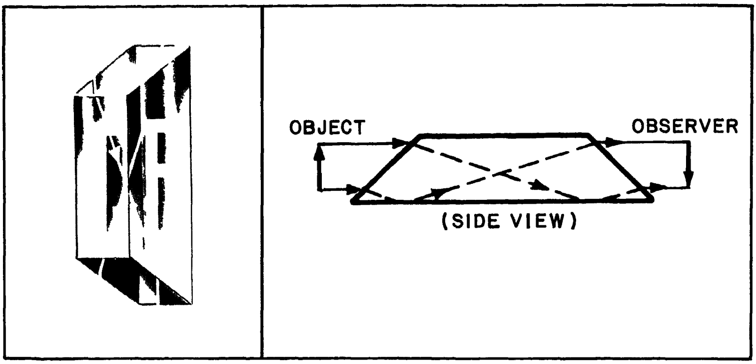

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Figure 3-11.—Dove prism.

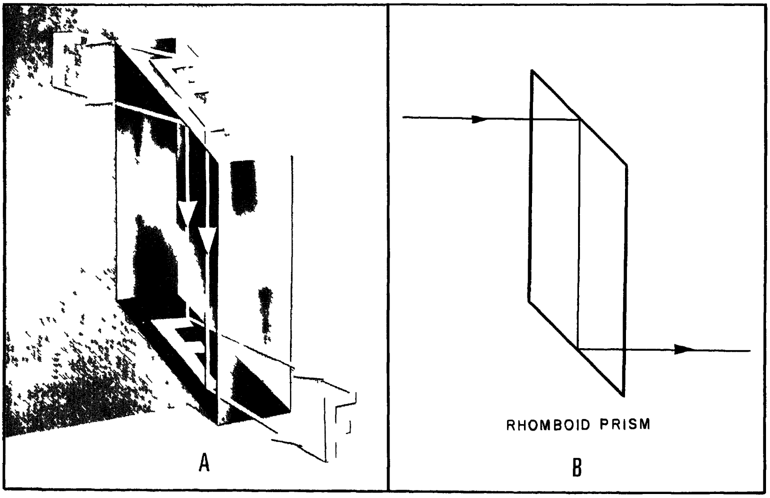

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Figure 3-12.—Rhomboid prism.

Dove Prism

As you can see in figure 3-11, the dove prism does not bend the line of sight. It inverts the image. Study the diagram for a minute. Then hold up a printed page, and look at it through a dove prism. Now slowly rotate the prism around the line of sight, and watch the image rotate. Notice that when you rotate the prism through 90 degrees, the image rotates 180 degrees. Notice also that the image is always reverted. This will occur whether it is right side up or not.

In an optical instrument, you will find the dove prism mounted in a way that will allow you to rotate it about the line of sight inside the instrument.

Rhomboid Prism

A rhomboid prism is a parallelogram. The upper and lower faces are cut at an angle of 45 degrees and are parallel to each other. Look at figure 3-12.

The rhomboid prism has two parallel reflecting surfaces. These surfaces provide two reflections in the same plane and transmit the image unchanged. (The reflecting surfaces are not silvered.) The rhomboid prism does NOT invert or revert the object or change the direction of light rays, but it does *offset* the light rays from their original direction.

Regardless of the manner in which you hold or rotate a rhomboid prism about the line of sight, the attitude of the object viewed is *always* erect and normal. The only purpose this prism serves is to offset the line of sight. This is done to make a new line of sight parallel to the old line of sight.

Penta Prism

A penta prism, shown in figure 3-13, reflects light from two reflecting surfaces by an amount equal to twice the angle between the silvered reflecting surfaces. Penta prisms always have silvered reflecting faces.

In figure 3-13, view B, you will see that if the angle between the silvered surfaces is 45 degrees (prism angle), the deviation will be 90 degrees; if the prism angle is 43 degrees, the deviation of the prism is 86 degrees. (Remember that the deviation is measured from *where the incident light has gone* to *where the emerging light actually goes*.) When a penta prism is held so that

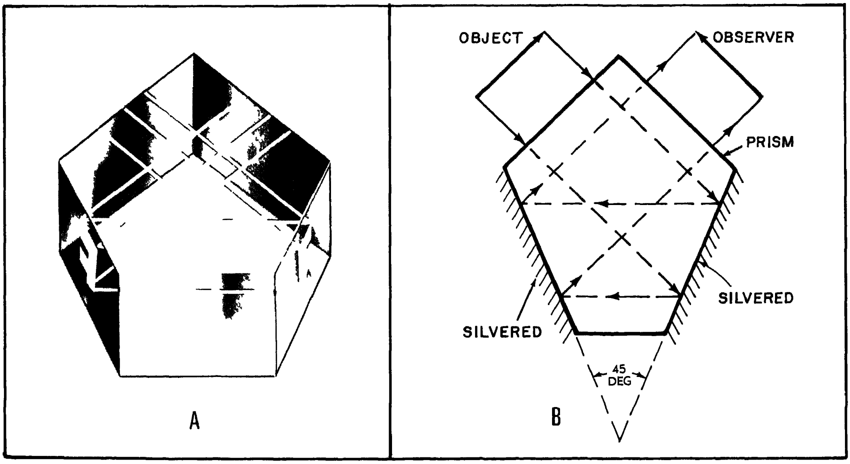

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Figure 3-13.—Penta prism.

reflection takes place in the horizontal plane or vertical plane, all objects viewed will be normal and erect. The prism may be rotated slightly without changing the apparent position of the object viewed. This is called *constant* deviation. There will be a slight amount of refraction at the entrance and emergence faces, but the refraction will be equal and in the same direction. The line of sight between the target and the observer does not change.

The constant deviation of the penta prism is very useful in rangefinders which rely on optical wedges to precisely measure the deviation of the line of sight.

Roof Edge Prism

You can easily understand the construction of a roof edge prism by referring to figure 3-14, view A. Light enters perpendicular to one surface and reflects left to right and right to left from the roof edge. It is also reflected to emerge perpendicular to the second surface. Light reflected from the roof edge in this manner will cause objects to appear reverted and inverted.

A roof edge prism may be ground so that the deviation of the line of sight is 90 degrees (fig. 3-14, view B) or 60 degrees (fig. 3-14, view C). A 90-degree roof edge prism is sometimes called an Amici prism. Regardless of 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 must be protected against chipping. Any chips on this edge will show up in the line of sight.

Schmidt Prism

A Schmidt prism (fig. 3-15) is used to erect and deviate the path of light in small navigation instruments. Its function is similar to the roof edge prism.

Light enters perpendicular to the entrance face and is reflected down to the roof edge from the back surface of the prism. At the roof edge, light reflects left to right and right to left. The light is then directed toward the entrance face, where it is again reflected and emerges perpendicular to the emergence surface.

The reflecting surfaces of the Schmidt prism are NOT silvered. This is because all reflection takes place at an angle greater than the critical angle.

PRISM DEFECTS

For a prism to perform its function in an optical system, it must first be produced from the correct type of glass and must be free from strain or internal defects. Second, the surfaces of the prism must be perfectly flat and ground to precise angles. This is done to keep a path of light in the exact direction desired.

Any difference in the density of the glass from which a prism is constructed will cause distortion of the line of sight. Likewise, bubbles or foreign objects in the glass can produce distortion or reduce light transmission.

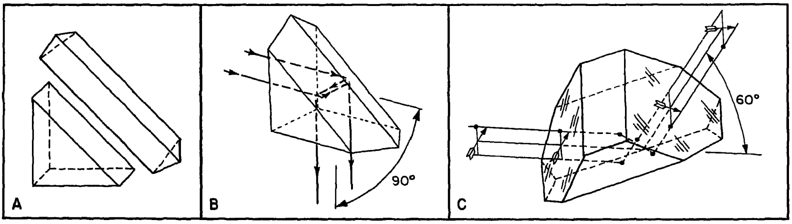

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Figure 3-14.—Roof edge prism.

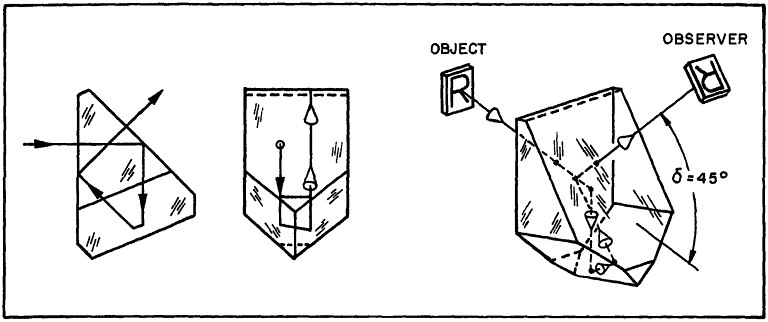

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Figure 3-15.—Schmidt prism.

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CHAPTER 4

LENSES

Of all the various optical elements used to control light, lenses are the most important and most widely used. Like the prisms and mirrors you studied in the last chapter, lenses are made from high-quality optical glass.

As you know, without glass there would be no optical instruments, or Opticalmen. You are a skilled mechanic of course, or if you are not you will become one; you will learn how to repair the mechanical parts of instruments. The optical elements you will work with are made of glass. We think your work will be more efficient and interesting if you know the properties of optical glass and how it is made, even if you never use the knowledge directly.

You may disagree with the statement that there would be no optical instruments without glass. We have heard a lot of rumors about plastic lenses, and you have probably heard them too. In several ways plastic would be better than glass. The most suitable plastics are more transparent than the best optical glass, and a manufacturer can cast plastic lenses close to their final shape. The casting temperature of plastic is much lower than that of glass. Glass lenses change their shape much more on cooling than plastic lenses. The final polishing of plastic lenses is quick and easy. They are also almost unbreakable.

What is wrong with plastic lenses? Research and development departments of major manufacturers have been working experimentally with plastic lenses since World War II. Two disadvantages keep arising that make plastic lenses almost worthless for use in Navy instruments. The first disadvantage is that plastic lenses are soft, and there is no practical way to clean them. Wiping them two or three times with lens tissue could ruin them. You might get around that by using glass objectives and eyelenses and by using plastic for the lenses inside the system. But then you would run into the second disadvantage of using plastics; plastics expand and contract much more than glass when exposed to temperature changes. The plastic lenses inside the instrument would change their focus length more than the glass at the ends. Since you have to correct the aberrations of the system as a whole, you can see that the idea is impractical.

When research scientists learn how to harden plastics and to reduce their coefficient of expansion, the Navy will probably use plastic lenses. We are not going to say we will never use plastics, but we will say that in their present state of development, plastic lenses are just not practical for our purposes.

COMPOSITION OF GLASS

We do not know how or when glass was discovered. As one legend goes, about 1500 years ago a group of Arabian traders were moving a cargo of soda ash across the desert. When they stopped for the night, they built a fire on the desert sand. One of the traders accidentally spilled some soda ash in the fire, and in the heat of the campfire the soda and desert sand melted to form glass.

It may surprise you to learn that glass is a liquid and not a solid. No, that is not a misprint. Glass is a liquid. Of course you would not want to drop a lump of glass on your toe. How do we know that glass is a liquid? In the first place, solids have a definite melting point. Ice melts at 0 °C and iron at 1535 °C. When they melt they change suddenly from a solid to a liquid, and there are no in-between states.

What is the melting point of glass? If you heat a glass rod over a flame, it will soon get soft enough to take a dent. Heat it a little longer and you will be able to draw it out to a thread. Heat it red hot and it will begin to flow. If you can raise its temperature to several thousand degrees, it will be almost as fluid as water. It is a liquid and does not have a melting point. (Some physics books refer to a supercooled liquid as an amorphous solid.)

You know that liquid flows. If you give it time, even a supercooled amorphous solid like glass will flow. If you want proof, do the following experiment. Drive two nails into the wall about 4 feet apart on the same horizontal level. Find a piece of thin-walled glass tubing that is a little more than 4 feet long, and rest it on the nails. It may sag a little because of its elasticity, but if you lift it off the nails it will straighten out again. Put the glass tubing back on the nails. With a pencil, mark the wall to show the lowest point of the curve.

If you go away and come back 6 months later, you will find the tube sagging lower than it did before. When you lift the tubing off the nails, it will keep the curve. What causes this to happen? The liquid glass has flowed to its new shape. The longer you leave the tube on the nails, the more it will flow.

We are not just quibbling when we insist that glass is a liquid. It is one of the most important properties of glass. A manufacturer of optical glass goes to a lot of trouble to keep glass a liquid. If a manufacturer lets the glass become a solid, it will have a crystalline structure. Crystalline glass is doubly refracting and will form two separate images at the same time. In choosing the ingredients for optical glass, the manufacturer is limited to compounds that can be made into supercooled liquids.

Glass is a mixture (or more accurately, a solution) and has no definite chemical composition. The manufacturer melts ingredients together, stirs them until they are dissolved in each other, and then cools them.

The legend of the Arabian traders is right on one point. Sand is an important ingredient of glass. Only the purest kind of sand is suitable for optical glass. It must contain not more than 0.1 percent impurities; the other 99.9 percent must be pure silica. Silicon (Si) is one of the chemical elements. Silica (SiO_2) is one of its oxides. Pure quartz is a crystalline form of silica, and the pure sands used for optical glass are disintegrated quartz.

The metallic elements (such as sodium, potassium, and lead) also form oxides, and when you melt these oxides with silica they form metallic silicates. Glass is a mixture of silica and metallic silicates. We cannot think of any reason why you should have to memorize the composition of various kinds of optical glass, but we will give you a couple of examples. Here is a borosilicate crown glass with an index of refraction of 1.5128:

Silica (SiO_2)	68.24%
Boron Oxide (B_2O_3)	10.00%
Potassium Oxide (K_2O)	9.50%
Sodium Oxide (Na_2O)	10.00%
Zinc Oxide (ZnO)	2.00%
Manganese Oxide (Mn_2O_3)	0.06%
Arsenic Pentoxide (As_2O_5)	0.20%

For another example, the most dense flint glass, with an index of refraction of 1.9625, has only two ingredients:

Silica (SiO_2)	18.00%
Lead Oxide (PbO)	82.00%

We can make a general statement about the composition of optical glasses without listing a lot of formulas. The CROWN glasses, with a fairly low index of refraction and dispersion, contains phosphorous or barium or boron, but they contain no lead The FLINT glasses, with a higher index of refraction and higher dispersion, may or may not contain small quantities of barium or boron, but they all contain lead. The more lead they contain, the higher the index of refraction will be.

OPTICAL QUALITIES

Optical glass must have a number of special qualities The manufacturer of ordinary glass does not have to be concerned about this For example, optical glass must be transparent and free from color. Transparency is important, especially in instruments with a large number of elements. The manufacturer of optical glass must make it as colorless as possible, although he will often use a slightly colored glass if it has other valuable properties. For example, hold up two lenses, one crown and one flint, and look at their edges. You will find that the flint element is slightly greenish when compared to the crown element.

Two of the most important properties of any optical element are the index of refraction and dispersion of the glass it is made of. The manufacturer cannot make up a batch of optical glass, measure its index of refraction and dispersion, and then decide what he is going to use it for. He has complete specifications for the glass before he starts to make it. To meet those specifications, he must use only the purest materials, and he must mix them in exactly the right proportions.

Optical glass is not good unless it is homogeneous—it must be uniform throughout. (A lens with a high index of refraction in one part and a low index in another part would form a fuzzy image.) The glass must be entirely free from STRIAE—little streaks with a higher or lower index of refraction than the rest of the piece. It must be free from dirt, dust, and bubbles. That requires careful handling. You would have to look at a lot of lenses before finding one with a particle of dirt suspended in it. In the first place, the manufacturers do everything possible to keep dirt out of the mix. Second, the manufacturers' inspectors would probably reject any lens with a particle in it.

A bubble or two, if small, is not a very serious problem. It stops light from passing through that one small area of the lens, but it does not hurt the quality of the image. Many glasses with very desirable optical properties are almost impossible to make without bubbles. You will sometimes find a small bubble in even the best lenses. But even so, the manufacturer must hold the bubbles to a minimum. The inspectors of precision lenses will reject any lens with more than two or three bubbles in it and any lens with a bubble as big as half a millimeter in diameter.

Since optical elements have to be cleaned from time to time, the glass must be very hard. The dense flint glass is considerably softer than crown glass.

Optical glass must be free from internal strains. If the glass is in a state of strain, it will probably break during the grinding and polishing process. If it becomes a finished lens, it will break as soon as it gets a shock or jolt. Strains result from rapid cooling. Glass contracts as it cools, and if the outer part of a lump of glass cools while the inside is still hot, the whole mass will solidify in a state of strain.

Here is an extreme example of strained glass you may have seen. RUPERTS TEARS are made by dropping molten glass, one drop at a time, into cold water. The drops solidify instantly. But, since the outside cools first, they are in a high state of strain. If you give one of the tears a jolt or break off its tail, it will shatter into powder.

To test for strain, the inspectors of optical glass use polarized light. Strained glass changes the plane of polarization, and it shows up as bands or rings of colored light.

Chemical stability is an important quality of optical glass. All air contains moisture, and it often contains traces of chemical fumes. When moisture condenses on glass, it will absorb carbon dioxide and form carbonic acid. In chemical laboratories where exacting analyses are performed, the distilled water is kept in specially made glass bottles. Why? Because pure distilled water will attack ordinary glass and dissolve it.

Hard crown and borosilicate glasses are chemically stable. All others, especially those with high-alkali silicates, are much less stable. Occasionally a lens designer will use glass with very special properties and find that it is chemically unstable. To get around that, the special glass may be used as the middle element of a triplet, but that is not often practical.

The ingredients for optical glass are carefully and thoroughly mixed together by hand. The melting is done in covered pots in glass furnaces. The pots vary in diameter from 30 to 50 inches and are made from fired clay with special properties.

Since the molten glass takes up less space than the raw ingredients, and since the materials froth while they are melting, the ingredients are melted in several different batches These batches are called charges, and each is smaller than the last As each charge melts, the next charge is added. This is done until the pot is nearly full. For each charge, the raw materials are mixed with a quantity of CULLET. Cullet is broken scraps of glass from a previous melt, and it does two things. First, cullet acts as a flux—it reduces the melting point of the raw materials Second, it saves money. The raw materials are extremely pure, and pure chemicals are expensive.

The next step is to raise the temperature of the melt until the glass becomes fairly fluid. The bubbles can then rise to the top. The glass must be kept at that temperature for about 30 hours. That is not a problem with the dense flint glasses, but it is not easy to do with the hard crown. The melting point of hard crown is so high that keeping it fluid long enough to let the bubbles rise often endangers the pot and the furnace. If any impurities float to the top, they are skimmed off at this stage.

Now comes the stirring. To make the glass homogeneous and free from striae, it must be stirred constantly as it cools. The stirring rod is a cylinder of red hot thoroughly burned fire clay. The stirring can take anywhere from 4 to 20 hours and is continued until the cooling glass is so thick that the rod will not move. The rod then stays in the glass.

At this point the workers must take the pot out of the furnace and quickly cool the glass to its annealing temperature. Why? Because, if the glass cools slowly it will crystallize and become a solid instead of a liquid. It would then show double refraction. When the glass cools to about 400° or 500°C, it goes to the annealing furnace and is cooled to room temperature over a period of 7 to 14 days, depending on the size of the melt.

When the glass reaches room temperature, workers withdraw the pot from the furnace and break it away from the glass. If they are lucky, they will have one big lump of optical quality glass weighing about 1200 pounds. But, that kind of luck is rare. Usually they will find a few medium-sized pieces. Inspectors will carefully examine every piece that is big enough to be useful.

Workers sort the pieces by size, reheat them, and mold them into rough blanks for lenses and prisms. To avoid strains in precision elements, they do not press the blanks into shape. Instead, they heat the glass red hot, put it into red hot molds, and let it settle into shape under its own weight. The final annealing usually takes about a week.

LENS SHAPES

Like prisms, lenses come in a variety of shapes. The diagrams in figure 4-1 represent cross-sectional views of the most common lens forms.

It is a good idea to memorize those names. As you can see, the only difference between a convexo-plano and a plano-convex lens is the way it faces (in diagrams, light is considered as coming from the left). If you want to, you can call both forms plano-convex.

The size and distance of an image depends only on the focal length of a lens. Why do we then have to bother with so many different shapes? Because, by combining two or more lenses, and by carefully choosing the curvature of each

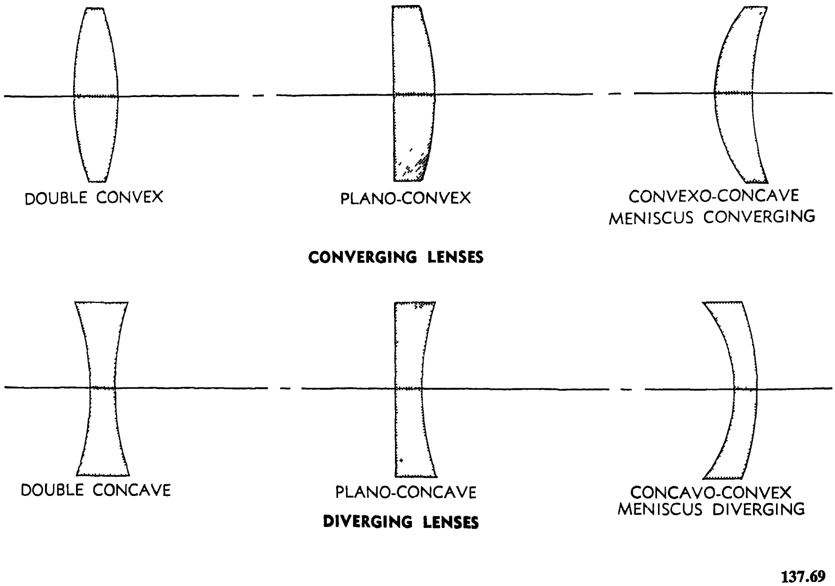

Figure 4-1.—Types of thin lenses.

surface, lens designers can control the aberrations of an optical system. They need a variety of shapes to work with. (We will discuss aberrations later in this chapter.)

You are not likely to find a lens that is not shaped like one of those in figure 4-1. The only exceptions we can think of are the azimuth circle and the range finder, both of which use a convergent cylindrical lens (fig. 4-2).

As you can guess from its name, the refracting surface of a cylindrical lens is part of a cylinder rather than a sphere. When parallel rays pass through a spherical refracting surface they form a CONE-SHAPED beam of light that converges to a point. What happens when parallel rays pass through a cylindrical refracting surface? They form a WEDGE-SHAPED beam that converges to a line. When light converges to a line, we call it ASTIGMATIZED LIGHT.

There is one important rule we have to stress when describing a lens. Read the surfaces of the lens according to the direction of the incident light.

LENS TERMINOLOGY

Before we go on with the study of lenses, you must understand some of the terms and phrases that are used to describe lenses and their uses in optics. Study the illustrations as we refer to them. They are there to help you understand the information in this manual.

CURVATURE

Curvature, as applied to lenses, is the amount of departure from a flat surface. Refer again to figure 4-1 and note the curvature of the lens surfaces. The surfaces appear to be only curved lines but, in effect, lens surfaces are spherical in shape. To visualize more clearly the surface of a lens, look at figure 4-3, which shows a segment of a sphere. The curvature of a lens surface is described as convex, plano, or concave. Convex surfaces are rounded like the exterior surface of a sphere; plano surfaces are flat; and concave surfaces are rounded inward like the interior surface of a sphere. If you consider the segment at the top as a lens, you would describe one surface as being plano on the flat surface and the other as convex.

RADIUS OF CURVATURE

In optics, the RADIUS OF CURVATURE is the amount of curvature of a lens surface. The radius is a line segment extending from the center of the sphere to the curved surface. Figure 4-3 illustrates a sphere with a diameter of 3 inches. The line segment, measured from the center of 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 the refracting ability of a lens. The smaller the radius of curvature, the more light will be refracted.

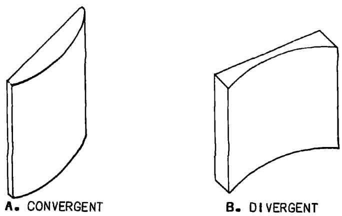

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Figure 4-2.—Cylindrical lenses.

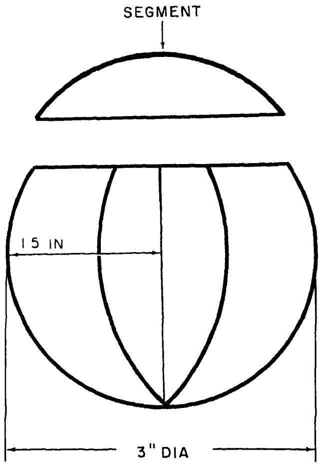

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Figure 4-3.—Sphere and segment.

FOCAL LENGTH

The focal length of all lenses is in the distance from the principal focus to the optical center. Figure 4-4 shows the focal lengths of a convergent lens; figure 4-5 shows the focal length of a divergent lens.

You can determine the approximate focal length of a convergent lens by holding the lens in a position 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; if you then measure the distance from the image to the optical center of the lens, you will get the focal length.

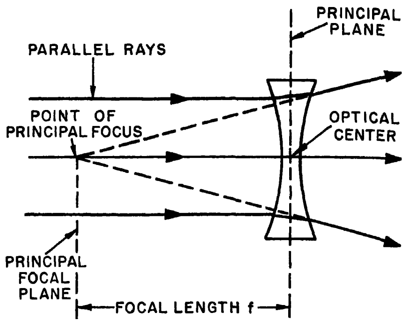

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Figure 4-5.—Focal length of a divergent lens.

Optical Axis

Line AB in figure 4-6 is the optical 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 the rear surface of the lens; point B is the center of curvature of the front surface of the lens.

Principal Plane

Both thin and thick lenses have two principal planes, which are imaginary planes at the point where the incident ray, if prolonged, would intersect the prolonged emergent ray. In figure 4-6 this plane is represented by line CD. Notice that incident ray B, parallel to the optical axis, is refracted upon entering and leaving the lens. If both the incident ray and the emergent ray are extended, as indicated by the broken lines, they would intersect at D on the principal plane. In a thin lens with equal curvatures, the principal planes coincide. In thick lenses, or lenses with unequal curvatures, there will be two definite principal planes, which can be located by using lines B-B[1] and C-C[1] as shown in figure 4-6.

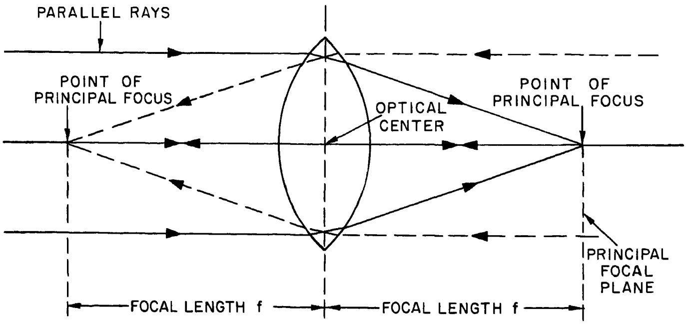

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Figure 4-4.—Focal lengths of a convergent lens.

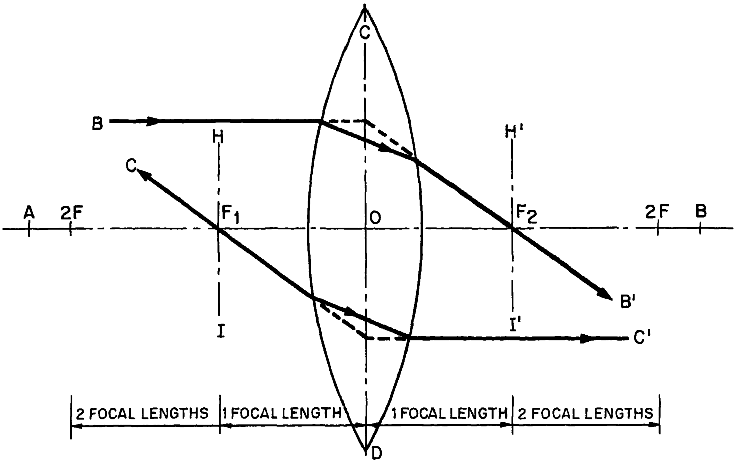

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Figure 4-6.—Lens terminology.

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 4-6; 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 in fig. 4-6); 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, is refracted by the lens, and emerges parallel to the axis.

This may seem confusing, but if you refer back to chapter 2 where you studied the law of reversibility, you will understand that a lens can have two principal focal points.

Principal Focal Plane

The principal focal planes are imaginary lines (HI and H^1I^1) perpendicular to the optical axis at the points of principal focus (fig. 4-6).Even though a lens has two principal focal planes, there are other points where an image can be formed. Image formation will be fully explained later in this chapter.

POSITIVE LENSES

Refer again to the group of converging lenses in figure 4-1. These lenses are called positive lenses because they will always converge light, regardless of surface curvature, as long as the lens is thicker in the center than at the edges. Look at figure 4-7, views A, B, and C. Notice how a series of prısms can be arranged to refract light to a common focus.

If you apply the law of refraction to the ray in figure 4-8, you will understand what happens when it passes through a convergent lens. When an incident light ray enters 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. All parts of the surface of the lens behave in the same manner. Look again at figure 4-7, views A, B, and C.

NEGATIVE LENSES

The diverging lenses shown in figure 4-1 are called negative lenses because they always diverge light, regardless of surface curvature, as long as

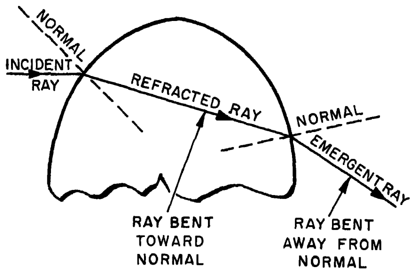

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Figure 4-8.—Refraction of light rays by a convergent lens.

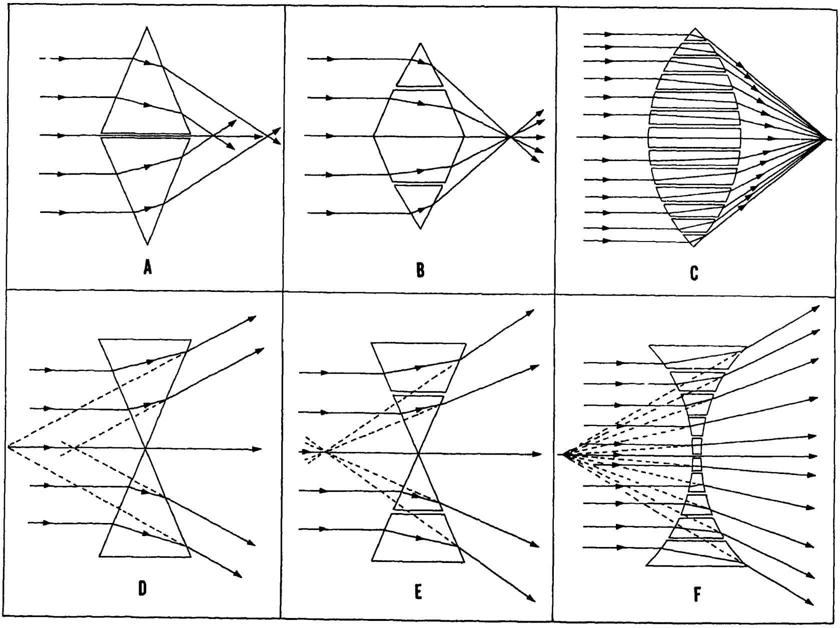

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Figure 4-7.—Lens constructed from prisms varying in number, size, and shape.

the lens is thinner in the center than at the edges. Figure 4-7, views D, E, and F, illustrates the path of light through a series of prisms assembled to duplicate a negative lens. Figure 4-9 shows how a single ray of light is refracted when it passes through a negative lens.

A positive lens converges incident light to a focal point that can be measured. A negative lens will not produce a real image; to determine its focal length, you must extend the emergent rays back through the lens to establish the imaginary focal length (fig. 4-7, views E and F).

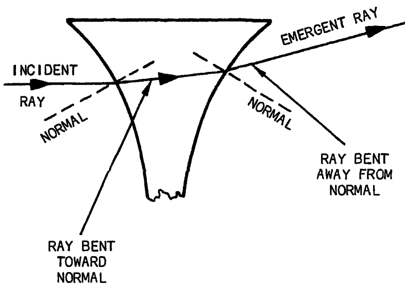

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Figure 4-9.—Application of the law of refraction to a divergent lens.

IMAGE FORMATION

As you know, light rays emanate from all points on an object and pass through a positive 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.

Look again at figure 4-8 to see how the laws of refraction may be applied to plot the path of any light ray through any type of lens. Then, study figure 4-10, 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 in figure 4-10 we use 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, refract toward the thickest part of the lens, and refract further when they emerge

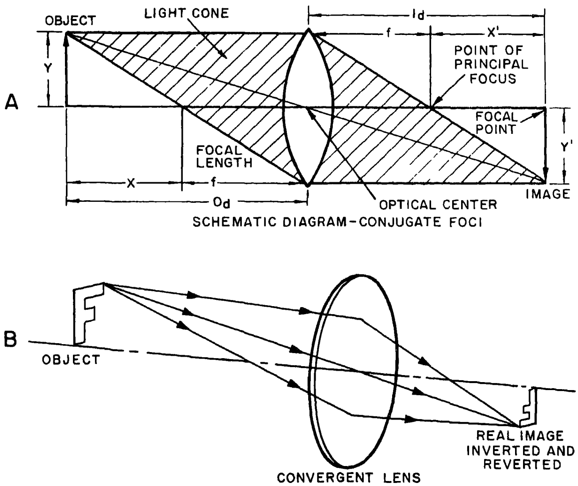

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Figure 4-10.—Image formation by a convergent lens.

from it. As shown in figure 4-10, they converge to a single point.

A light ray that passes along the optical axis through a lens does not bend because it strikes the surfaces of the lens at the normal.

Study figure 4-10 carefully. The central ray passes through the optical center of the lens and, even though it is not on the optical axis, does not deviate. Any ray of light passing through the optical center of a lens will actually be offset, but the deviation is so slight it is ignored.

View B of figure 4-10 shows how three rays of light from object F are refracted to reproduce that point on the image Ⅎ. Every point on the object forms its point of light on the image in the same manner. Rays from the object form points of light on the corresponding image, which is transposed diametrically and symmetrically across the optical axis from the object. This image is real, inverted, reverted, and diminished.

Principal Light Rays

Refer to the four principal rays of light in figure 4-11. These rays are used to plot image formation in any lens, thick or thin. When these light rays pass through a lens, they ALWAYS follow definite rules. Line XY in the illustration is the optical axis of the lens. Notice that rays A, B, C, and D do not follow the law of refraction as shown in figure 4-8. This is done to simplify plotting image formation and to illustrate that refraction appears to take place in a lens at the principal plane (broken line perpendicular to the optical axis).

LIGHT RAY A.—Light ray A is any incident ray that passes through the optical center (O in figure 4-11) of a lens and emerges from the lens without deviation from the path it was following before it entered the lens.

LIGHT RAY B.—Light ray B is any incident light ray that travels parallel to the optical axis of a lens, strikes the lens, and is refracted to the principal focal point F_2 behind the lens.

LIGHT RAY C.—Light ray C is any ray that passes through the principal focal point F_1, strikes the lens, is refracted, and emerges parallel to the optical axis. NOTE: The C ray is opposite of the B ray.

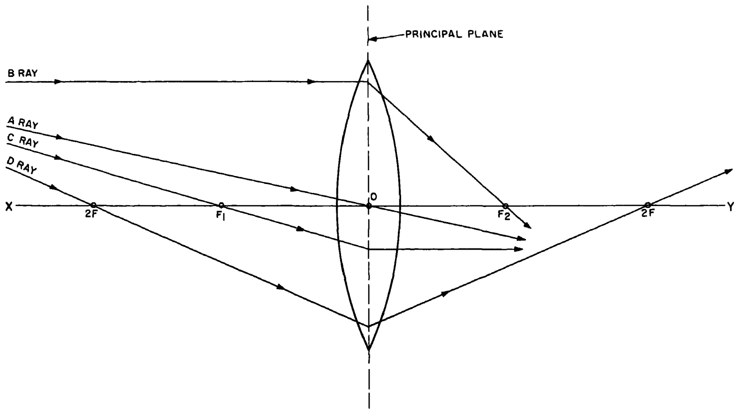

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Figure 4-11.—Principal light rays.

LIGHT RAY D.—Light ray D is any ray that passes through a point two focal lengths in front of a lens, 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.

The four principal light rays just discussed can travel to the lens from any angle as long as they follow the rules that pertain individually to them.

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; the image is formed by the light rays at the secondary focal point.

If the object is at a distance beyond two focal lengths, but less than infinity (fig. 4-12), a real, inverted, reverted, diminished image is formed between the secondary focal point and 2F on the opposite side of the lens. Note the size of the image in figures 4-12 through 4-17 as compared to the object. When an object is brought closer to a lens, the images formed become larger than images formed by the object at greater distances from the lens.

In figure 4-13 you see an object placed two focal lengths in front of the lens. The image the lens forms of this object 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

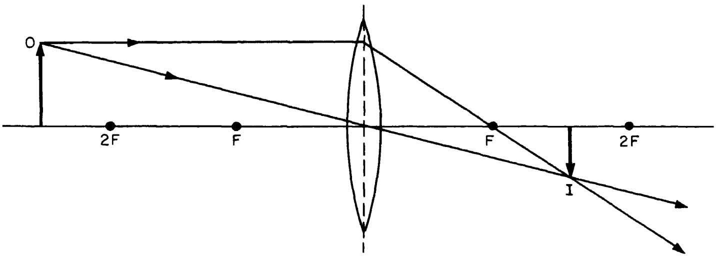

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Figure 4-12.—Position of an image formed by a convex lens when the object is more than two focal lengths distant.

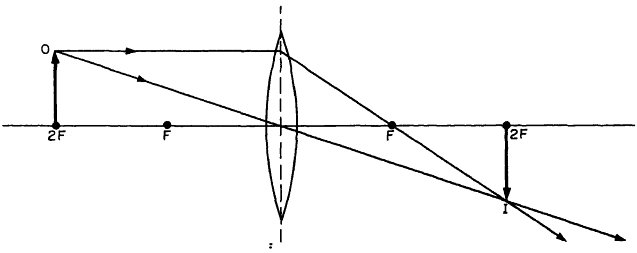

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Figure 4-13.—Position of an image formed by a convergent lens when the object is at a distance equal to twice the focal length.

in figure 4-14, the image is real, inverted, reverted, larger than the object, and at a distance of 3F on the other side of the lens.

Figure 4-15 shows an object at the principal focus of a lens; the emerging light from the lens is parallel and therefore 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 lens cannot converge or make it parallel. The emerging light from the lens is merely less divergent than the incident light, and the rays appear to come from a greater distance than the actual distance of the object. See figure 4-16. These rays appear to converge behind the object to produce an erect, normal, enlarged, virtual image located on the same side of the lens as the object.

From this discussion of images created by objects, you will understand that (1) as you move an object closer to a lens, the image created by the object moves away from the lens, and (2) 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. When the object is located between the principal focal point and the lens, the lens becomes a magnifying glass.

Negative Lenses

The point of principal focus, focal points, and focal planes resulting from the nearness of an

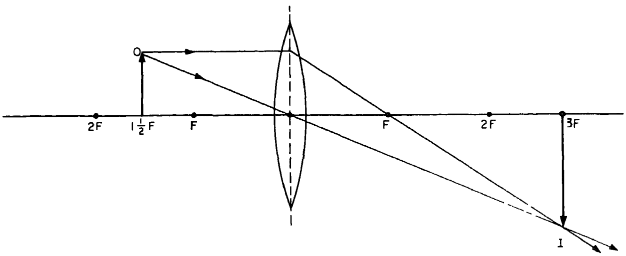

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Figure 4-14.—Position of an image formed by a convex lens when the object is between the first and second focal lengths.

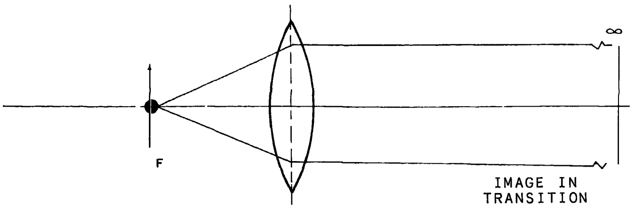

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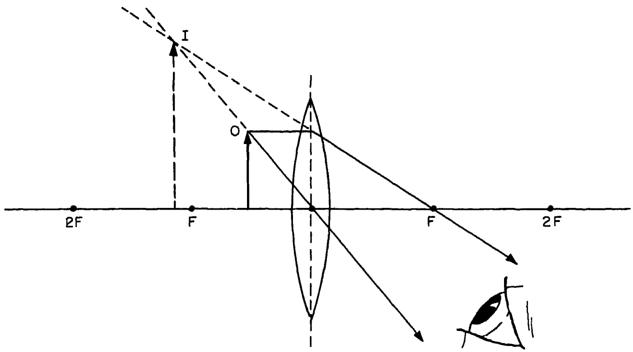
Figure 4-15.—Image formation by a convergent lens when the object is closer to the lens than the focal point.



137.84

Figure 4-16.—Formation of a virtual image by a convex lens when the object is closer to the lens than the focal point.

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 4-5 for terminology pertaining to 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, virtual, and slightly smaller than the object.
2. If you move the lens away from the page, 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.

To see how a negative lens functions, refer to figure 4-17. The three arrows (O_3, O_2, and O_1) on the optical axis represent a far, intermediate, and close object. The ray of light parallel to the optical axis is common to all three arrows, and separate rays are drawn from the arrows to pass through the optical center of the lens. The broken line is an extension of the emergent ray. Arrows

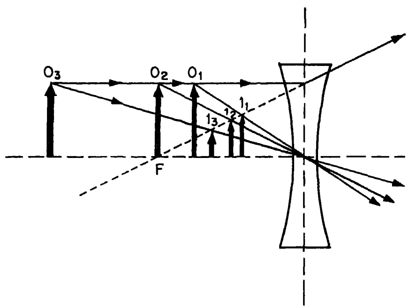


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Figure 4-17 —Image formation by a divergent lens.

I_1, I_2, and I_3 show how objects O_1, O_2, and O_3 would look if you were observing them through the lens.

Refer to figure 4-12. Notice that the B ray and A ray were used to plot image formation in positive lenses discussed previously. Those two rays were also used to plot the virtual images in figure 4-17.

CYLINDRICAL LENSES

A cylindrical lens is an optical element whose surfaces (one or both) are portions of a cylinder rather than being ground as a portion of a sphere.

See figure 4-18. Cylindrical lenses can be positive (view A) or negative (view B).

The positive cylindrical lens converts a point source of light (O in figure 4-18, view A) into a narrow line of light. This is useful in some optical instruments as an indicating mark. The negative cylindrical lens converts a point of light into a broad band of lesser intensity. This lens is sometimes used to provide illumination, using a small light bulb.

Positive and negative cylindrical lenses are often used in eyeglasses to correct vision defects (discussed later in the chapter).

SPHERICAL MIRROR

You perhaps have been at an amusement park where a building designated as "Fun House" used curved mirrors to make you look ridiculously tall or disgustingly fat. Convex rearview mirrors are also used on automobiles and

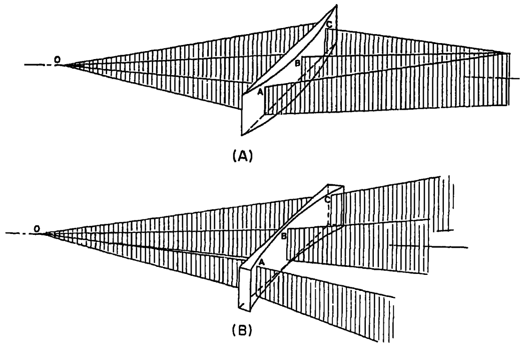

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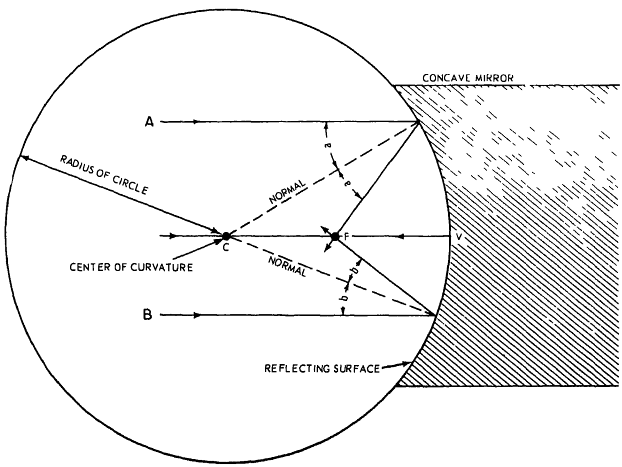
Figure 4-18.—Cylindrical lenses.



137.56

Figure 4-19.—Construction of a concave mirror.

trucks to give the drivers a wide view (field of vision).

A spherical mirror either converges or diverges light. A positive (convex) mirror will diverge light striking it, and a negative (concave) mirror will converge light to a focus.

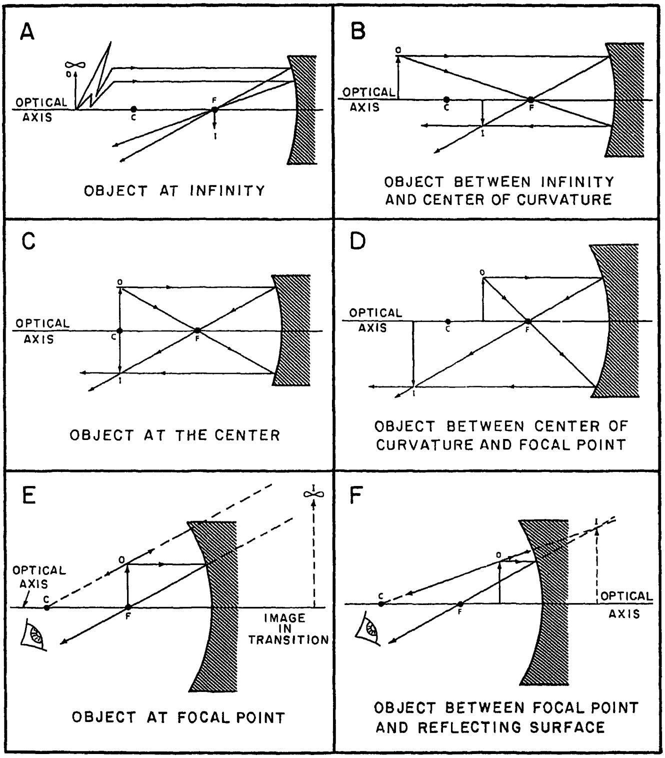
Concave Spherical Mirrors

At this time that you should learn the terms pertaining to a concave mirror. Refer to figure 4-19 as frequently as necessary during your study of the following discussion.

The degree of curvature of a spherical mirror varies according to the purpose for which it is intended. The procedure for making this kind of mirror must be accomplished by using a specific formula.

Line CV in figure 4-19 is the radius of the size of a circle needed to produce the reflecting surface of the mirror. Point F, the focal point of this mirror, is located halfway between the center of curvature C and the mirror surface V. Parallel light rays A and B strike the mirror surface and converge to a common focus. The normals at the points of incidence are quite simple to accurately locate since they are nothing more than the radius of the circle used to construct the mirror.

To understand how images are formed under a variety of situations using a concave mirror, refer to figures 4-12 through 4-16. Then, study figure 4-20. It should soon be obvious that a



137.59

Figure 4-20.—Position of image formed by a concave mirror.

concave mirror affects light rays just like a positive lens.

To understand the images formed by concave mirrors illustrated in figure 4-20, first review figure 3-4, which shows how to compare objects and their corresponding images.

Concave mirrors will form real images under most circumstances, but you must remember we are dealing with reflected light rather than refracted light. Therefore, when an object is located beyond the center of curvature of a concave mirror, the image attitudes will be real, inverted, normal, and diminished (fig. 4-20, view B). As the object moves closer to the mirror, the image size increases but the image attitude remains the same.

When the object is located at the focal point (fig. 4-20, view E), no image is formed because the reflected light is parallel.

With the object located between the focal point and the mirror surface, the image will be virtual, erect, reverted, and enlarged.

Concave spherical mirrors are used in reflecting telescopes, which will be explained in chapter 5. They are also used as reflectors for most external automobile lights and flashlights.

Parabolic Reflectors

The image formations illustrated in figure 4-20 represent ideal situations, which seldom exist.

If a very small luminous source is located at the principal point of focus of a concave spherical mirror, 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. 4-21). For this reason, a parabolic mirror is used whenever parallel reflected rays are desired.

Study figure 4-22. A parabolic mirror is a concave mirror with the form of a special geometrical surface—a paraboloid of revolution. Light rays that emanate from a small source at the focal point of a parabolic mirror are parallel after they reflect from its surface.

The source of light (usually a filament or arc) is located in the principal point of focus, and the rays diverge. All rays that strike the parabolic mirror (except those that are diffused or scattered) reflect from the mirror nearly parallel with each other, thereby providing for the formation of a powerful beam of light that diverges only slightly.

Convex Mirror

Study figure 4-23, which shows three objects (arrows O_1, O_2, and O_3) of the same size but of different distances from a convex spherical mirror The ray of light that 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 arrowheads to the center of curvature locate the virtual image positions produced by the three arrows. Object O_1 creates I_1, and so forth Note that the size of the image is larger when the object that formed it is moved nearer to the mirror, but an image can never become as large as its object.

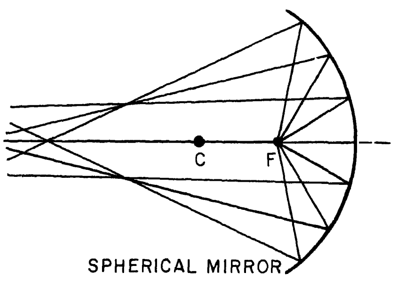


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Figure 4-21.—Convergent of light rays produced by a point source of light.

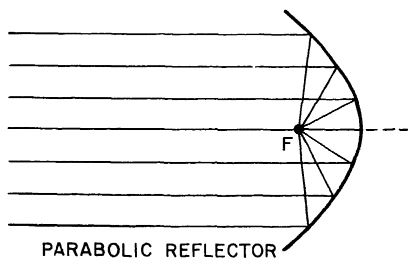

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Figure 4-22.—Parallel light produced by a point source.

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

The radius of curvature of a convex mirror is negative and the image is always virtual. The focal length (F) and the image distance (I_1, I_2, and I_3) are therefore negative quantities.

LENS FORMULAS

So far in this chapter, we have been concerned primarily with describing lenses and spherical mirrors and how they form images. Now, we will discuss the formulas that are used to determine focal length, magnification, image size, image distance, object size, object distance, magnifying power, dioptric strength, and relative aperture.

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.

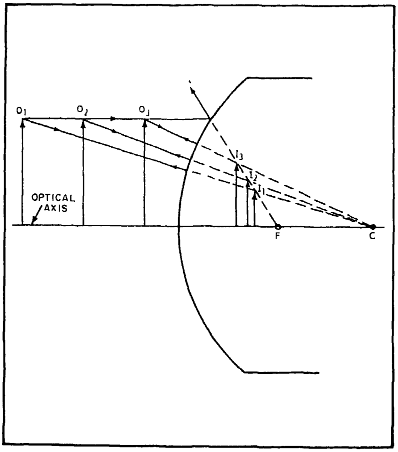

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Figure 4-23.—Image formation by a convex mirror.

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

$$F = \text{focal length}$$

$$D_o = \text{Distance of object}$$

$$D_i = \text{Distance of image}$$

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 (∞), $\frac{1}{D_o}$ 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.

IMAGE POSITION

Now, use the lens formula to calculate the positions of the image in figure 4-12. Assume that $F = 2$ inches and $D_o = 5$ inches, and substitute in the lens law

$$\frac{1}{2} = \frac{1}{5} + \frac{1}{D_i}$$

$$5D_i = 2D + 10$$

$$3D_i = 10$$

$$D_i = 3.33 \text{ in}$$

Now try the formula on a situation like figure 4-16. Remember, the image is formed on the same side of the lens as the object, therefore, the image distance (D_i) will be negative. Substitute your own numbers for F and D_o and see what happens.

When you work with a negative lens (fig. 4-17), you must deal with two negative quantities. The focal length (F) is negative since it is on the same side of the lens as the object; likewise, the image distance (D_i) is negative.

Given an object (D_o) of 2 inches and a focal length of -2 inches, find D_i.

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

$$D_i = -D_i - 2$$

$$2D_i = -2$$

$$D_i = -1$$

The image distance for arrow O_2 in figure 4-17 is -1 inch.

The lens law formula will work for any lens or mirror, positive or negative, as long as you know two of the three terms of the formula. You also must remember under which conditions the focal length and image distance are negative to obtain a correct solution. When your figures are correct, you determine image distance to be a negative quantity, the image is virtual. (See the two previous examples.)

MAGNIFICATION

Magnification is the apparent enlargement of an object by an optical element. You can more easily understand magnification if you consider a single positive lens used as a simple magnifier.

A positive lens works as a magnifier because it makes the light rays subtend a larger angle at your eye than is possible with the unaided eye. Figure 4-24 illustrates an object viewed by an unaided eye (view A), and an object viewed through a magnifier (view B).

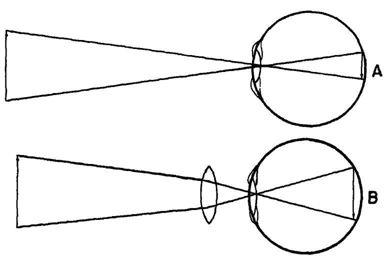

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Figure 4-24.—Object viewed with the unaided eye and through a magnifier.

The amount of magnification apparent in dealing with lenses or mirrors depends on image and object size and image and object distance. The formula is expressed as:

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

To understand the lens law formula and the formulas dealing with magnification, you can actually draw the examples presented next. If your drawings are accurate and if you use the principal rays dealing with image formation properly (fig. 4-11), you can prove that the formula works.

Draw a convergent lens that is 3 inches high, and use dotted lines to show the optical axis and the principal plane. 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. Now, draw an arrow 1 inch high with its tail on the optical axis and placed 3 inches to the left of the principal plane.

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.

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 have drawn, do not 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 its optical axis. The image of the arrowhead is at the point where that ray crosses the first one you drew.

There is another ray you can plot. 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 will be in opposite directions. For a ray passing through the optical center, the total deviation is zero. When 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. 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 have made your drawing carefully, all three rays will meet at the image point.

You have 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 also be at a right angle to the axis. So, draw a line from the image of the arrowhead to the axis, and there is your image of the arrow. Your drawing should look like figure 4-14.

If you have made the drawing carefully, you can use it to check the formulas for image size and distance. In the drawing, you have an object 1 inch high, 3 inches from a lens of 2-inch focal length. Use the lens law to find the image distance. The formula is:

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

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

$$3D_i = 2D_i + 6$$

$$D_i = 6$$

In the drawing, the image should be 6 inches from the lens. Measure to 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 formulas for magnification. The formula is:

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

substitute

$$\frac{6}{3}$$

$$M = 2$$

The image is twice the size of the object.

Now use the other formula for magnification.

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

substitute

$$2 = \frac{S_i}{1}$$

$$S_i = 2$$

Again, the image is proved to be twice the size of the object. Therefore, the magnification is 2.

Now, 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. This time make the arrow 2 inches long. To locate the image, find the point that is the image of the arrowhead, and then find the point that is the image of the tail. When you connect the two, there is the image of your arrow. Remember, 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 have finished your drawing, it should look something like figure 4-13.

Use the lens law formula to determine image distance, then use the two formulas for magnification. If your work is correct, the image is the same size as the object. Consequently, the magnification is 1.

The formulas for magnification will work for any situation dealing with image formation, even negative lenses or concave mirrors. All you have to do is remember which situations involve negative focal length or image distance.

Just for practice, construct some examples like figures 4-12, 4-16, and 4-17, and solve for magnification.

So far, we have talked about objects a short distance outside the focal point of the lens. Before going on, let us work out a more practical problem. Suppose you are looking at a ship through a telescope. The object lens of your telescope (the one in front—the one nearest the object) is a convergent lens. Assume that the objective lens has a focal length of 10 inches and that the ship you are looking at is 200 yards long and is 5,000 yards from your telescope. How far from the objective lens of the telescope is the image of the ship? How long is the image? Before you can substitute in the formula, you must get all the distances in the same units. Since you want the answer to be in inches, you must convert the other units into inches. The ship is 200 × 36 inches long, or 7,200 inches long. Its range is 5,000 × 36, or 170,000 inches. Now use the lens law.

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

substitute

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

solve for

$$D_i$$

$$18{,}000\ D_i = D_i + 180{,}000$$

$$17{,}999\ D_i = 180{,}000$$

$$D_i = 10.0005 \text{ in.}$$

The distance of the image is a little over 10 inches. 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 size of the image? You know the object is 7,200 inches long. You can use the formulas for magnification to to determine the size of the image.

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

therefore

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

substitute

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

solve for S_i

$$180{,}000\ S_i = 72{,}000$$

$$S_i = \frac{72{,}000}{180{,}000}$$

$$S_i = 0.4 \text{ inches}$$

You may not believe that an image only 0.4 inch long is practical, but you are using a telescope and the small image will be magnified by an eyepiece.

MAGNIFYING POWER

To understand magnifying power, first recall how an optical element affects the size of an image. As you know, image size depends on focal length, object size, and object distance. The focal length of any particular optical element is constant, but image size, depending on object distance, is variable. An image can be any size from a mere point of light up to one so large that there will not be enough light to reproduce the image distinctly.

When you want to make an object appear larger, you can either use a magnifying lens or move the object closer to your eyes. If you bring objects closer, your eyes must accommodate constantly (change refractive power) for you to clearly focus on the object. There is a limit to how close an object can be and still allow clear vision. This minimum distance is generally considered to be 10 inches and is called the distance of distinct vision.

Magnifying power is, therefore, a constant factor depending on how an object or image will appear if it is examined from a distance of 10 inches. Thus, for an optical element, the magnifying power is the PRACTICAL LIMIT OF MAGNIFICATION.

When computing the magnifying power of a lens, the formula is

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

If you have a lens with 5-inch fL, the MP will be

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

$$MP = 2$$

Since most lens computations use the metric system, always remember to convert 10 inches to the same metric unit used to express fL.

LENS DIOPTER

A lens diopter (generally called 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 and is directly related to focal length.

A lens with a focal length of 1 meter has the refractive power of 1 diopter. Study figure 4-25. The refractive power of a converging lens is positive; the refractive power of a diverging lens is negative.

The refractive power of a lens that does not have a focal length of 1 meter is the reciprocal of the focal length 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. The lens with the shortest focal length has the greatest positive or negative dioptric strength.

To find the dioptric strength of a lens with a focal length of 25 centimeters, use the following formula (remember that 25 centimeters equals 0.25 meters):

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

$$\text{Diopters} = \frac{1}{0.25} \text{ meters}$$

$$\text{Diopters} = 4$$

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

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

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

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

RELATIVE APERTURE

The aperture of a lens is the largest diameter through which light can enter a lens to form an

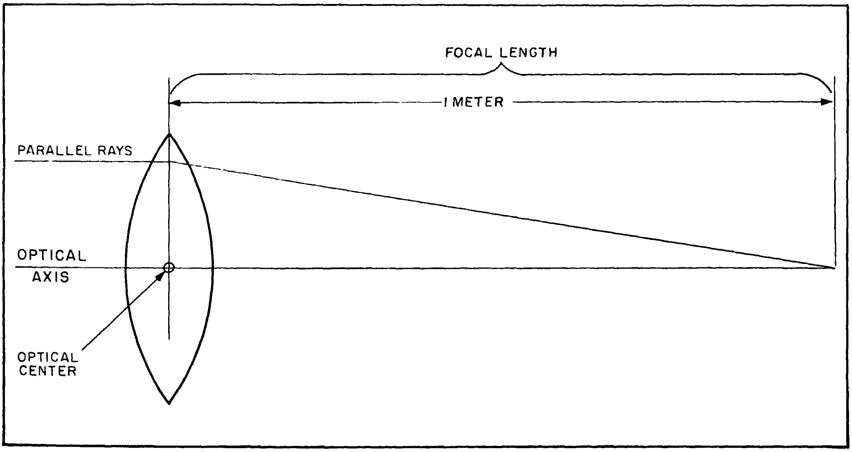

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Figure 4-25.—Lens diopter.

image. The light-gathering ability of a lens is determined by (1) its aperture and (2) its focal length.

Look at the lenses in figure 4-26, 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.

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. Since the diameters of the two lenses are equal, the lens with the shorter focal length will form a brighter image than the lens with the longer focal length, because the light it receives is concentrated in a smaller area.

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:

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

RELATIVE IMAGE BRIGHTNESS

When you compare the light-gathering ability of one lens with another, consider the relative aperture (focal length divided by diameter) of both lenses. This is sometimes referred to as the speed of a lens.

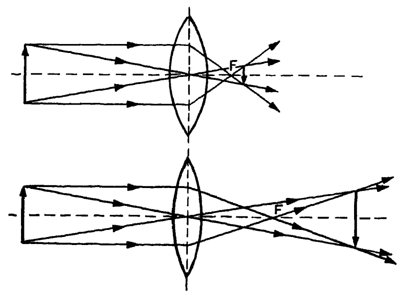

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Figure 4-26.—Brighter image formed by short focal length lens.

If you have two lenses with different relative apertures, you can tell which one will form the brighter image by using a 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 (similar to fig. 4-26).

If the focal lengths of these two lenses were equal, the f:2 lens would be twice the diameter of the f:4 lens (similar to fig. 4-27).

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.

Suppose you want to purchase a camera and have narrowed your search down to two models. One has an f:1 9 lens, the other has a f 3 6 lens Which camera will form the brighter image, and

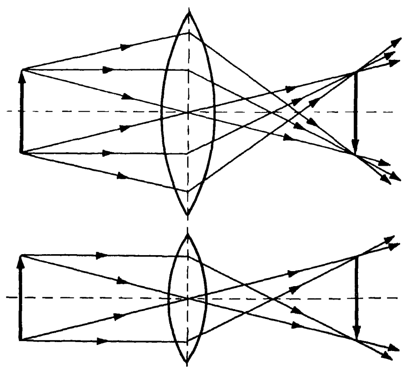

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Figure 4-27.—Image brightness increased by enlarged lens aperture.

how much brighter will it be? Use the formula to find out.

LENS ABERRATIONS

Earlier we said this: When rays of light diverge from a point and pass through a convergent lens, they will converge and meet at another point behind the lens (the focal point). But this is true only of single PERFECT lenses. Actually, there is no such thing as a perfect lens. When the rays pass through a lens with spherical surfaces, some of them will converge to a point, and some of them will converge at other points. There is no single point at which they all come to a sharp focus.

There are several things about the behavior of light that keep a single lens from forming a sharp image. We call these things ABERRATIONS and divide them into two general classes. Some aberrations depend on the fact that white light is a mixture of colors; we call them CHROMATIC ABERRATIONS. (Chromatic comes from the Greek word for COLOR.) Other aberrations will be present even if you use light of a single wavelength. We call them MONOCHROMATIC ABERRATIONS.

Some books refer to aberrations as lens defects, but that term is misleading. Aberrations are not caused by a manufacturer's carelessness. Even a manufacture's best lens will have aberrations. They are caused by the behavior of light and not by the quality of the lens.

CHROMATIC ABERRATION

In chapter 2 we discussed how a prism breaks up a beam of light into separate colors. We called that DISPERSION. In chapter 3, we discussed a lens and how we can think of it as being made up of an infinite number of prisms. It is reasonable to think that a lens would disperse the light into separate colors, and it does. Examine figure 4-28.

What three things determine the focal length of a lens?

1. The shape of its refracting surfaces.
2. The thickness of its refracting surfaces.
3. The index of refraction of the glass.

For any given lens, the shape and thickness are fixed, and cannot vary. The index of refraction of any piece of glass depends on the

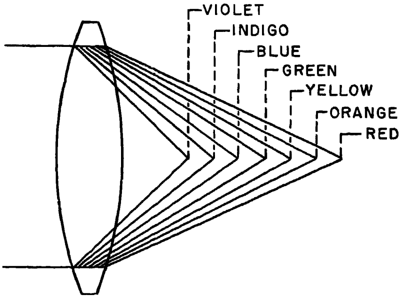

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Figure 4-28.—Chromatic aberration in a lens.

wavelength of light. The index of refraction is higher for short wavelengths as compared to long wavelengths. Figure 4-28 shows what happens. (When we use a drawing to show an aberration, the drawing will assume that the lens has no other aberrations except the one we are discussing.)

Here we have two parallel rays of white light striking a convergent lens. The index of refraction for violet light is relatively high. So the focal length for violet light is short, and the violet image is close to the lens. For red light, the index of refraction is lower So the focal length is longer, and the red image is farther from the lens. You will have a different image for each wavelength, and the images will be strung out along the axis. There is no point where they all come to a single focus.

As you probably remember, the size of the image depends on the focal length of the lens. Since the lens has a different focal length for each color, each of the images will be a different size. If you bring any one of the point images to a sharp focus on a ground glass screen, it will be surrounded by colored halos. If you make a telescope of single lenses, without correcting the chromatic aberration, you will see a fuzzy, indistinct image of your target. Why? The image of each point would be surrounded by the colored halos and overlapped by the halos from other points.

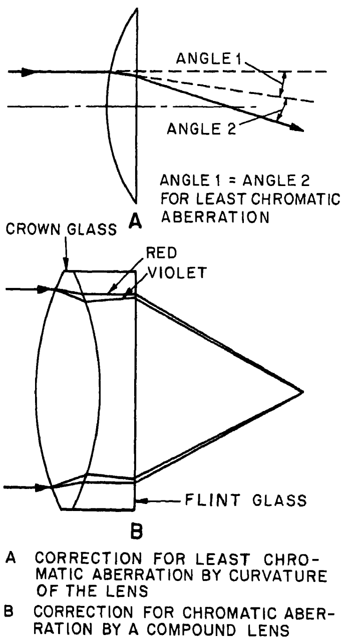
When we correct the chromatic aberration in a lens or a lens system, we say that the corrected system is ACHROMATIC. How can we correct chromatic aberration? In a single lens, there is nothing we can do about it. But, by combining two lenses, we can make the abberation of one lens cancel the aberration of the other lens. For example, if you use two thin convergent lenses made from the same kind of glass, separated by half the sum of their focal lengths, you will have an achromatic system. (There are calculations to prove this, but the math is pretty complicated.) Many telescope eyepieces are achromatized this way.

Other eyepieces, and most objectives, are corrected by using two lenses of different kinds of glass, with little or no separation between them.

In flint glass, both index of refraction and dispersion are higher than they are in crown lass. (To ensure understanding, we will define those terms again.) When we discuss INDEX OF REFRACTION (without mentioning wavelength), we mean the index for the color your eyes are most sensitive to—a certain wavelength in the yellow-green. DISPERSION is the DIFFERENCE between the index of refraction for violet and the index of refraction for red.

We can say that the index of refraction of flint glass is a little higher than that of crown glass, but the dispersion of flint glass is CONSIDERABLY greater than that of crown glass.

Figure 4-29 shows how an achromatic lens will correct the chromatic aberration. You have a convergent lens of crown glass. Cemented to it is a divergent lens of flint glass. The first lens makes the light converge. Violet light converges more than red light. The second lens will tend to diverge the rays and will diverge the violet light more than the red light. Since the dispersion of flint glass is greater than that of crown glass, we can make the convergent lens more powerful than the divergent lens. The combination will still be a convergent lens. It will still bend rays of light to a focus. If it is properly designed, it will bring the violet and the red rays to a focus at the same point.



A CORRECTION FOR LEAST CHROMATIC ABERRATION BY CURVATURE OF THE LENS

B CORRECTION FOR CHROMATIC ABERRATION BY A COMPOUND LENS

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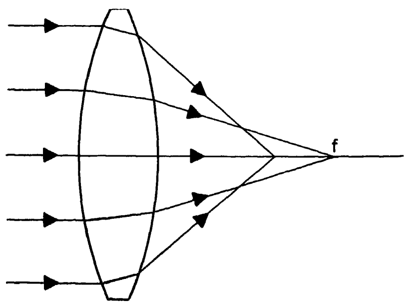
Figure 4-29.—Correction of chromatic aberration in a lens.

SPHERICAL ABERRATION

We told you earlier that a convergent lens will bend parallel rays to a focus only if its surface



137.102

Figure 4-30.—Spherical aberration in a convergent lens.

is a rather small part of a sphere. Figure 4-30 shows what happens.

The rays near the edges of the lens are bent more sharply than those near the axis. There is no single point at which they all come to a focus. As you probably remember, we call that spherical aberration. This is not a defect of the lens. It is just the way light acts when it strikes a spherical surface.

Now look at figure 4-31 and note the 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) the thickness of the lens and (2) its focal length. A thin lens with a long focal length has less aberration than a thick lens with a short focal length.

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. Then use a field stop to mask out all rays that pass through the lens beyond this circle (fig. 4-32, view A). Note the rays blocked by the

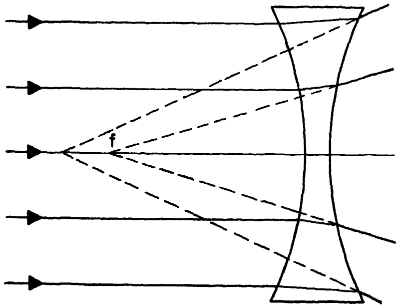


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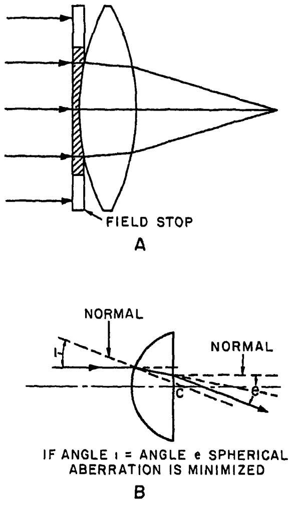
Figure 4-31.—Spherical aberration in a divergent lens.



137.104

Figure 4-32.—Reduction of a spherical aberration by a field lens.

field stop. The 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 that passes through it.

Spherical aberration in a lens can also be minimized by bending the lens. This 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, but reduces the amount of aberration (fig. 4-32, view B). 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. To reduce the amount of spherical aberration to a minumum, the angle of emergence of a ray (e) 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. 4-33). 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. Notice that this method of eliminating spherical aberration is quite similar to the correction for chromatic aberration.

COMA

Coma has the same cause as spherical aberration; the edges of the lens have a higher refractive power than the center. Spherical aberration affects the rays that are parallel to the axis, or nearly parallel to it. Spherical aberration gives this result: the image of a point is a blurred disk.

Coma affects rays from a point OFF the lens axis. The image of that point, instead of being a disk, is shaped like a comet. The image is made up of a number of partly superimposed disks, each formed by a different part of the lens.

Figure 4-34, view A, shows how these disks form a coma, and figure 4-34, view B, shows what it looks like. Both pictures are greatly magnified, of course.

We can eliminate coma in the same way we minimize spherical aberration. This is done by making a proper choice of curvatures for the refracting surfaces. Unlike spherical aberration, coma can be completely eliminated from a single lens, for one particular object distance. (It will still show coma for objects at other distances.) Unfortunately, the curvatures that eliminate coma from a lens system are not the same as those that minimize spherical aberration. The people who design lens systems must choose between these two aberrations, or make compromises between them.

A lens system that is free from coma, chromatic abberation, and spherical aberration, FOR ANY ONE OBJECT DISTANCE, is an APLANATIC system.

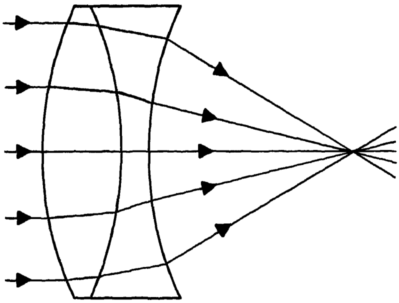


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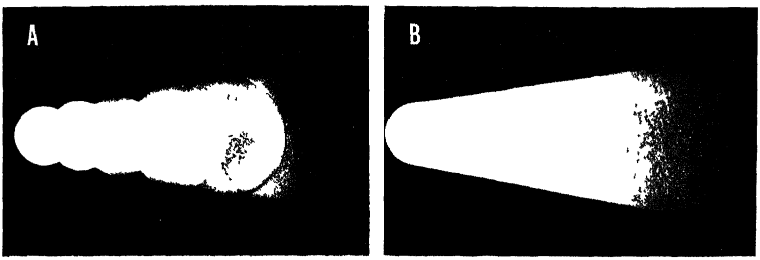
Figure 4-33.—Elimination of spherical aberration by a compound lens.



A. FORMATION
B. APPEARANCE AFTER FORMATION

137.106

Figure 4-34.—Coma.

ASTIGMATISM

ASTIGMATISM has two meanings. One refers to a true aberration, caused by the behavior of light at spherical surfaces. The other refers to a lens defect and happens when the surface is not truly spherical.

Like coma, astigmatism affects the images of points some distance off the axis, but the effects are different. Coma spreads out the image in a plane perpendicular to the axis. Astigmatism spreads the image in a direction along the axis.

What can we do about astigmatism? By properly selecting the curvatures of the lens surfaces, we can make the secondary image plane coincide with the first. The image will then be sharp all over. It will lie on a curved surface, and you will have CURVATURE OF FIELD. (See fig. 4-35.)

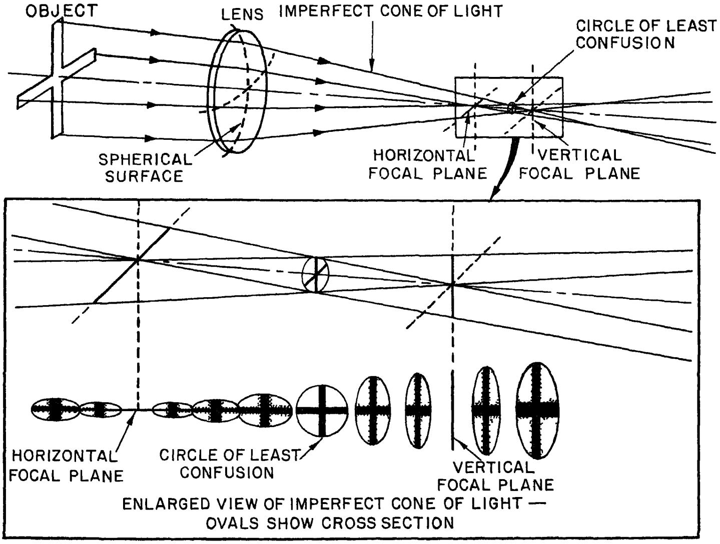
If we choose lens surfaces that give the two images equal and opposite curvatures, the circles of least confusion will lie in a plane, and the image will be flat. But, astigmatism will be at its worst. The image will be sharp at the axis, but near the edges of the field it will be badly blurred.

How can we correct this problem? You cannot correct both astigmatism and curvature of field in a single lens. With a suitable combination of lenses and a suitable arrangement of stops on the axis, you can bring both of these aberrations under control. But as soon as you put stops on the axis, you create more problems.

The most common method of correcting this aberration is by use of a combination of lenses called field flatteners. They produce an opposite curvature of field and cancel aberration.

DISTORTION

All other aberrations affect the sharpness of an image. An image can be perfectly sharp all over, but it can still be distorted. What causes this problem? The lens has a different magnification for objects off the axis than for objects on the axis. If magnification is less for objects off the axis, you will have



137.108

Figure 4-35.—Astigmatic refraction of light.

BARREL DISTORTION (fig. 4-36, view A). If it increases as you leave the axis, you will have PIN-CUSHION DISTORTION (fig. 4-36, view C).

A single thin lens will form an undistorted image. As soon as you put a diaphragm on the axis, you will get distortion. If you put the diaphragm in front of a lens, the image formed by that lens will show barrel distortion. If you put the diaphragm behind the lens, you will get pin-cushion distortion. What can you do about it? Use a compound lens with a stop between the two elements. Let the distortions cancel each other.

NEWTON'S RINGS

If convergent and divergent lenses of slightly unequal curvature are pressed against each other, irregularly colored bands or patches of color will appear between surfaces. See figure 4-37. 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 accuracy of grinding and polishing during lens manufacture. Light waves from an object never focus perfectly at a corresponding point on an image. They form, instead, a diffused image with a central white spot surrounded by a series of concentric rings of light that fall off rapidly in intensity. This is called a DIFFRACTION PATTERN (fig. 4-38). Diffraction sets the final limit to the sharpness of the image formed by a lens, resulting from the natural spreading tendency of light waves. It occurs in images formed by all lenses, regardless of the perfection with which they are constructed.

CORRECTING THE ABERRATIONS IN A LENS SYSTEM

There is no possible way you can correct all of the aberrations in a single lens. Only by using a number of elements, so you will have many surfaces to work with, can you make a highly corrected lens system. No matter how many surfaces you have to work with, you cannot eliminate all of the aberrations at the same time. For example, you can eliminate either coma or astigmatism, but you cannot eliminate both of them at once. The people who design lens systems must decide whether they are going to have coma or astigmatism or a little of each.

They base that decision on what the instruments will be used for. Telescopes (and most of the instruments will be working with) have a fairly narrow field of view Most of the rays that enter a telescope lie fairly close to the axis For

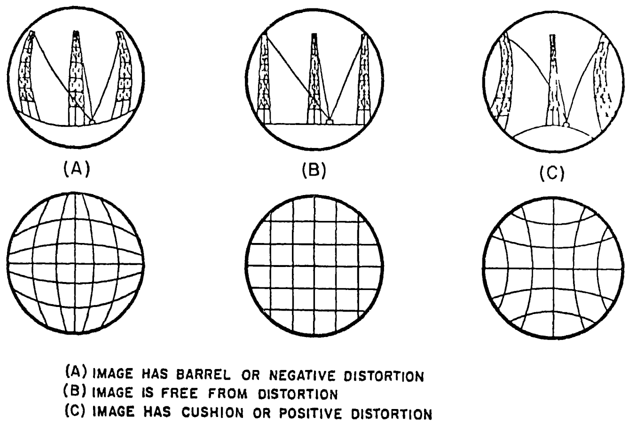


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Figure 4-36.—Distorted images formed by a lens.

rays near the axis, coma is more objectable than astigmatism. The people who design telescopes will correct the optical system for coma.

On instruments with a wide field of view (such as a camera), astigmatism is more objectionable than coma. The people who design camera objectives will correct it for astigmatism, and will not try to eliminate coma. (In an expensive camera objective, astigmatism is the primary correction. We call those lenses ANASTIGMATS. A lens system that is correct for astigmatism is an ANASTIGMATIC system.)

Lens designers have a tricky problem. Anything they do to correct one aberration will affect all of the others, usually for the worse. (It is like one of those puzzles where you have to get six little balls in six little holes. As soon as you get one of them in, another one falls out.)

Lens designers have the following variables to work with:

1. The radius of curvature of the various refracting surfaces
2. The distance between surfaces (thickness of lenses, and the distance between them)
3. The difference in index of refraction between different kinds of glass
4. The difference in dispersion in different kinds of optical glass
5. The position of stops along the optical axis

We have discussed previously that the people who design lens systems can control the most important aberrations by calculating the proper combination of those variables. We know this is a vague explanation. We could make it more definite by showing you some of the calculations, but we do not feel that the math is necessary at this point in your training.

Lens designers are highly specialized and highly trained. Even so, it sometimes takes them months to calculate the design of a new lens system.

We have not tried to tell you how to design a lens system, but we HAVE tried to get the following points across:

1. Optical instruments are PRECISION INSTRUMENTS. They are expensive because they are hard to design and to make. They should be carefully handled.

2. The repair of optical instruments is PRECISION WORK. A careless repair job can be worse than none at all. Many of your adjustments must be critically exact.

3. The corrections depend not only on the curvature of the surfaces, but also on the order in which the light strikes them. If you put a lens in backwards, you may destroy the quality of the image.

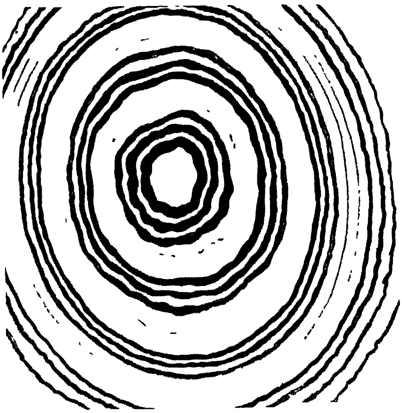

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Figure 4-37.—Newton's rings.

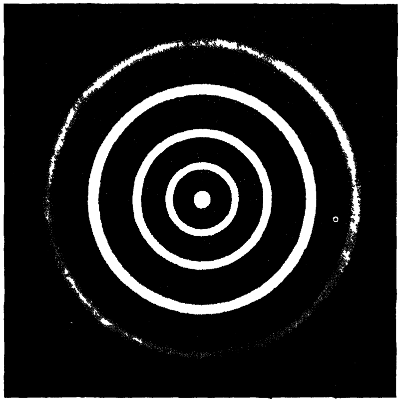

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Figure 4-38.—Diffraction pattern (greatly magnified).

THICK LENSES

Thus far our discussion on lenses has dealt with thin lenses. It is now important that we explain the path of light through a thick lens.

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

The Navy uses the following three types of thick lenses:

1. Single thick lenses
2. Compound lenses
3. Two thin lenses combined to make one thick lens

Two equiconvex lenses are illustrated in figure 4-39. Both lenses have the same index of refraction and radius of curvature; their diameters are equal, but their thicknesses are unequal.

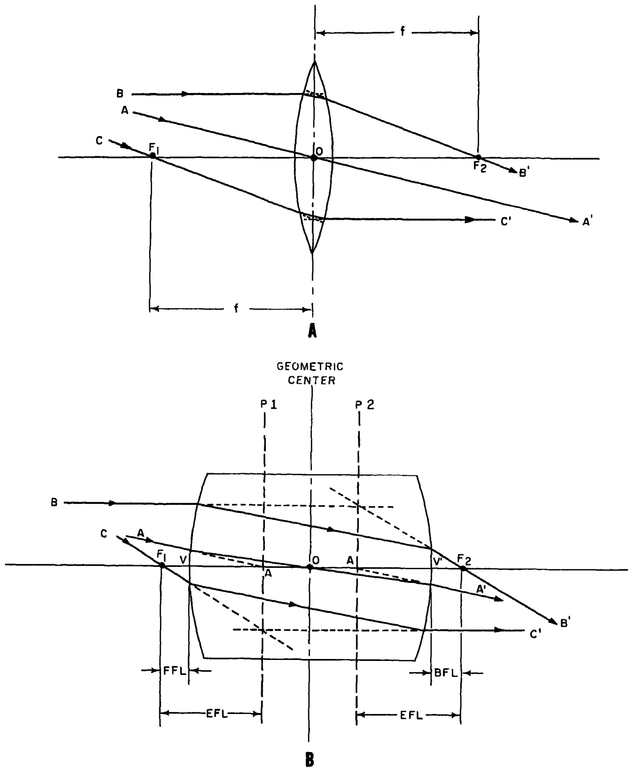

Figure 4-39.—A thin lens and a single thick lens.

As you probably know, an A ray is any ray that passes through the optical center of a lens and emerges from the lens parallel to the incident ray without deviation. This rule applies to both thick and thin lenses. But notice the differences in the A rays that are passing through the two lenses in figure 4-39. In the thin lens in view A, the A ray is traveling toward the optical center and passes directly through without refraction or deviation.

For a ray of light to pass through a thick lens without deviation, it must travel along the optical axis, or travel as shown in view B of figure 4-39. When the ray strikes the lens, it is refracted according to the laws of refraction and passes through the optical center. Upon emerging from the second surface, the ray appears to have come from the second principal point (A^1) and is parallel to the incident ray, slightly offset (not deviated) from its original path.

When converging incident light strikes a thick lens, an undesirable result can occur. 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 4-39 is the same, but the ray in the thicker lens travels a greater distance than the ray in the thinner lens. Observe also that the principal plane (P2) of the B ray is now located to the right of the optical center of the thick lens.

Now compare the C 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 the C ray of the thick lens does not appear to be refracted at the same point as the B ray—it traveled a greater distance in the thin lens The location of the principal plane (P1) for the C ray is to the left of the optical center. Apparent refraction, therefore, does not take place in the exact center of the thick lens as it does in the thin lens.

Because the principal planes of a thin lens coincide, we measured the focal length as the distance from the surface of the lens to the principal focus. As shown in figure 4-39, the principal planes of a thick lens do not coincide. 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

The distance measured from the principal focal point on the left to the vertex of the front surface is the front focal length (F1 to V in fig. 4-39), abbreviated FFL.

EQUIVALENT FOCAL LENGTH

The distance measured from a principal plane to its corresponding principal focal point to the equivalent focal length (P1 to F1 and P2 to F2 in fig. 4-39), abbreviated EFL.

BACK FOCAL LENGTH

The distance measured from the vertex of the back surface of the lens to the focal point on the right is the back focal length (V′ to F2 in fig. 4-39), abbreviated BFL.

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 control defects that are present in a single lens. These are called compound lenses; they will often be thick enough to be classified as a thick lens (fig. 4-40).

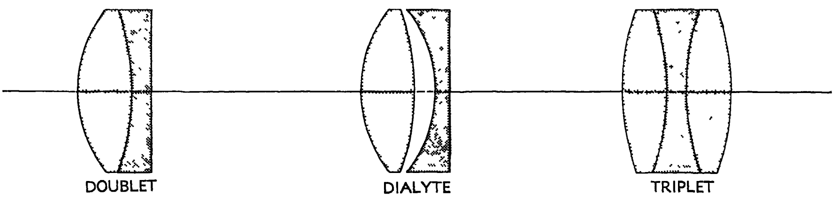

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Figure 4-40.—Compound lenses.

Two elements that are cemented together with their optical axes in alignment are called 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 meet.

NOTE: The lenses of doublets that are 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. They cannot be cemented together. The two lenses are separated by a thin spacer ring, or tinfoil 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 4-41, which illustrates two symmetrical thin lenses used as a thick lens. All the laws of refraction apply here as they did in figure 4-39. The only variation in the two systems is the way you measure focal distances. Because the two lenses are very thin, the principal planes of each lens lies in the geometrical center. For this reason we 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 length on each side will still be equal because the EFL is calculated from the principal planes in the combination.

The formulas for computing the three focal distances are:

$$\text{FFL} = \frac{(\text{F1} \times \text{F2}) - (\text{S} \times \text{F1})}{\text{F1} + \text{F2} - \text{S}}$$

$$\text{BFL} = \frac{(\text{F1} \times \text{F2}) - (\text{S} \times \text{F2})}{\text{F1} + \text{F2} - \text{S}}$$

$$\text{EFL} = \frac{\text{F1} \times \text{F2}}{\text{F1} + \text{F2} - \text{S}}$$

F1 = focal length of lens X (in combination)

F2 = focal length of lens Y (in combination)

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

Refer again to figures 4-39 and 4-41. Notice how the C ray is used to establish the first principal plane (P1) and the B ray establishes the second principal plane (P2). In figure 4-41, the first principal plane is to the right of the second principal plane. This is entirely correct and quite common in two lens combinations. Remember, when you measure EFL, measure from F1 to P1 or F2 to P2. The distances will be the same regardless of the difference between the two lenses.

Actual refraction of light rays passing through each lens in figure 4-41 is now shown By now you should have a good idea of what happens at each lens surface Refer to figure 4-42, which illustrates the use of two thin lenses in combination in 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.

As you study the illustration, you will notice that lens X is within the focal length of lens Y, and it makes diverging rays from focal plane F1 less divergent. Also notice that the focal length of lens Y is longer than the EFL. This helps to illustrate 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 focal length of either lens.

MISCELLANEOUS OPTICAL ELEMENTS

To form the image, and to control its position and the line of sight, optical instruments use

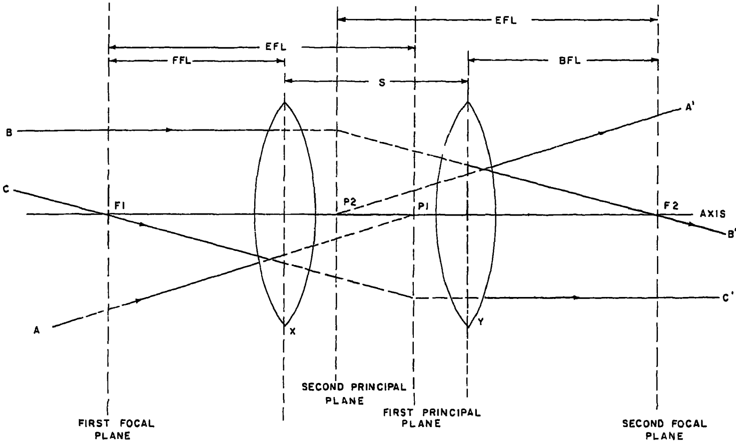

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Figure 4-41.—Symmetrical thin lenses used in combination as a thick lens.

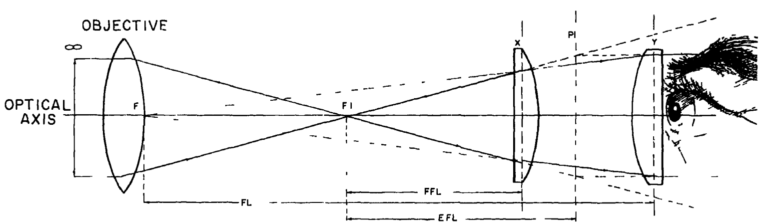

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Figure 4-42.—Two thin lenses used as an eyepiece.

lenses, mirrors, and prisms. In some instruments the light passes through other elements that have no effect on image formation or line of sight. These elements are windows, reticles, and filters.

WINDOWS

Windows are made of optical glass, with the two surfaces flat and parallel. You may find them at the objective end of the system, the ocular end, or at both ends. Their principal function is to protect the optical system from dirt, moisture, and physical damage.

RETICLES

Reticles (also called RETICULES) consist of thin lines engraved on glass. Usually, the lines are engraved on a flat disk with parallel faces. Occasionally, you may find a reticle engraved on the plane surface of a lens. The reticle has only one function. That function is to superimpose one or more reference marks on your view of the target. (Some optical instruments include an electric lamp to illuminate the reticle.)

COLOR FILTERS

Color filters (also called RAY FILTERS) are flat disks of colored glass. You can often use them to increase the contrast of the image. This is done to make the target stand out against its background.

We know that colored glass will let some of the wavelengths pass through and hold back others. For example, a yellow filter will hold back a high percentage of the blue and violet, but it will let a high percentage of the other colors pass through. Suppose your target is a gray ship against a background of blue sky and blue water. If image contrast is low, your target may be hard to see.

Suppose you slip a yellow filter into the line of sight. It will hold back most of the blue and violet. The ship will still look bright. This happens because it is reflecting all colors. Most of the light from the sky and water is blue and violet. Through a yellow filter they will look fairly dark. What is the result? The ship stands out against its background.

An orange or a red filter will hold back more of the blue light than a yellow filter. They will make the contrast even greater, but of course they will decrease the brightness of the target image. An orange or red filter may make the whole image too dark to be useful.

Figure 4-43 shows the different types of color filter mountings. In figure 4-43, view A, the filters are in individual mounts that slip or screw on to the lens barrel. In figure 4-43, view B, the filter mounts swing on a pivot, and you can swing any filter (or any combination of filters) into your line of sight. In figure 4-43, view C, you have three filters and a disk of plain glass in a mount that rotates on a pivot. You can select the filter you want by turning the mount.

POLARIZING FILTERS

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

To understand how polarizing filters work, we will 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 does not represent the wave motion of light You can get a clearer picture of light waves if you have a number of parallel ropes and shake them up and down, sideways, and at various angles in between. Light waves vibrate in all possible directions at right angles to their line of travel.

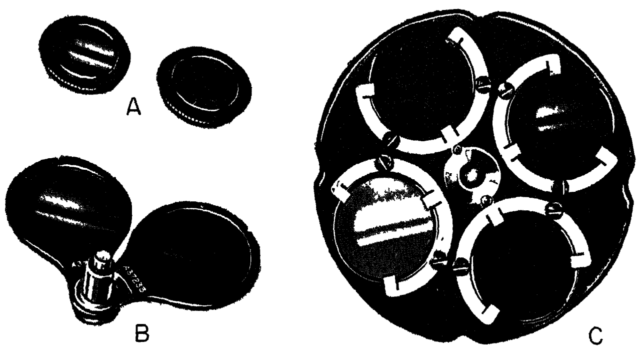

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Figure 4-43.—Color filter mountings.

Suppose you are shaking a rope to make a wave motion. Imagine that somewhere along its length the rope passes between two vertical slats that are an inch apart. If you shake the rope up and down you will make vertical waves, and these vertical waves will pass easily between the vertical slats. If you shake the rope sideways, you will make horizontal waves, and the vertical slats will stop them dead.

Now suppose you have a number of parallel ropes, and they are passing between a series of parallel vertical slats. You shake some of the ropes up and down, sideways, and at various 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 will be vertical. Beyond the slats, all of the wave motion will be in one direction. When wave motion is all in one direction, we say that it is POLARIZED.

Ordinarily, light waves vibrate in all directions. But when light strikes a series of microscopic parallel slats, all of the light that passes through will be vibrating in one direction and we have POLARIZED LIGHT. Polarizing filters polarize the light that passes through them. Look at figure 4-44.

Polarizing filters contain a microscopic grid to polarize the light. Figure 4-44, view A, represents a polarizing filter with a vertical grid. 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. Look at figure 4-44, view C. Then all the waves that pass through the filter will be polarized in a horizontal plane.

In figure 4-44, view B, we have a beam of light that is vibrating in all directions and is striking a polarizing filter with a vertical grid. (In this diagram, the light is coming from right to left. To keep it simple, we have shown only the vertical and horizontal waves.) All of 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 polarizing 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.

REMEMBER THIS: Figure 4-44 is only a diagram. We do not intend for it to be a picture, either of light waves or of polarizing filters.

How does a polarizing filter polarize light? Many mineral crystals show double refraction. They have two DIFFERENT indexes of refraction for each wavelength. The crystal splits each ray that passes through it into two separate rays. Each of these rays will be polarized, and their planes of vibration will be at right angles to each other.

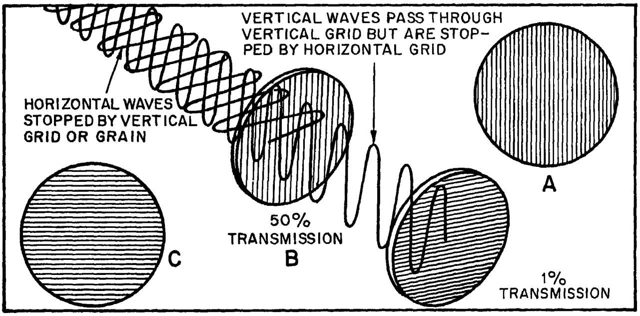

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Figure 4-44.—The polarization of light.

A few doubly refracting minerals have a property that we call DICHROISM. A dichroic crystal will split each ray into two separate polarized rays and then will absorb one of them. (Tourmaline is a good example of a dichroic crystal.) If you cut a dichroic crystal to the right thickness, any light that passes through it will be almost completely polarized.

A polarizing filter is a film of plastic, and is 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 of these crystals are lined up in the same direction, they polarize all of the light that passes through the film.

Getting those crystals lined up is the tricky part. The manufacturer stirs them into the plastic while it is still soft and syrupy. Then he pours it out in a thin film to harden, and as it hardens he stretches it. The strain inside the film pulls the crystals in the direction of the stretch. When the film hardens, all of the crystals are lined up and locked in place.

Much of the light you see every day is polarized. The light reflected from any nonmetallic surface is always partly polarized. At one particular angle of incidence, the reflected light is COMPLETELY polarized. All of the reflected light is vibrating in a plane PERPENDICULAR to the plane of incidence.

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

When a pair of polarizing filters are used, one filter remains stationary and is oriented to reduce the glare of sunlight reflecting from water. (When light reflects from any surface it is partially polarized.) The other filter can be rotated to any position desired. Therefore, you can vary light transmission through the filter from maximum (grids parallel) to minimum (grids at 90 degrees).

Some instruments use a single polarizing filter, and it can be turned to eliminate glare from various surfaces. Most military instruments now use a pair of filters. This permits a full range of capabilities.

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CHAPTER 5

BASIC OPTICAL SYSTEMS

In previous chapters we have discussed the use of various optical elements to form images. Now we will combine some of those elements into basic optical systems. MIL-STD-1241A defines an optical system as "A combination of optical elements arranged to perform one or more optical functions." Of all the optical systems you come in contact with, the most important is the human eye. Understanding its function will more clearly explain the operation of optical instruments in the Navy.

When sailors line up targets in a gunsight telescope, they are using a fairly complicated optical system. What is the most important part of the system? It is the sailors' eyes and not the objective lens, the eyepiece, or the barrel of the telescope.

A camera is one of the simplest optical instruments. Nearly everyone in America has used a camera at one time or another. Of all of the optical instruments you are likely to use, the camera is the most familiar, and the eye is the most important. If you are going to be an expert on optics, you should know something about both the eye and the camera.

If you can imagine the basic elements, the eye and the camera are quite similar (fig. 5-1). Each has a lens, and each forms an image on a sensitive surface (the film in the camera and the retina in the eye). Each is enclosed in a light-tight housing. This prevents stray light from spoiling the image. Each has a means of focusing, and both the camera and the eye have a means of varying the aperture (the iris in the eye, the diaphragm in the camera).

THE EYE

The human eye is a complicated organ. Figure 5-2 shows its principal parts. The human eye is about an inch in diameter and nearly spherical in shape. The SCLERA, a tough outer whitish coat, holds the eye in shape. In front, where light enters the eye, the sclera is transparent and bulges out to form the CORNEA. The space between the cornea and the lens contains a watery salt solution—the AQUEOUS HUMOR. Behind

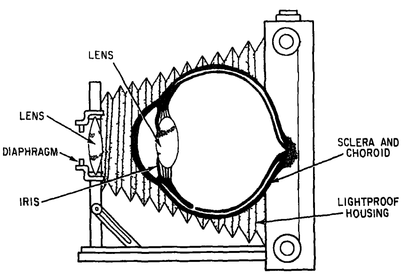

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Figure 5-1.—Comparison of the eye and the camera.

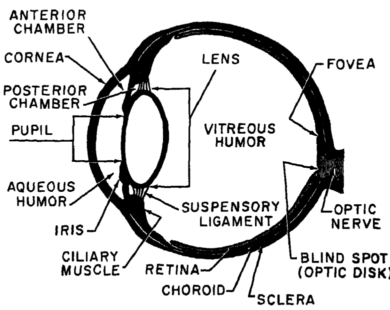

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Figure 5-2.—Construction of the human eye.

the lens is the VITREOUS HUMOR—a transparent gel with about the same consistency as egg white. The LENS is a tough transparent capsule that is also filled with fluid.

Everything inside the sclera is under pressure (about 8 ounces per square inch), and that pressure helps the eye hold its shape.

The cornea and the lens act together as a convergent lens system and form a real image on the RETINA. Most of the refraction takes place at the surface of the cornea. (The cornea has a high index of refraction, and its surface is in contact with the air. The angle of refraction depends on the difference in the index of refraction between two medias. The lens has a high index of refraction, but it is surrounded by fluids. Its refractive power is fairly small compared to the cornea.)

If you want a demonstration of the refractive power of your cornea, think back to the last time you swam underwater. Unless you wore goggles, you could not see clearly, even though the water was very clear. When the surface of your cornea is in contact with the water, it loses more than half its refracting power. It cannot bring light rays to a focus on your retina, regardless of how hard you strain the lens.

Now take another look at figure 5-2. Inside the sclera is the CHOROID—a layer containing the principal blood supply of the eye. It contains black pigment. The pigment serves the same purpose as the dull black on the inside of a camera. It helps to make the optical system light tight and prevents scattered reflections inside.

Get a mirror, and look at your eyes. That circular opening in the center of each eye is the PUPIL. Why are they black? Because the inside of an eye reflects very little light—the choroid absorbs it.

The colored area around the pupil is the IRIS. It is a continuation of the choroid and retina layers, with the choroid facing outward. This part of the choroid usually contains a lot of pigment, though not as much as inside the eye. If the choroid layer of your irises are heavily pigmented, your eyes are black or dark brown. If the choroid layer contains less pigment, your eyes are light brown, hazel, or grey. If the choroid layer contains no pigment at all, it is transparent and you can see the blue color of the retina layer through it.

Now, if you can, go to a dimly lighted room. Take a flashlight and a mirror. When your eyes get used to the dim light, look at your irises in the mirror Then shine the flashlight into your

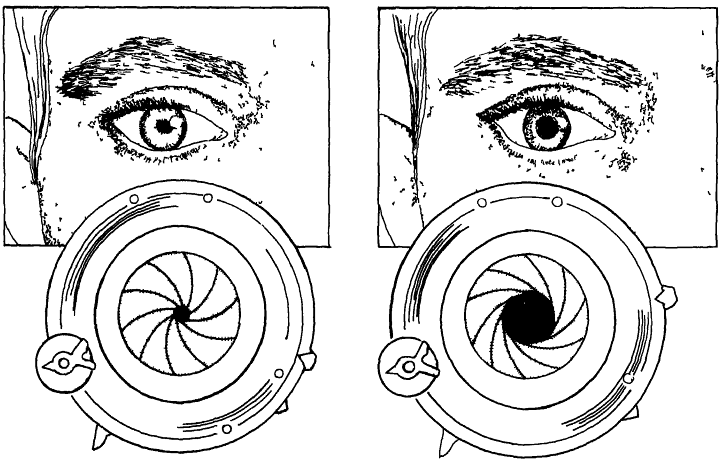

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Figure 5-3.—Iris and diaphragm of a camera.

eyes, and watch the irises contract. Figure 5-3 shows the similarity between the iris of an eye and the iris diaphragm of a camera.

The retina is a complicated structure and covers most of the area behind the CILIARY MUSCLE. Figure 5-4 shows a cross section of the human retina magnified about 500 times. The retina translates light energy into nerve impulses and contains the first coordinating nerve cells in the visual system. In this picture, the 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 other layers of tissue containing a network of nerve fibers and blood vessels. These layers are extremely thin, and do not absorb much light. But, they do affect the sharpness of the image.

In some lower animals, the sensitive layer is at the front of the retina, with the blood and nerve supply behind it. Those animals can probably see more clearly than we can. But the human retina has this advantage: the sensitive layer is in contact with the blood supply of the choroid. That keeps the retina at peak efficiency over a longer period of time.

Fixation is the act of looking at something. When you look closely at a small object, you FIXATE on it. Fixate on this period (.). When you fixate on that period, you can probably make out a few of the letters near it. But you cannot possibly read the rest of the page without moving your eyes. You have a very small area of clear vision; the rest of what you see is pretty hazy.

What does that mean? It means that there are small spots on your retina that are much more sensitive than the rest of your eye. Figure 5-2 shows the position of this sensitive spot. It is called the FOVEA CENTRALIS. (A fovea is a pit, and centralis means in the middle.)

The fovea is a small depression in the surface of the retina. There are no rods in the fovea, but its cones are especially large and close together. In the exact center of the fovea the layer of nerves and blood vessels are extremely thin. The cones are near the surface of the retina.

What happens when you fixate on a small object? You turn your eyes so that its image falls on your fovea centralis. The area of sharpest vision is extremely small. For a demonstration, fixate on this colon (:). You can fixate on either the top dot or the bottom dot, but you have to move your eyes to change from one dot to the other.

If you take another look at figure 5-2, you will see a point where the nerve fibers of the retina enter the optic nerve. There is an area here much larger than the fovea centralis that has neither rods or cones. Because you cannot see light that falls on this area, each of your eyes has a blind spot. But, because you are so accustomed to the blind spots, you will not notice them.

Look at figure 5-5. Hold the paper about 10 inches from your eyes Close your left eye and fixate on the center of the white cross with your right eye. Now slowly move the page closer, keeping your eye on the cross. When the image of the white disk falls on your blind spot, you will not see it.

ACCOMMODATION

When your eyes are completely relaxed, distant objects form sharp images on your retinas. Your far point of distinct vision is at infinity If you hold your hand in front of your face when your eyes are relaxed, you cannot see it clearly unless you readjust your optical system. When you readjust an optical system, you focus. When you readjust your eye for a nearby object, you ACCOMMODATE.

The closer you bring an object to your eyes, the more you have to accommodate. But, there

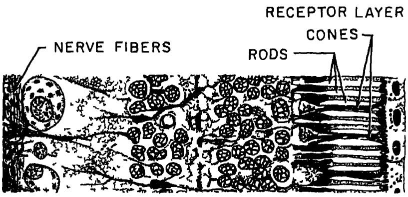

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Figure 5-4.—Section of the human retina (500X).

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Figure 5-5.—Blind spot demonstration.

is a limit. As you bring an object closer and closer to your eyes, you will eventually reach your near point of distinct vision. If you bring the object closer than that, you cannot see it clearly, even with maximum accommodation. (If your eyes are normal, your near point is about 10 inches. As you grow older, your near point will gradually recede.)

In the animal kingdom there are several different means of accommodation. Some fish accommodate by changing the position of the lens inside their eyes. Birds accommodate by increasing the curvature of the cornea. The human eye accommodates by increasing the curvature of its lens (fig. 5-6).

Here is how the lens accommodates: Remember, the lens is an elastic capsule filled with a liquid under pressure. If you were to remove the lens from an eye, it would become nearly spherical in shape. This is because of the pressure inside it. The SUSPENSORY LIGAMENTS hold the lens in place and keep it under tension. When you accommodate, you contract your ciliary muscles. That relaxes some of the tension in the suspensory ligaments. Then, because of its internal pressure, the lens bulges.

Because the lens capsule is thinnest at the center of its front surface, the curvature is greatest at that point. When you accommodate, your iris contracts and covers the flatter parts of the lens surface. Only the strongly curved area forms the image.

Here is an experiment on accommodation. You will need a dimly lighted room, a candle, and a friend. Ask your friend to fixate on an object in the far corner of the room. Note the size of your friend's iris. Now ask your friend to hold one hand about 8 inches in front of his or her face, and fixate on a point on that hand. Watch your friend's iris contract during accommodation.

Now ask your friend to relax his or her eyes again. Light the candle and hold it at eye level, a little to one side. Move the candle around until you see three images of it reflected in your friend's eye. These are reflections from the three refracting surfaces of his eye. The cornea and the front surface of the lens act as convex mirrors. The back surface of the lens acts as a concave mirror.

If you remember what we discussed earlier about spherical mirrors, you can identify the three images. The cornea forms a bright, erect virtual image. The front surface of the lens also forms an erect virtual image. This image is not as bright as the one in the cornea, but it is larger because the lens surface does not curve as sharply as the cornea. The back surface of the lens forms the smallest of the three images and is real and inverted. Now ask your friend to hold a hand close to his or her face, and focus on that hand. While your friend accommodates, watch the three reflected images in the eye There will be no change in the brightest image This is because the cornea does not change its shape The small

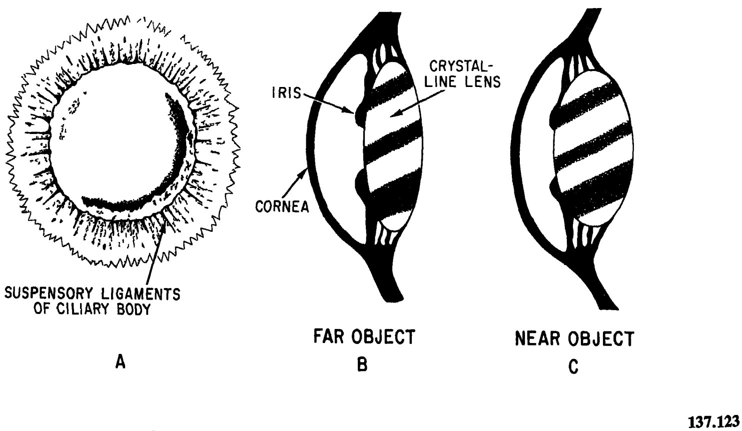

Figure 5-6.—Suspension and action of the lens.

inverted image will become slightly smaller, but you might not notice it. The images in the front surface of the lens will show a big change. It becomes much smaller as the curvature of the surface increases.

Aberrations of the eye (the optical system of the eye) suffers from the same aberrations as an optical system of glass lenses. The eye is partly corrected for spherical aberration. This is because its refractive surfaces—especially the front surface of the lens—are not quite spherical.

The eye has a strong curvature of field, but that comes in handy because of the curvature of the retina.

The chromatic aberration of your eyes is more than you may realize. When you look at an object, you automatically focus its green and yellow rays on your retinas. The blue image falls short of the retina, and the red image falls beyond it.

If you can, get a piece of cobalt glass, take it into a dark room, and look at a small bright light through it. Cobalt glass transmits red and blue light and absorbs the colors in the middle of the spectrum. You will see only the out of focus red and blue images. They will look like halos.

The optical system of a nearsighted eye has too much refraction. Rays from nearby objects are divergent, and the eye can focus them on the retina. On distant objects, the rays are less divergent when they reach the eye. The eye bends them too strongly, and they come to a focus too soon. What is the remedy? Just make the rays more divergent before they reach the eye. All we need to do that is a divergent lens. The spectacles of a nearsighted person contain divergent lenses (fig. 5-7, views A and B).

A farsighted person cannot focus on nearby objects. That person does not have enough refractive power to focus divergent rays. What is the remedy for that? Convergent lenses, of course, will correct the problem (fig. 5-8, views A and B).

If your eyes are normal, it is hard for you to imagine how things look to a nearsighted or farsighted person.

VISION

When you look at an object, the optical systems of your eyes form images of that object on your retinas. Then what happens? How can you see an object, just because there is an image on your retina? Nobody knows for sure. Up to now, we have given you facts about your eyes. Now the best we can offer you is a theory.

The rods and cones of your retina contain a substance called visual purple. Visual purple is a light-sensitive pigment. When light falls on one

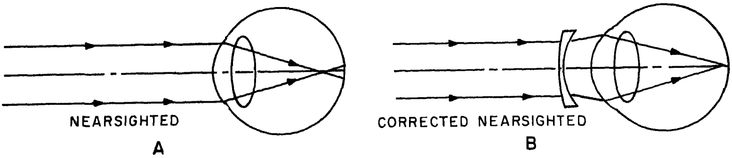

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Figure 5-7.—Nearsighted vision and correction.

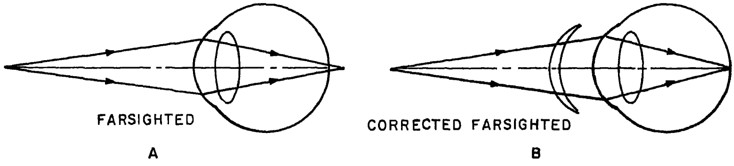

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Figure 5-8.—Farsighted vision and correction.

of the dye molecules, that molecule splits into two smaller colorless molecules. New molecules stimulate the rod or cone. These new molecules start a nerve impulse that travels across the retina, up the optic nerve, and into the brain. The brighter the light on any spot in the retina, the more visual purple will be broken down, and the more frequent will be the nerve impulses. Your brain judges the brightness of light by the frequency of these impulses. Because some parts of any image are brighter than others, the rods and cones in some areas of the retina will send impulses to the brain more frequently than those in other areas. That is how your brain can judge the shape of an image.

What happens when the nerve impulses get to your brain? How can your brain interpret this "picture"? We cannot tell you. We do not know, and we cannot find a good theory.

When a rod or cone reacts to a flash of light, it sends nerve impulses up the optic nerve for a short time after the light is gone. That is called PERSISTANCE OF VISION.

What happens to visual purple after the light bleaches it? The broken molecules recombine to form more visual purple. If the light is bright, the visual purple bleaches faster than it can recombine. When that happens, the sensitivity of your retina gradually decreases. Here is an experiment to prove it. You will need two sheets of white paper and a small piece of black paper that is about an inch square.

Put the white sheets side by side under a fairly bright light. Put the black square in the middle of one sheet. Sit down, make yourself comfortable, and stare at the middle of the black square. Keep staring, without moving your eyes, for about 30 to 40 seconds. Then quickly turn your eyes, and look at the middle of the other white sheet. You will see a small bright square in the middle of the page. That is an AFTER-IMAGE. Why do you see the afterimage? Because, where the image of the black square fell on your retinas, the visual purple is in good condition, and the retinas are sensitive. But, where the image of the white paper fell on your retinas, the visual purple is partially bleached, and the retinas are less sensitive. Close your eyes for a minute, and let the visual purple build up. Then look again. Your whole retina will be sensitive again, and the bright square will be gone.

Night Vision

Most physiologists believe that we use our cones in daylight and our rods when the light is very dim. They have good reason for that theory. Animals that hunt at night and sleep in the daylight have retinas composed almost entirely of rods. Animals that go to sleep as soon as it is dark have retinas composed almost entirely of cones. And people, who get around both day and night, have both.

After you have spent some time in the dark, your eyes become dark adapted. After about an hour in complete darkness, your eyes are nearly a thousand times as sensitive as they are just after you have seen a bright light.

What happens during that hour? The visual purple in your rods builds up to its maximum concentration.

If you have been outside at night looking at the stars, you have probably noticed that you can see a small dim object better by looking to the side of it as compared to looking straight at it. A dim star may disappear when you fixate your eyes on it, but it will reappear if you shift your eyes slightly. Why does this happen? It happens because your dark-adapted eyes are using only rods for vision, and as you probably remember, your fovea centralis does not have rods.

Color Vision

There are several theories on what causes color vision. Any good theory will have to answer these questions: What causes a mixture of colors to look like a single color? For example, what causes red light and green light to give the sensation of spectral yellow? How is it possible to match the sensation of any given color by mixing the primary colors red, green, and blue?

We know color vision is a function of the cones. How do we know this? Because color sensitivity is greatest at the fovea centralis That is where the light cones are tightly packed together The dark-adapted eyes, which depend entirely on rods, cannot distinguish colors And the extreme edge of the retina, where there are no cones, is color blind.

A 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 we see depends on the radiant energy in the light.

We know that white light is a combination of all the wavelengths of the visual spectrum and that a colored object is reflecting or emitting waves of a certain range. These different wavelengths stimulate the iodopsin in varying amounts to produce the different color sensations.

Although the cone cells are less sensitive to light than the rods, the cones are the more sensitive cells in color vision. At very low levels of illumination, all radiation, regardless of wavelength, is distinguished only as varying shades of gray and black.

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 10 men and 1 in 100 women have varying degrees of color deficiencies. The most common deficiency is poor red-green discrimination; relatively rare defects are in blue-yellow vision.

With a color deficiency, one is unable to distinguish certain colors. The type of color confusion indicates the kind of irregularity. A person who has red deficiency sees red, brown, dull green, and bluish-green as the same color when they have the same brightness. A person with green deficiency confuses 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 will exclude a person from working where medium color discrimination is important. Seriously deficient individuals should be excluded from all occupations that require color recognition.

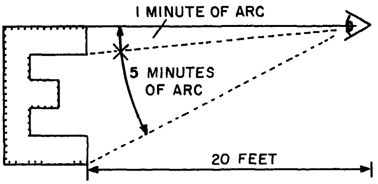

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Figure 5-9.—Standard 5-minute square letter.

Visual Acuity

The overall condition of the eye determines the degree of sharpness of vision. Printed charts, consisting of letters of different sizes are used for measuring the sharpness of vision, called VISUAL ACUITY. The standard is a 5-minute square letter, the individual details of the letter subtending at the observer's eye 1 minute of arc (fig. 5-9). The reference line on the chart is normally viewed at 20 feet. Other lines on the chart have graded sizes of letters for different distances. For example, the line marked 40 feet would subtend an angle of 1/2 minute, and the line marked 10 feet would subtend an angle of 2 minutes.

Visual acuity is expressed as a fraction—the numerator is the design distance for the chart, and the denominator is the line that can be read at that distance. With such a chart, 20/20 vision is normal, 20/15 is better than normal, and 20/30 is subnormal. Vision 20/30 means that the observer can read at 20 feet the line normally read at 30 feet; 20/15 vision means the observer can read at 20 feet the line normally read at 15 feet.

Resolving Power

The resolving power of the eye, or of an optical system, is its ability to distinguish between two adjacent points. It is often expressed as the ability to distinguish between fine lines and small angles. Resolving power is an important property of any optical system. After all, what good would an instrument be to the Navy if we had a magnified image, but we could not distinguish any of the details in the image.

Figure 5-10 illustrates what is meant by two adjacent points forming an angle with the eye.

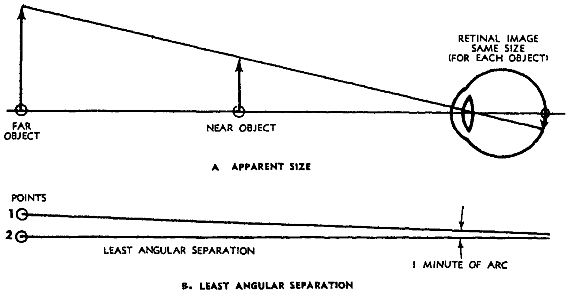

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Figure 5-10.—Visual limitations.

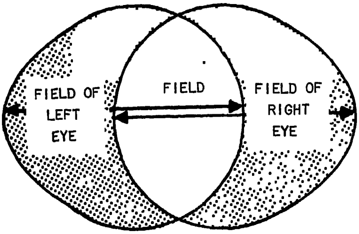

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Figure 5-11.—Field of view with two eyes.

The average eye can resolve details subtending 1 minute of arc; an image falls on the retina and stimulates more than one cone, with a separation of at least one unstimulated cone between them. Therefore, a normal eye can distinguish between two equally bright objects, separated by an angle of only 1 minute.

The rods and cones give the retina a mosaic structure which determines resolution. Maximum resolution depends on three factors:

1. Retinal location of the image: 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.

2. Nature of the image: The image must be bright enough to stimulate the retina. The smallness of a light or bright spot that can be seen will depend solely on its brightness.

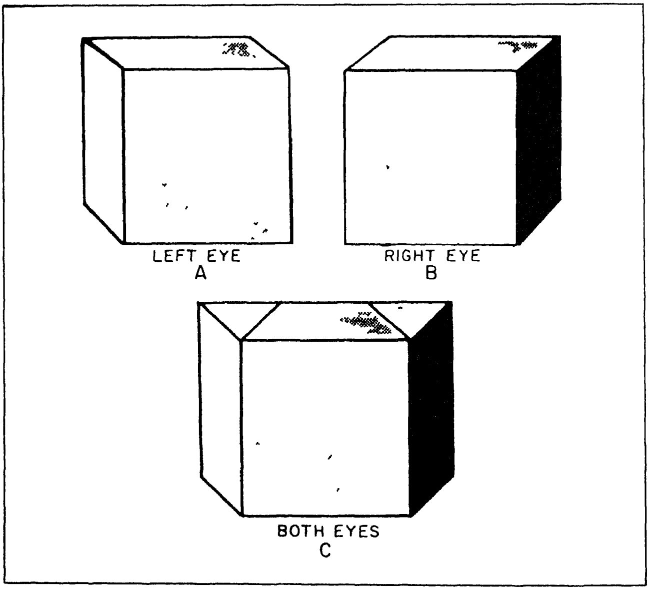

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Figure 5-12.—Stereoscopic vision.

3. Adequate time for stimulation: An image must fall on the retina long enough to cause stimulation of the nerve cells. Bright objects will stimulate quicker than dim objects.

You can fully appreciate these three factors when you look out to sea at night. If you see a small but very bright light, you have quick stimulation and the light is very noticeable. If, when looking out, you see a dim light, you must concentrate for a much longer time to discern it.

Stereoscopic Vision

Having 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 5-11 shows the normal field of view with each eye and also the binocular field. The field of view with both eyes is normally about 160° on the horizontal and 70° on the vertical. The field includes the area seen by the left eye, the right eye, and both eyes. The binocular field exists only in the area of the field of view where the fields of the separate eyes overlap.

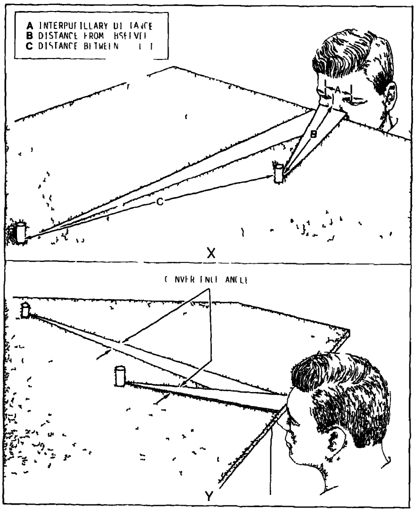
Another more important advantage of binocular vision is the experience of depth, which is called STEREOSCOPIC VISION The basis of stereoscopic vision is horizontal dissimilarity of retinal images on corresponding points of the two retinas.

Figure 5-12 shows a cube demonstrating the stereoscopic effect when you look at a near object. In studying this illustration you can see the difference in the retinal images on the two eyes. This difference is brought about by the spacing of your eyes, which allows you to see objects from slightly different angles. The spacing between the human eyes (normally about 64 millimeters) is measured from the pupil and is called INTERPUPILLARY DISTANCE (IPD). 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 objects from you, and their distance from each other (fig. 5-13). Other factors of depth perception being equal, the wider your interpupillary distance, the better the depth perception you secure through stereovision. 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 angles of convergence on both objects. 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.



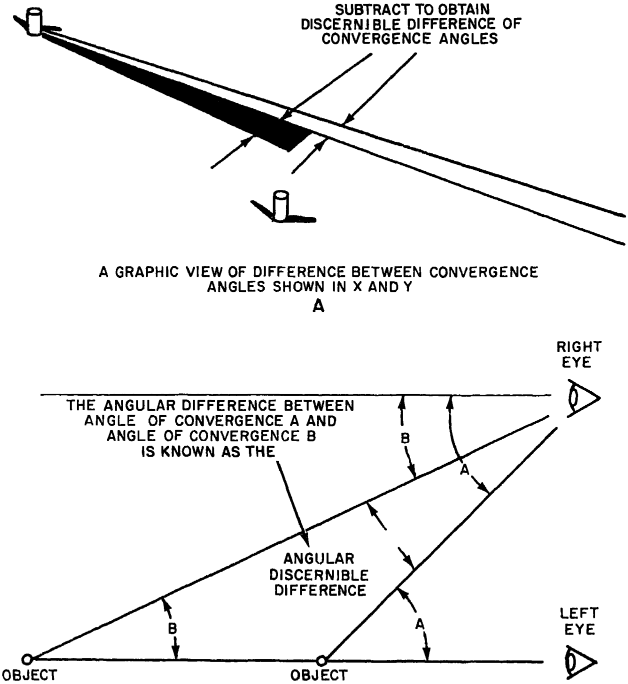
137.130

Figure 5-13.—Distinguishing the distance between two objects.

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 5-14, view A, shows the difference between the angles of convergence shown in figure 5-13.

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. 5-14, view B). It is measured in fractions of minutes and seconds of arc. Stereoscopic vision for the unaided eye is effective up to only 500 yards. This distance, however, can be increased through the use of binoculars or range finders, which increase the interpupillary distance between the eyes and therefore increase stereoscopic vision.

STEREO ACUITY, in contrast with visual acuity, is sharpness of sight in three dimensions, or the ability to gauge distance by perception of the smallest discernible differences of convergence angles. The minimum difference that you can discern between two angles of convergence is



A GRAPHIC VIEW OF DIFFERENCE BETWEEN CONVERGENCE ANGLES SHOWN IN X AND Y

A

CONVERGENCE ANGLES IN STEREOSCOPIC VISION

B

137.131

Figure 5-14.—Angular discernible difference.

dependent upon your quality of vision, your training, and the conditions that 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.

EYEPIECE SYSTEMS

As you 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 to be clearly seen. Thus we must add extra lenses to magnify the objective image and form an image suitable for comfortable viewing. The added lens or combination of lenses is 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 inches) and infinity. Figure 5-15 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.

BASIC FUNCTION

In general, the eyepiece has three basic functions in an optical instrument.

1. It must, with the objective, form a good aberration-free image of the object being viewed.
2. It must serve as a magnifier.
3. It must be designed so that the observer's eye can be placed at the exit pupil. Hence, the exit pupil must be located at least 10 to 12 mm away from the last glass surface—this being the nearest the normal eye can approach the eyepiece surface with comfort.

The objective brings nearly parallel light from a distant object to a focus, turning it into diverging rays. The eyepiece directs these diverging rays as a parallel beam into the pupil of the eye. Since most eyepieces are adjustable (focusing), the operator can focus the eyepiece to obtain a comfortable view of the image.

Magnification of the image is accomplished in the following manner: Parallel light (solid lines in fig. 5-15) enters the objective, comes to a focus, then exits the eyepiece as a parallel beam. The dotted lines represent light coming from a point on the target a distance off the optical axis. The angle of light entering the objective (abc) indicates the convergence angle presented to the unaided eye. The angle (ABC) represents the convergence angle increased by the eyepiece.

Optical instruments may be classified as (1) monocular, for use by one eye, or (2) binocular, for use by both eyes. Because optical instruments affect functioning of the eyes, certain adjustments must be made to the instruments to accommodate them to each eye. Most people have a dominant eye (one which is used more than the other), so the eyepiece on a monocular instrument is designed to allow the operator to use either eye.

Adjustment of a binocular optical instrument requires that the two optical systems of the unit be properly aligned with each other, conform to

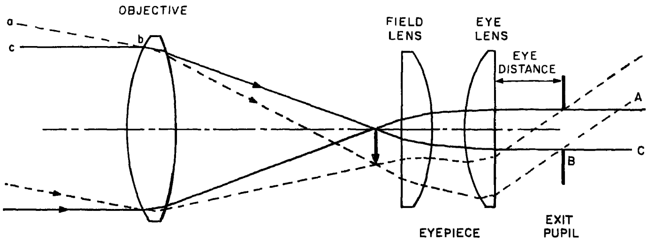


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Figure 5-15.—Basic eyepiece function.

the interpupillary distance of the eyes of the observer, and allow for focusing of each individual eyepiece.

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. A serious error often made by a novice is forcing the eye to focus.

When you allow your eyes to accommodate on an object before the instrument is set for proper focusing, your eyes will be under a constant strain. The following procedure is the correct way to focus an instrument with an adjustable eyepiece:

1. Allow your eye to become completely relaxed by viewing a distant area.
2. Move the eyepiece to the extreme PLUS diopter position (all the way out).
3. 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.
4. When 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 in eye strain the entire time you are using the instrument.

Because telescopes with a magnification of 4X or less provide a sufficiently wide range of accommodation, a single-focus setting is satisfactory for most users. These telescopes have a 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.

NOMENCLATURE

Eyepieces in general use in military optical instruments may consist of one, two, or three lenses, of which any or all may be compound lenses. The field lens is the front element of the eyepiece, and the eyelens is the rear element.

The area behind the eyelens, where the diagonal bundle of light crosses the optical axis (broken line, fig. 5-15) establishes the EYE DISTANCE and EXIT PUPIL. Figure 5-16 illustrates the path of marginal and axial rays through two types of eyepieces.

The field lens collects light from the objective image plane, which would otherwise be lost, and presents it to the eyelens. If a third element is used, it is called the intermediate or center lens, and it functions in conjunction with the field lens.

TYPES OF EYEPIECES

General types of eyepieces used in optical fire control instruments will be discussed in the following paragraphs However, you must remember that when working on an optical instrument you will often find modifications to

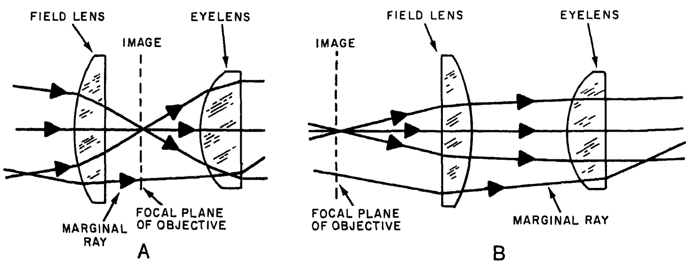

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Figure 5-16.—Path of light through eyepiece lenses.

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 changes to produce a quality instrument. One of the prime concerns of an instrument designer is to eliminate aberrations in the 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. 5-17) is made of two single lenses. (Usually both are convexo-plano, and both are 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. The field lens 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 is not very noticeable at relative apertures less than f:7. If you want to use it at an aperture greater than f:7, you must overcorrect the objective of the eyepiece.

The Huygens eyepiece can be made entirely free from coma. It shows some pin-cushion distortion, which in many instruments is not 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 cannot use a reticle. The aberrations of the ocular as a whole are corrected, but those of the eyelens alone are not. So if you put a reticle in the image plane, its image will be distorted and show color fringes.

The magnifying power of the Huygens eyepiece is limited to 10X. (If you make the focal length shorter than 1 inch, the exit pupil is too close to the eyelens.)

Ramsden

Figure 5-18 shows the Ramsden eyepiece. It is 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 objective lens. As you can see, the eyepiece forms an enlarged virtual image at infinity.

The Ramsden eyepiece has one outstanding disadvantage: chromatic aberration is rather serious. It has no coma, and all the other aberrations are less than those of the Huygens eyepiece. Besides controlling all the aberrations except color, the Ramsden has another advantage over the Huygens: you can put a reticle in the image plane since the real image is outside the eyepiece.

Except for chromatic aberration, the Ramsden is a desirable eyepiece. For any given focal length, the eye distance is about 1.5 times that of the Huygens, so you can use a higher magnifying power. 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

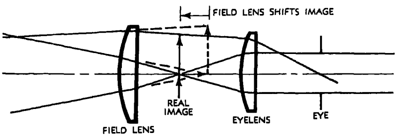

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Figure 5-17.—Huygens eyepiece.

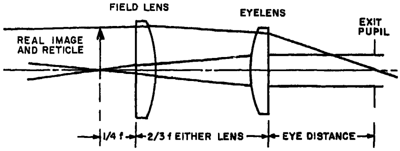

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Figure 5-18.—Ramsden eyepiece.

aberration is by forming the image inside the eyepiece, and then you cannot use a reticle.

Kellner

The Kellner eyepiece (fig. 5-19) is a modification of the Ramsden, the only difference being that the Kellner eyelens is a doublet. The Kellner has 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 would have to put the field lens in the plane of the real image, but then you could not use a reticle. Most instruments that use the Kellner 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

Symmetrical and two-doublet eyepieces are constructed of two cemented, achromatic doublets (fairly close together) with their positive elements facing each other (fig. 5-20). 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 a two-doublet eyepiece. The eyelens of the two-doublet eyepiece is generally slightly smaller in diameter and has a shorter focal length than the field lens.

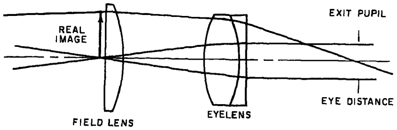

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Figure 5-19.—Kellner eyepiece.

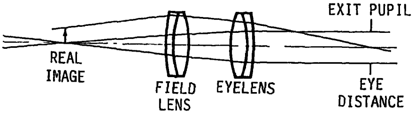

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Figure 5-20.—Symmetrical eyepiece.

Symmetrical and two-doublet eyepieces are often used in fire control instruments that recoil. The eye distance on these instruments must be fairly long to prevent the eyepiece from striking the gunner's eye. These eyepieces provide the necessary eye relief as well as a large exit pupil at moderate magnification. For this reason, symmetrical eyepieces—along with Kellner—are used extensively in optical instruments, particularly rifle scopes and binoculars.

Orthoscopic

The orthoscopic eyepiece is illustrated in figure 5-21. It employs a plano-convex triplet field lens and a single plano-convex eyelens with the curved surfaces of both elements facing each other. It is free from distortion and is useful in high-power telescopes because it gives a wide field and high magnification with sufficient eye relief. It is also a very useful eyepiece for range finders 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. To do this and still be able to accommodate for the visual variations between different observers, there are several types of internal focusing eyepieces that can be used These usually consist of three elements. One type is illustrated in figure 5-22 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 that can be moved longitudinally by rotation of the focusing knob. The eyelens is fixed and acts as a seal for the eyepiece.

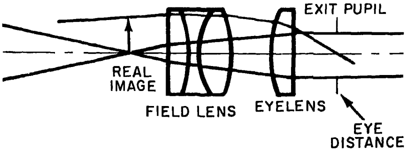

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Figure 5-21.—Orthoscopic eyepiece.

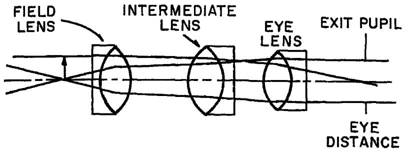

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Figure 5-22.—Internal focusing eyepiece.

Figure 5-23 is a mechanical drawing of the focusing operation.

Internal focusing eyepieces are not limited to the three-doublet combination as shown in figure 5-22. For example, the Mk 102 Mod 3 telescope has a triplet field lens, doublet intermediate, and singlet eyelens. The basic principle is the same in all combinations; the field lens converges light rays that otherwise would miss the intermediate lens, and the intermediate lens converges light that would otherwise miss the eyelens. The eyelens converges light to the exit pupil.

SIMPLE TELESCOPES

A telescope is an optical instrument containing a system of lenses or mirrors, usually having magnification greater than unity. The magnification renders distant objects more clearly visible by enlarging 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; this will be explained later in the chapter.

ASTRONOMICAL TELESCOPES

The ancient astronomers had only the naked eye to observe and record the relative positions of the moon, sun, stars, and planets. The invention of the telescope about 1600 A.D. was a major breakthrough that has led to the highly technical instruments that are used today.

In the process of refraction and reflection by a telescope system, the image becomes inverted.

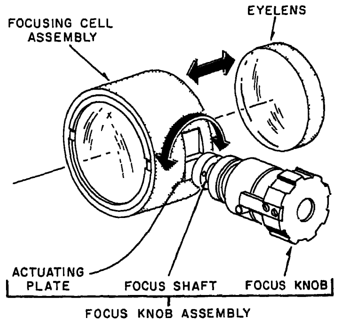

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Figure 5-23.—Mechanical schematic of internal focusing eyepiece.

With astronomical bodies, it makes little difference whether or not the object is viewed upside down. Telescopes that give the observer an inverted view are called astronomical telescopes. Since they need no erecting system, they are optically more simple. For this reason we study them first in our attempt to understand the general nature of the telescope.

Reflecting

In chapter 4 you studied the effect that concave mirrors have 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 are looking at distant stars, you want the image to be as bright as possible. The brightness of an image depends on the diameter of the mirror that forms it. There is no light lost due to passage through optical elements.

There is 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. A lens much bigger than that could not be mounted in a telescope barrel. In the first place, it would not be easy to cast a big enough piece of good optical glass. 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 could be supported only at its edges.

It may easily sag 20 or 30 millionths of an inch, which is all the sag you need to ruin the image.

Another thing: an objective lens must have at least two elements to correct aberrations, which means you must grind and polish at least four surfaces. With a mirror, you have only one surface to grind and polish. And of course, a mirror has no chromatic aberration. Since the light does not pass through the mirror, the glass does not need to be optically perfect all the way through.

At one time, the biggest reflecting telescope in the world was in the observatory on Mount Palomar, in southern California. Its objective is a concave mirror 200 inches—about 17 feet in diameter. The Corning Glass Company at Corning, New York, made the blank for it from Pyrex glass. (Pyrex expands and contracts less than ordinary glass when the temperature changes.) To keep it from developing strains, the mirror was annealed in an electric furnace. Its temperature was reduced just 1° each day. Interestingly enough, the Cohocoton River runs right beside the glass works, and in 1936 the river flooded. The water did not 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.

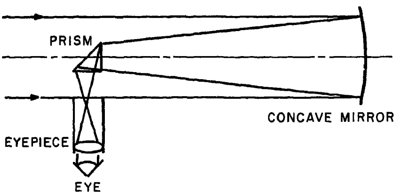

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Figure 5-24.—Newtonian reflecting telescope.

The California Institute of Technology had spent 4 years grinding the mirror when 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.

Figures 5-24 and 5-25 illustrate two types of reflecting telescopes. Notice that a reflecting element is placed in the path of incident light in both examples. Since the concave mirrors are rather large, and since incident light comes from such a great distance, the placement of a small prism or mirror in the path of light will have no adverse effect on the final image. Also notice that the images formed are located outside the body of the telescopes, allowing direct observation of celestial targets or substitutions of a photographic plate for the eyepiece.

Refracting

Figure 5-26 shows a simple astronomical telescope. We will use this illustration to explain

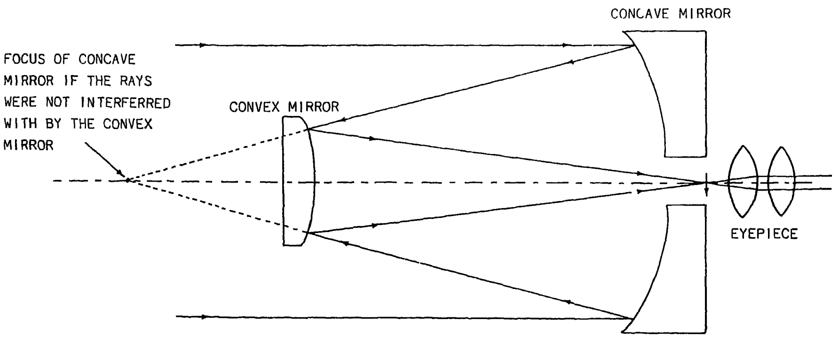

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Figure 5-25.—Cassegranian reflecting telescope.

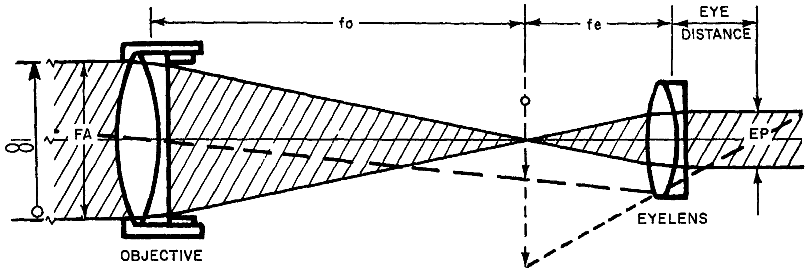

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Figure 5-26.—Simple astronomical telescope.

various optical principles common to more complicated arrangements presented later. Note that the parallel light rays entering the objective lens are refracted and converge to a focal plane. (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, reverted, diminished image of the object is formed. The eyepiece is so placed that the image formed by the objective lens is located at the primary focal point of the eyepiece. The diverging rays, diverging from the real image, enter the eyepiece, are refracted, and emerge parallel to the optical axis of the telescope. The eyepiece acts as a magnifying lens to magnify the real image. If you look through the telescope eyepiece, you see a virtual, inverted, reverted, enlarged image that 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.

FREE APERTURE is a term that denotes the entrance pupil of the objective, which is limited by the inside diameter of the objective mount or the inside diameter of the objective lens retainer ring (FA in fig. 5-26). The entrance pupil can be viewed as such from the objective end of the instrument, and it can be measured with a ruler directly across the objective.

EXIT PUPIL is the term given the diameter of the bundle of light leaving an optical system. You can see this small circle, or disk of light, by looking at the eyepiece of an instrument that is directed at an illuminated area. The exit pupil is actually a real image of the objective lens aperture 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 5-26.

EYE DISTANCE, often called eye relief, is the 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. 5-27).

TRUE FIELD is the width of the target area, or field, that can be viewed. More specifically,

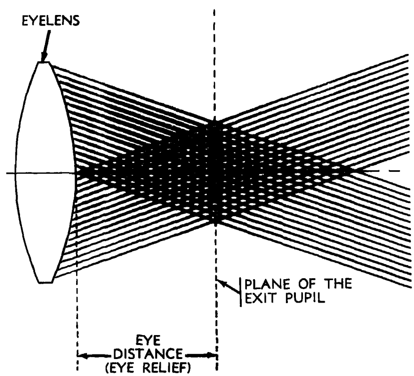

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Figure 5-27.—Eye distance and exit pupil plane.

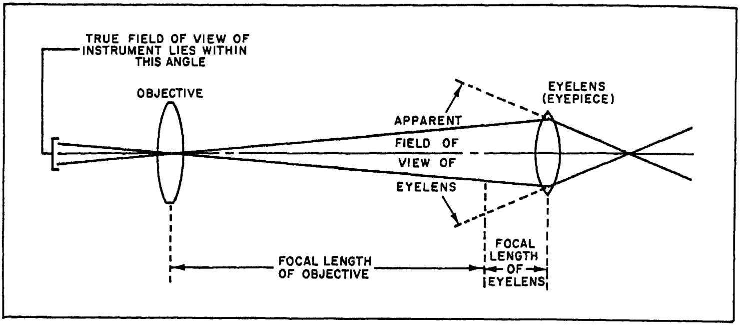

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Figure 5-28.—True field and apparent field.

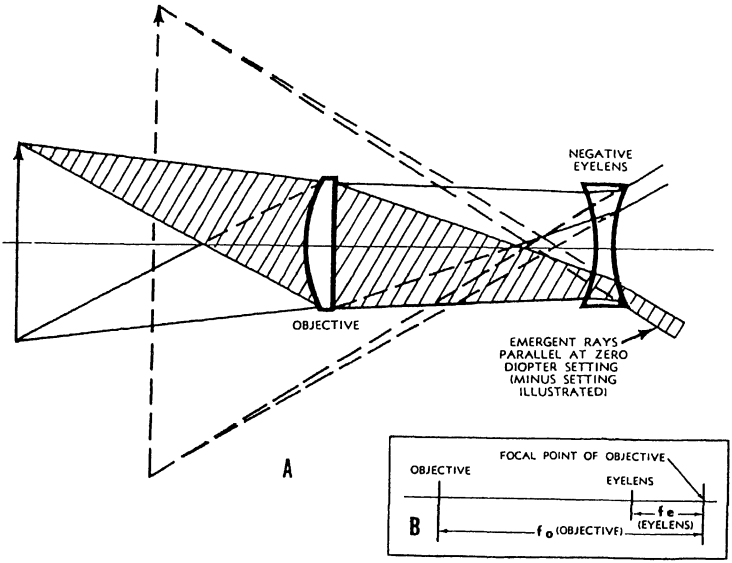

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Figure 5-29.—Galilean telescope.

t is the maximum cone or fan of rays, ubtended at the entrance pupil, that is transnitted by the instrument to form a usable image fig. 5-28).

APPARENT FIELD is the size of the field of iew angle as it appears to the eye. It is ipproximately equal to the magnification of he instrument times the angle of the true field fig. 5-26).

[ERRESTRIAL TELESCOPES

A terrestrial telescope gets its name from he Latin word *terra*, which means earth. \ terrestrial telescope is used to view obects as they actually appear on earth, normal and :rect.

Galilean

The simplest form of terrestrial telescope was nvented by the scientist Galileo. His first telescope 1ad a power of 30 (fig. 5-29, view A). Its eyepiece :onsists of a negative eyelens positioned a distance :qual to its focal length (f_e, fig. 5-29, view B) in 'ront of the objective focal point. Such positionng of the negative eyelens makes converging rays 'rom the objective diverge before they form a real mage; therefore, no real image exists in this)ptical system. If you look through the eyelens /ou see an enlarged, erect, virtual image of the)bject, which appears to be at a point between l0 inches and infinity.

The relation of the optical elements in a Galilean telescope (fig. 5-28, view B) 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 either farsighted or nearsighted eyes and also for objects at various distances.

In a Galilean telescope, the diameter of the objective controls the field of view because the objective is both the field stop and the free aperture. No exit pupil is formed because there is no real image plane in this system. Magnification in a Galilean telescope is accomplished by increasing the visual angle, as shown by the broken line in figure 5-29, view A.

Lens Erecting Systems

Any astronomical telescope can be converted to a terrestrial telescope by inserting a lens between the eyepiece and the objective to erect the image. Figure 5-30 shows the optical elements of the basic form of terrestrial telescopes. Note the position of the REAL IMAGES.

In addition to erecting the image, proper positioning of the erector system can also have a direct effect on the magnification of the instrument. The possible arrangement of optical elements in a one-erector telescope is illustrated

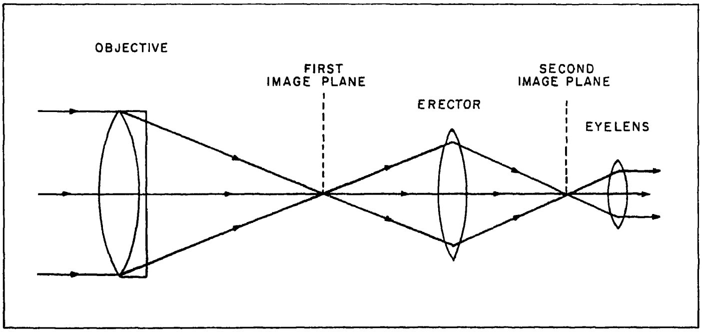

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Figure 5-30.—The basic terrestrial telescope.

in figure 5-31. Note 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 that leave the real image diverge as though the image itself were an object. When you place an erector lens behind the objective image, the erector receives the diverging rays and refracts them to form an image behind the erector. The image formed by the erector is then magnified by the eyelens.

In figure 5-31, view A, the erector is 2 focal lengths from the objective image plane, and the image the erector forms is 2 focal lengths from the erector. As you recall from chapter 4, the two images will be the same size. Consequently, the magnification of this telescope will depend on the focal length of the objective (f_o) divided by the focal length of the eyelens (f_e).

$$M = \frac{f_o}{f_e}$$

Now refer to figure 5-31, view B. Notice that the erector is located 3 focal lengths from the objective image plane and that it forms an image 1 1/2 focal lengths behind the lens. In this case, the erector will change the size of the image presented to the eyelens.

Remember the formula magnification explained in chapter 4:

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

If D_o is 3 focal lengths and D_i is 1 1/2 focal lengths,

$$M = \frac{1.5}{3} = 0.5$$

then the image formed by the erector is only half the size of the objective image.

What will this do to the magnification of the telescope? Assume the objective focal length (f_o) is 4 inches, and the eyelens focal length (f_e) is 1 inch:

$$M = \frac{f_o}{f_e} = \frac{4}{1} = 4 \text{ power}$$

Now, multiply the basic telescope magnification (4) by the magnification of the erector (0.5):

$$4 \times 0.5 = 2 \text{ power}$$

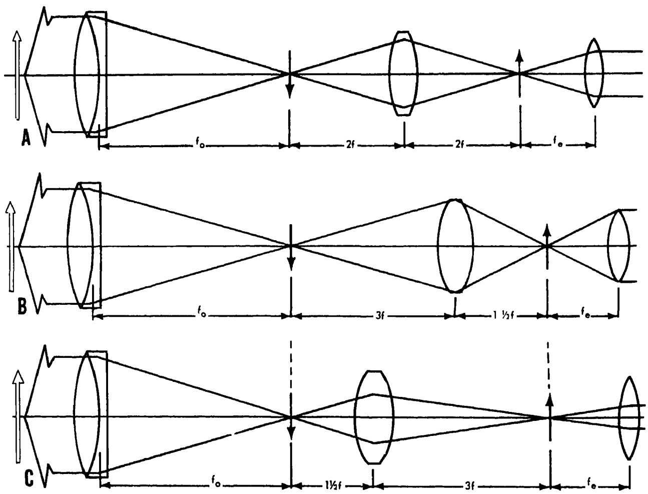

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Figure 5-31.—One-erector telescope.

Figure 5-31, view C, shows the position of the erector lens reversed in relation to figure 5-31, view B. How will this affect the magnification of the telescope? (Use the same figures as in the previous example.)

Erector magnification equals:

$$M = \frac{D_i}{D_o} = \frac{3}{1.5} = 2$$

Basic telescope magnification equals:

$$M = \frac{f_o}{f_e} = \frac{4}{1} = 4$$

Total magnification equals:

$$4 \times 2 = 8$$

Figure 5-31, view A, illustrates a basic terrestrial telescope with a magnification of 4 (4X). Depending on the position of the erector lens, magnification can be changed to 2X (figure 5-31, view B) or 8X (figure 5-31, view C). What we have demonstrated is a change of power, or a change of magnification system.

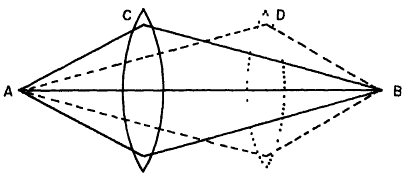

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Figure 5-32.—Conjugate points.

Change of power in an optical system depends on the law of reversibility. Figure 5-32 shows the conjugate points (A and B) that correspond with the lens positions (C and D). One is just the reverse of the other.

The image planes (A and B) do not change when the lens is in position C or D (fig. 5-32). For any other position of the lens, the observer could not focus on the final image with the eyepiece. Therefore, the erector must be at one or the other position to take advantage of the conjugate points.

Two-Erector

Refer to figure 5-33 to see how a terrestrial telescope with two erecting lenses is constructed. The erectors 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 magnification, which the objective and eyepiece alone could not do.

The erecting lens is positioned 1 focal length from the objective focal plane. The divergent rays that enter the erecting lens are refracted and emerge parallel to the optical axis.

Since the rays that 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 that 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.

Parallel rays that enter the second erecting lens are refracted and converge to the focal plane to form a real, erect image.

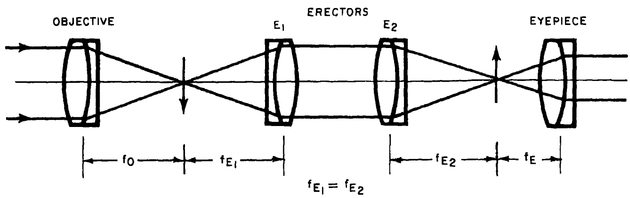

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Figure 5-33.—Two-erector telescope.

The eyepiece of the telescope is again positioned as necessary to have the image of the second erector at its focal plane. If you look through the eyepiece of the telescope, you see a virtual, erect, enlarged image.

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 single erector lens used for the same purpose.

Most optical systems are designed to magnify a target. An important fact to remember about magnification is that when power (magnification) is increased, the field of view decreases; you can see details of the target better when magnified, but you cannot see as much of the target.

When using a handheld optical instrument, any movement you make will be increased in direct proportion to the power of the instrument. For this reason, hand held instruments are usually limited to about 6X. The Navy does use several types of telescopes at 10X and 16X, but they are very difficult to hold on target.

Variable Power

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 will 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 simple home movie cameras have this feature.

In the change of power telescope (fig. 5-31), there are only two positions of the erecting lens for which the two image planes are conjugate; that is, you cannot 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.

It is impossible to change the focal of a lens, but, if two lenses are used in combination (fig. 5-34), you can vary the EFL of the combination and still maintain the same focal plane.

In figure 5-34, the object is the objective image plane. At the low-power position (fig. 5-34, view A), there is little difference between the size of the two images. In figure 5-34, view B, both lenses are moved different distances toward the objective, and a significant enlargement of the image is produced by the erector combination. Notice that the image plane remains stationary.

At any position between the low- and high-power positions of the erectors, the image will be in sharp focus if the mechanism that moved the erectors is properly designed. A variable power system will usually provide three to four times as much magnification in the high-power position than in the low-power position (3X to 9X or 6X to 24X rifle scopes).

Prism Erecting Systems

Thus far, we have discussed telescopes with one or two erecting lenses and a straight line of sight to the target. The Navy uses many types of instruments that must present an erect image, but prisms are used as erectors

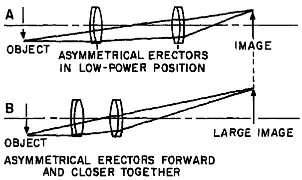

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Figure 5-34.—Variable magnification in a two-erector telescope.

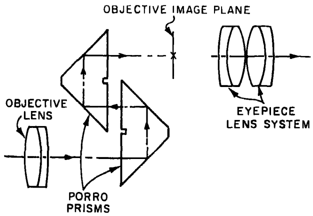

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Figure 5-35.—Porro prism erecting system.

Figure 5-35 illustrates a telescope with two Porro prisms placed within the focal length of the objective lens. As you recall from chapter 3, two Porro prisms invert and revert the line of sight. Thus, they cancel the inverted, reverted objective image and the observer views an erect, normal image.

A Porro prism cluster used in this manner will provide a very compact instrument. Trace the path of light through the prisms, then imagine how much longer the instrument would be if an erector lens were used.

The line of sight through an instrument using a prism cluster will be offset but still will be considered a straight line telescope.

In figure 5-36, a 90-degree roof edge or Amici prism is used as an erector. Some similar instruments use a 60-degree roof edge prism. In either case, the line of sight is deviated but the observer views an erect, normal image.

Various other combinations of prisms, mirrors, and lenses are used in military optical instruments, most of which you will see later. The optical system used in any particular instrument depends on how the instrument will be used and where it will be mounted.

GUNSIGHT TELESCOPES

The Navy uses a wide variety of terrestrial telescopes as gunsights, some of which are very complex in their construction. This section will give you a basic understanding of 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. Anytime an Opticalman engages 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 view of distant targets as follows:

1. It gathers and concentrates a greater quantity of light from the target than the unaided eye can gather, thus rendering the target more distinct.
2. It erects the target image and superimposes a reticle upon it, thus sharply defining the line of sight to the target.
3. It magnifies the target image so that the distant target appears closer.

In many instances, the eyepiece of gunsight telescopes is inclined at an angle with respect to the line of sight, so that the observer can comfortably view targets at various angles.

Reticles, such as those shown in figure 5-37, are used in fire control instruments to superimpose 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

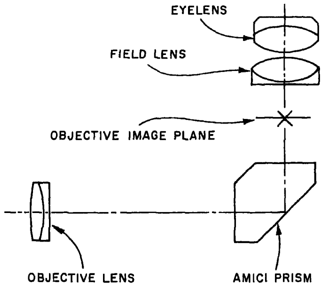

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Figure 5-36.—Amici prism erecting system.

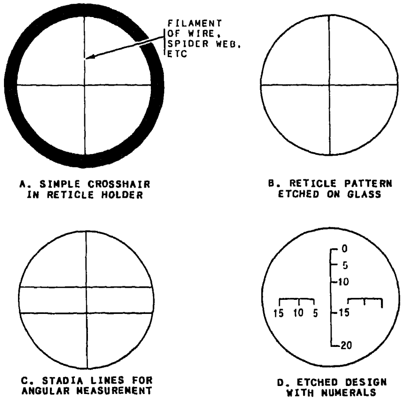

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Figure 5-37.—Examples of reticle patterns.

fixed at a definite angle to the bore for long-range firing. A reticle is used as a reference 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 that has a lens erecting system, the reticle can be placed either in the objective image plane or in the erector focal plane. If the erecting system increases magnification, when the reticle is placed in the image plane of the objective, the reticle lines will appear wider than if they were placed at the focal point of the eyepiece. Therefore, 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 formed in the same plane as that in which the reticle lies. If this does not occur (fig. 5-38), parallax is present. You can detect parallax by moving your 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 presence of parallax (fig. 5-39).

To correct the parallax, 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 for making this adjustment.

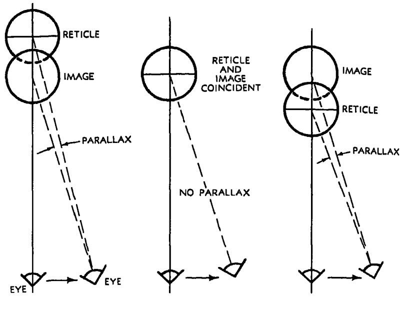

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Figure 5-39.—Relative motion of parallax.

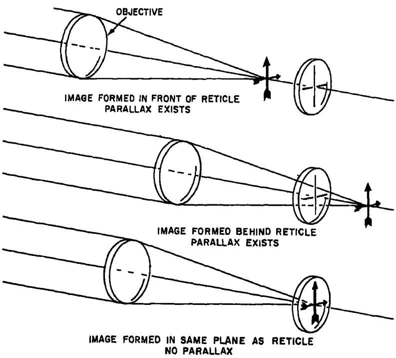

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Figure 5-38.—Optical parallax.

TELESCOPE MAGNIFICATION

In our explanation of various types of telescopes, we have discussed magnification and the various methods of determining the power of an optical system. It is appropriate that we now review and amplify these procedures

To determine the power of a telescope WITHOUT A LENS ERECTING SYSTEM, there are three methods that can be used

1 Divide the focal length of the objective by the focal length of the eyepiece (EFL)

$$M = \frac{f_o}{f_e}$$

2 Divide the apparent field by the true field

$$M = \frac{\text{App field}}{\text{True field}}$$

3. Divide the objective lens opening (free aperture) by the size of the exit pupil:

$$M = \frac{FA}{EP}$$

To determine the power of a telescope with a lens erecting system, multiply the formula (f_o/f_e)

by the magnification produced by the erector lens systems (D_i/D_o).

$$M = \frac{f_o}{f_e} \times \frac{D_i}{D_o}$$

The other two formulas, app field/true field and FA/EP will work for any optical system.

Most optical instruments have an attached nameplate that indicates the power (3X, 6X, 10X, and so on). Technical manuals on optical equipment have all specifications for the instruments listed (power, apparent field, true field, length, weight, type of instrument).

At times you may be called on to work with an unfamiliar instrument, or you might need to determine certain characteristics of a portion of the optical system. In such cases, you will find the information contained in this manual most useful.

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 that 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 measurements is sufficiently accurate for most purposes.

You can determine the diameter of the exit pupil of a telescope in three simple steps:

1. Point the instrument toward a light source (out a window, for example).
2. Insert a piece of plain paper in the plane of the exit pupil.
3. Measure 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 (fig. 5-40). A dynameter is 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 on the eyepiece of the instrument you are testing, and focus the dynameter until the bright disk of the exit pupil is sharply defined on its frosted reticle. Then compare the diameter of the exit pupil with the dynameter reticle (usually graduated in 0.5 mm) and read the eye distance on the scale on the dynameter tube.

To keep the image of the exit pupil in focus, the frosted reticle must be moved a distance equal to the eye distance of the instrument being tested.

You have already learned that the true field of an optical instrument is the angular area of a target that can be transmitted through the objective of an instrument to form an image. The apparent field is the amount this small angle is magnified by the eyepiece system.

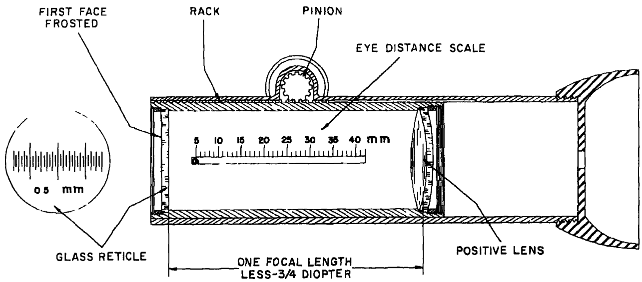

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Figure 5-40.—Dynameter.

You can approximate the actual amount of apparent and true field of an instrument by using the following procedure:

Point the instrument you are testing toward a prominent target and adjust it to a sharp focus. Observe some distinctive feature of the target at the extreme left and right sides of the field. Now lay a plastic protractor on a table or windowsill and put a small straight pin through the center. Using the pin as a sight, place a card on the curved edge of the protractor and align the pin, card edge, and one edge of your selected target. Next, without moving your head or the protractor, align another card with the opposite side of your selected target. You can read the approximate true field, in degrees, from the protractor. If you are very careful, you may be accurate to within 1/2 degree.

To determine the apparent field, turn the instrument around, look at a target through the objective lens, and align the extreme edges of the field with some easily distinguished landmarks. Now, repeat the procedure with the protractor to determine the size of the apparent field angle.

Remember, if you are using a telescope of 6X to look at a target through the objective end, the target will only be 1/6 as large as it appears to your unaided eye. Therefore, you must select very prominent features at the edges of the field if you attempt to measure apparent field in this manner

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 simple magnifying lens, as covered in chapter 4. In a compound microscope, the objective lens forms a primary image that is further magnified by the 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. This illustration should clarify much of the information, magnification, and the relationships between focal length and image and object distance

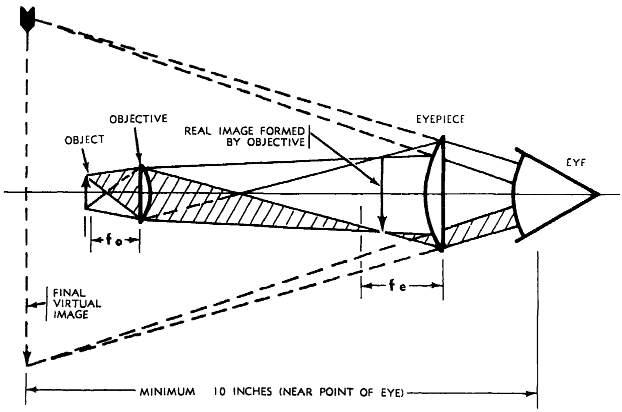

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Figure 5-41.—Image creation by a compound microscope.

To find the magnification of a compound microscope, you must do two things: First, determine the magnification of the objective; then multiply by the magnifying power of the eyepiece.

Suppose the objective has the following characteristics:

$$D_o = 0.5 \quad D_i = 6 \text{ inches}$$

then:

$$\text{Mag} = \frac{D_i}{D_o} = \frac{6}{0.5} = 12$$

If the eyepiece has a focal length of 0.5, then:

$$\text{MP} = \frac{10}{\text{fl in.}} = \frac{10}{0.5} = 20$$

The magnification of the microscope is therefore:

$$12 \times 20 = 240 \text{ power}$$

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, if any, increase in the details of an object is obtained after the object has been magnified 400 times.

REFERENCES

Military Standard, "Optical Terms and Definitions," MIL-STD-1241 A, 31 March 1967.

Military Standardization Handbook, "Optical Design," MIL-HDBK-141, Sections 6, 12, 13, 14, and 15, Defense Supply Agency, Washington, DC, 5 October 1962.

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

CHAPTER 6

DESIGN AND CONSTRUCTION OF OPTICAL INSTRUMENTS

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 construction of an instrument housing is influenced by three factors. the location of the instrument when it is in use; the use of the instrument; and the arrangement of the instrument within the housing. For example, the housing of a pair of binoculars is not subjected to the same pressures as a submarine periscope, nor is a binocular's line of sight offset like that of a periscope.

Figure 6-1 illustrates the housing features of a Mk 74 gunsight. The housing is rather small and simple in construction. It weighs about 15 pounds and contains 11 optical elements with a line of sight that is deviated 90°.

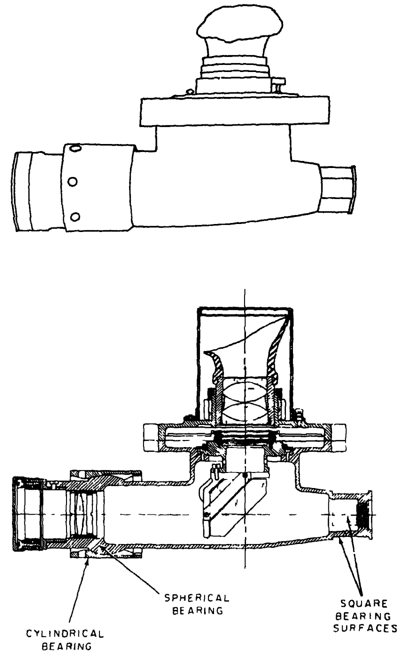

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Figure 6-1.—Housing features of a Mk 74 gunsight.

Figure 6-2 illustrates a Mk 67 gunsight telescope. The housing is large and very complex. Its gunsight weighs about 135 pounds and contains 17 optical elements. These large telescopes, when fixed in position on a gun mount, offset the line of sight about 2 feet and enable you to follow fast-moving targets without changing body position. The line of sight is elevated and deflected by rotating prisms that are driven by shafts and gears in the sight mechanism.

Note the differences in the housings in figures 6-1 and 6-2 and the location of the optical elements. All of these elements must be positioned and secured in the housing so that they will remain in place under normal circumstances. This is done to prevent the effectiveness of the instrument from being impaired through unwanted movement.

Material

The material used to construct a body housing is selected with reference to the specific instrument. If the instrument is to be hand held

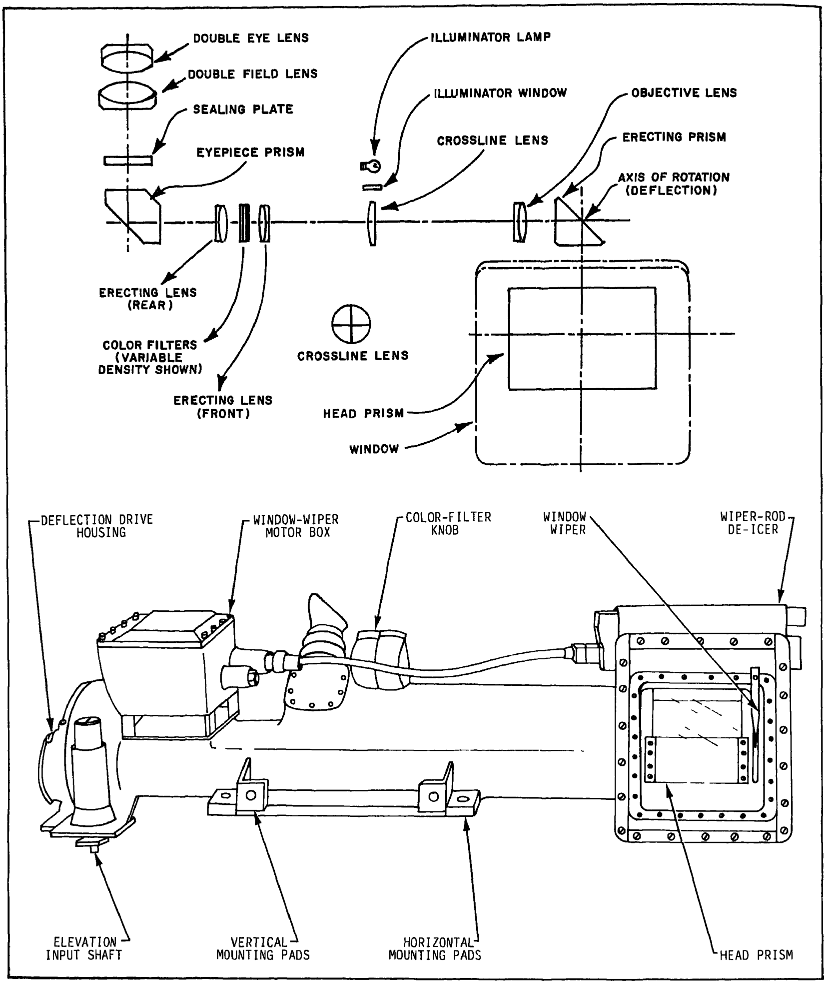

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Figure 6-2.—A Mk 67 gunsight telescope.

and portable, the material must be lightweight 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 considerable shock. Most housings of gunsight telescopes are made from cast bronze or steel alloys, which are strong enough to support and protect the optical and mechanical components of the telescope. The material specifications for a telescope housing are shown on the appropriate drawing. Before attempting any repairs to the housing, Opticalmen should know what type of material they will be working with.

Arrangement

The location of the optical and mechanical components of an instrument is a prime factor in determining how a housing must be constructed.

Figure 6-3 is a cutaway view of the Mk 102 Mod 2 telescope, showing the complexity and importance of a housing arrangement. Refer to this figure as you read the description that follows.

The telescope housing assembly is made of cast bronze and is finish-machined with great precision. It is open at the front and back. The front of the housing is closed by a window and

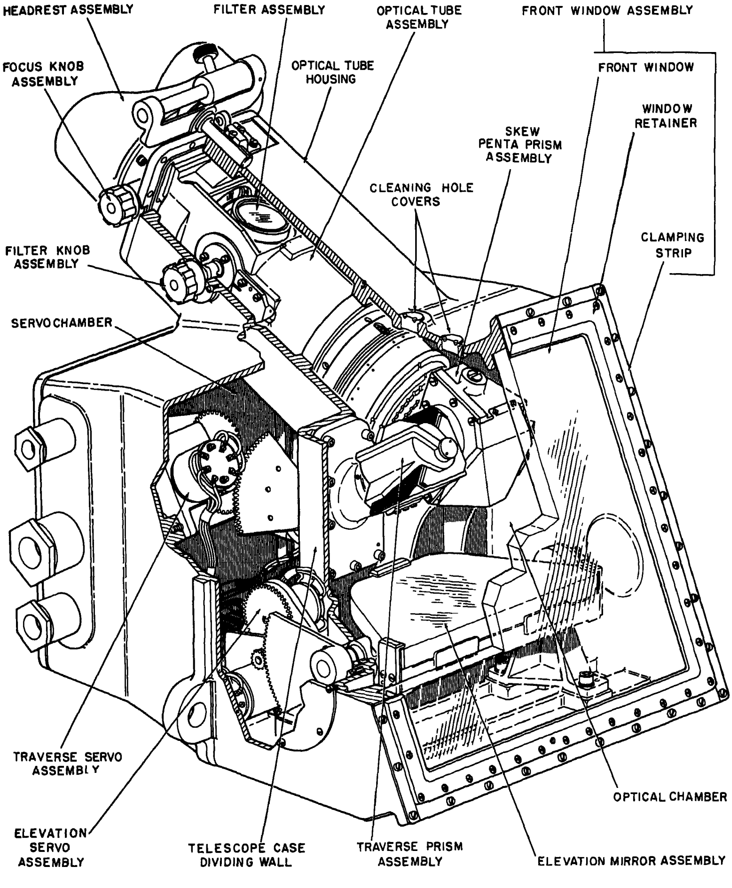

Figure 6-3.—A Mk 102 Mod 2 telescope.

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 servochamber. The gastight optical chamber is in front of the dividing wall, and the watertight servochamber is in the rear. A square box-shaped section rises from the top rear of the housing to position and support the headrest assembly, optical tube, and focusing 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 machined with precision 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 losing the watertight seal in the servochamber. The focusing knob and the filter knob are sealed by a packing gland where the shaft passes through the housing.

The optical tube assembly is a brass cylinder. It houses the objective lens, filter assembly, and reticle in position within the body housing.

The elevation mirror, traverse prism, and skew penta prism assemblies are positioned in the optical chamber by brackets. Two servo assemblies, mechanically connected to the mirror and traverse prism, allow the line of sight to be elevated and deflected.

Access and Adjustment

You have seen how the design of a housing is affected by the positioning of the instrument components. Accessibility is another problem a designer must consider. 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. A number of access holes and cover plates are provided for this purpose. The number of openings in any instrument housing is always kept to a minimum. Each opening is a source for gas to escape and moisture or dirt to enter.

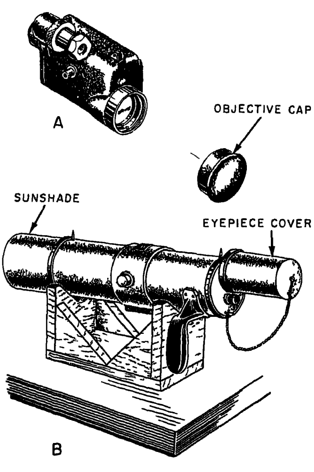

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Figure 6-4.—Lens caps.

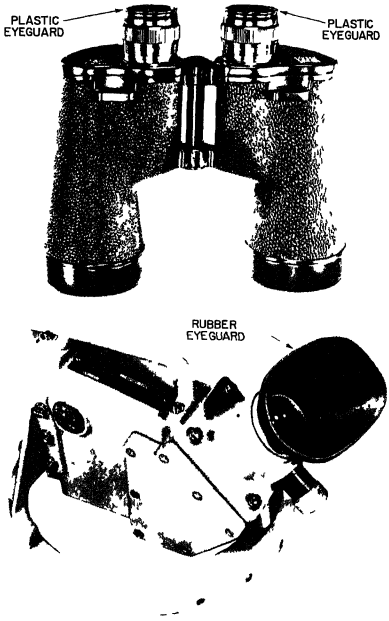

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Figure 6-5.—Eye guards on instruments.

SHADES AND CAPS

When an optical instrument is not in use, it should be placed in a case. The case will protect the exposed optical elements. If the instrument is mounted in such a manner that the use of a case is not feasible, some other form of protection should be provided.

Lens Caps

Use of a lens cap is a very effective and convenient way to protect an eye lens or objective lens. These caps are made of metal with a friction fit over the area to be protected, or they are threaded onto the telescope. Part A in figure 6-4 illustrates a slip-on objective cap for an azimuth telescope, and part B shows a threaded cover for a ship's telescope eyepiece. When a ship is at sea, the external optical surfaces are exposed to saltwater spray, stack soot, direct sunlight, and grime, which will damage optical elements very easily. For these reasons, the protective caps should always be in place when the instruments are not in use.

Sunshades

An optical instrument that is used extensively in sunlight will have a sunshade to reduce glare. The sunshade will prevent the sunlight from directly striking the outer face of the objective lens. Sunshades, as illustrated in figure 6-4, are usually tubular sections of metal fitted around the objective A sunshade also protects the objective from rain, heat, and the sun, which would harm the cement used on elements of an achromatic objective

Eye Guards

Eye guards similar to those illustrated in figure 6-5 are used extensively on optical instruments. These guards, made of plastic or rubber, protect the observer's eye from gunfire shock or similar disturbances. An eye guard also maintains proper eye distance and keeps 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. Refer to figure 6-6 as you read the following sections on stops.

Field Stop

A field stop is a diaphragm that limits the field of an instrument to the area that is most illuminated. A field stop is placed at the image plane and helps to produce a sharply focused image by eliminating the peripheral rays, which 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 of the first so that slight inaccuracy in size or positioning will not conflict with the sharply defined image of the first.

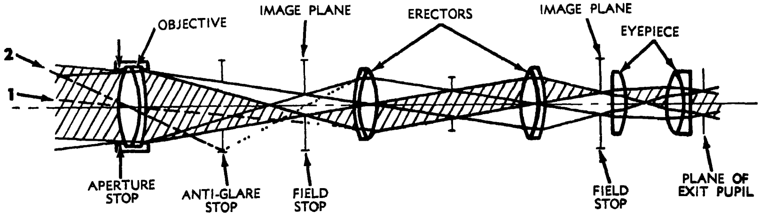

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Figure 6-6.—Diaphragm locations.

Aperture Stop

An aperture stop is a diaphragm that limits the size of the aperture of a lens. In most telescopes this is usually the objective lens mount or retainer ring. 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 reduce only the illumination and exit pupil size without reducing lens aberrations. In the event the objective of an instrument is so complex that two or more separate lenses are used, an aperture stop between the elements may reduce aberrations.

Antiglare Stops

Antiglare stops are diaphragms placed in optical instruments within the focal length of the objective. These stops prevent marginal rays from reflecting off the interior of the instrument and causing glare. Antiglare stops are finished with nonreflecting paint or oxide coatings.

In straight line telescopes, the stops can be merely washers or disks with a hole in the center. In the construction of binoculars, the prism's shelf is designed to act as a stop for stray light.

MOUNTING OPTICAL ELEMENTS

After the designer of an optical instrument 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 strain, which would cause a distorted image or could break the element. If the element is adjustable, he must design the mount so that it can be adjusted without looseness or play. The following discussion covers the most common mounts with which you will be working as an Opticalman.

LENS MOUNTS

After a lens has been ground and polished to the proper curvature, it is ground on the edge to its final diameter. Since the edge of the lens is 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, as with the objective lens of the Mk 75 Mod 1 boresight telescope shown in figure 6-7. 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 uses a lens cell similar to that shown in figure 6-8. 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. This is done to 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 retainer ring. Lenses mounted in a cell can be adjusted and placed in the instrument as an assembly.

An adjustable lens mount (fig. 6-9) is often used to mount a single lens in an instrument so that it may be axially adjusted during assembly 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

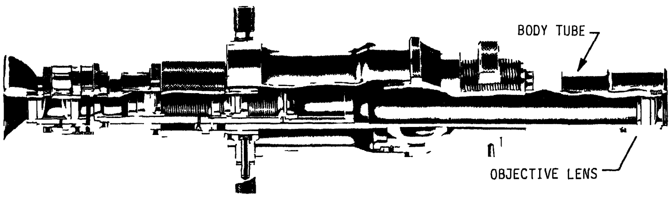

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Figure 6-7.—Cutaway view of a Mk 75 Mod 1, boresight telescope.

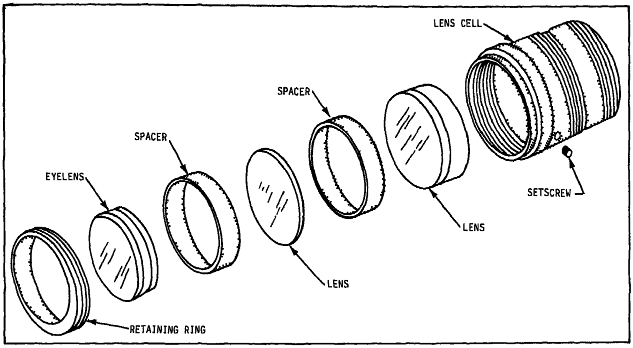

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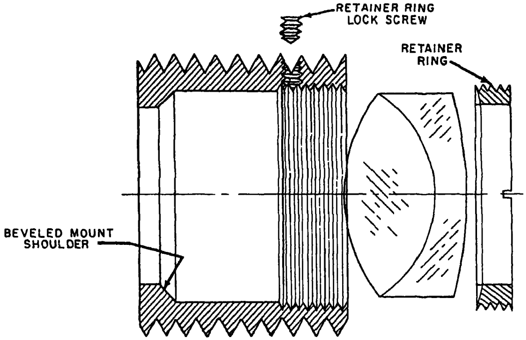
Figure 6-8.—Lens cell, lenses, spacers, and retaining ring.



136.166

Figure 6-9.—Adjustable lens mount.

position; it is locked in place by a lock ring or setscrew.

Retainer Rings

In our discussion of lens mounts, we have frequently illustrated and referred to retainer rings. You have seen how they are used to hold a lens in a mount and how they are used to secure a mount in place. Most instruments that you work on in the Navy have retainer rings. They are a very important part of an instrument. When a retainer is loose, the lens is also loose and the instrument's effectiveness is impaired or lost.

You will be working with rings that range from small and delicate to large and cumbersome. All rings must be handled carefully so that you will not damage the fine threads or distort their shape. Most retainer rings and other threaded mechanical parts are locked in place by a setscrew or locking compound that hardens when dry, such as shellac. BE VERY SURE THAT YOU REMOVE ALL SETSCREWS AND LOCKING COMPOUNDS BEFORE TURNING THE RING. Otherwise, you will damage the threads on the mount and the retainer. This will cause added repair work or loss of the part. Note the setscrews that lock the retainer in figures 6-8 and 6-9. Not all locking screws are so prominently located, so examine the parts carefully for hidden lock screws.

Screw Adjusting Mounts

Occasionally an element must be adjusted after the instrument has been assembled. In such cases you will find a screw adjusting mount similar to that illustrated in figure 6-10. This mount has four adjusting screws located at 90-degree intervals. They are used for horizontal and vertical adjustments. The adjusting screws extend through the telescope body and can be either a slotted head type (illustrated) or a thumbscrew type. By letting out on one screw and taking up on the other, you can position the element with great accuracy. Be careful when tightening the screws so that no undue strain is placed on the mount or element.

Eccentric Mount

The optical axis of an instrument must coincide with its mechanical axis if the instrument is to be in alignment. To assure alignment, lenses are sometimes placed in an adjustable eccentric mount. This allows movement of the lens and its optical axis in a plane perpendicular to the axis of the instrument. Figure 6-11 illustrates the eccentric objective mount of a binocular; refer to it as you read the following description. The lens mount has a machined bearing surface that offsets it from the mechanical axis of the mount (eccentric). A ring whose inner and outer surfaces are eccentric to each other is placed over the bearing surface of the mount. It acts as a bushing to hold the assembly in the binocular body. By rotating the entire assembly or by rotating the outer ring around the mount, you can move the optical axis of the lens to any desired point within a relatively large area. Since most lenses have some inherent eccentricity, you can obtain some additional movement by rotating the objective lens in its mount. The objective assembly is then locked in place by a setscrew or retainer ring or both.

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 shapes of prisms. Since practically all lenses are round, designers use tubular mounts for most lenses. However, prism mounts must be individually designed to fit the shape of a particular prism. Space does not permit a full description of all prism mounts used in Navy instruments, but we will briefly explain a few.

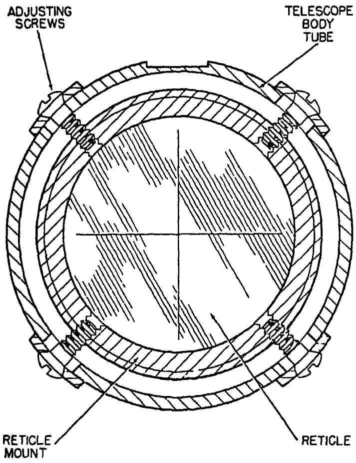


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Figure 6-10.—Adjustable reticle mount.

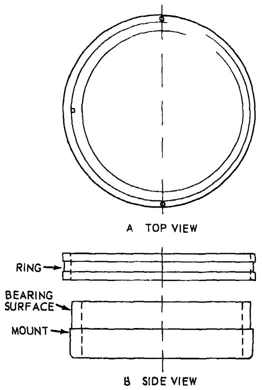

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Figure 6-11.—Eccentric lens mount assembly.

Roofedge

The roofedge prism mount, shown in view A of figure 6-12, 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 secured by screws to the bracket. The bracket is fastened to the telescope body with four screws which can be loosened to adjust the prism mount. View B of figure 6-12 shows disassembled parts.

Right-Angled

Mounts for right-angle prisms vary in design according to needs. One mount (fig. 6-13) 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 during the shock of gunfire.

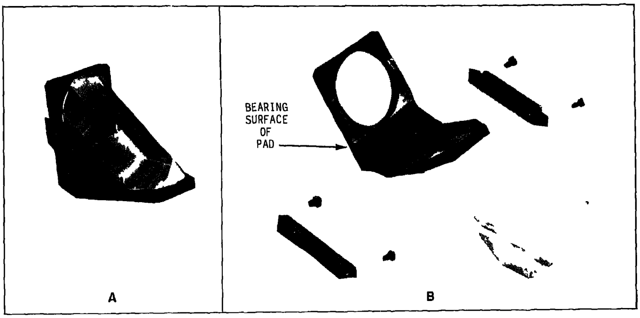

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Figure 6-12.—Roof-edge prism mount.

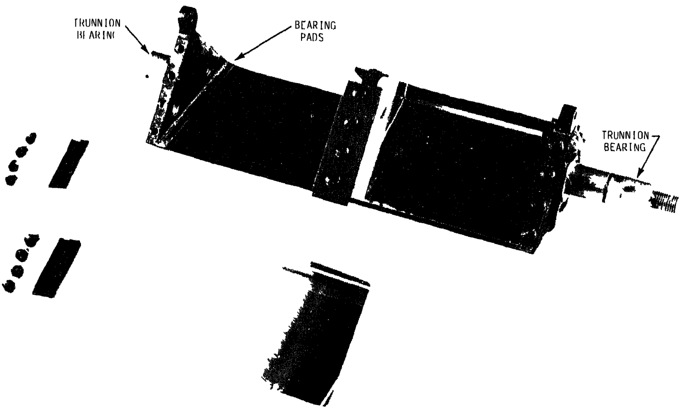

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Figure 6-13.—Right-angled prism mount.

Porro Prism

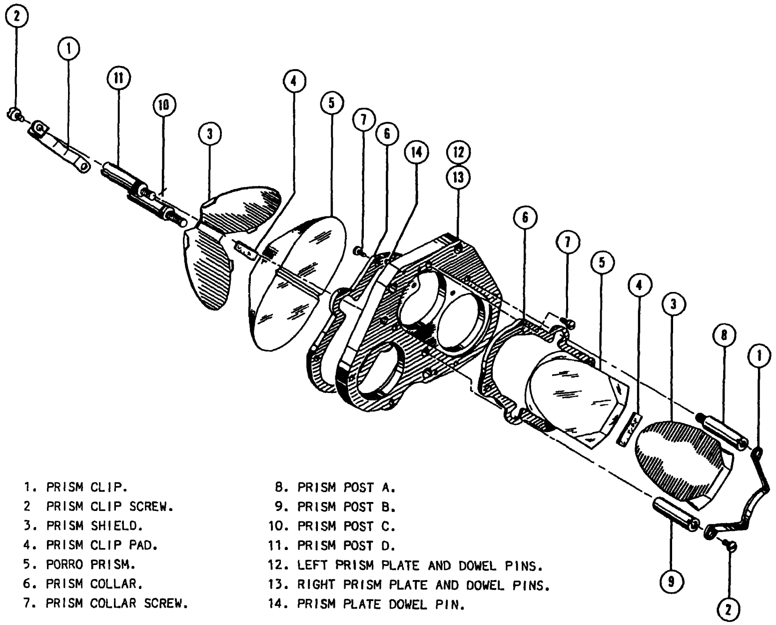
A porro prism mount (fig. 6-14) consists primarily of a flat, metal plate shaped to the interior of a telescope body. It is machined to hold one prism on each side of the plate. The hypotenuse surfaces of the prisms are mounted parallel to each other, and they are set over holes machined in the plate to allow light to pass from one prism to the other.

To maintain the APEX surfaces of the two mounted prisms at 90-degree angles to each other, a rectangular metal adjustment ring (prism collar) is placed snugly around each prism. If the two prisms are NOT at 90-degree angles to each other, LEAN is created in the prism cluster. Lean means that an object viewed through the prism cluster appears to lean at an angle when compared 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 is secured to two posts, one on each side of the prism; 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 not touch the reflecting surfaces of the prisms; 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

Since most instruments must be adjustable to the individual observer's eye, the majority



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.

137.170

Figure 6-14.—Porro prism mount.

of focusing arrangements with which an Opticalman comes in contact are eyepiece assemblies.

Lenses in an eyepiece are usually secured in a tubular type of mount. The field lens and the eyelens may be fastened separately, each with a retainer ring. They may also be secured together by the same retainer ring with a spacer placed between the field lens and the eyelens. The spacer will hold both lenses at the correct distance from each other.

The distance between the reticle and the eyepiece in an optical instrument must be adjusted to the observer's eye. The reticle and image of the object are then sharply defined, eliminating eye fatigue. To provide this adjustment, the lenses (two or more) of the eyepiece are mounted in a single lens cell, or tube. During adjustment of the focus, the 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.

Some of the focusing arrangements used on eyepieces are shown in figure 6-15.

Draw Tube

A draw tube focusing arrangement (fig. 6-15, view E) consists of a metal tube that contains 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 is not widely used by the Navy because the draw tube focus can be disturbed by a slight jar.

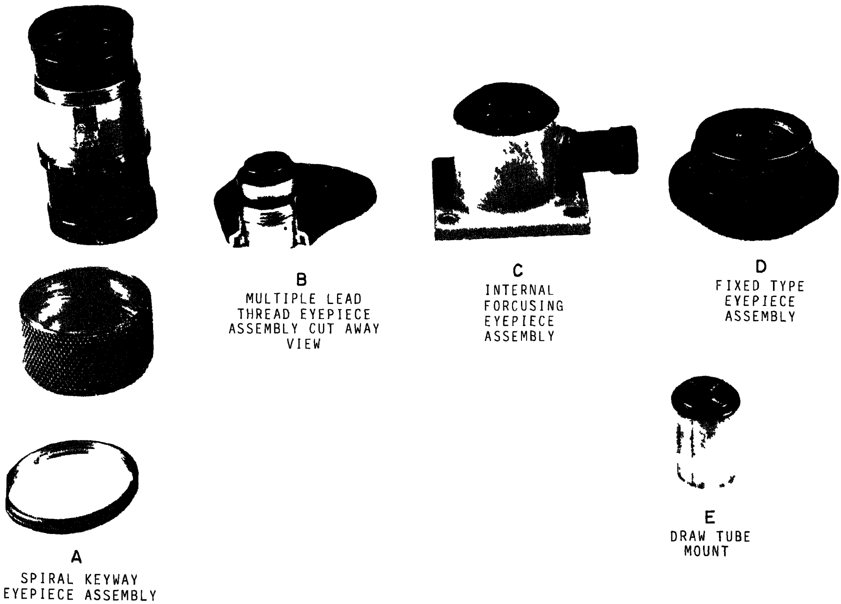


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Figure 6-15.—Focusing arrangement.

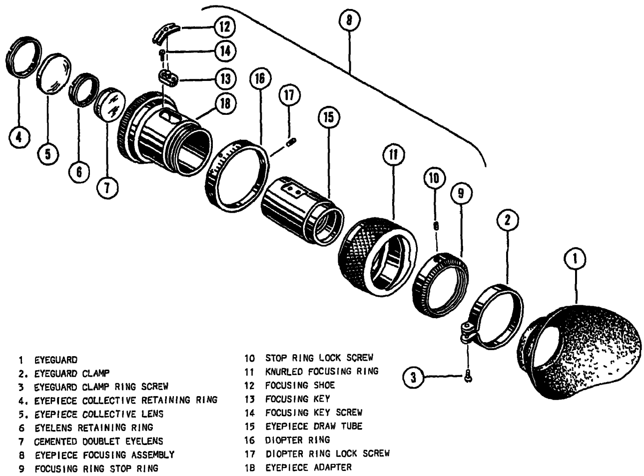

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Figure 6-16.—Spiral keyway focusing arrangement.

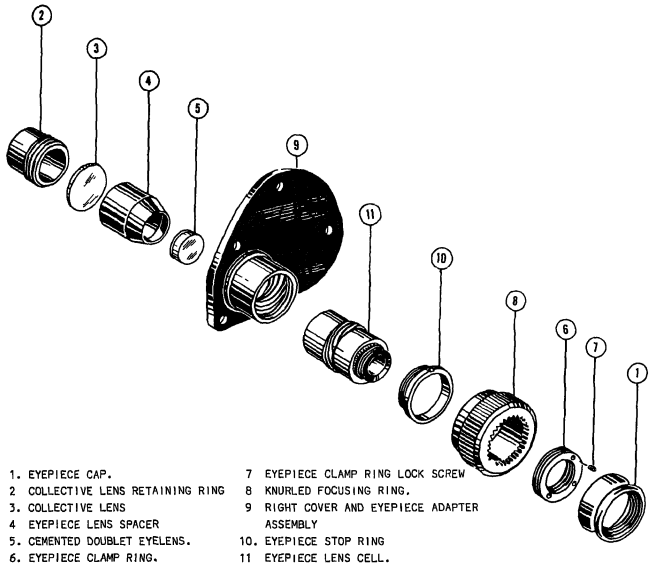

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Figure 6-17.—Multiple-thread eyepiece lens mount.

Spiral (Helical) Keyway

A spiral keyway focusing arrangement (fig. 6-16) is a modification of a draw tube. It is similar in construction to a draw tube with the additional following components: a focusing key or shoe, a focusing ring, a retainer ring, and a diopter-ring scale.

A straight slot, which guides the focusing key, is cut through the eyepiece adapter parallel to the optical axis of the telescope. The focusing key is fastened to the draw tube, protrudes through the straight slot, and holds the focusing shoe which engages a spiral groove or keyway in the focusing ring. The focusing ring turns on the eyepiece adapter but is prevented from moving along the optical axis by a shoulder on the adapter and the stop ring on the opposite side. The diopter ring is mounted on the shoulder of the eyepiece adapter; it is read against an index mark on the focusing ring. Mating parts of this type of focusing arrangement must fit snugly to eliminate lost motion, yet must allow smooth movement.

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. More adjustment is provided on the minus diopter side because most people focus the diverging rays more comfortably. When the focusing ring is turned either way, the focusing shoe follows the spiral keyways and moves the draw tube in or out to focus the eyepiece. As the operator, you focus the eyepiece to your eye and note the diopter scale reading; you can save time by adjusting to that reading each time you use the optical instrument.

Multiple Lead Thread

A multiple-thread eyepiece (fig. 6-17) is tubular with external multiple lead threads. It screws into a guide tube or eyepiece adapter with matching threads. When the eyepiece cell is screwed all the way into the adapter, it is stopped by the focusing ring. A stop ring is screwed into the top of the adapter. This prevents extraction of the eyepiece cell 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 cell. It is held in place by a clamp ring.

Internal Focusing Mount

An internal focusing eyepiece mount (fig. 6-18) consists of a housing secured and sealed to the rear of the telescope body. The housing contains an eyelens, secured by a retaining ring. 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. This, in turn, slides the movable lens mount toward or away from the eyelens during focusing for individual eye corrections. The dioptric scale is on the focusing knob, and the index mark is on the focusing shaft housing.

Focusing-type eyepieces are designed to provide fast focusing with minimum turning of the focusing ring, or knob. This design permits the eyepiece (when turned completely out) to stop on 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 thread eyepiece mounts are responsible for this type of focusing. In internal focusing eyepieces, the eccentric plate

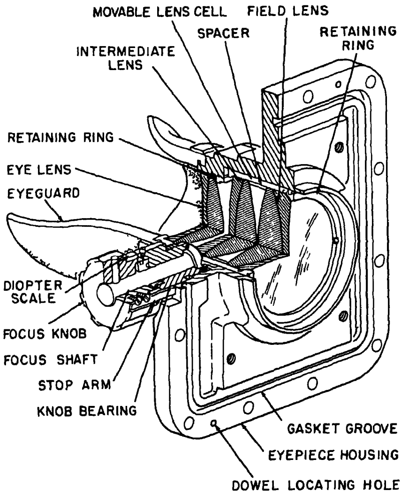

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Figure 6-18.—Internal focusing eyepiece mount.

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 revolve in a small circle. For this reason, eyepieces with draw tubes which slide in and out without rotating 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 that has a reticle, the image of the target appears to move under the reticle image in a small circle.

One advantage internal-focusing eyepieces have over spiral keyway and multiple lead thread eyepieces is that they can be sealed to prevent entrance of foreign matter and moisture. When properly assembled, telescopes with these types of eyepieces can be submerged in water.

Spiral keyway and multiple lead thread eyepieces breathe during focusing and cannot be submerged under water. When you focus them in, they compress the air within the telescope and force it out through 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 on the optical elements of the telescope diminish or obliterate vision through the instrument.

FIXED EYEPIECE MOUNT

A fixed-type eyepiece (fig. 6-15), as the name implies, is fixed in position and cannot be focused for individual eye correction. The eyepiece mount may consist of a housing that contains the eyelens, separator, field lens, and retainer ring secured and sealed at the rear of the telescope body. The eyepiece housing may also be part of the main telescope body. If the eyepiece housing is part of the main telescope body, the lenses and the spacer slide into the eyepiece housing from inside and are secured in place with a retaining ring

This type of eyepiece cannot be focused for individual eye correction. The light rays that leave it are slightly divergent with a value of −3/4 or −1 1/2 diopters. This fixed minus diopter setting is used because the majority of operators set focusing eyepieces slightly on the minus side of the dioptric scale.

BEARINGS

When a shaft is mounted in a device to hold it during rotation, friction develops at the

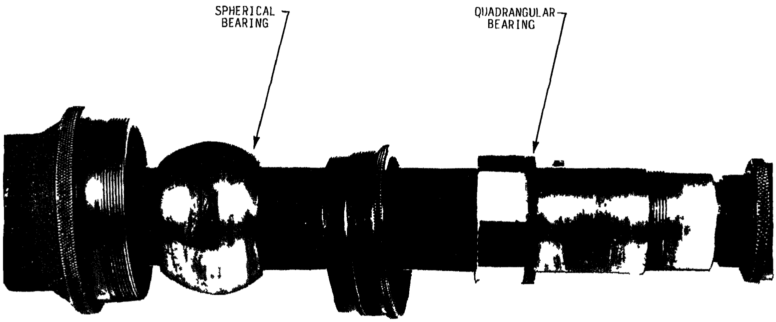

Figure 6-19.—Cylindrical bearing and square bearing in an instrument assembly.

contact point between the shaft and the device. Friction develops heat. Therefore, friction produced in a shaft housing must be kept to a minimum for satisfactory performance and longer life of the shaft. Devices that reduce the amount of friction produced by shafts in their housings are called bearings.

Except for simple types, optical instruments have many moving parts. Movement of these parts, however, must be restricted so that motion takes place only in the direction desired. To provide friction-free movement in a specific direction, movable parts of an optical instrument must be supported and retained by some suitable means.

Before we discuss the different types of bearings, we will explain the different types of loads bearings must carry.

- NORMAL LOAD: A load applied toward and perpendicular to the bearing surface.

- RADIAL LOAD: 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.

- AXIAL LOAD: A load directed along the axis of rotation or surface of an object.

- ANGULAR LOAD: A load that is a combination of the other loads described above.

Sliding Surface Bearings

A sliding surface bearing usually has a stationary member that 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. Sliding surfaces are not always flat; they may be square, angular, spherical, or circular. The piston and cylinder bore of an internal-combustion engine constitute a circular sliding surface bearing.

Square and spherical sliding surface bearings are used to mount some of the smaller gunsights so they may be easily boresighted (aligned with the gun). Refer to figure 6-19, which shows these two bearings as used on an instrument. The spherical bearing is secured in its mating mount, which is firmly attached to an adapter or gun mount. The spherical bearing holds the front of the instrument securely and at the same time allows radial motion of the body.

The square bearing (quadrangular) provides a surface for bearing pads and adjusting screws, which can accurately lock the instrument in any desired position. 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. 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 surface. It has little, if any, sliding motion 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 are reference surfaces for aligning optical elements.

Rotational Bearing

A rotational bearing generally has a stationary member for holding the rotating member. The stationary member is called the sleeve. The rotational member is usually in the form of a shaft with precision-finished surfaces called trunnions.

Trunnion bearings (fig. 6-13), such as those on the ends of a Mk 61 telescope right-angled prism mount, are used on many kinds of telescopes They keep the optical axis of a telescope or prism mount in a true vertical plane during elevation or depression of the line of sight.

Ball Bearings

Because rolling friction is much less than sliding friction, precision ball bearings are used extensively in optical instruments. In self-contained units, precision ball bearings are classified according to their design. Differences in ball bearing design features are generally not apparent externally. In 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 read about the most common designs of self-contained precision ball bearings in the following paragraphs, refer to figures 6-20 and 6-21 to determine their differences.

Radial ball bearings (fig. 6-20, view A) are designed to carry loads applied to a plane perpendicular to the axis of rotation. They prevent movement of the shaft in a radial direction. Thrust ball bearings (fig. 6-20, view C) are designed to take loads applied in the same direction as the axis of the shaft. They prevent endwise movement.

Radial and thrust bearings are therefore designed to carry loads in a specific direction—perpendicular or parallel to the axis of supported shafts.

An angular ball bearing (fig. 6-20, view B) supports an angular load. This load has components of radial and axial thrust and is exemplified by the bearings in the front wheel of a bicycle. Angular ball bearings are normally used in pairs, in a manner that enables the angular contact surfaces of one bearing to oppose the corresponding surfaces of the other. This arrangement of bearings provides a technique known as PRELOADING. Preloading removes give or softness before the bearings are subjected to their normal loads.

The principle of preloading is illustrated in figure 6-21. Preloading can be obtained (and normally is) by subjecting the inner races to a 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. The parts act as the bearing races with the desired number of steel balls rolling between them. This type of bearing is used between polaroid filter plates in optical instruments. It provides smooth and free rotation.

CAUTION: Dry metallic surfaces under an appreciable load, though smoothly machined, will not slide over each other without abrasion; they must be kept covered CONTINUALLY with an approved lubricant. If properly lubricated, precision-made ball bearings wear very little. When wear does occur in ball bearings, replace them. Adjustment is impossible.

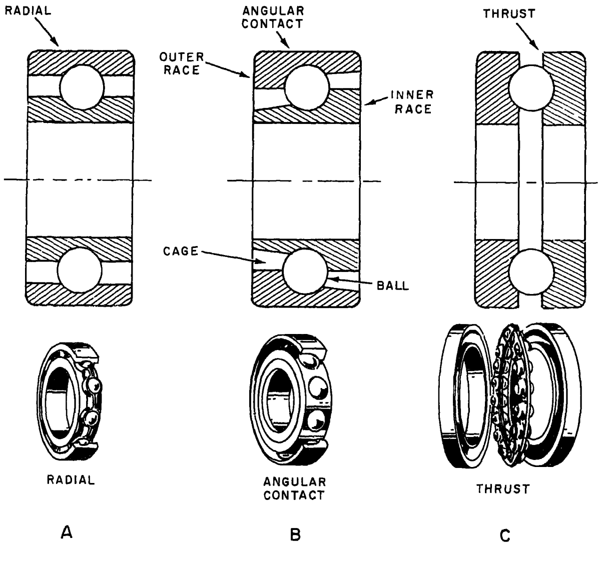

Figure 6-20.—Different types of ball bearings.

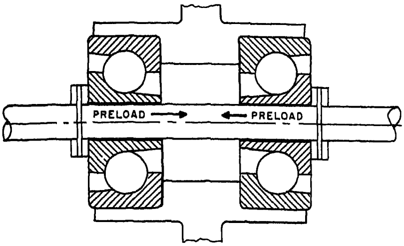

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Figure 6-21.—Preloading produced by pairs of angular ball bearings.

OPTICAL INSTRUMENT GEARS

In order to provide the type of motion and speed required, an instrument designer must know what type of gears to use for a specific function. Because you must work with these gears in optical shops, knowledge of the following basic types will be beneficial to you.

Spur Gears

The spur gears shown in figure 6-22 are from a Mk 74 gunsight. In optical instruments, spur gears are used more than any other type of gear. They are used to transmit power from one shaft to another.

Teeth on spur gears vary in size and are stated in terms of PITCH, or DIAMETRAL PITCH (number of teeth per inch of pitch diameter). A spur gear with 16 pitch and a pitch diameter of 1 inch has 16 teeth, and so forth.

The speed ratio between shafts having spur gears is important. The ratio is defined as the reciprocal of the quantity of teeth of the two gears. For instance: if two mating gears have 40 teeth and 10 teeth respectively, the ratio is 4 to 1. The speed of the 10-tooth gear will be 4 times that of the 4-tooth gear.

Brass, aluminum, and steel are generally used in small spur gears. Cast iron is widely used in large spur gears. Spur gears, however, are also made of nonmetallic substances.

Bevel Gears

Bevel gears used in optical instruments can be put on shafts that intersect at desired angles, provided the angle of the teeth is correct in relation to the shafts.

When one component of a pair of gears that mesh together is bigger than the other (views A and B in fig. 6-23), the bigger component is usually called the GEAR and the smaller component is called the PINION.

Bevel gears are made with straight or curved teeth, but they CANNOT be interchanged with spur gears. By using different sizes of bevel gears, as shown in figure 6-23, you can obtain a different

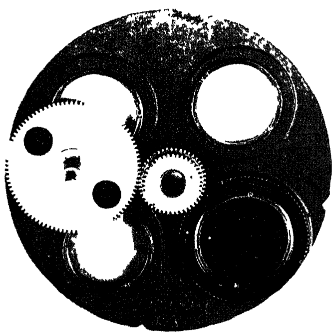

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Figure 6-22.—Types of spur gears.

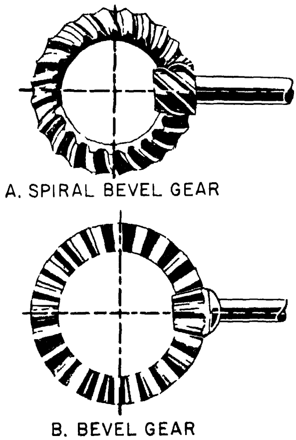

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Figure 6-23.—Types of bevel gears.

speed ratio. When these gears are the same size, they are called MITER GEARS. NOTE: If lapped pairs of bevel gears are used in an optical instrument, almost perfect quietness of operation is obtained.

5.22.9

Figure 6-24.—Sector gear and worm.

The shape of bevel gears, especially those with spiral teeth, causes them to exert considerable thrust. For this reason, the end of a shaft that contains the gear is generally supported by an angular ball bearing, and the other end has a radial ball bearing.

Worm and Sector Gears

Study figure 6-24. The top part is called a WORM, and the bottom part is called a SECTOR GEAR.

If a worm has only one continuous thread, it is called a SINGLE-THREAD worm. More than one thread may be cut on a worm. A worm with two continuous threads is called a DOUBLE-THREAD worm; a worm with three continuous threads is called a TRIPLE-THREAD worm. On a worm with a single thread, lead and pitch are equal, but the lead is twice the pitch on a double-thread worm and three times the pitch on a triple-thread worm. Therefore, if a single lead worm is used, one revolution of the worm advances the sector one tooth. With a double or triple-thread worm, the sector will advance two or three teeth with each revolution of the worm

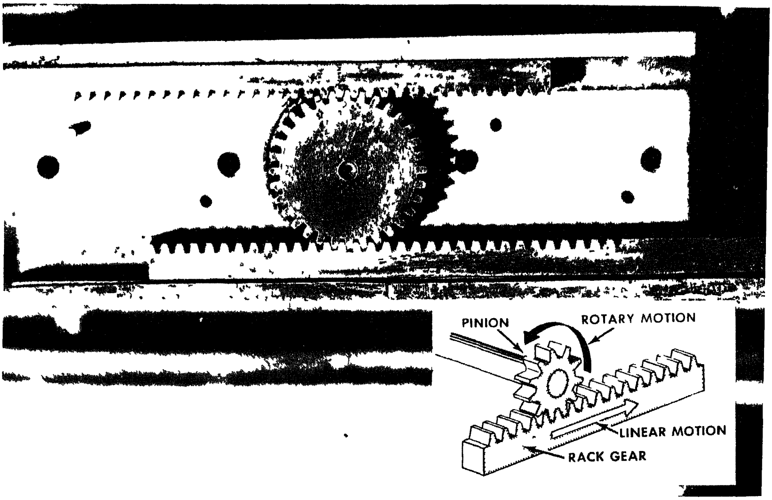

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Figure 6-25.—Rack and pinion.

As you can see from figure 6-24, the rotation of the sector is limited to approximately 90°. If the sector were made with teeth all the way around (full 360° rotation), the arrangement would be called a worm and worm gear.

Helical Gears

Helical gears are closely related to worm gears in function and general arrangement. Mating helical gears are usually of the same thickness, and the teeth are cut at a 45-degree angle to the axis of rotation.

With a worm and sector or worm and worm gear, the worm is the driving member. The worm causes the gear or sector to revolve, but not vice versa. With helical gears, even those of different diameters, either gear can drive the other.

Rack and Pinion

Some optical instruments use a rack and pinion such as the one illustrated in figure 6-25. The rack gear moves in a linear motion, as indicated. 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 withstand submersion in water.

All openings in optical instruments are sealed with sealing compound or gaskets. A combination of both is often used The gaskets may be made of rubber, plastic, or lead.

Instruments are waterproofed by using gaskets on all outside joints. Where a gasket cannot be used because of physical limitations, sealing compound is used. A well-designed waterproof instrument will have gaskets for all seals except for such small, nonflexing joints as a setscrew going through a body.

Standard techniques for waterproofing and sealing are provided in the following paragraphs.

Sealing Compound

The sealing compound used most often is called RTV. After being exposed to air for a short period of time, RTV sets into a tough, flexible consistency. It is available in black, clear, or grey and comes in tubes with a tapered spout. To make a small bead, cut off the tip of the spout. To make a larger bead, cut off more of the spout.

Following is a procedure to be used to seal lenses:

1. Place a bead of RTV around the area to be sealed. Excess sealer may prevent optics from seating evenly, and too little compound at any point will provide a poor seal.
2. Set the optical element in its mount, and press down firmly and evenly all the way around.
3. Replace the retainer. For lenses, tighten the retainer ring snugly. Window retainers (usually rectangular) must be tightened by taking up on opposing screws much as you would for tightening cylinder head bolts.
4. Wipe away excess sealer.

CAUTION

Optics must not be cocked when the retainer is tightened. They will either break, cause distortion in the image, or fail to seal properly. Firm pressure is sufficient.

Optics sealed with sealing compound will appear tight because they are stuck in the compound. However, they will come loose eventually if the retainer is not snug.

The sealing of mechanical parts is not a series of step-by-step operations which can be used in all situations Closing an opening is the basic purpose of sealing, yet each sealing operation must be studied to determine where the opening is and where to apply the sealing compound. Your objective is to form a neat, satisfactory seal and to hide the joint if possible.

PREFORMED GASKETS

Optical instruments are usually sealed with preformed gaskets. They provide the best seal and are used extensively when an instrument must be watertight or pressuretight. Three types of preformed gaskets are used on Navy instruments;

flat gaskets of irregular shape (fig. 6-26) and round O-rings and flat gaskets (fig. 6-27).

When sealing an instrument with flat gaskets, you must strictly adhere to the following procedures:

1. Use the proper gasket for each joint.

2. Use new gaskets.

3. Be sure the gasket surface on the part and the gasket itself are clean. Foreign matter may cause a gap in the seal.

4. Place the gasket in the correct position, and make sure it is flat against the part it is sealing.

5. Tighten the parts to be sealed sufficiently to squeeze the gasket. However, do not overtighten. Excess pressure may cut the gasket.

6. After the part has been reassembled, if possible, check the gasket to ensure that it is in the proper position.

O-rings

An O-ring seal on an optical instrument is engineered to meet a set of standards that applies to all O-ring seals. All O-rings are molded and trimmed to extremely close tolerances. An O-ring is generally fitted into a rectangular groove machined in the mechanism to be sealed. 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 a 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. Figure 6-28 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.

When pressure is applied, the O-ring moves away from the pressure and into the path of leakage. This completely seals the passage (fig. 6-28, view B). The greater the pressure applied, the tighter the seal becomes. When the pressure is decreased, the resiliency and elasticity of the seal returns the O-ring to its natural shape. Due to age and temperature variations, O-rings can become set (loss of resilience) and fail to perform as a seal.

O-rings are an excellent means for sealing shafts projecting through an optical instrument body housing and for sealing windows, inspection plates, and various other fittings attached to optical instruments. When O-rings are used, the seating surfaces must be clean and absolutely free of dents or scratches The O-ring must be in perfect condition, and the correct O-ring for each sealing application must be used

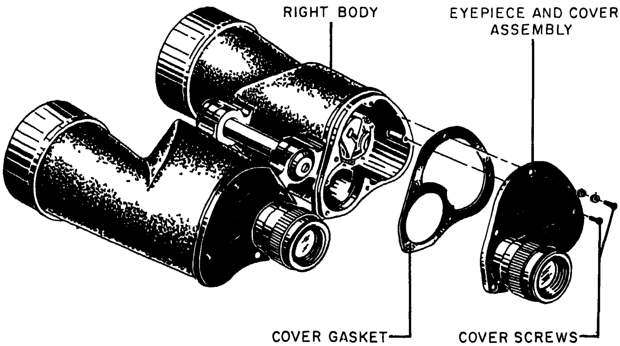

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Figure 6-26.—Eyepiece and cover assembly gasket.

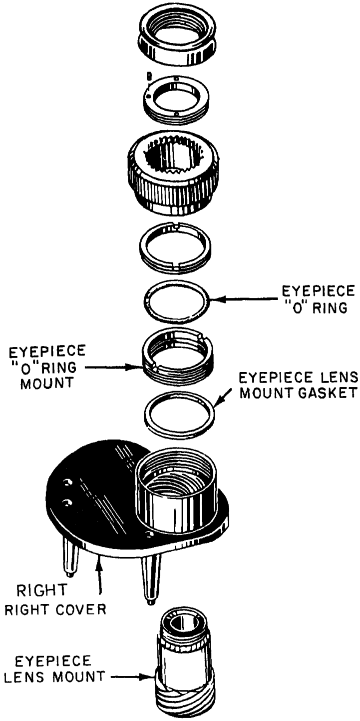

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Figure 6-27.—Eyepiece O-ring seal.

Because of the requirements for perfect seating surfaces, O-rings are removed and installed with wooden dowels or with special brass tools. Careful use of these tools will prevent damage which causes unnecessary waste of time and material.

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.

By rolling the O-ring on an inspection cone or dowel, you can check the inner diameter surface 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. Make a further check of each O-ring by stretching it between your fingers, but be careful 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 in identifying and inspecting O-rings than to repeatedly overhaul components because of faulty seals. If an O-ring has any defect, discard it.

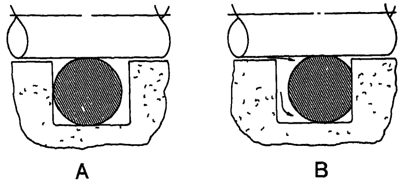

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Figure 6-28.—Properly installed O-ring.

The problem of positively identifying the correct O-ring to use is difficult because many of these seals appear identical in size and color even though they are intended for different applications. For this reason, O-rings are sealed in envelopes with a label that indicates part number, size, and life expectancy. Always keep O-rings in their original package until they are ready for use, and determine exactly which seal to use for each application.

Packing

As used in mechanics, the term *packing* refers to the material used to seal an opening when the two component parts move in relation to each other. The type of material used depends on several factors, such 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 korseal. These packing materials come in wide ranges of density, tensile strength, and shape. Packing can be in either preformed shapes, as shown in figure 6-29, 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 within a specified time.

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 manufacturer's 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 manual, manufacturer's publication, or *Naval Ships' Technical Manual.*

It has been found from experience that packings deteriorate with age. Therefore, knowing and understanding packing shelf life will save you many hours of unnecessary toil in repacking a unit. A unit may continue to leak as a result of packing that is defective due to age.

Prior to installing natural and synthetic rubber packings, you must check 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 a ship, at stock distribution points, or furnished as an integral part of a component.

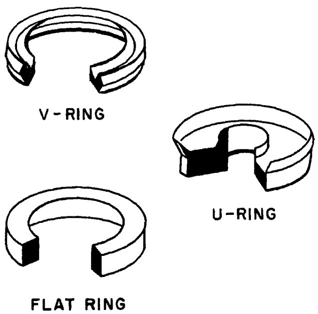

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Figure 6-29.—Packing rings.

Positive identification, indicating the source, cure date, and expiration date of packings must be made.

Cure date means the time the packing was manufactured, and it 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.

Expiration date is the date after which a packing CANNOT be used in service. Time of delivery is the date of acceptance by the purchaser. All packing must be scrapped if it is not put into use by the the expiration date.

Packing is packaged and coded by the manufacturer. The code indicates the year and quarter of manufacture and the expiration date.

If a package does not have a legible expiration date, reject it. Likewise, if any packing is not in its original package, do not use it.

Packing should always be stored away from sunlight and in a low-humidity area. Storage area temperatures are also important. A range from 60° to 100°F is usually satisfactory, and in no case should the temperature exceed 125°F.

LUBRICATION

Proper lubrication is an important part of optical instrument repair. It is a matter that has been regarded too lightly in the past. Some people believe that any grease or oil will do Experience proves that such an idea can be detrimental to the best performance of the instrument.

A lubricant may work perfectly in temperate zones, but may 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. The heat could soften the lubricant to the point where it will flow into other locations and impair the functioning of the instrument.

A very thin film of improper grease or oil on an optical surface could cause the instrument to be 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.

An excessive amount of lubricant is a waste, and often is as bad as, or worse than, not using enough. Where closely mated parts require only a very thin film of lubricant, an excess can introduce errors in instrument readings.

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.

The Navy buys ready-made lubricants which have been found to be satisfactory for use on optical instruments. These recommended lubricants are manufactured in different grades and are adaptable to all types of applications and temperature ranges.

As an optical repairman, you should always follow the specifications in technical manuals when lubricating optical instruments. When specific instructions are not available, ask your shop supervisor for advice on which lubricants to use.

Application of Lubricants

To apply grease to a surface, use a round hardwood stick with a chisel point on one end. Dip the end of the stick into the grease container, and pick up a small amount of grease. Apply the grease to the surface to be greased. Smooth it out with the stick so that the entire bearing surface is covered with a thin film of grease. Fit the greased parts together and run them in. 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. Use the stick to pick off the bulk of unneeded lubricant. Wipe grease from areas where none should remain. Use a clean, lintless cloth moistened with solvent.

Keep the oils in small individual instrument oil cans that are fitted with a cap for protection against dirt. Greases must be kept in clean jars or cans and kept covered when not in use. This prevents contamination by dust, grit, and dirt. All containers should be properly labeled with the name of the lubricant and also the material specification number.

REFERENCES

Military Standard, "Optical Terms and Definitions," MIL-STD-1241A, 31 March 1967.

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

CHAPTER 7

MAINTENANCE PROCEDURES

This chapter provides information on repair and maintenance of optical instruments. We will stress the importance of careful handling and cleanliness of the instruments you will maintain and the tools you will use.

Optical instruments are expensive, precision-built devices, and we cannot overemphasize the care in maintaining them. If an instrument is handled roughly or dropped, the shock may result in misalignment or breakage of the optical and mechanical parts. When this happens, you have only one choice—REPAIR. You must unseal the instrument, disassemble it, make repairs, reassemble, and collimate. This amounts to 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 shop, check the containers for damage and cleanliness; then, if you do not start to work on the instruments at once, 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 to secure the instruments in position. When you put an instrument into its container, place it gently in position and carefully close the lid. DO NOT TRY TO FORCE AN INSTRUMENT INTO ITS CONTAINER NOR SLAM THE COVER SHUT. If the instrument does not slip easily into its case, check for an extended drawtube or something else that is hindering smooth entrance into proper position.

CAUTION

Always secure the cover of the container with the catches installed by the manufacturer.

INSPECTION AND TESTING

Your duties as an Opticalman will always call for you to inspect and test optical instruments. The inspection may be held aboard ship before the instrument is delivered to the shop, or you may hold it just before you begin the repair work. In any case, the inspection and the testing of an optical instrument are vital, and you should have a thorough knowledge of the instrument and the procedures used to inspect it. If an instrument is unfamiliar to you, study all information concerning it in ordnance pamphlets (OPs), NAVORD publications, NAVSHIPS manuals, and blueprints. Never attempt to dissemble and repair an instrument until you fully understand it.

INSPECTION OF INSTRUMENTS

There may be occasions when you will be given full responsibility for inspecting all optical instruments aboard ship. By carefully locating all deficiencies, you will be able to save yourself and your repair activity considerable work.

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.

During predisassembly inspection of an instrument, use a casualty analysis inspection sheet and record all your findings on it. A sample casualty analysis sheet is shown in figure 7-1.

Mechanical Condition

Carefully examine mechanical controls, and check gear mechanisms for slack or excessive tightness. If the instrument is mounted on bearings, check them for dents, gouges, and corrosion.

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 is damaged or improperly lubricated.

Backlash in the focusing action of an eyepiece is usually caused by a loose stop or retainer ring, but it may be caused by a loose key in a 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 is at

7-50 BINOCULAR

CASUALTY ANALYSIS SHEET

Mark______ Mod ______ Serial______

Optical Condition

External Cleanliness		Coating
Internal Cleanliness		Cement
Moisture		Chips

Mechanical Condition

Focusing Action	LEFT	RIGHT
Hinge Tension		I P D Scale
Eye Caps		Objective Caps
Paint		Covering

Collimation

Step	Divergence
Lean	0 Diopters

____

REPAIRMAN

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Figure 7-1.—Binocular casualty analysis sheet.

midthrow (halfway in and halfway out). The focusing action should be such that the index mark clears all graduations (plus and minus) during full travel of the focus knob.

If the instrument has a ray filter assembly, check the action of the control knob. If rotation of the ray filter shaft 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 probably 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, setscrews, 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 gauge to the gas inlet fitting. Then crack the valve screw and read the pressure on the gauge. Correct pressure in nitrogen-charged optical instruments is indicated in the manufacturer's technical manual for each particular instrument. If the instrument gauge indicates zero pressure, the instrument probably has 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 Inspection

Because optical elements constitute the heart of an optical instrument, inspection of the optical system is very important, and you must 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. With experience, however, you will be able to see each element in the system, and you will be able to pinpoint defects.

The best method for inspecting the optical system of an instrument is to point it toward an illuminated area and look for the following:

Dirt and dust: Dirt and dust show up as dark spots (specks) on the surface of an optical element.

Chips, scratches, and breaks: These defects in an optical element show up as bright, starlike specks, scratches, or large bright areas when light is reflected from them.

Grease or oil: Grease or oil on an optical element is indicated by streaked, clouded, or nebulous areas, with an occasional bright translucent spot.

Moisture: Moisture shows up as a sharply defined nebulous area, with brilliant reflection or a diffused, clouded appearance when the area is not illuminated.

Fungus or watermarks: Brown or green patches, or stains, indicate the presence of fungus or watermarks. Deposits of salt cause a grainy, milky color similar to that of frosted glass.

Deteriorated balsam: Deterioration of Canada balsam used to cement lenses together is indicated by a dark yellow color, or areas between the elements appear milky colored or opaque. When the cement just begins to separate, bubbles or 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 the elements have completely separated.

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, if 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.

Modern optical instruments have a transparent metallic coating on optical elements to improve light transmission through the instrument. With uncoated optics, there will be an approximate 5 percent loss of incident light at each air-glass surface due to surface reflection. When magnesium fluoride is correctly applied to optics, this loss of incident light is reduced to about 1 percent.

The magnesium fluoride coating is deposited on optics to a depth of one-fourth the wavelength of yellow-green light. This amounts to four millionths of an inch (0.000004). You do not need to actually measure this coating when you perform an inspection. If you view an optical element under a strong white light, properly coated optics will show a reddish-purple reflection.

A few scratches on the coating of an optical element will have no effect on light transmission; however, if most of the coating has been removed through improper cleaning or chemical action, the element should be replaced.

Reticles or other optics that are located at an image plane are never coated since scratches or other defects in the coating would be visible and very undesirable.

The mating surfaces of cemented lenses are not coated since there is no air-glass surface; therefore, surface reflection is not a problem. Reflecting surfaces of prisms are not coated for the same reason.

Inspect silvered prisms and mirrors for signs of wear, peeling, or darkening of the silvered or aluminized surfaces. All of these defects show up as blisters and cracks in the coating, or a yellowish color.

Some optical defects are illustrated in views A through K in figure 7-2. If available, get some lenses with the defects shown, and study them as you read the following information.

CHIP.—A chip (fig. 7-2, view A) is a break at the edge of a lens or prism caused by uneven pressure or burrs on the seat of the lens mount.

NOTCH.—A notch (fig. 7-2, view B) is a ground-off surface of a lens or prism. A notch is serious only if it is located where it will interfere with sealing or light transmission.

SCRATCH AND STRIPE.—A scratch (fig. 7-2, view C) remains visible as you rotate a lens or prism through 360°; a stripe, on the other hand, vanishes at some position as you rotate the optical element. You can see scratches and stripes most easily in optical elements when you place the elements against a dark background.

RING.—A ring (fig. 7-2, view D) is a circular mark around the external edges of a lens, and it is caused by wear of 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 (fig 7-2, view E) is a fracture of the lens or prism generally caused by a sudden change of temperature, because the center of the optical element does not expand or contract as rapidly as its edge section.

BUBBLE.—A bubble (fig. 7-2, view F) may result from gases left in the glass during manufacture or from air that did not escape from the cement when the elements were joined.

STRIAE.—Striae (fig. 7-2, view G) 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 (fig. 7-2, view H) 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 of 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 (fig. 7-2, view I) in the layer of a cement between lenses may eventually cause a blister. You can see this type of foreign matter in a lens most easily by transmitting light through it against a dark background. Dirt fuzz is caused by careless cleaning and cementing.

STAIN.—A stain (fig. 7-2, view J) is usually brown or green and is produced by evaporation of moisture that gets on lenses or prisms and dissolves some of the antireflecting coating, thereby causing a very faint deposit (sometimes bacterial in growth)

UNPOLISHED CONDITION.—An unpolished optic (fig 7-2, view K) results from the manufacturer's failure to remove grinding pits from it. In some instances, however, this condition is apparent on optical surfaces exposed to gases, grit, and particles of all sorts in the atmosphere

PARALLAX AND COLLIMATION.—The last step in checking the optical system of an instrument is to test for parallax and collimation. Always check the collimation of an instrument before you disassemble it. The information you obtain will help you during repair and reassembly steps.

You can check the collimation of an optical instrument in two ways: (1) look through the instrument at an outside target, or (2) check it more accurately with an auxiliary telescope and a collimator. The first method, however, is generally used when quick results are desired.

Focus the instrument on a distant target and check for parallax by moving your eye from side to side and up and down. If parallax is present,

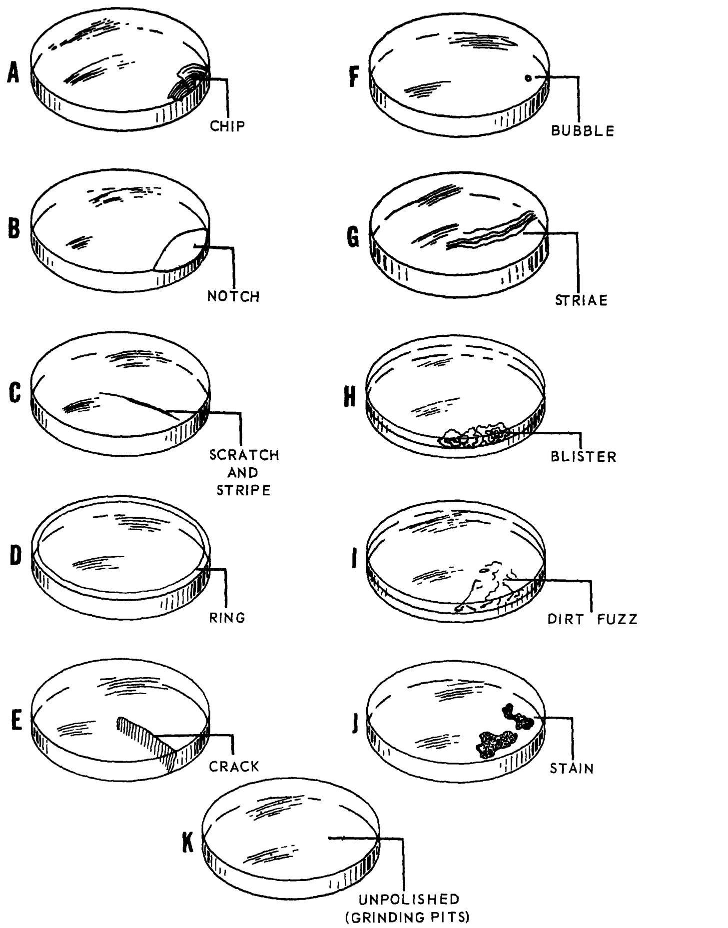
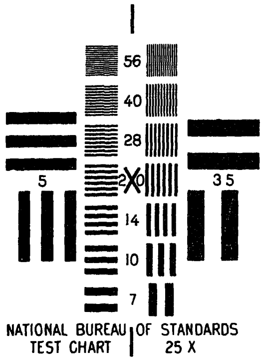


Figure 7-2.—Optical defects.

the reticle (crossline) will appear slightly out of focus and seem to move back and forth or up and down over the target. If parallax is not present, the reticle will be in sharp focus with the target, regardless of the direction in which you move your eye behind the eyepiece.

DIOPTER SETTING.—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, 0 diopters is incorrect.

LEAN.—If the instrument has a porro prism erecting system, check the optical system for lean. This is done 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 lean in the optical system; that is, the image through the instrument appears to lean in relation to the image observed with the naked eye. This lean will occur if the porro prisms are not mounted 90° to each other.



137.182
Figure 7-3.—Image fidelity test chart.

137.566
Figure 7-4 —Astigmatism pattern.

TESTING OF INSTRUMENTS

As you know, good performance of an optical instrument is obtained only when the images it creates are free of aberrations. 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 incorrect optics all cause poor image fidelity.

Image Fidelity

The accuracy of reproduction in an image and the absolute clarity of an image are termed IMAGE FIDELITY. When you check the image fidelity of an optical instrument, check for two things: CENTRAL RESOLUTION and CENTRAL ASTIGMATISM.

Take a close look at figure 7-3, which shows a standard test chart for testing image fidelity in optical instruments, and figure 7-4, which is the test pattern for astigmatism. These test charges are available through naval supply channels.

Image fidelity test chart values (fig. 7-5) list the space between the centers of adjacent lines as lines 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 pattern for the astigmatism test is 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.

The angular limit of resolution is related inversely to the diameter of the objective lens, which means that it is advisable to have large objectives for sharp definition A target shooter would choose a scope with a 1 1/4-inch objective (diameter), or even larger A pair of 7 × 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 × 35 binoculars, with a 35 mm objective.

To test the image fidelity of any particular instrument, select the proper pattern from the chart (fig. 7-5), locate the pattern at the distance specified, and focus the instrument on the pattern. If you do not get a clear, undistorted image of the test pattern, image fidelity is poor.

Although the resolving power of the human eye is equal to 1 minute of arc, it is reduced to 2 or 3 minutes of arc by eye fatigue after continuous observation. For continuous operation, therefore, you need an instrument of greater power to get the same definition you

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 7-5.—Image fidelity test chart values.

would get with a lower-power telescope used for short intervals.

Use the following procedure to test an optical instrument for astigmatism:

1. Use the proper test chart and set it at the distance given in the listing of values. Sight the test pattern 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 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 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.

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 instrument has excessive internal reflection. The defects indicate that the optics need recoating or that the interior of the instrument needs a nonreflecting coating.

Illumination and Contrast

Reproduction of an image depends upon the amount of light received by the objective and the effective transmission of this light through the instrument. For maximum efficiency at any given light intensity, the exit pupil of an optical instrument must equal the entrance pupil of the eye under the same conditions. Opaque foreign substances—dust, oil, or lint, for example—on any optical surface reduce illumination in the system and adversely affect the contrast between light and dark shaded areas of the target

To test for illumination and contrast in an optical instrument, focus the instrument on a distant object and check the clarity of the image. The image should be nearly as bright and well defined as the object appears to the naked eye. If the image is dim or indefinite, look for dirty, stained, or uncoated optical surfaces, darkened mirrors or cement, or damp or oily optics.

Spherical Aberration

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

Use the following procedure to test an optical instrument for chromatic aberration:

1. Set up a white disk against a black background, far enough away so that you can focus the instrument sharply. When the image is in focus, it should have no color fringes.
2. Focus in a short distance and look for a light-yellow fringe around the image of the disk.
3. Refocus and then focus out a short distance, at which point the image should be fringed with pale purple.

The two fringes around the image (light yellow and pale purple) 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

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.

Distortion

Use the following procedure to test an optical instrument for distortion:

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 will use a wide variety of tools; you will need special skills and a lot of information on many subjects. Only by careful practice can you develop skill in using your hands. You will 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 will give you a brief introduction to subjects like these: the use of hand tools; soldering and silver brazing; handling chemicals; the use of blueprints; heat-treating metals; cleaning and painting optical instruments; and cleaning and cementing optics. We will introduce you to your tools, tell you what they are for, and give you a few tips that will save you time and trouble. The rest is up to you. Stay alert, look around, and ask questions. Learn all you can about each job. Then, when you understand it, try it yourself.

Keep your working space, your clothes, your tools, and your hands clean. It is 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 cool water. Any fingerprints you leave on an optical element will etch the surface and destroy the optic.

The old saying "a place for everything and everything in its place" is especially true in the optical shop. You cannot do an efficient repair job if you have to stop and look around for every tool you need. Keep each tool in its place, whether it is in your toolbox or the shop toolroom. When you have finished working with a tool, do not put it back until you have cleaned it. You will do better work, with less effort, if you keep your tools in good shape and use them only for the job for which they are intended.

COMMON TOOLS

Many of the tools used in optical repair work are common hand tools, which are thoroughly discussed in *Basic Handtools*, NAVEDTRA 10085 However, the quality of the tools and their condition are vital to the work done on precision optical instruments. When you select a tool for use in the optical shop, be certain that it is the highest quality tool available and that it is in good condition. Your skill in selecting, maintaining, and handling tools is a measure of your expertise in the OM rating.

SPECIAL TOOLS

Of all the various tools used by an Opticalman, the most vital are special tools which are used specifically for optical work. These special tools may be manufactured by the repairman 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 which 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 the 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 wrenches shown in view A of figure 7-6. These wrenches are known

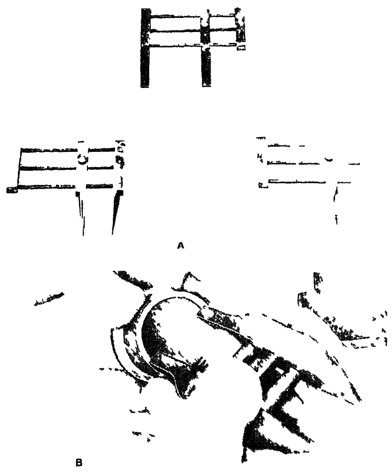


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Figure 7-6.—Retaining ring wrenches.

as adjustable spanner or pin wrenches and are manufactured by the repairman. View B of figure 7-6 shows an Opticalman using the blade portion of a pin wrench to rotate a slotted retainer ring in a lens mount. A retainer ring may be made with two small holes (instead of slots) spaced 180° apart, in which case the pointed tips of the wrench are used to turn the ring. This special tool is adjustable and can be used to remove or tighten retaining rings of various sizes.

> **CAUTION**
>
> Slippage of a pin wrench during use can damage unprotected optical surfaces, as well as the retainer ring and mount. To prevent any damage, be very careful when you use the wrench; be sure it fits properly in the slots or holes of the retainer ring; and protect optical surfaces with rubber, blotting paper, or clean cardboard disks.

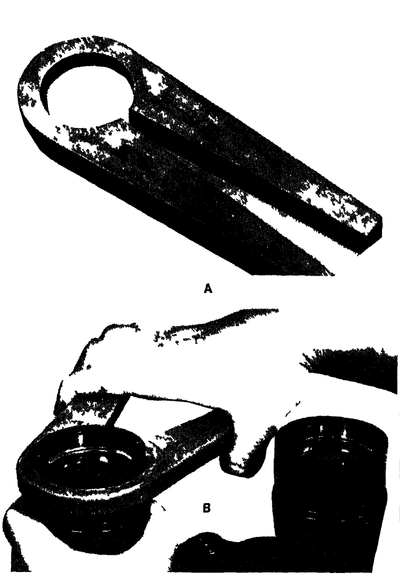

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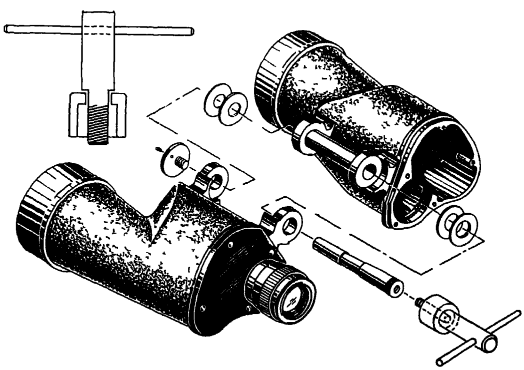
Figure 7-7.—Grip wrench and procedure.

Grip Wrenches

Figure 7-7 shows a grip wrench (view A) and the procedure for using it (view B) A grip wrench is made of fiber with holes in steps of 1/16 inch, ranging in size from 1/2 inch to about 1 inch, and



137.187
Figure 7-8.—Binocular hinge pin puller.

then at 1/8-inch intervals up to sizes of about 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 can exert tremendous pressure. Most optical parts are, by necessity, thin and light. Grip wrenches improperly used may cause binding of these parts and prevent their removal. To prevent crushing the parts, try to use the grip wrench over the portion of a tube reinforced with a retainer ring or lens mount. Rosin may be used to keep a grip wrench from slipping without requiring excessive pressure.

Hinge Pin Puller

Some special tools are useful for only one purpose and are used on only one type of instrument. A binocular hinge pin puller is an example of such a tool. Figure 7-8 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

Special Retainer Wrenches

Take a look now at view A of figure 7-9, which shows a special wrench used to remove or tighten a retainer ring. View B shows another type of retainer ring wrench which you will use occasionally for making and holding an adjustment with the center wrench, while tightening the lock pin with the outer wrench.

Bench Block

Figure 7-10 shows a bench block It is used to support mechanical parts for center punching and for driving out taper pins or similar retainers. You can manufacture this particular design yourself, or you can make a bench block of any style to suit your purposes.

Thread Chaser

The thread chaser is an indespensable tool used for removing dirt, corrosion, and burrs from

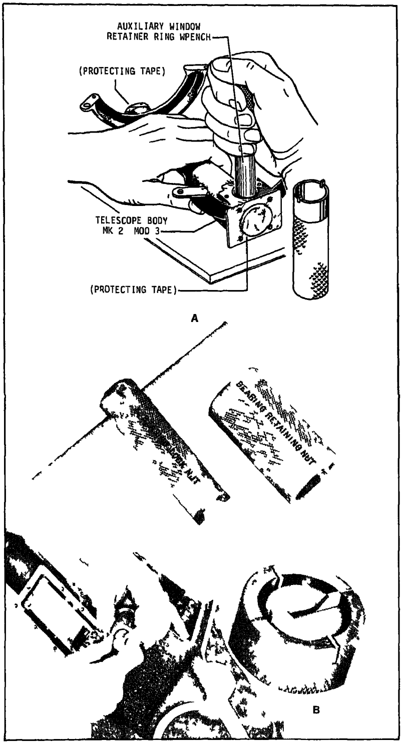


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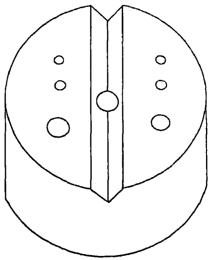
Figure 7-9 —Special retainer ring wrenches



137.525
Figure 7-10.—Bench block.

threaded parts. There are two basic types (fig. 7-11)—one for inside threads and the other for outside threads. Be sure to use the right type of thread chaser, and carefully check the thread size before you use it.

Since optical instruments are manufactured with many nonstandard thread sizes, you cannot use taps and dies on many components to restore threads. For this reason, thread chaser sets are available in sizes from 3 threads per inch to 80 threads per inch. Thread files are also available through the Navy supply system and may be used on external threads.

Geneva Lens Measure

A Geneva lens measure (fig. 7-12) is an instrument for measuring the dioptric strength of thin lens by indicating the amount of curvature on their surfaces. 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

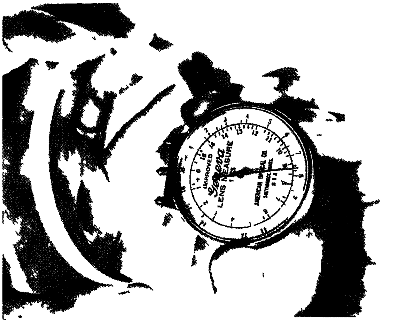


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Figure 7-12.—Geneva lens measure.

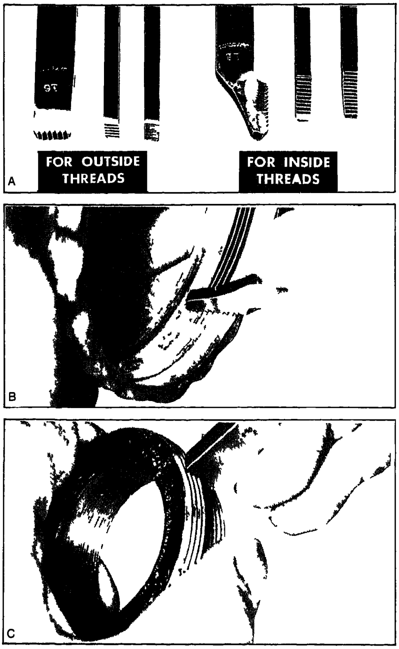

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Figure 7-11.—(A) Types of thread chasers. (B) Reshaping inside threads. (C) Reshaping outside threads.

The index of refraction of the glass for which a Geneva lens measure is designed is printed on the dial (1 53); this number is the index of refraction of crown glass A formula, however, permits you to use the gauge 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. To ensure accurate readings, hold the gauge perpendicular to the surface of the lens and in the center The outer points (2) of the gauge are stationary, and the center point activates the dial pointer. If the pointer indicates zero, the surface of the lens is PLANO. Readings for convex surfaces will be PLUS; readings for concave surfaces will be MINUS

Take the reading in diopters of one lens surface, and then measure the other surface. When you add the dioptric strength of each lens surface, you get the total dioptric strength of the lens, if its index of refraction is 1.53.

When you must take a reading of a lens with an index of refraction other than 1.53, use the following formula: (n = index of refraction of lens)

$$\text{True DP of Lens Surface} = \frac{n-1}{0.53} \times \text{reading of lens surface with the gauge}$$

To use this formula, take a reading of the first lens surface and transpose its dioptric strength into the formula to get the true dioptric strength of the first surface. Then, take 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.

Remember, the dioptric strengths of the two lenses have opposite dioptric value, and the negative lens has a negative dioptric value. You must account for this when you add the two values.

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 get the dioptric strength of the individual elements and add both results to get the dioptric strength of the combinations.

Since a Geneva lens measure is designed to measure the curvature of a lens' surfaces, use a Geneva lens measure to make certain that the positive lens surface matches the negative lens surface when you cement compound lenses.

DISASSEMBLY

Before you do any repair work on optical instruments, clean your work space and get everything ready and in position. Clean the 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 only an approved cleaning agent.

If your casualty analysis indicates that the instrument must be partially or completely disassembled to effect necessary repairs, follow the procedure discussed next.

Procedure

If you do not fully understand an instrument, you must overhaul; get a disassembly sheet and follow it or follow the disassembly procedure in the applicable naval publication (NAVSHIPS manual; ordnance pamphlet). The 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 begin disassembly until the pressure is fully released.

In the interest of production, experienced optical repairmen work on more than one instrument at a time, 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 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. To satisfactorily identify 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 then be #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 or she fits certain parts by hand and, if there is danger of incorrect assembly of these parts during a later overhaul, 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; if they are missing, make appropriate marks of your own. Figure 7-13 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 the following information on the frosted portion: 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 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 curvatures of the lens against those listed on the optical diagram.

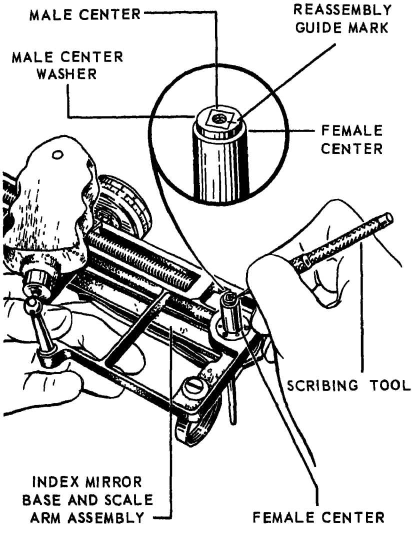

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Figure 7-13.—Scribing an assembly mark.

Start your disassembly of an optical instrument by removing exterior parts that 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 stuck 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. If the moisture seal of the instrument is faulty, salt-laden moisture will most likely cause seizing inside the instrument.

Frozen Parts

Use the following procedure to remove frozen parts:

1. Apply penetrating oil, or, when time permits, soak frozen joints in penetrating oil.
2. To prevent damage to parts that come off easily (especially optics), remove them first.
3. Use proper tools, and do not crush parts with wrenches.
4. If you cannot remove a lens, cover it with a pad of blotting paper or a rubber disk of the same size.
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. Then use a pin wrench or grip wrench of the proper size to attempt to remove the frozen part.
6. If a joint is still frozen after you have soaked it a reasonable time in penetrating oil, proceed as follows:
   a. Remove the part from the vise and tap the joint sharply with a rawhide mallet while turning the part.
   b. Tap all around the joint several times with the mallet. The sharp blows, combined with the penetrating oil, will often free the joint.
   c. Replace the part in the shaped blocks in the vise; then use the proper wrench to separate the parts.
   d. If the parts do not break free after you use the rawhide mallet, apply heat to the joint. Do not use so much heat that you burn the paint;

you merely want to expand the outer portion of the joint. Now try the wrench again.

e. If the parts are still frozen, apply more penetrating oil to the hot joint. You may need to use impact to try to separate the parts. Hold your wrench firmly and strike the wrench sharply with a mallet. Several sharp blows will usually free a stubborn retainer.

CAUTION

Use extreme care and patience when you apply heat and pressure to frozen joints. Impatience may result in distortion (twisting and bending) of the metal parts and breakage of the optical elements.

7. If frozen parts do not yield to the above procedures, salvage the most expensive part or parts by carefully cutting, breaking, or machining away the other frozen part or parts. When a retainer ring is frozen, for example, drill a hole down through it towards the lens; but use care, do NOT drill too deeply and ruin the lens. 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.

NOTE: 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 the edge of the ring. You can soften this compound by repeated applications of lacquer thinner or alcohol.

8. To remove screws and setscrews with stripped slots or heads twisted off, 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 by any other means.)

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 the proper size. You can often 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 will 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 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 that secure them. Some of these screws may be hidden under sealing compound, so check for them carefully. Failure to remove these setscrews may ruin a part.

Be extremely careful when you remove optical elements and gear assemblies through openings in the optical chamber. These parts can be easily damaged by striking other parts or the chamber housing. When you remove a part that exposes the interior of the optical chamber of an instrument, make sure you tape the opening or close it in some manner to keep out 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 the 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 further disassembly after you complete the major disassembly of mechanical components.

Removing Lenses from Mounts

The techniques we will discuss for removing lenses from mounts are primarily for lenses mounted with a sealing compound, but they are also applicable to the removal of optics difficult to disassemble. The procedures to follow (and precautions to use) when you disassemble optical elements from their mounts cannot be formulated as step-by-step instructions. The information you should keep in mind 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.

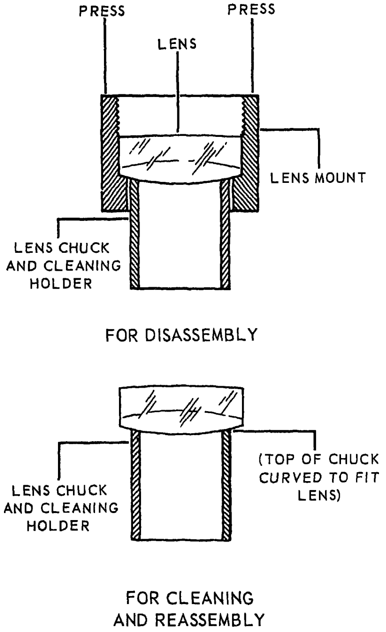

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Figure 7-14.—Lens chuck and cleaning holder.

NOTE: Removal of the eyepiece and the objective lens is usually more difficult than removal of other optics, because these two lenses are usually sealed in their mounts with a sealing compound or gasket. Also, these lenses are often 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 a compound lens out of its mount, press down squarely and evenly over a large part of its area. A device similar to that in figure 7-14 may be used to support the lens. Note the name of this device, LENS CHUCK AND CLEANING HOLDER. It 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 points 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.

NOTE A temperature of 125° to 140°F softens Canada balsam used to cement the elements of compound lenses together. If a compound lens does not 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 temperature of about 300°F 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 ensure you reassemble it correctly; then wrap the lens in lens tissue (several thicknesses) and place it where the mechanical parts cannot damage it.

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 to prevent cocking. 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, hold it so 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 PROCEDURES

When you start to overhaul and repair an optical instrument, refer to the notations you made on the casualty analysis sheet prior to and during disassembly. Use this information as you proceed with the repair process.

Cleaning and Inspecting Parts

The first phase of overhaul of the instrument is cleaning the mechanical parts. Cleaning solvents, which may be slightly toxic and irritating to your skin, must be used in well-ventilated spaces only. Avoid prolonged contact of your 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 7-15 is excellent for cleaning small

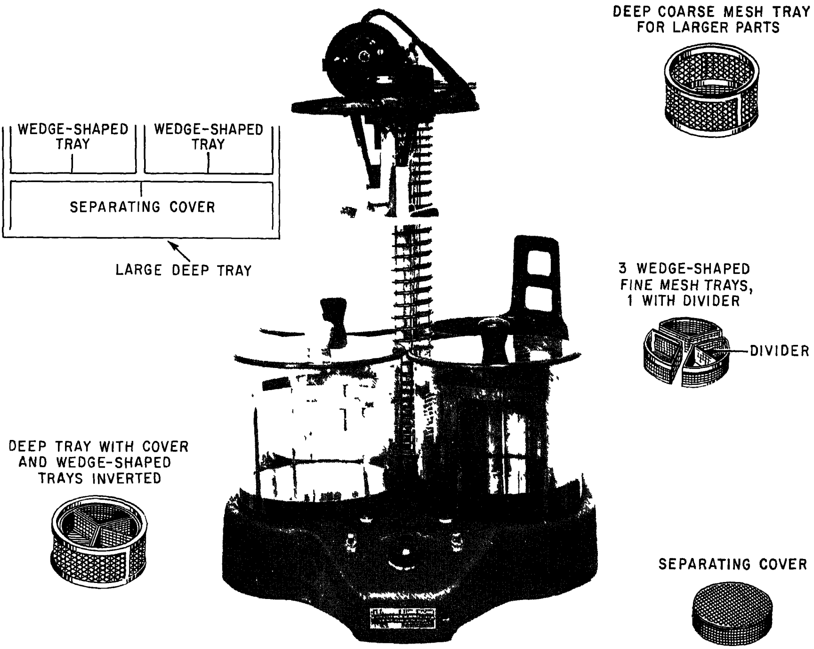

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Figure 7-15.—Instrument cleaning machine.

mechanical parts of optical instruments. An electric motor on the machine revolves a basket of parts in two cleaning solutions and a rinse solution. The machine also dries the parts by blowing hot air through the basket.

Another type of instrument cleaning machine consists of a tank of solvent agitated by low-pressure air. The newest types of cleaning machines use ultrasonic sound to act on an approved liquid cleaning agent to degrease and 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 container of cleaning solvent. This is one of the best methods for cleaning large or very dirty parts. Solvents leave an oily residue on clean parts, and you must remove it by rinsing the parts in an approved degreasing agent or by scrubbing the parts in hot soapy water. (Traces of oil on the interior of an optical instrument may later get on the lenses and affect image fidelity.)

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 indiscriminately. These surfaces should be scraped only to remove burrs. As you examine each cleaned part, look for defects previously hidden by dirt, wax, or grease. Also check each part for corrosion, and replace the parts that are excessively corroded.

Place the cleaned parts in a 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 methods: (1) repairing 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 sections.

REPAIRING OLD PARTS.—Repair reusable old parts, as necessary, and refit them into the instruments from which you removed them.

If a part must be straightened or re-formed to its original shape, strike it carefully with a soft-faced hammer.

CAUTION

Give the part necessary support before you strike it to avoid further damage.

When you discover stripped or damaged threads in a tapped hole, drill the hole out whenever possible and retap it for a screw of larger size; but do not go over 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 the original size; plug the hole with a screw of corresponding metal. Use silver solder to secure the plug; then file the plug flush with the surface of the part, and drill and retap a hole of correct size.
2. 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 done 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 according to prescribed shop procedures.

Be careful when you repair parts. Precision bearing surfaces are easily damaged. Use a stone or a bearing scraper to remove burrs from a bearing surface, and be careful to remove only the burr. Do NOT file a bearing surface; 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 the surface to make a part fit properly. Redrill undersized holes and make other necessary changes to your repair job to make the part fit properly. After you fit a part, DO NOT FORGET to make an assembly mark on it to indicate the direction of installation.

> **CAUTION**
>
> Reassembly of an instrument containing improperly fitted parts may require later disassembly of part or all of the instrument.

REPLACING 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.

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 to correct size wherever required. Do not forget to make assembly marks on the new parts after you fit them, to ensure correct fitting into the instrument later.

MANUFACTURING PARTS.—Occasionally, your shop supervisor can have parts made by submitting an intershop job order. There will also be times when you will be required to manufacture parts. Use the following procedure to manufacture parts:

1. Use information on the old part, or its name, to locate the blueprint. Follow the blueprint dimensions to manufacture the part.
2. If a blueprint cannot be located, use the old part as a sample to obtain the dimensions.

Miscellaneous Repairs

When you give an instrument a predisassembly inspection, you may note undamaged moving parts in the instrument which are dry, tight, grinding, or rough in action. You will find in some instances a combination of these malfunctions, and others not mentioned here.

When you make miscellaneous repairs to an instrument, look for all types of troubles and remedy them, 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 mating parts.
2. Make a trial assembly, but do not force parts.
3. Check for proper clearance to determine the cause of binding or excessive lost motion.

When cleaning, lubrication, and proper alignment 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 tapered sleeve bearings, ball and socket bearings, and multiple-lead thread eyepieces, do this:

1. Make a thin solution of pumice and light oil (small amount of pumice at first) and put a little of the solution on the parts as you reassemble the bearing.
2. Work the parts back and forth, or rotate them, until their movement is of the desired freedom.
3. Disassemble the parts and wash out all traces of the pumice and oil.
4. Reassemble and lubricate with the proper type of lubricant, 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 is to prevent 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 light 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-eight motion to ensure uniform removal of the metal. Do NOT remove too much metal.

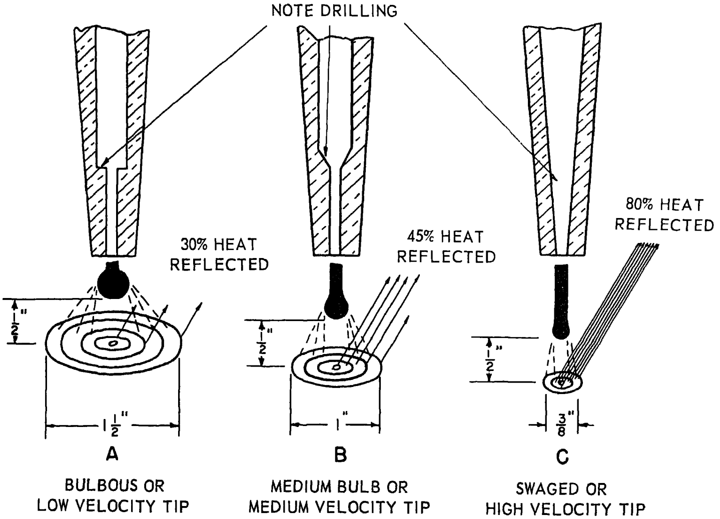
EXCESSIVE CLEARANCE.—If there is no way to adjust the desired fit by removing excessive clearance with shims or if the bearing does not have some means by which it can be adjusted, replace it with a new one. If there is some way to adjust the bearing, however, adjust it as necessary to get a tight fit, 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.

SOLDERING AND BRAZING

As an Opticalman, you may occasionally need to join metals by either soft soldering, silver soldering, or brazing. Soft soldering is done at temperatures below 800 °F with a lead alloy solder. Silver soldering and brazing require a temperature above 800 °F to melt the silver solder or brazing rod.

Optical instruments and related fittings and test equipment are manufactured from brass, bronze, cast iron, steel, stainless steel, or aluminum. Information on the repair of damaged aluminum components is outside the scope of this manual. However, we will discuss the joining of other metals which you can do in the optical shop.



11.115

Figure 7-16.—Tip designs.

SOFT SOLDERING

Many optical instruments use switches and wiring for electrical or electronic circuits contained in the instruments. To make repairs or replace defective components, you will need to know how to make or remove soldered connections.

It is also likely that you can use soft solder to manufacture special fittings or to repair a damaged instrument component. *Tools and Their Uses*, NAVEDTRA 10085, shows detailed procedures for soft soldering operations.

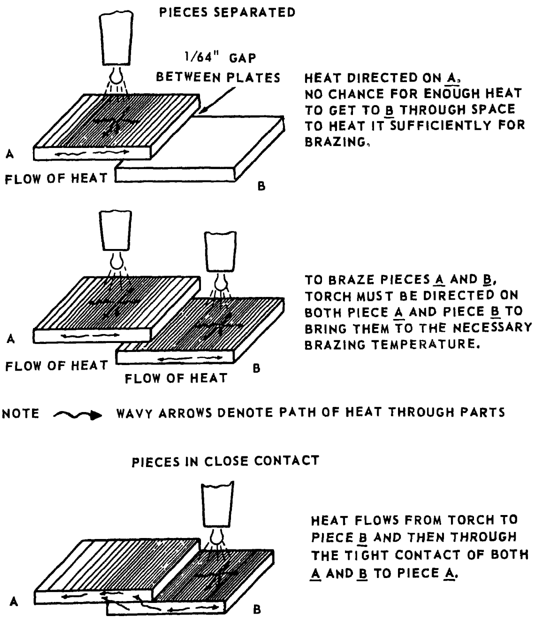
SILVER SOLDERING AND BRAZING

While soft soldering can be done with a small torch or soldering gun, an oxyacetylene torch is needed for silver soldering and brazing. Figure 7-16 shows various tip shapes to use in this operation. View A shows the tip to use for heating large areas, view B shows the tip to use for heating a smaller area, and view C shows the tip that will produce a small cone of flame for fine work.

Control of heat is the most critical part of silver soldering and brazing. Factors to consider are the tip to use, regulation of oxygen and acetylene, how and where to apply heat (torch manipulation), and the thickness of the parts to be joined. Your shop supervisor is the best source of information and assistance until you have enough experience to handle the job yourself.

Heat flow in metals must be considered whenever you silver solder or braze. Also important is the distance between elements to be joined. Figure 7-17 shows how heat must be applied to join two components with varying separations.

A soft metal, like copper, requires a longer application of heat than a harder metal steel because the softer metal is more conductive (heat



11.118

Figure 7-17.—Flow of heat.

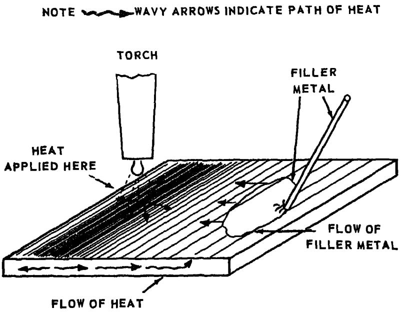
flows away from the source more rapidly). Another problem you will encounter is joining a large casting with a smaller piece of tubing or bar stock. You must manipulate your torch to keep both pieces at the correct temperature to cause the molten filler metal (silver solder or brazing rod) to flow between them. Figure 7-18 shows how filler metal flows toward the heat.

Except for cast iron, silver soldering or brazing can be used to join brass, copper, bronze, steel, or stainless to similar metals or others listed. Brazing alone works best for cast iron.

There are a number of different silver solder and brazing filler metals available. The commonly used filler metal alloys include silver, copper, zinc, phosphorus, cadmium, and nickel. The percentage of the various metals included in any filler metal determines the color of the alloy, its strength, melting point, and flow point.

FLUXES

All silver soldering and brazing operations require the use of a flux. The flux prevents oxidation of the metal surfaces and removes oxides already present. Flux also increases the flow of the filler metal and increases its ability to adhere to the base metal. It brings the filler metal into immediate contact with the metals being joined and permits the filler to penetrate the pores of the metal, thus forming a strong joint. Prior to applying flux to any joints, be sure the parts are thoroughly cleaned, degreased, and polished.



11.119

Figure 7-18.—Flow of molten filler metal.

The fluxes used by the Navy are selected according to specifications to meet the requirements for using various alloys. For best results, a flux must become active at a temperature slightly below the melting point of the filler metal and must remain fluid at the brazing temperature. If you use the wrong flux with any particular filler metal, you could possibly overheat the flux and destroy the adherence of the filler metal.

Flux comes in three forms: liquid, paste, and powder. When used either in paste form or in liquid form, apply the flux with a brush to both parts of the joint; you can obtain best results when you give the filler metal a coat also. Use a circular motion when brushing it on, and let the flux extend outside the joint or fitting. Brushing the flux on with a circular motion gives a uniform coating and lessens the possibility of bare spots that will oxidize during heating. Fluxing the filler metal can be done by heating the filler rod and dipping it into the flux. Sufficient flux to do the job will stick to the hot rod.

When applying flux or assembling the parts, avoid handling the polished parts of the joint or you will defeat the purpose of cleaning. Flux should always be applied as soon as a joint area is cleaned, even though it will not be joined immediately.

SILVER BRAZING TECHNIQUES

The process by which heat flows from molecule to molecule through a metal is called CONDUCTION. Conduction takes place quite rapidly in most metals, but air is a very poor conductor of heat Therefore, if two pieces of metal that are to be joined are not in contact with each other, each piece must be heated separately. If the two pieces are in contact with each other, you can heat them both by applying heat to one of them; the second piece will be heated by conduction. When two pieces of different metals are to be joined by silver brazing, the difference in heat conductivity of the two metals must be considered

The filler metal and the flux used in silver brazing cannot occupy the same space at the same time. Therefore, a clearance must be provided in the setup of the joint so that the filler metal can flow in and the flux can flow out when the filler metal reaches the bonding temperature.

The STICK-FEED METHOD, shown step-by-step in figure 7-19, is most often used in the optical shop.

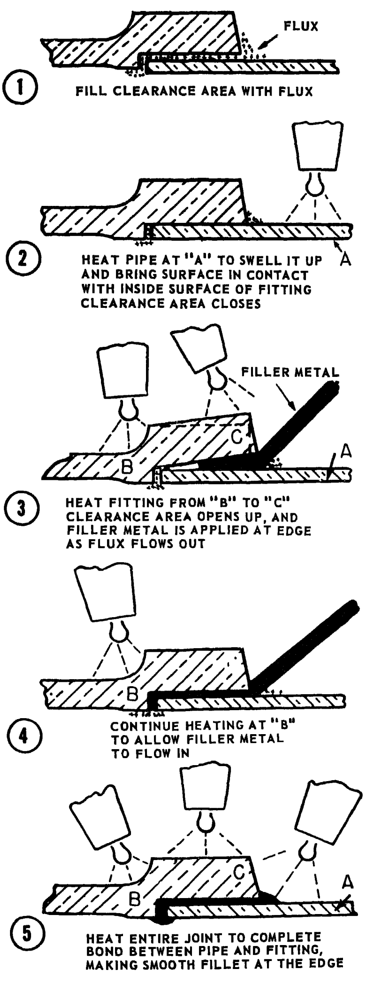


Figure 7-19.—Feed-in method of silver brazing.

In this method, the judgment of the individual performing the job determines when both parts are properly heated and when to feed the filler metal. It is also left to the operator's judgment to determine when sufficient filler metal has been fed into the joint to completely fill the space between the two parts being joined. Skillful torch manipulation is necessary to apply heat to the proper component at the correct time to form a perfect joint. Overheating will burn out the flux and destroy the joint. After joining is satisfactorily completed, flush the joint with warm water to remove the flux residue.

HEAT-TREATING AND TEMPERING

As an Opticalman, you will work with metals at various times while working on optical instruments. Thus, you should be familiar with types of metals, the properties of metals, and the heat-treating processes for the most common 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.

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 that 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 an Opticalman needs to understand about the metals most commonly used? They include the mechanical properties of (1) hardness, (2) toughness, (3) ductility, (4) malleability, (5) brittleness, and (6) tensile strength. Following is an explanation of the meaning of these terms.

The HARDNESS of a metal is the property that resists scratching, denting, cutting, or abrasion. 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, which provides resistance to scratching and cutting.

TOUGHNESS is the property of a metal that withstands shock loading without breaking. It is thus related to strength and to ductility. Usually, the hardness of a metal increases as the toughness decreases.

DUCTILITY is the property that renders a metal capable of being drawn into wire form. In other words, when the metal is stretched, it elongates rather than breaking.

MALLEABILITY is the property of metal that permits it to be rolled, forged, or hammered into sheets without cracking or breaking.

BRITTLENESS is the tendency of a metal to break with little or no prior deformation. Hard materials are often brittle, but a metal or alloy that is properly heat-treated can be hard without being brittle.

TENSILE STRENGTH is the property of a metal that resists forces that tend to pull the metal apart. It is measured in terms of pounds per square inch, which represents the pull that must be exerted on a cross-sectional area to break the metal.

CORROSION RESISTANCE, though not a mechanical property, is also of primary importance. Corrosion resistance is the property that withstands chemical or electrochemical attack by air, moisture, soil, or other agents.

The various mechanical properties described may be desirable at times and undesirable at other times, depending on the purpose for which the metal is to be used. But resistance to corrosion is always a highly desirable characteristic.

FERROUS METALS

A few examples of ferrous metals are 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.

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.

Of all the different metals and materials that you will use while in the Navy, steel is by far the most important. 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, tube, 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 HTS, 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 It has been specially treated to obtain hardness and toughness.

Stainless steel, referred to as SST, is generally designated by the percentage 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.

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. Alloyed with copper, it produces bronze. Tin-base alloys have a high resistance to corrosion; they also have a low fatique 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 a high strength per unit weight, but its tensile strength is only one third that of iron, and one-fifth 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 major element. It contains 64 percent to 69 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. Monel 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 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 is gained 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 specific temperature, holding it at that temperature for a specified length of time (soaking), and then cooling it to room temperature. Both the temperature of the operation and the weight of cooling depend upon the metal being treated and the purpose for which it is to be used.

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 675°F. Nickel-chromium alloys, which can withstand extremely high temperatures without appreciable damage, must be heated to annealing temperatures between 1800° and 1950°F.

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. Normalizing refines internal grain structure and relays stresses and strains caused by welding, forging, uneven cooling of castings, machining, and bending. When steel is to be hardened, it is advisable to normalize it first; low-carbon steels generally do not require normalizing, but a normalizing treatment will cause no harmful results.

The process of normalizing—like other heat treatment processes—consists of three steps: (1) heating the metal to a specified temperature, (2) soaking it (that is, holding it at this temperature), and (3) cooling it. 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 it to the correct temperature and then rapidly cooling it in oil, water, or brine. A point to remember is that a cooling rate that is too rapid 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. Cooling (quenching) in oil, fresh water, or brine firmly fixes the structural changes that occurred during heating, and thus causes the metal to remain hard.

If allowed to cool too slowly, some metals will lose their 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 brine for high-carbon and alloy steels. (NOTE: Water or brine gives a faster quench but does not necessarily increase hardness. Hardness is dependent upon the type of steel used with the correct quenching medium; an oil-hardened steel will not be harder if it is quenched in brine.)

In cooling, you have to bring carbon steel to a temperature somewhat below 1000°F in less than 1 second. 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.

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 temperatures are always BELOW the red hot point.

As it reduces brittleness, the tempering process also softens the steel. One property must be sacrificed to some extent so 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 done by heating the hardened steel to a temperature for a sufficient time to penetrate the whole piece, and then cooling the piece rapidly 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 used, the operation is frequently called TOUGHENING. You will soon learn, by trial, the temperature at which a tool must be tempered.

The following list gives the temperature for tempering various plain carbon steel tools as well as the color of the heat:

Tool	Heat Color	°F
Hammer faces, machine cutting tools	Pale yellow	400
Taps and dies	Light straw	460
Punches, reamers, dies, knives	Dark yellow	480
Twist drills	Brown yellow	500
Drift pins, punches	Brown purple	520
Cold chisels	Purple	540
Screwdrivers, springs	Dark purple	550

The following description of a common method used to harden and temper chisels will help 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 (red hot). Then, using tongs to hold the chisel, quench the tool 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 make sure you keep the point immersed 1/2 inch in the quenching medium.

When the metal has cooled to a black heat (900° to 950°F in about 1 second), remove the tool from the quench tank, quickly polish the tapered end with an emery board, and watch the temper color "run out" until the desired color appears (usually purple to dark blue). Then quench the entire tool to temper it.

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: 1350W 400 or 1600 O. The first means to heat to 1350°F, quench in water and temper at 400°F. The second means to heat to 1600°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 from a molten mass.

Stress relieving is done 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 it 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 you count the hold time 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.

CLEANING AND PAINTING

Having completed all repairs to your instrument, you are now ready to do the essential cleaning prior to painting. Reclean all parts on which you made repairs to remove traces of moisture, dirt, metal chips, grease, and corrosion. 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 must get it thoroughly clean. If the surface of the object is covered with rust, dirt, or grease, the paint cannot reach the metal. It forms a loose coat that chips 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 so the paint will adhere and give a good finish. Use approved commercial compounds. Always follow the manufacturer's instructions when you use these products, and protect yourself by following safety precautions.

If you do not have an approved corrosion removal compound, you can make some (for different metals) by using the following formulas:

> **CAUTION**
>
> Do NOT handle chemicals until you understand the safety precautions that pertain to them. NEVER USE CORROSION REMOVAL COMPOUNDS ON BEARINGS OR GEAR TEETH.

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.

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 corroded brass surface is bright in spots, it was probably polished and protected with clear lacquer. 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 it 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 is to be painted and not polished.)

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 nonchemical methods for removing corrosion and giving a bright, smooth finish to metal parts. These methods involve wire brushes, buffing wheels, and abrasive cloth.

Removing Corrosion with a Wire Brush

There are two types of wire brushes which a used to remove corrosion from metal—rotai power and hand.

> **CAUTION**
>
> To prevent damage to your eyes from flying wire and other debris, always wear goggles. Do NOT use a power-driven brush on a bearing surface or an engraved part.

To use a rotary-power wire brush, mainta enough pressure to force the moving wire bristl into the corrosion, and use a slow, even mov ment. Start in the center of the part and mo toward the edges to ensure thorough cleaning the edges. Use a fine hand wire brush on delica parts and the inside corners of irregular piece

Removing Corrosion with a Buffing Wheel

A buffing wheel gives a part a brighte polished finish than a wire brush or emery clot but it will not remove heavy corrosion. To spe up the buffing process, clean the parts first in corrosion remover or use a wire brush. Do n use these wheels on large areas, but use them polish small irregularly shaped metal parts whi must remain bright.

Use a polishing compound on the buffi wheel, and polish a part until you have t desired finish. Then remove the remains of t polishing compound with a solvent, dry the pa thoroughly, and apply at least one coat of cle lacquer.

> **CAUTION**
>
> A buffing wheel turns at high speed, so use light pressure to avoid the heat of friction. Also, remember that a buffing wheel can pull parts out of your hand and propel them across the work space at high speed. It is also important to remember that power brushes and buffing wheels will remove metal and leave low spots on the work if you do not use steady movement and pressure.

Removing Corrosion with Abrasive Cloth

You can remove corrosion from metal with an abrasive cloth in the following manner:

1. Polish flat pieces by hand using various grades of emery cloth laid on a workbench.
2. Polish irregular pieces in a vise. Use wood or metal in the jaws of a vise to protect these pieces, and secure them ONLY as tightly as necessary. It is often beneficial to wrap abrasive cloth around a file for this operation.
3. 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 just enough to get the polish desired.

NOTE: Sandpaper of various grades is used to finish wood surfaces. Metal is polished with emery cloth, crocus cloth, or wet or dry abrasives. Emery cloth is available in grades from 60 (very coarse) to 320 (fine). Wet or dry abrasives usually span 320 to 600 grit (most often used in auto paint and body shops). Crocus cloth has about the same abrasive quality as the finest metal polish.

SAFETY PRECAUTIONS FOR USING CHEMICALS

You probably learned a great deal about safety precautions in the basic naval training courses you studied. The safety precautions discussed in the next section are particularly important to Opticalmen and should be repeated. Study the following rules when you work with all kinds of chemicals If you remember them, you may be able to prevent injury or death.

1. DIRECTIONS FOR USE Study the directions on the container before using any chemical Do not mix chemicals improperly or in incorrect proportions, they may explode or release deadly fumes.

WARNING

NEVER MIX CHEMICALS AT RANDOM, OR PLAYFULLY, JUST TO FIND OUT WHAT HAPPENS. IF YOU DO, YOU MAY NOT LIVE LONG ENOUGH TO SATISFY YOUR CURIOSITY. ALWAYS WORK WITH CHEMICALS IN A WELL-VENTILATED AREA TO AVOID BREATHING DANGEROUS FUMES.

2. LABELS: Keep the labels on the containers of chemicals intact. If you notice that a label is coming loose, glue it back in place. Then coat the label.

WARNING

NEVER USE A CHEMICAL FROM AN UNLABELED CONTAINER. DISPOSE OF IT IMMEDIATELY.

3. WATER AND ACID: If you must mix water and acid, POUR THE ACID VERY SLOWLY INTO THE WATER. If you pour water into acid, the mixture will boil over and burn everything it touches.
4. 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 contamination may ruin your work.
5. CHEMICAL POISONING: Many chemicals are poisonous, and some of them can burn your clothes and skin. (CAUTION: Wear rubber gloves, a rubber apron, and goggles whenever you work with chemicals.) Remember the antidotes for poisoning and chemical burns. This knowledge may save a life. Even after you administer an antidote or neutralize a chemical, report to sick bay.

TREAT ACID BURNS AS QUICKLY AS POSSIBLE. Wash off the acid with an abundance of water, and then wash your hands under a spigot if they were involved. Continue by neutralizing all remaining acid with lime water (calcium hydroxide), 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. Weak acids, such as vinegar or lemon juice, neutralize bases (alkalies) or caustics, such as lye.

ANTIDOTES FOR POISONS

Study these antidotes carefully; better still, memorize as many as possible.

Acetic Acid

Use an emetic to cause vomiting. Magnesia, chalk, soap, oil, mustard, and salt are emetics. A quick method for making a good emetic is to stir a tablespoon 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 strong alkalies are vinegar, lemon juice, orange juice, oil, or milk. You can easily remember these antidotes.

Denatured Alcohol

Antidotes 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 stirred in water.

PAINT REMOVAL

When you are to repaint a surface that is already painted, you will usually need to remove the old paint first (stripping). Apply a commercial paint remover by brushing it onto the painted surface. (After you have used a brush for paint remover, do not use it again for any other purpose.) Brush-on paint remover dissolves synthetic-bristle brushes, so use a natural-bristle brush.

Leave the paint remover on the part as long as necessary for it to dissolve the paint, and then rinse off the loosened paint in running water. To remove all traces of paint remover, which sometimes leaves a waxy film, scrub the parts in strong soapy water, rinse in hot water, and blow dry. Because it is difficult to wipe brush-on paint remover out of holes and corners, you will experience some difficulty in using it.

If an instrument has a good paint job except for a few chips on the corners, you can sometimes dress the chipped areas with fine emery cloth, scrub and dry the surfaces, and then paint the instrument.

Immersion-type paint and carbon removers are available through Navy supply channels and, also, commercially. They are designated as SUPER cleaners. Besides stripping paint, they remove heavy carbon, grease, varnish, and sticky gums.

You will get best results with a paint and carbon remover by putting at least 10 gallons in a stainless steel tank and soaking the parts in it as long as necessary. Then wash each part with hot water, remove the water with compressed air, and bake each part briefly in an oven. It is then ready for painting.

TYPES OF PAINT

Many aluminum parts have a very smooth, hard finish that appears to be painted. This finish is called ANODIZE, and it is deposited by an electrochemical process. If an anodized finish becomes scratched, corrosion will start and the part will require painting after the corrosion is removed.

The paint you will be using is usually either gray or black. It is available in dull, semigloss, gloss, and also wrinkle finish. Lacquers and enamels are preferred. Dull, flat black paint is used to cut down surface reflections, and it is also used to kill internal reflections on the inside of optical instruments. Paints that give a semigloss appearance and a hard, durable finish are used on parts that receive considerable handling and on such small articles as eyepiece focusing rings, knobs, handles, and pointers. You will generally use a semigloss black finish paint on most optical instruments.

Grey or black wrinkle paint is often used on body castings of large instruments or on smaller portable navigation instruments. Wrinkle paint offers the most durable finish available.

Always use clear lacquer on parts subject to corrosion, but which are not painted, to protect their high polish.

CAUTION

Never cover enamel with lacquer, because the lacquer loosens the enamel from its base and causes it to blister.

A baking enamel of high quality gives a hard, durable finish, but air-dried enamel is good for touching up or painting an instrument that cannot be subjected to heat in a baking oven. Acrylic enamels sprayed from aerosol cans are widely used in optical shops. Results are not as good as enamels sprayed from a gun, but such paints are satisfactory for most instrument finishes, and they are easy to use.

Lacquers have one outstanding characteristic; they dry quickly, but they cannot resist chemicals and are therefore not as durable as enamels.

PREPARING PAINT

Prepare lacquer, enamel, or wrinkle paint in the same manner for use in a spray gun, as follows:

1. Stir the paint thoroughly to mix the pigment back into the liquid used to suspend it. Unless you do this, the paint will not cover surfaces with uniform luster or color.
2. Thin thick paint before you put it into a spray gun; otherwise, it will clog the gun or give you an unacceptably thick finish. Follow the manufacturer's instructions when you thin the paint.

Do not add more than 20 percent of thinner to the paint, lest you get it so thin that it will not cover properly. It is best to add small amounts of thinner and stir thoroughly until the desired consistency is reached. Dip a pencil vertically into the paint and then withdraw it. If the consistency is correct for spraying, the paint will run off the pencil in a smooth, thin stream.

3. When you have the paint properly thinned 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 produce a poor finish.

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 paints, oils, thinners, and so forth in a container with a self-closing cover, and dispose of them completely as soon as practical. Stow paint materials in a locker that will not tip over and at a temperature less than 95 °F but above freezing.

CAUTION

Permit no smoking in the sprayroom, and have a CO_2 fire extinguisher available.

INSTRUMENT PAINTING

The three reasons for painting metal parts of optical instruments are 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 optical instrument creates a good impression on all who see and use the instrument.

Once a surface is clean and otherwise ready for painting, you must mask areas where paint is not desired, such as bearing surfaces, screw threads, and the interior of the instrument. Be very careful when masking these areas. You must NOT touch a prepared surface with your fingers.

Be sure to trim excess masking tape with a razor blade or sharp knife.

To paint screwheads, punch small holes in a cardboard box and insert the screws. This not only keeps paint off the body of the screw, but also helps you avoid losing these small parts.

Other small parts to be painted can either be laid on pieces of cardboard or you can suspend them from wire hooks.

REMEMBER: Once a part is clean, you do not want to touch it or allow it to touch anything else until after the paint is dry.

Before you use a spray gun for the first time, seek 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 gaskets. When you reassemble the spray gun, lubricate all moving parts and make sure the gun is clean.

NOTE: Your air supply should have an air pressure and reducing valve with a water and oil trap (and filter) that works properly all the time Drain the trap regularly. If water and/or oil get into your spray gun and paint, it will ruin the appearance of your work.

The air pressure to use for spray painting should be from 10 to 25 pounds per square inch The pressure to use depends on the type and consistency of the paint and the size of the parts to be painted. Your spray gun can be adjusted to provide a cone-shaped spray or a horizontal or vertical fan-shaped spray. You can also control the amount of paint contained in the spray with a fluid needle.

For small or irregularly shaped parts, use a light cone-shaped spray. For larger parts, adjust the gun to provide a heavier, vertical fan-shaped spray.

Hold the spray gun about 10 inches from your work, and keep it moving smoothly 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 the paint near the edges of the work, which causes sagging. Start at the top of a surface and work down, and cover the last lap with about half of your new lap. If you follow this procedure, your paint will uniformly cover the entire surface.

Do not apply the paint too thickly. In the first place, a thick coating will not be as durable as several thin coats. Secondly, a thick coating will sag or actually drip off the surface, which will destroy the appearance of your paint job.

When each part is painted, hang it in the oven or in a protected area for air drying. Even a space as clean as the optical shop will have some dust or lint in the air. If these foreign particles end up on a painted surface, you may have to start all over again.

After you finish a paint job with a spray gun, wipe any paint out of the vent hole for the paint cup. You can hang the gun up with paint in it if it is to be used several more times during the day. At the end of the day, or if the gun will not be used again, completely disassemble the gun and wash all parts in lacquer thinner Then dry, lubricate, and reassemble it so that there will be no delay when you start the next day's work

BAKING PROCEDURE

Always follow the paint manufacturer's instructions on baking and drying the paint you use. When you do not have specific instructions, a good rule of thumb is to bake for 2 1/2 hours at 250°F

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), 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.

FINISH DEFECTS

Following is a list of difficulties sometimes experienced in spray painting, with the reason for each difficulty given.

FINISH REFUSES TO DRY: You neglected to remove the oil and grease from the metal surfaces of your work or from your air supply.

FINISH SHOWS OCCASIONAL ROUGH SPOTS: There was too much dust or lint in the air or on the piece being painted.

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 (common with lacquer).

FINISH IS UNIFORMLY GRAINY: 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 air 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, held it too close to the work, or adjusted the gun improperly. Generally, the coat was too heavy

THE FINISH SHOWS ORANGE-PEEL EFFECT The consistency of the paint was too thick, your spray was too fine, and you held the gun too far from the work.

LENS CLEANING AND CEMENTING

The Navy's standard for cleaning optical elements is 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 some 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 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 required.

CLEANING EQUIPMENT

The equipment you need for cleaning optical elements includes a rubber or metal bulb syringe, several small camel-hair brushes, medically pure acetone, lens tissue (soft, lintless paper), absorbent cotton, wooden swab sticks, stoppered containers for acetone, and a container to keep the cotton absolutely clean.

Pure alcohol is sometimes used as a precleaner (before using acetone). 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 with cotton or lens tissue. To make a cotton swab, use the end of a wooden swab stick to pick up the top fibers of the cotton. Thrust 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 a swab of desired size. Shape the swab by rotating it 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. Do NOT use commercial cotton-tipped swabs (Q-tips); they use an adhesive that acetone dissolves.

Figure 7-20 shows the step-by-step procedure for making a swab out of lens tissue. 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 swabs by cutting a packet of 4- × 6-inch lens tissue down the center lengthwise so that you can remove the strips one at a time.

Press the tip of the round swab between the cover and the top tissue to obtain a flat, chisel-like cleaning tip.

You can make a large, useful lens cleaning pad by folding two thicknesses of 8- × 11-inch 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 following is the recommended procedure for cleaning optics:

1. Blow all coarse and loose dust from the surface with a bulb syringe. Then 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 with the bulb syringe.

2. If the element is large, use several pads of lens tissue dampened with alcohol to remove stubborn particles and oil film. Change cleaning pads or swabs frequently to prevent damage to the optic by dirt or grit. Use a cotton or lens-tissue swab on small optics, with alcohol as the cleaning agent.

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 remaining from precleaning. Acetone will not remove grease, which must be removed with solvent, then washed in soapy water, and finally cleaned with alcohol and acetone.

WARNING

ACETONE IS HIGHLY FLAMMABLE; KEEP IT AWAY FROM FIRE AND HEAT.

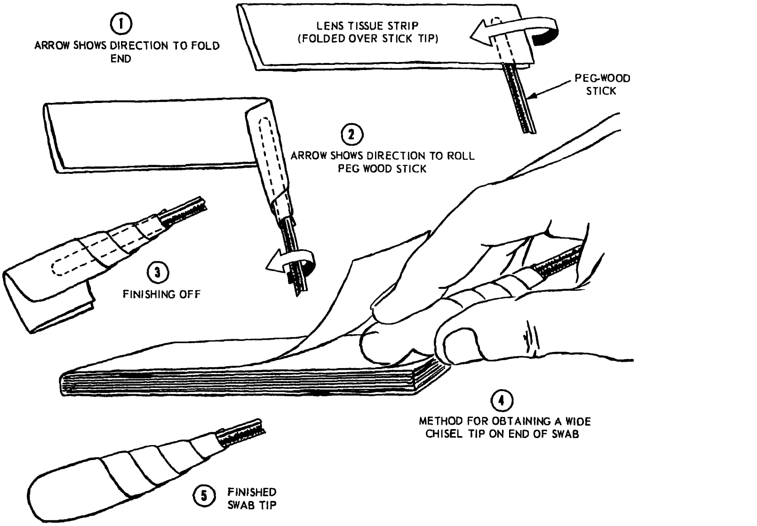


Figure 7-20.—Procedure for making a lens-tissue swab.

Some special optical elements are made from plastics. Acetone will destroy the polished surfaces of these elements. Consult your shop supervisor or the appropriate technical manual to determine the composition of the optics. If you use a swab or pad moistened with acetone for more than 20 seconds, it will leave streaks or watermarks 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.

4. As you clean an optic, swab lightly in a straight line when possible, and work from the center to the edges. If you lift a damp swab from the surface of an optic, it will leave a smudge. If your acetone or swab is contaminated, it will leave streaks. Avoid excessive rubbing, since this could cause the element to become charged with static electricity. If an optic is charged, lint from the swab or lens tissue cannot be removed. The only remedy is to wash the element in warm soapy water.

Figure 7-21 shows the recommended method for holding a lens and swab. To hold smaller lenses for cleaning, you should use a lens chuck (fig. 7-13) or a retaining ring of the same diameter as the lens. Holding the lens with a chuck or retaining ring will reduce the possibility of contaminating the swab with perspiration from your fingers.

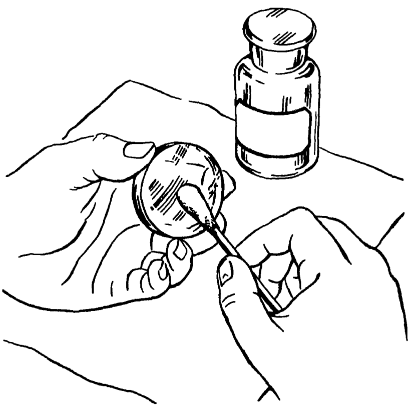


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Figure 7-21.—Cleaning a lens with a cotton swab.

5. When you think an optic is clean, examine it in a strong light and check for smudges and streaks. Reclean it if necessary. Sometimes a smudge is caused by fungus growth on the glass. This can be removed by rubbing the affected area with a soft cloth dipped in a paste of precipitated chalk or even cigarette ash. Rub just enough to remove the fungus. Do not remove more of the magnesium fluoride coating than necessary.

6. If you are satisfied that an element is perfectly clean, wrap it in lens tissue until you are ready to reassemble the instrument.

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 two matched V-blocks, an electric hotplate with controlled heat, a piece of black photographic paper, a rubber-tipped tool, tongs or brass tweezers for handling warm optics, a small glass bell jar or similar cover for the optical elements, and Canada balsam or other approved lens cement. Canada balsam is usually available in prepared form in metal tubes, through Navy supply channels.

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 glass with different rates of expansion, which causes separation of the cement during temperature changes. Some large lenses are also ground with different curvatures on their mating surfaces, which makes 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 reduce surface reflection and improve light transmission. 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 elements are cemented together, and very little reflection when a crown glass is cemented to flint glass.

3. Because a soft glass 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.

You will occasionally find a lens doublet (generally from a gunsight) that will not separate when it is heated. If the elements of a compound lens do not separate at a temperature of 300 °F, they were probably cemented together with a thermosetting plastic, which a manufacturer sometimes uses for two reasons: (1) it resists temperature changes better than balsam, and (2) it speeds up lens production.

When you have reason to believe that lens elements have been secured together with a thermosetting plastic, check the lens under ultraviolet light for FLUORESCENCE. If the cement between the elements is thermosetting 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 hotplate on LOW, or set it at approximately 250 °F. Place a piece of black paper on the burner surface to serve as a temperature indicator. Put the lens on the paper and cover it with the bell jar. Watch the black paper for signs of scorching, which shows that the hotplate is too hot and the temperature should be reduced.

When the lens is hot enough (between 275 ° and 300 °F), gently slide 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, clean them thoroughly with acetone. If the elements do not separate at 300 °F, the lens is probably cemented with thermosetting plastic A single-edge razor blade inserted between the elements will usually separate them, and acetone will clean off the plastic cement.

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 turn on the hotplate.

When the elements are hot enough, put a little balsam on the concave element, pick up the positive element with your tweezers, and join the two elements. 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 and excess cement. The black paper on the hotplate makes air bubbles in the elements appear bright.

Use the lens-centering instrument (fig. 7-22) to center (align the optical axis) the elements. This instrument consists of an upper astronomical telescope with a crossline and focusing eyepiece and a lower collimator telescope mounted on a common stand. The objective lens of one instrument faces the objective lens of the other instrument. The crossline mount of the collimator telescope moves in a threaded mount, which enables you to bring the image of its crossline into focus with the image of the astronomical telescope, regardless of the size lens mounted between the telescopes. A lens chuck on the lower telescope grips the element being centered. The entire lower telescope can be freely rotated to check for eccentricity. To save time when centering a cemented doublet, you should place the lens in the centering instrument and focus the two telescopes prior to separating the lens.

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 lower telescope, and observe the eccentric movement of the lower crossline Move the

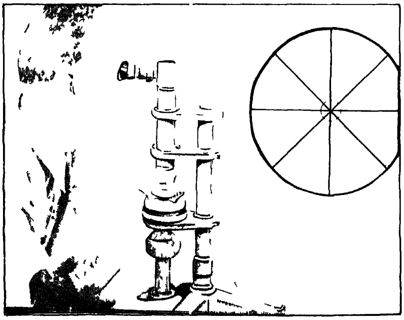

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Figure 7-22.—Lens-centering instrument.

upper element of the cemented lens over the lower one, as necessary, to remove all eccentricity as the lower telescope is rotated.

The insert in figure 7-22 shows the crossline pattern of the two telescopes. The plain diagonal crossline is the image from the lower telescope. This crossline must stay within the small circle as the lower telescope is rotated; however, perfect coincidence is more desirable.

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. When cool, 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. 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: Elements whose diameters differ cannot be cemented in this manner.)

REFERENCES

Military Standard, "Optical Terms and Definitions," MIL-STD-1241-A, 31 March 1967.

Military Standard, "Painting of Naval Ordnance Equipment," MIL-STD-1303B(OS), 15 April 1985.

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

CHAPTER 8

BASIC INSTRUMENT REPAIR

Now that you have completed the essential repairs to instrument parts (the necessary refinishing, the required cementing of optical elements, and the cleaning), you are ready to reassemble the instrument.

REASSEMBLY

If you have accomplished your repair and overhaul well, reassembly will be smooth and easy. If you are not very familiar with the instrument you are working on, follow a reassembly sheet. Because reassembly is different for each instrument, set procedures cannot be given in this manual. However, the reassembly tips presented in the next few pages will be helpful.

REPLACING LENSES

Before mounting lenses 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, you can remove most particles by covering the open ends of the cell with masking tape. Then hold the cell in an upright position, and tap the exterior with a small 2- or 3-ounce fiber mallet. The dirt will loosen from the cell and drop to the end of the cell, where it will stick to the tape You can also use this procedure on large body tubes and castings.

All of your clean optics should have been wrapped in lens tissue. When you unwrap lenses, prior to replacement in their mounts, you will usually find a few pieces of lint from the lens tissue adhering to the lenses. Blow this lint off with an air bulb before replacing the lens in its mount. If you are replacing an objective lens or eye lens, make sure the gasket is positioned properly in the mount to maintain the seal.

To avoid fingerprints on the edge of a lens, hold the lens on its retainer ring, or use a lens chuck as you insert the lens in the mount. Be sure the lens is facing the proper direction, or you will have to disassemble the instrument later. The lens must be fully seated, without being cocked, and the retainer ring must be snugly tightened. If the retainer is loose, collimation will be impossible, and the seal may not hold. If the retainer is too tight, there is the risk of distortion or cracking.

REPLACING PRISMS

After you assemble all lenses in their cells and mounts, assemble the prism clusters, or prism mounts. 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 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 position and throw the instrument out of adjustment.

When assembling a porro prism cluster, check the assembly for 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. Figure 8-1 shows how lean

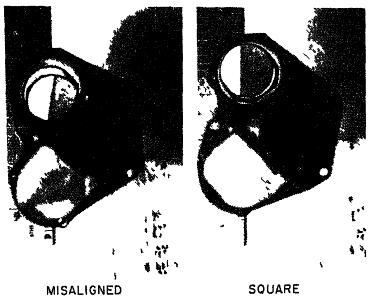

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Figure 8-1.—Porro prism cluster squaring.

appears. Any deviation from a perfect 90-degree orientation will result in twice the amount of deviation as you view a target through the cluster.

Various adjustments are provided on prism plates to remove lean. Some have collars that fit the prism tightly. These collars have four oversize holes for the securing screws, and allow slight movements in any direction. Others use eccentric washers, or tapered washers that bear against the edges of the prism.

When assembling porro prism clusters, you should place the prism in the center of the milled out depression in the prism plate, tighten the strap over the top of the prism, and then snug the adjusting screws. Be careful not to touch the polished surfaces at any time while adjusting a prism cluster.

To remove lean from a prism cluster, look through the cluster with one eye and at a prominent vertical or horizontal reference (such as a stanchion, door frame, or graph paper) with the other eye. By shifting one prism slightly, you can align the inverted-reverted reference you see through the cluster with the normal reference you see with your other eye. This procedure will require some practice since you must train your eyes to see two different objects at the same time. If adjusting one prism does not remove lean, you may have to adjust the other prism or reverse a prism on the prism plate. After lean is removed, tighten the prism strap and check to ensure the adjusting screws are tight.

During assembly and adjustment of a prism cluster, it is easy to cock a prism. You can remove lean with a cocked prism, but the prism may chip, deviating the line of sight through the cluster too much to allow collimation.

ASSEMBLING MECHANICAL PARTS

As you assemble parts in an instrument, be sure to match all assembly marks; otherwise, you will need to disassemble the instrument, make corrections, and reassemble it.

As you reassemble each part, check it for fragments of foreign matter that may be 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 the tape only when you must make additional installations. Follow this procedure as you reassemble each part and until you make the final closure.

As you replace components and parts in an instrument, try to work from the top downward. This will prevent unnecessary work and perhaps damage.

Do not force a part into place in an optical instrument; press lightly with your fingers. If a part must be fitted in position by force, it must be done according to specifications. If there is a bind, determine the cause.

You can make some adjustments to parts as you assemble them in an instrument. Whenever possible, these adjustments should be made during collimation. In some instances an adjustment is impossible after reassembly because of inaccessibility of parts.

Threads on retaining rings, lens mounts, caps, screws, and setscrews are extremely fine and can be cross-threaded easily. When you assemble a part, turn it in a counterclockwise direction until the threads snap into place; then turn it clockwise.

Lubricate components with approved lubricants during assembly. Use lubricants sparingly—you do not want to contaminate an otherwise clean optic with a smudge of grease. Do NOT use grease on a lens retainer ring. Use an antiseize compound on external screw threads and threaded portions of body tubes. Silicon grease is an excellent antiseize compound It will not melt or run, and it will prevent corrosion

COLLIMATION

One of the final steps in the overhaul and repair of an optical instrument is collimation Collimation is the alignment of the optical axis of an instrument to its mechanical axis In simpler terms, collimation is directing all lenses in an optical system in such a manner that they coincide with each other in a straight line and are parallel to the mechanical axes of the bearing surfaces (telescope mounting pads, for example). Collimation also consists of adjusting the focus of individual lenses and assemblies so that the target (and crossline if included) will be in perfect focus.

COLLIMATION EQUIPMENT

Collimators are precision instruments (with both optical and mechanical elements). They 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, they all operate on the same principle. Figure 8-2 shows the Mk 4 Mod 0 collimator used on 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 aligning support fixtures.

The collimator telescope is secured to the bearing surface on a V-block support with two square keys holding the collimator telescope support in alignment with the base. The collimator telescope can be rotated by hand to change the orientation of the crossline.

Figure 8-3 shows two auxiliary support fixtures that are used with the Mk 4 Mod 0 collimator. The fixtures differ because of the physical

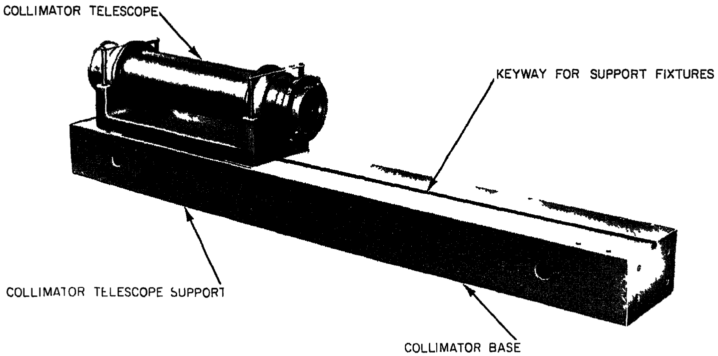

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Figure 8-2.—Mk 4 Mod 0 collimator.

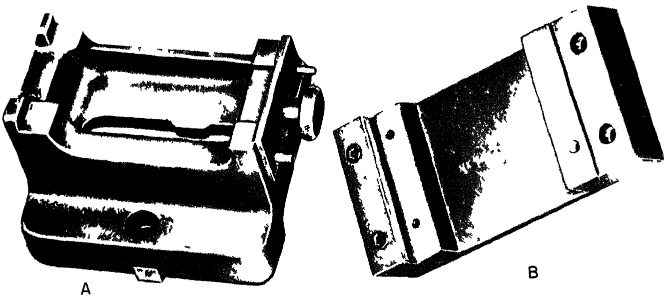

Figure 8-3.—Auxiliary support fixtures.

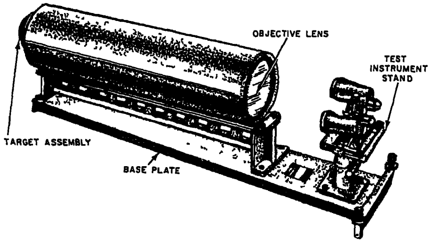

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Figure 8-4.—Mk 5 binocular collimator.

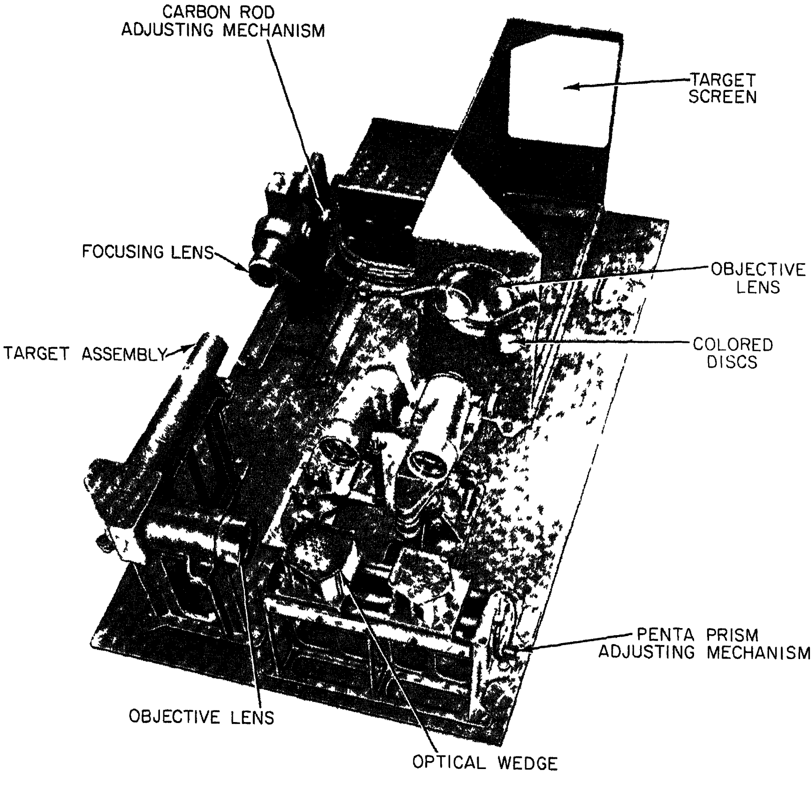

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Figure 8-5.—Mk 13 binocular collimator.

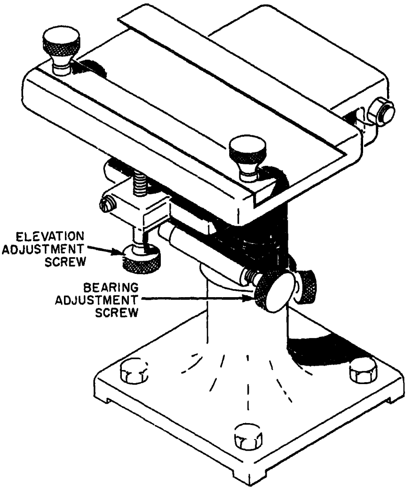

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Figure 8-6.—Test instrument mounting stand.

configurations of the telescopes for which they are designed, yet both fixtures fit the Mk 4 Mod 0 collimator.

Figures 8-4 and 8-5 show two entirely different collimators that can be used to align hand-held binoculars. The mounting stand shown in figure 8-6 fits the Mk 5 collimator and adapts to binoculars, sextants, and stadimeters. The Mk 13 collimator will accept only binoculars. The optical system of the Mk 13 collimator is shown in figure 8-7.

Large tilting prism gunsights are collimated on the Mk 9 collimator (fig. 8-8). This instrument is rather large and bulky, since it is designed to accept large gunsights, but it is a precision instrument. The support plate, which can be rotated, has numerous tapped holes that are used to secure a variety of telescope supports that hold all types of gunsights. Notice the double bank of collimator telescopes. This feature allows the collimation of both single eyepieces and binocular-type gunsights. These collimator telescopes are mounted at −25°, 0°, +25°, and +90° so that gunsights can be adjusted through the full range of elevation and depression

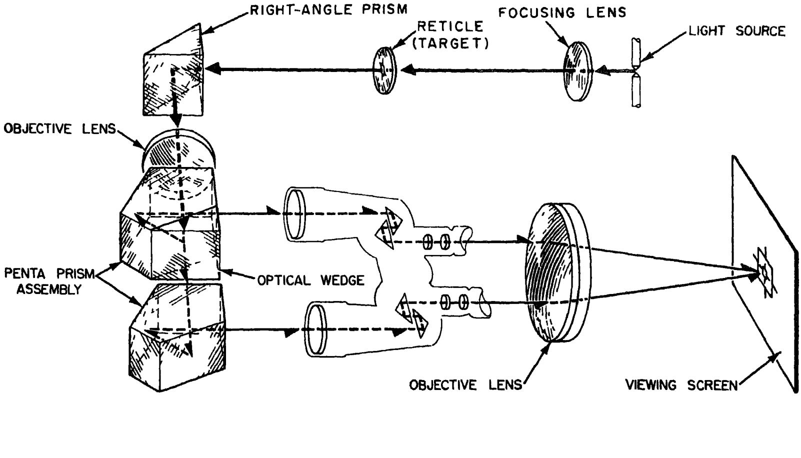

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Figure 8-7.—Mk 13 binocular collimator—operational schematic of optical system.

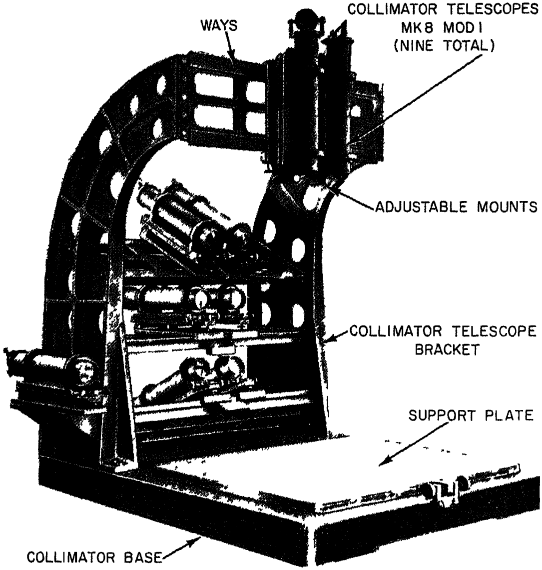

Figure 8-8.—Mk 9 collimator.

The collimator telescope used on a Mk 9 collimator is shown in figure 8-9 It is normally used with a mirror (to reflect light and illuminate the crossline). For special purposes, such as establishing a true line of sight between two collimator telescopes, it is available with an eyepiece.

For further information on collimators, consult OP 1417, *Collimators for Optical Instruments*.

Collimation of submarine periscopes presents two unique problems—the length of the instruments and the need for an adjustable target. Figure 8-10, view A, illustrates the collimator mounted in the horizontal position on the periscope rail. Figure 8-10, view B, illustrates a closeup of the collimator. The periscope rail shown is about 45 feet long. The sliding V-blocks support the periscope to prevent sagging of the tube.

Of all the tools you will use as an Opticalman, the auxiliary telescope is the most common for adjusting most of the instruments for which you are responsible

Auxiliary Telescope

Figure 8-11 illustrates the auxiliary telescope with a rhomboid prism attachment With this attachment you can look through an instrument and see a magnified image of a collimator, while at the same time you can see a reduced image of the collimator superimposed on the main line of sight. The rhomboid prism attachment slips over the objective end of the auxiliary telescope when needed.

The auxiliary telescope is a three-power astronomical telescope (inverted reverted image) with a focusing Kellner eyepiece. Its main purpose is to correct for, and neutralize, inherent eye defects you may have and to slightly magnify so that you can adjust an optical system more accurately.

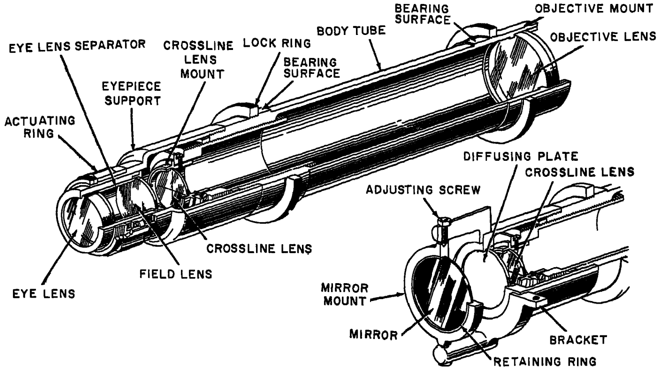

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Figure 8-9.—Mk 8 Mod 1 collimator telescope with auxiliary eyepiece, mirror mount, and diffusing plate—cutaway.

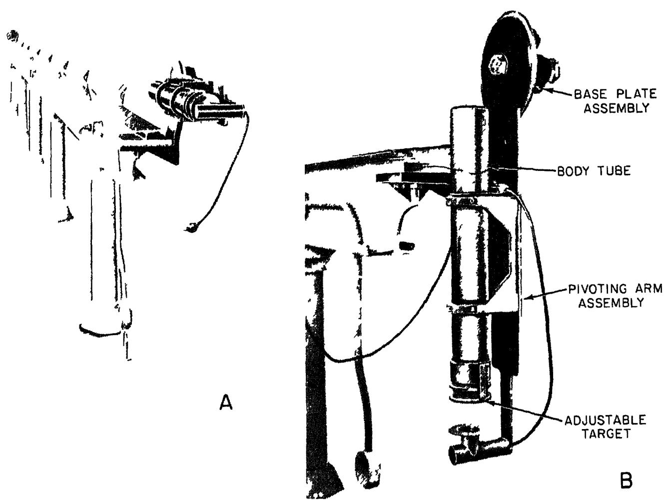

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Figure 8-10.—Periscope collimator and rail.

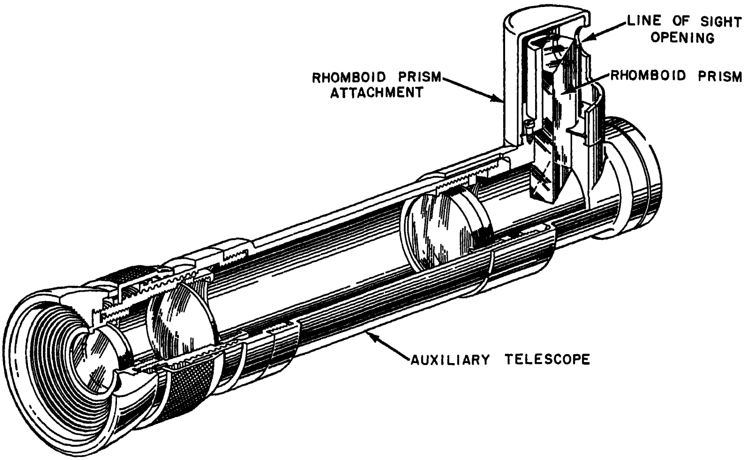

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Figure 8-11.—Mk 1 auxiliary telescope with rhomboid prism attachment—cutaway.

To determine the dioptric setting of your eyes, focus the auxiliary telescope from plus to minus on an infinity target, or on a collimator telescope crossline, until the image is sharply defined. For best results, take five readings and use the reading that appears most. Remember to keep your eyes relaxed while focusing.

After you get this dioptric setting, do NOT change the focus until you check your setting again to adjust for eye fatigue or strain.

You can use an auxiliary telescope for the following collimation operations:

1. To set focusing eyepieces to the NORMAL or ZERO diopter setting
2. To set fixed-type eyepieces to their required diopter setting
3. To check for and aid in removing parallax in an instrument

The auxiliary telescope increases the accuracy of these adjustments by a factor of three. If you are adjusting a six-power instrument with an auxiliary, the final magnification of the collimator image will be 18X. (3X auxiliary multiplied by 6X telescope.)

NOTE: Always use an auxiliary telescope during collimation procedures.

COLLIMATOR ADJUSTMENT

Alignment of a collimator serves two purposes. It establishes parallelism between the base and the optical line of sight, and it sets up the collimator to correspond with alignment specifications for the instrument being collimated.

Figure 8-12 shows a Mk 4 Mod 0 collimator and the equipment necessary to square the collimator crossline. Light leaving the collimator is parallel. An auxiliary objective with a 10- to 15-inch focal length is placed near the collimator. An adjustable auxiliary eyepiece is positioned behind the auxiliary objective so that you can see a sharp image of the collimator crossline. Now place a machinist's square in the image plane of the auxiliary objective. You should see the collimator crossline and the edge of the machinist's square in sharp focus. Simply rotate the collimator telescope to align the vertical line with the edge of the square. No further alignment is necessary on the Mk 4 collimator.

Some collimators must be aligned with special, single-purpose equipment. Others can be aligned to accommodate a variety of different telescopes by using a checking telescope.

The Mk 7 checking telescope (fig. 8-13) has a graduated dial and vernier index so that you can set the telescope at any angle of elevation or

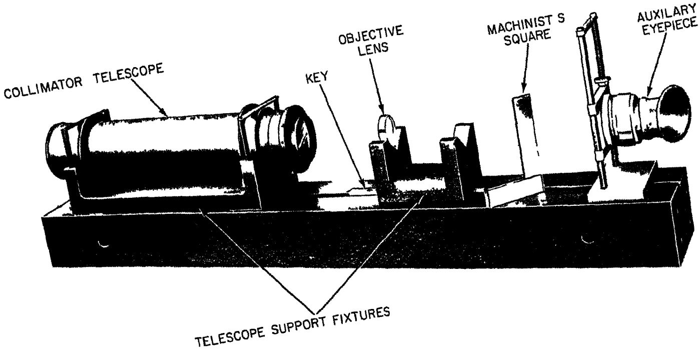

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Figure 8-12.—Squaring collimator crossline.

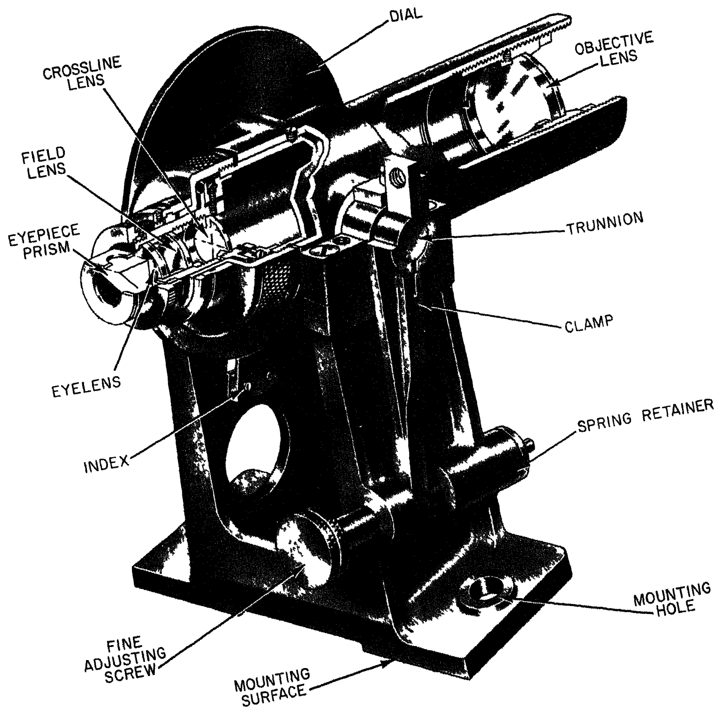

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Figure 8-13.—Mk 7 checking telescope.

depression. The eyepiece prism is fully rotational so that you can comfortably view the target from any position.

To align a collimator using the Mk 7 checking telescope, mount the checking telescope on the appropriate support fixture, set the dial to the specified elevation, and adjust the collimator telescope to align with the checking telescope. (The checking telescope is the primary reference.)

Adjust the collimator immediately prior to collimating an optical instrument. In some cases, you will need to make readjustments during collimation because temperature changes will affect alignment of the collimator.

COLLIMATION PROCEDURES

Collimation procedures vary for different types of optical instruments. While one type of instrument may require several hours of complicated adjustment, another can be completed in a few minutes. You will encounter situations when making one adjustment will change a previous adjustment, and some instruments will need to have subassemblies collimated before you can collimate the complete telescope. In tilting prism gunsights, you may have to shim or scrape mounting surfaces to obtain proper tracking of the line of sight.

To obtain detailed procedures for collimation of any particular instrument, you must consult a job sheet or technical manual.

The following general procedures apply to most optical instruments and are listed in the order in which they should be performed.

1. Collimate the collimator.
2. Remove parallax.
3. Square and superimpose the crossline.
4. Set zero diopters.

Removal of Parallax

To check for parallax in an instrument, place an auxiliary telescope on the eyepiece of the instrument, sight through the auxiliary telescope, and focus the eyepiece of the instrument until the image of the collimator crossline, or the instrument crossline (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 be in focus at the same time. To determine the amount of parallax, focus the eyepiece of the instrument in until the first crossline is sharply defined, and note the diopter reading to which the index marker points. Continue to focus until the other crossline is sharply defined, and observe the point of the index mark on the diopter scale. 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 crossline of the instrument, for example, came into focus at +2 diopters on the diopter scale, and the crossline of the collimator came into focus at −3 diopters on the diopter scale, the total amount of parallax is 5 diopters.

If the instrument crossline comes into focus before the collimator crossline, the objective lens is too far from the crossline. If the collimator crossline comes into focus before the instrument crossline, the objective lens is too close to the crossline.

The problem now is to place the instrument crossline in the focal plane of the objective lens, in one of two ways:

1. Move the objective lens until its focal plane is in the same plane as the instrument crossline. This method is preferred for removing parallax. The objective lens is usually mounted in a threaded mount, which can be moved axially along the interior of the instrument. When the objective lens mount is moved any amount, the image of the collimator crossline moves in the same direction in the same amount as the objective lens.

2. Alternatively, you can move the instrument crossline forward or aft axially until it is in the focal plane of the objective lens

In some instruments, spacers or separators are placed in front of and behind the objective lens mount (not threaded externally). This allows for the elimination of parallax by trial and error There is NO tolerance for parallax in any optical instrument.

Continue adjusting the instrument until both crosslines are in perfect focus at the same time.

Squaring and Superimposing the Crossline

To square the instrument crossline to the collimator crossline, use the following procedures:

1. Loosen the crossline retainer ring.
2. Rotate the crossline with a rubber-tipped tool.

3. When the crosslines are aligned, tighten the retainer.

The crossline may turn past the desired position. This procedure can sometimes be quite frustrating, but it must be done carefully and accurately. As you make adjustments to the crossline, it could become smudged or dirty. If it does, you will have to remove and clean the crossline again. THE CROSSLINE MUST BE ABSOLUTELY CLEAN.

Once the instrument crossline is perfectly squared, and clean, superimpose it on the collimator crossline. Instruments are designed in a variety of ways to accomplish this adjustment. One design allows you to shift the prism erecting system (which may cause lean), another allows you to adjust the crossline lens mount (screw adjusting mount). The eccentric objective mount is the most common design in use. With proper manipulation of the eccentric rings, you can vary the line of sight to provide perfect alignment.

Eccentric rings are locked in position with setscrews, lock rings, or both. When you lock the eccentrics, your adjustment may be thrown off slightly, so be sure to check it. If full throw of the objective is not enough to superimpose the two crosslines, you may need to shift prisms, recheck for lean, and try again If you have difficulty superimposing the collimator and instrument crosslines, try the following procedures:

1 Check the collimator alignment.
2 Check the instrument mounting surfaces
3. Disassemble the instrument and look for cocked lenses, prisms, or mounts.

After you have squared and superimposed the crosslines, recheck for parallax.

Setting Zero Diopters

Instruments with a focusing eyepiece are set to zero diopters with an auxiliary telescope. This allows anyone using the instrument to automatically set the eyepiece at his or her own diopter setting without wasting time on focusing. During reassembly of spiral keyway eyepieces, you will set the index mark at mechanical midthrow (zero diopter position) and adjust lenses during collimation. This establishes a perfect focus at zero diopters.

To set optical zero diopters, use an auxiliary telescope set to your eye correction, and focus the instrument being tested until the collimator is in sharp focus. (NOTE: Always focus from the plus side (out) to the minus side (in).)

When you removed parallax, the instrument crossline and collimator target were in focus at the same time. This common focus may not correspond with the zero mark on the instrument eyepiece. For instance, if both crosslines are in focus at -2 diopters, the final image plane is in too far. On the other hand, if both crosslines are in focus at $+1$ diopter, the final image plane is out too far.

To establish a perfect zero diopter focus in a two-erector telescope, simply move the rear erector in the same direction you want the image plane to move. For instruments with a single erector, move the erector in the opposite direction you want the image to move (remember the optical theory discussed in earlier chapters).

In instruments without a crossline, using a prism erecting system, the focal length of the objective lens or the axial positioning of the objective lens will determine the zero diopter setting.

The collimation procedures just discussed generally cover fixed prism gunsights and straight-line telescopes without crosslines. Instruments with elevation and deflection prisms or mirrors must be checked against a properly adjusted collimator for true horizontal and vertical tracking as well as mechanical backlash.

Modern gunsights are precision manufactured to fine tolerances to keep possible misalignment to a minimum. However, damage or incorrect reassembly can cause problems. The technical manual for each type of instrument fully covers the correct overhaul and collimation procedure and lists the tolerances for errors in elevation, deflection, and backlash As a rule, the line of sight can vary no more than 1 or 2 minutes of arc from the desired plan of movement, and backlash is held to 30 seconds or less. Proper adjustments include shimming, scraping, or replacing machined spacers, as specified in technical manuals.

SEALING, DRYING, AND CHARGING OPTICAL EQUIPMENT

After you collimate an optical instrument, the last step in overhaul is to seal the instrument, remove any moisture present, and charge the instrument with a dry inert gas, when appropriate. Much of the sealing process is usually accomplished during reassembly, except for areas needed for access during collimation.

Optical instruments are designated as (1) moisturetight, (2) gastight, or (3) pressuretight. Methods used for sealing, drying, and charging vary with the type of instrument being overhauled.

MOISTURETIGHT SEALING

Hand-held optical instruments, and those not permanently mounted on a ship's weather deck, are classified as moisturetight. They have focusing-type eyepieces and are sealed against the entrance of moisture by gaskets, sealing compound, and grease (in the eyepiece focusing mechanism). These instruments are sealed in the optical shop at normal atmospheric pressure. They will withstand mist or light rain, but cannot be submerged in water.

GASTIGHT SEALING

Instruments that are permanently exposed to weather must be sealed with a positive gas pressure of 2 to 5 psi. They have fixed focus or internal focusing eyepieces, and all joints and optics are sealed with gaskets. Since these instruments use control shafts that pass through the body casting, the shafts are sealed with packing. The packing holds internal pressure and allows the control shafts to be rotated.

PRESSURETIGHT SEALING

Instruments that must withstand high external water (hydrostatic) pressure for extended periods of time are sealed with O-rings, packing, and gaskets They will also be charged with inert gas at a pressure of 5 to 7 1/2 psi. 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 rendering them useless.

A gastight instrument may be charged with dry nitrogen or helium. A pressuretight instrument should be charged with dry nitrogen ONLY. Dry nitrogen and dry helium are used to charge instruments. These gases are used because they are inert and do not react chemically to cause or support corrosion.

Drying and Gassing

The gas used to charge optical instruments normally is not completely free of moisture and foreign matter. You must clean the gas before you use it. You should force the gas through an optical instrument dryer. The dryer is actually a filter containing a quantity of silica gel to absorb moisture from the gas as it passes through. The silica gel used in instrument dryers is impregnated with cobalt chloride and serves as a moisture indicator. When silica gel is completely dry, it is deep blue. When silica gel contains moisture, it is lavender; when it contains 50 percent moisture, it is pale pink. At a saturation of almost 100 percent with moisture, silica gel is very pink.

You can check the color of silica gel through a window on the side of the cylinder. 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° to 350°F for a minimum of 4 hours, after which its color should be deep blue. If silica gel turns brown, replace it. While the silica gel is being baked, clean the inside of the dryer and the filters.

The use of nitrogen and helium for pressure-testing gastight and pressuretight instruments, as prescribed in the various instrument manuals, requires you to be familiar with safe handling practices concerning high-pressure gases and storage cylinders.

SAFETY PROCEDURES FOR HANDLING CYLINDERS

Strictly observe the following rules for storage, handling, and use of cylinders

- Avoid abusing cylinders. They are carefully checked at the charging plant to ensure that they are safe Abuse may render them unsafe.

Ensure the cylinders contain the proper gas, and do NOT tamper with the identifying code numbers and markings.

Store cylinders in an approved vertical storage rack where they cannot be knocked over or damaged by passing or falling objects. If a cylinder falls over, it may crack and explode. A full cylinder contains 1800 pounds per square inch of pressure. If the cylinder valve is broken, the cylinder will take off like a rocket. Keep cylinders away from stoves, radiators, furnaces, and other heat sources.

- While moving cylinders, prevent them from being knocked over or from falling. Use a suitable handcart with retaining devices.

• Keep cylinders from being knocked over while in use. Use a rack to hold a cylinder in an upright position.

• Use full cylinders in the order in which they are received from the charging plant.

• Never allow cylinders to come in contact with live wires and ground wires of electrical equipment.

• Always close the cylinder valve when work is finished. Always close the valves of empty cylinders while in storage or before returning them to the charging plant.

• Return empty cylinders promptly.

NEVER use a cylinder that contains less than 400 pounds of pressure. Empty gas cylinders may contain impurities which could enter and contaminate an instrument.

CHARGING PROCEDURES

Figure 8-14 shows a typical setup for purging, pressure-testing, and charging an optical instrument. In this illustration, a rangefinder is being charged with helium, but the same equipment is also used with nitrogen and on other instruments.

A plastic hose must be used from the dryer to the instrument. Rubber hoses are not clean and tend to "shed" foreign matter. It is also advisable to use a plastic hose from the regulator to the filter.

The following procedures are prescribed to protect you and the equipment:

• Set nitrogen cylinders in a vertical position in racks. Always observe the safety procedures for handling cylinders. Make sure the cylinders contain nitrogen.

• With the cylinder firmly in the rack, unscrew the valve protection cap from the top.

• Open the cylinder valve one-quarter turn, and then close it immediately. (Do NOT stand in front of the outlet pipe; stand behind it.) This procedure will clear the valve and the 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.

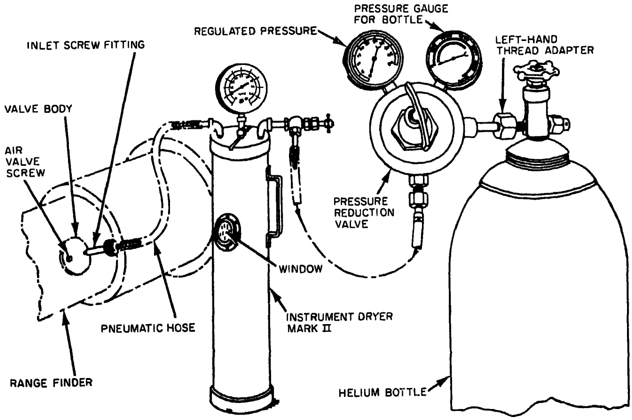

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Figure 8-14.—Setup for charging.

> **WARNING**
>
> Do not use a wrench on the cylinder valve. It should open with hand pressure. If it will not yield to hand pressure, replace the valve protection cap and return the cylinder to the charging plant with an explanation attached.

- Assemble the pressure-reducing regulator to the cylinder, and tighten the union-joint nut securely.

- Turn the pressure-adjusting control screw of the regulator counterclockwise (to the left) until it is loose. This is done to protect the regulator and its gauges from possible damage when the cylinder is opened.

- Stand to one side of the front of the regulator and open the cylinder valve slightly. If the cylinder is opened quickly, the sudden rush of gas might damage the regulator. Open the valve only 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.

> **WARNING**
>
> If there is a leak between the cylinder and the regulator, close the cylinder valve before tightening the coupling or before doing anything else.

- Connect the hoses and the instrument dryer together as illustrated in figure 8-14. Make sure the hose from the regulator is attached to the inlet side of the dryer.

- Turn the pressure-adjusting control screw of the regulator clockwise until the regulated pressure gauge reads 5 pounds. This will blow out the filter and lines.

- Reduce the pressure again. The system is now ready for use.

Testing for Leaks

The following general procedures should be followed when an instrument is to be tested for leaks:

- Connect the hose from the outlet side of the dryer to the charging valve screw fitting (the small screw) on the optical instrument (fig. 8-15, view A).

- Open the gas inlet screw (large screw) on the valve.

- Tighten the gas outlet screw on the opposite end of the optical instrument.

- Turn on the nitrogen supply until the pressure gauge on the instrument dryer reads approximately 5 pounds per square inch (fig. 8-15, view B).

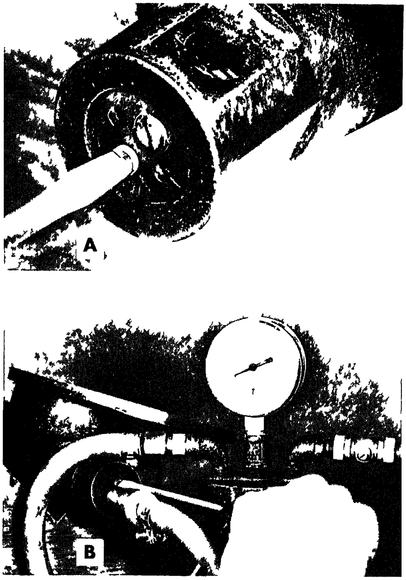

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Figure 8-15.—Attaching the hose to the instrument charging valve.

● While you maintain this pressure, brush a soapsuds solution around all fittings, gaskets, screws, the objective window, and the rear eye lens to check for leaks. See figure 8-16.

● 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 leaks.

● After you repair the leaks, connect the hose to the instrument, apply the same pressure test, and check again for leaks with soapsuds.

● After the instrument passes the soapsuds test, maintain 5 pounds of pressure and close the gas valve screw on the inlet valve.

● 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 leaks as soon as you remove the instrument from the tank; then repair them. Follow up by applying 5 psi test pressure, and submerge the instrument in the tank again to double check for leaks

When you are certain there are no leaks in the instrument, remove it from the tank, dry the exterior with a clean, soft cloth, and recharge it to exactly 5 pounds Twenty-four hours later, attach a pressure gauge 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 leaks. Then make necessary repairs. The instrument is now ready for drying and charging.

148.33

Figure 8-16.—Testing for leaks.

Drying and Charging

The following procedures should be used to dry and charge an instrument with nitrogen:

● Reconnect the outlet hose from the dryer to the inlet valve.

● Open the outlet valve.

● Turn on the nitrogen at 5 pounds of pressure, and let it cycle through the entire instrument.

● Purge the instrument by holding a finger over the outlet valve. When the gauge on the dryer shows a pressure up to but not exceeding 5 pounds, remove your finger from the outlet valve and allow the gas to escape. At about 5-minute intervals, during a period of approximately 1/2 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 2 pounds, or as indicated in the overhaul manual.

● 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. Turn off the nitrogen bottle, and replace the small inlet screw in the charging valve.

Some moisturetight instruments have inlet and outlet screws (not valves) that can be used for purging, but they cannot be used for pressure testing.

Pressuretight instruments must undergo a special testing procedure. Check with your instructor or shop supervisor for the instructions and specifications applicable to a particular pressuretight instrument.

Securing the Equipment

A special procedure must be followed for securing the equipment. The following

CHAPTER 9

MACHINE SHOP PRACTICES

Machine tool operations require a knowledge of some mechanical principles that apply to all machine work. These include the principles of cutting tools, cutting speeds and feeds, and the actions of gears, screws, and cams. All of these principles are applied in the construction of machines and are used during various machine operations.

As an Opticalman, you will occasionally work on instruments that do not have available replacement parts and require special tools. When this situation arises, you must be prepared to manufacture the parts or tools needed.

This chapter describes the machine tools common to optical shops and will help you in gaining a working knowledge of machining operations. First and foremost, you must remember:

> No job is so important and no service is so urgent that you cannot take time to perform your work safely.

GRINDERS

Grinding is the term used to describe the removal of metal by the cutting action of an abrasive. Offhand grinding is a term that describes the manual holding and manipulation of a workpiece that is being ground. To grind accurately and safely, using the offhand method, you must have adequate experience. In addition, you must know how to select and install grinding wheels and how to sharpen or dress them. You MUST know the safety precautions pertaining to grinding.

To properly grind small hand tools, single-edged cutting tools, and twist drills, you must understand the terms used to describe the angles and surfaces of the tools. You must know for which operations each tool is used, and you must know the composition of the tool material and abrasive wheel.

Bench grinders are relatively simple machines. The main components include a motor with an extended shaft for mounting grinding wheels, a mounting base for the motor, grinding wheel guards mounted over the grinding wheel as a safety feature, a provision for coolants, an adjustable tool rest to steady the workpiece, and a shield fastened to the wheel guards to protect the operator from flying chips.

Figure 9-1 shows a bench grinder. The grinding wheel on the left is usually a coarse, general-purpose wheel used for rough work or for removing large amounts of metal. The wheel on

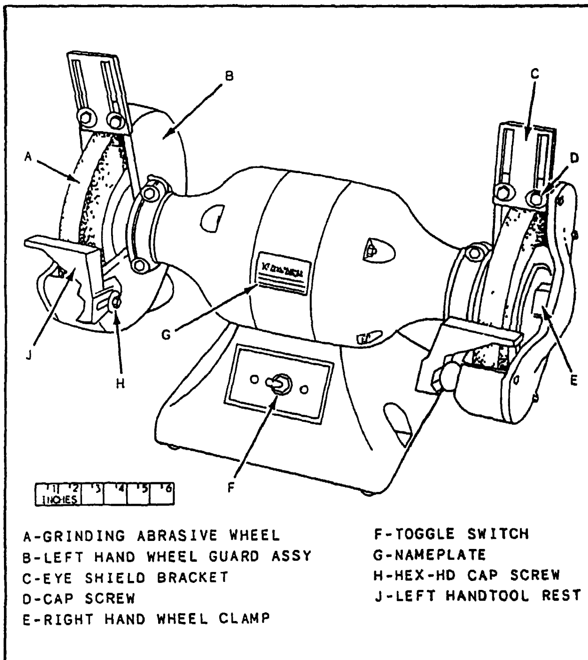

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Figure 9-1.—Bench grinder.

the right is a fine, finishing wheel that is used to produce a polished appearing surface. Grinding wheels up to 8 inches in diameter and 1 inch in thickness are normally used on bench grinders.

GRINDING SAFETY

Grinding wheels are fragile cutting tools that operate at high speeds. We must place great emphasis on the safe operation of all grinders. Observance of safety precautions, posted on or near all grinders used in the Navy, is mandatory.

What are the most common sources of injury during grinding operations? Grit generated by the grinding process causes most of the serious eye injuries. Bodily contact with a wheel can cause abrasions. Abrasions can be quite painful and serious. Segments of an exploded wheel or a tool "kicked" away from the wheel can cause cuts and bruises. These injuries can become infected if they are not protected from the grit and dust generated by grinding.

Safety requires the use of common sense. You must concentrate on the job at hand. Before you grind a tool, consider all safety precautions, and use all safeguards to protect yourself from injury. Consider how handicapped you would be if you lost your sight or lost or mutilated an arm or a hand. You should adhere to the following safety precautions:

- Read posted safety precautions BEFORE you use a machine

- Secure all loose clothing and remove rings or other jewelry

- Inspect the grinding wheel, wheel guards, tool rest, and other safety devices to ensure that they are in good condition and are positioned properly. Set the tool rest so that it is within 1/8 inch from the wheel face, and level with the center of the wheel. For small work, the rest can be positioned within 1/16 inch from the wheel.

- Clean the transparent shields on the grinder, and put on goggles. A transparent shield is NOT a substitute for goggles. Dust and grit may get around a shield, but goggles will give you full eye protection. WEAR GOGGLES during grinding operations.

- When starting a grinder, stand to one side until the operating speed has been reached. An exploding wheel, caused by a defect, can result in serious injury.

- Use light pressure when beginning a job. Too much pressure on a cold wheel can cause failure.

- Grind only on the face of a grinding wheel, unless the wheel is specifically designed for side grinding.

- Use coolant frequently while grinding. Dip the work often in water to prevent overheating and loss of temper (in most metals you grind). Dipping also keeps the work cool enough to hold in your hands.

- The primary purpose of a bench grinder in optical shops is to sharpen steel-cutting tools and to form special hand tools from ferrous metals. It should NOT be used to grind nonferrous metals. Nonferrous metals will cause the wheel to collect the ground metal, and can cause accidents and spoilage when the wheel is used to grind steel Nonferrous metals like aluminum, brass, or Monel collect in the wheel and actually force themselves into the pores. If this metal is allowed to build up, it could crack the wheel, causing it to disintegrate at operating speeds ALWAYS check the wheel of any grinder to be sure that metal has not adhered to the wheel. When metal has collected on the wheel of the grinder, the wheel should be dressed down with a proper dressing tool until it is completely free of foreign particles

GRINDING WHEELS

The abrasive particles in a grinding wheel provide thousands of small cutting edges that remove metal chips from the stock being ground. For the most efficient use of a grinding wheel, you must select the correct wheel and ensure that it is installed properly

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. Approximately 40 percent of the composition of a grinding wheel is made up of the abrasive and another 40 percent of the bond. The remaining 20 percent is empty space between abrasive grains.

Abrasives

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 most 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 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.

Bond

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 the letter V) is the most common. It is a glasslike substance that makes a strong rigid grinding wheel that 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 in grinding edged tools.

In general, the softer materials to be ground require harder bonds and a coarse grain size, and the harder materials require softer bonds and a fine grain size. A proper bond for a specific grinding application should retain the abrasive grains until they become dull

Grain Size, Grade, and Structure

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 that designates 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, combining the letter and number symbols given in the preceding paragraphs, is used for selection. For example:

A 36 K 10 V

Abrasive type
Grain size
Grade
Structure
Bond type

For additional information relating to grinding wheels, refer to *Tools and Their Uses*, NAVEDTRA 10085 series.

GRINDING WHEEL INSTALLATION

The wheel of a bench grinder must be properly installed; otherwise, accidents may occur and the wheel will not operate properly. Before installing a wheel, inspect it for visible defects, and "sound" it by tapping lightly with a piece of hardwood to determine whether it has invisible cracks. A good wheel produces a clear ringing sound when tapped; a cracked wheel produces a dull thud.

Ensure that the wheel fits on the spindle without play. Do not use force, however, as this may cause the wheel to crack when it is placed in operation, or it may cause the wheel to be slightly out of axial alignment. Recessed flanges (fig. 9-2) 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

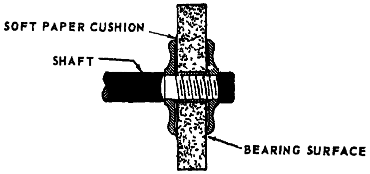

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Figure 9-2.—Method of mounting a grinding wheel.

ensure even pressure on the wheel and to dampen vibration between the wheel and the shaft when the grinder is in operation. Tighten the securing nut enough to hold the wheel firmly; tightening too much may damage the wheel.

NOTE: The right end of a grinder shaft has a right-hand thread. The left end has a left-hand thread.

GRINDING WHEEL MAINTENANCE

Like other cutting tools, the cutting surfaces of grinding wheels require frequent reconditioning to perform efficiently. Dressing is the term that describes the process of cleaning the periphery of grinding wheels. Dressing breaks away dull abrasive grains and smooths the surface so that there are no grooves. Truing is the term that describes the dressing of the cutting face of the wheel so that the resultant surface runs absolutely true to the grinding wheel shaft.

A wheel dresser (fig. 9-3) is used for dressing grinding wheels. 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 9-3, and bring it in firm contact with the wheel Move the wheel dresser across the face of the wheel until the surface is clean and square with the sides of the wheel.

Sometimes grinding wheels get out of balance because they are out-of-round. Dressing the wheel will usually remedy this condition After dressing a wheel, reset the clearance between the wheel and the tool rest. 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 the wheel and cleaning the shaft, spindle, and spindle hole in the wheel and the flanges.

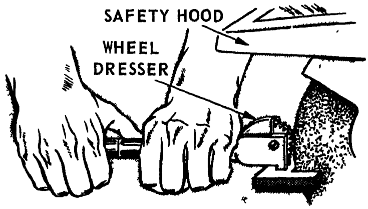

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Figure 9-3.—Using a grinding wheel dresser.

GRINDING METHODS

Successful offhand grinding requires patience, concentration, and a light touch. Practice on non-critical grinding jobs will develop your skill and increase your confidence so that you can handle any grinding job.

The way you stand while grinding is very important. You should keep your feet slightly spread, with weight evenly distributed, so you can comfortably move in any direction and still see the work and the action of the grinding wheel.

The tool rest should be square and level with the face of the grinding wheel, with no dents or nicks on the edge or the surface. In many grinding operations, you slide the work across the top of the rest or across the edge, so there can be no restrictions to free movement.

Coordination is essential in precision grinding. One hand holds the work to apply steady pressure against the wheel, while the other hand guides the work to produce the desired contour. At the same time, you should move the work back and forth across the face of the wheel to prevent grooving. Since any type of grinding produces heat, you must frequently quench the work in water When you resume grinding, you must develop a "feel" for the work to pick up where you left off and avoid destroying previous efforts. Methods for grinding various tools are illustrated in *Tools and Their Uses*, NAVEDTRA 10085 series

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. You must be well acquainted with the machine and the methods of operation of drill presses and drills found in Navy shops.

A drill press (fig. 9-4) is used for drilling small holes in work under conditions that make it necessary for the operator to "feel" what the cutting tool is doing. The tool is fed into the work

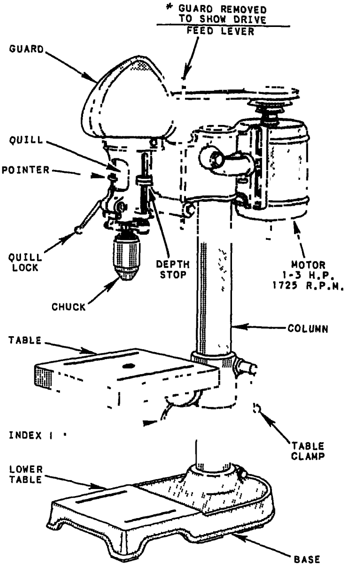

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Figure 9-4.—Drill press.

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. These drill presses are used in drilling holes less than 1/2 inch in diameter. The high-speed range of these machines and the holding devices used make them unsuitable for heavy work.

DRILLS

Figure 9-5 shows 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. The body clearance assists in the reduction of friction during drilling. The LIP is the cutting edge, and the area behind the lip is ground away to provide lip clearance, which allows the drill to advance into the work. The CHISEL POINT is the sharp edge located at the tip of the drill, which separates

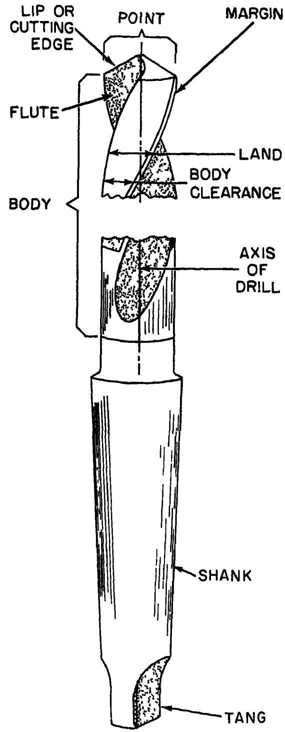

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Figure 9-5.—The parts of a twist drill

the two cutting edges. The WEB of the drill is the metal column that 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 drills. It fits into a slot in the 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 fits into the spindle, or chuck, of the drill press. There are several types of shanks, the most common of which are shown in figure 9-6.

Twist drills are made of cobalt alloy or high-speed steel, and they are capable of cutting any metal softer than that from which they are made. For cutting extremely hard materials, carbide inserts are silver soldered to the cutting lips of a drill.

Figure 9-7 shows a typical plastic cutting drill and a typical metal-cutting drill. Note the smaller point angle on the drill used for working with plastics.

Figure 9-8 shows the standard dimensions and clearances of a twist drill. You can reduce the point angle and increase the lip clearance for soft metals and plastics, or increase the point angle and reduce the lip clearances for metals that are difficult to drill.

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). Number size drills are used most often in optical shops.

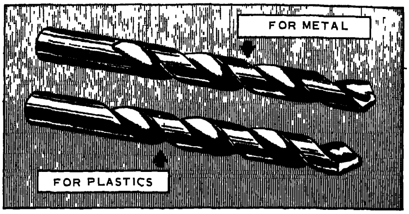

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Figure 9-7.—Comparison of a twist drill for plastics with one for metals.

DRILLING OPERATIONS

A drill press will probably be the first machine tool you will learn to operate It is relatively simple to operate and understand as compared to other machine tools in the shop, but skill and accuracy 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

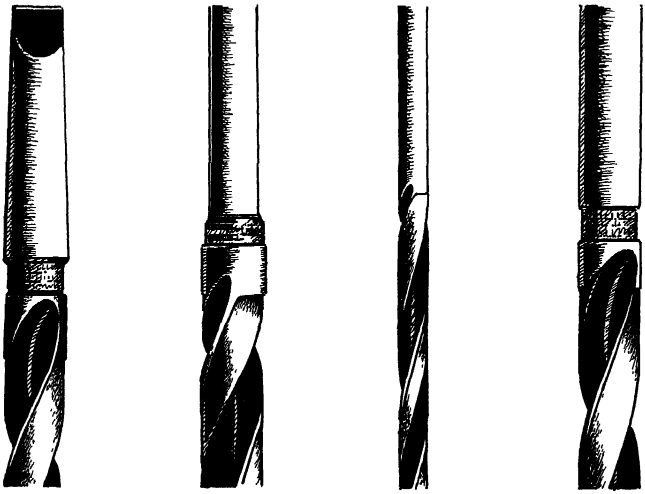

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Figure 9-6.—Four popular shanks.

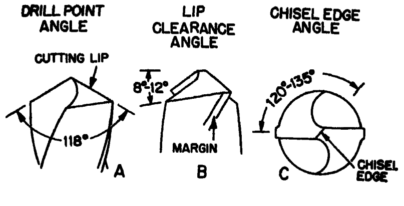

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Figure 9-8.—Specifications for grinding a regular point twist drill.

machine tools combined. The skill you develop in using a drill will often determine whether an optical instrument is made serviceable or is scrapped.

SPEEDS AND FEEDS

Experience will help you in selecting the best feeds and speeds for drilling. While you are learning, it is best to start slowly

The correct cutting speed for a job depends upon the degree of machinability of the metal, the size of the drill, the speed, and the type of drill used The following cutting speeds are recommended for high-speed drills.

Metal	fpm
Alloy steel	50-70
Machine steel	70-100
Cast iron	70-150
Brass	200-300

The cutting speed of a drill is expressed in feet per minute (fpm) and is computed by multiplying the circumference of the drill (in inches) by the drill revolutions per minute (rpm) The result is divided by 12. For example, a 1/2-inch drill with a circumference of approximately 1 1/2 inches turning at 100 rpm has a cutting speed of approximately 13 feet per minute.

$$\text{fpm} = \frac{\text{circumference} \times \text{speed (rpm)}}{12}$$

$$\text{fpm} = \frac{(3.14 \times 0.5) \times 100}{12}$$

$$\text{fpm} = \frac{157}{12} = 13.08$$

This cutting speed is quite low compared with the preceding table. Work the formula using a speed of 400 rpm, and see what happens.

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. This will prevent drill breakage and rough edges on the work. The rate of feed also depends on the size and speed of the drill, the material being drilled, and the rigidity of the setup.

The drill presses used in optical shops are normally limited to four to six different spindle speeds (controlled by V-belts and step pulleys). The deciding factor in selecting a particle spindle speed is the size of the drill and the recommended cutting speed of the metal being drilled. If your drill press is capable of operating at 550, 1500, 2100, and 2700 rpm, what speed would you select to drill brass with a 1/4-inch drill?

$$200 \text{ rpm} = \frac{(3.14 \times 0.250) \times (\text{rpm})}{12}$$

DRILLING HINTS

Many factors contribute to successful drilling. Among these are spindle speeds, rate of feed, selecting a properly sharpened drill, clamping of the work, and the basic accuracy of the drill chuck

Before any drill can start a hole, the spot to be drilled must be center punched The center punch mark will keep the point of the drill from "walking away," and at the same time the mark will provide a depression for the cutting lips to bite into.

Select the correct size drill for the hole you wish to make. For small holes (1/4 inch or less), you can use the same size drill. For larger holes, or when extreme accuracy is necessary, use a smaller pilot drill followed by the finished size drill. At times, you can improve the accuracy of a hole by starting the hole with a center drill (fig. 9-9). Even a perfectly sharpened drill will

28.57X

Figure 9-9.—Combined drill and countersink (center drill).

produce a hole several thousandths of an inch oversize. When a drill has been ground with unequal length cutting lips, you may end up with a 0.005- to 0.015-inch oversize hole with small drills.

Chuck the drill securely in the drill press, and turn your machine on and off to check for runout (eccentricity). If the drill wobbles, there could be a burr on the drill shank, chips in the chuck or drill press spindle, or a bent drill. To correct the condition, first examine the drill shank. Small burrs can be filed or ground away, and the drill can still be used. Next clean the chuck and drill press the spindle hole. If the drill still wobbles, you probably have a bent drill. The working parts (fluted) of a drill are brittle, but the shank is usually softer and can be carefully tapped into alignment with a hammer handle.

You are now ready to clamp your work for drilling. Work can be clamped directly to the table with straps and holddown bolts; it can be held in a machinist's vise or clamped to V-blocks. Always mount the work so the drill will not touch the table or vise when it goes through the work.

The work must be secured to prevent spinning and to prevent the work from jumping as the drill passes through the bottom Either event could be disastrous to the operator or bystanders. No one should take unnecessary chances. Carelessness can result in the possibility of fingers being lost, a chest being slashed by a piece of rotating metal, or someone being hit with a flying vise.

As you are clamping the work, position the center punch mark directly under the drill point. Small, light pieces tend to center themselves if you bring the drill down to the punch mark For heavier stock, check the drill head on and 90° either left or right as you set the point on the punch mark. If the drill bends, tap the work into alignment with a mallet, then clamp it down.

NOTE: Always wear eye protection equipment when drilling.

Now start the drill press and lightly touch the work with the drill. Check for perfect alignment, and make any corrections necessary before proceeding with the hole.

As previously mentioned, when using a sensitive drill press, you can feel what the drill is doing. Generally, fingertip pressure is sufficient for most small drilling operations. Pay attention to sound, vibration, and the chips being produced. Let the drill do the work. If you force a small drill too rapidly into the work, overheating will be the least of your problems. You do not want to have to explain to your shop supervisor why a $500 component is ruined because you broke a $1 drill in a hole.

If the drill squeaks while in use, the speed is too high, metal has built up on the margin, the drill is dull, or there is insufficient lip clearance. When you hear a snapping sound while using a small drill, the drill is turning too slowly, or there is too much lip clearance.

For drilling brass or steel, the drill cutting edge should be modified as shown in figure 9-10. Grinding the cutting lip surface parallel with the axis of the drill strengthens the cutting surface, prevents digging in, and greatly reduces the possibility of chipped lips or broken drills.

After a drill has been sharpened repeatedly, the chisel point will become wider due to the tapered web construction. When this happens, it is difficult to start a drill in a center punched hole. The web thickness can be reduced by grinding as shown in figure 9-10. The drill should be held at a slight angle from vertical

CUTTING LUBRICANTS

Lubricants serve several important functions during drilling They reduce heat and friction, carry chips out of the work, and provide a smoother hole Some shallow drilling can be done dry with a sharp drill, especially in brass and aluminum, however, cutting oil is essential with hard steel Brass and aluminum tend to build up on the margin of a drill during dry drilling This will cause galling, which ruins the drill and the hole For best results, use a lubricant A thin solution of soluble oil is very effective

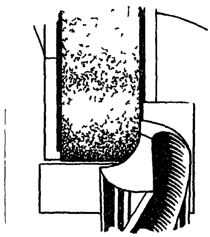

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Figure 9-10.—Grinding a twist drill for brass or steel.

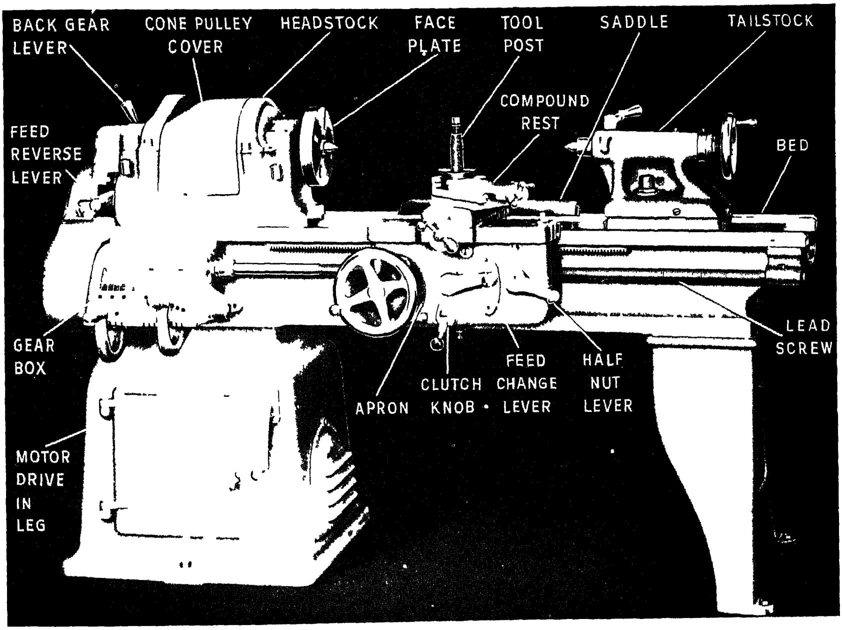
LATHES

An engine lathe such as the one shown in figure 9-11, 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, and grinding. 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 crossfeed. (Longitudinal feed is movement of the cutting tool parallel to the axis of the lathe; crossfeed 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 × 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 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, remember that lathes of different manufacture differ somewhat in details of construction, but all are built to provide the same general functions. As you read the description of each part, find its location on the lathe by referring to figure 9-11. For specific



28.69X

Figure 9-11.—An engine lathe.

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. Its main features 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.

Figure 9-12 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 V-ways are guides that allow movement over them in a longitudinal direction only. The headstock and tailstock are aligned by the V-ways. The flat way (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, a lathe must 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 the ways or damage their finished surface in any way. Keep them clean and free of emery dust and chips. Wipe them off daily with an oiled rag to help preserve their polished surface.

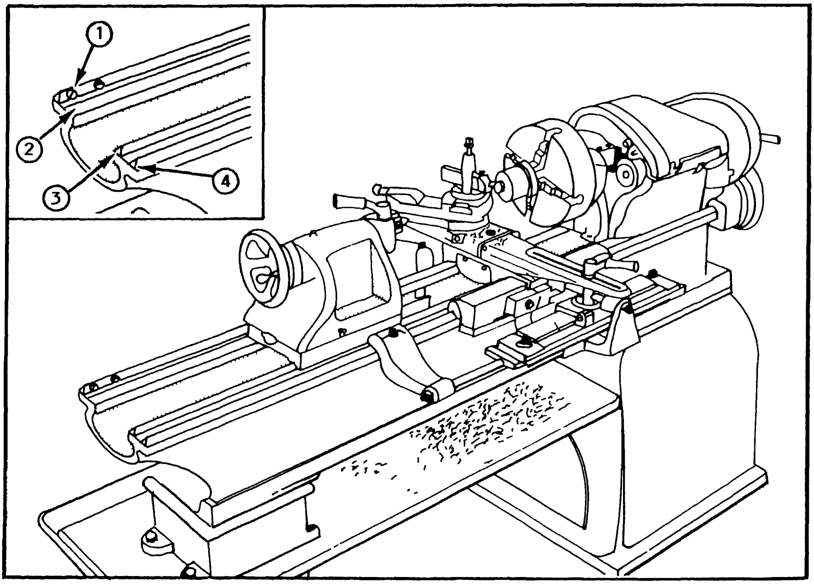


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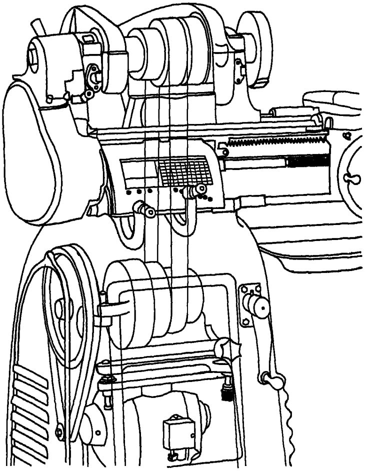
Figure 9-12.—Rear view of lathe.



28.71
Figure 9-13.—Belt-driven type of headstock.

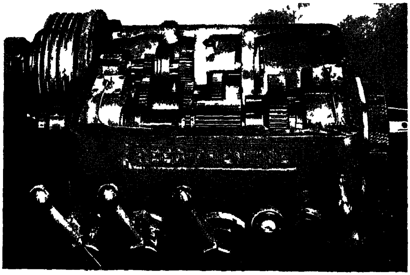


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Figure 9-14.—Sliding gear type of headstock.

Headstock

The headstock carries the headstock spindle and the mechanism for driving it. In the belt-driven type (fig. 9-13), the driving mechanism consists merely of a step pulley that drives the spindle directly or through back gears. When being driven directly, the spindle revolves with the pulley; when being driven through the back gears, the spindle revolves more slowly than the pulley, which, in this case, turns freely on the spindle. Thus two speeds are obtainable with each position of the belt on the pulley; if the pulley has four steps as illustrated, eight spindle speeds can be obtained.

The geared headstock (fig. 9-14) is more complicated but more convenient to operate. This is because speed can be changed 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 the different spindle speeds. Always stop the lathe when you shift gears to avoid possible damage to gear teeth.

The headstock casing is filled with oil for lubricating 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 must keep the oil up to the level indicated on the oil gauge, and drain and replace the oil when it becomes dirty or gummy.

The headstock spindle is the rotating element of the lathe and is directly connected to the work, which revolves with it. The spindle is supported in bearings at each end of the headstock through which it projects. 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 and held in a chuck at the nose. The chuck end of the spindle is bored to a Morse taper to receive the live center. A gear at the other end of the spindle drives the feed and screw-cutting mechanism through a gear train located on the left end of the lathe.

The spindle is subjected to considerable torque because it not only drives the work 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 (fig. 9-15) 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 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 (8). The spindle is kept from revolving by a key (4) that fits a spline or keyway (5) cut along the bottom of the spindle. A binding clamp (10) locks the spindle in place after final adjustment.

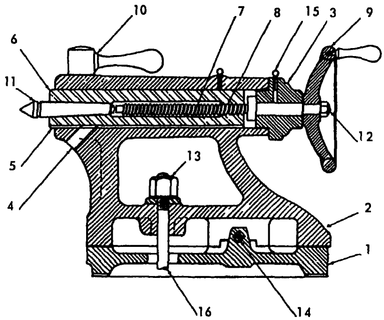
The tailstock body is made in two parts. The bottom or base (1) is fitted to the ways; the top (2) is capable of lateral movement on its base. Setscrews provide close adjustment for this lateral movement. Zero marks scribed on the base and top indicate the center position.

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 GEARBOX. There are a number of types used on different lathes, but they are all similar in principle (fig. 9-16).

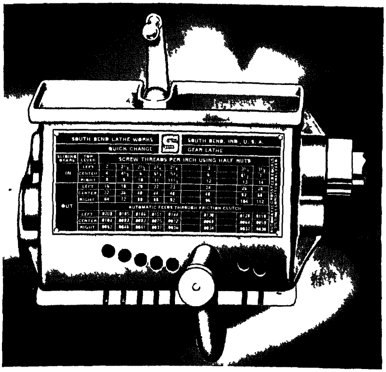
The mechanism consists of a cone-shaped group of change gears. You can instantly connect any single gear in the gear train by a sliding tumbler gear controlled by a lever. This cone of gears is keyed to a shaft that drives the lead screw directly or through an intermediate shaft. Each



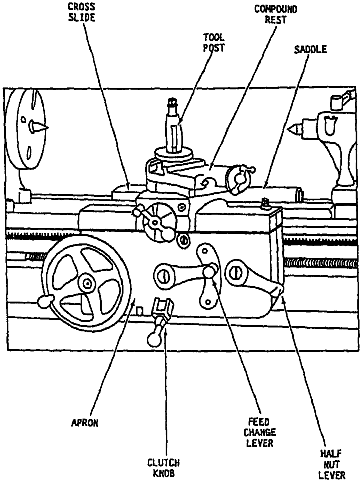
1. Tailstock base
2. Tailstock top
3. Tailstock nut
4. Key
5. Keyway (in spindle)
6. Spindle
7. Tailstock screw
8. Internal threads in spindle
9. Handwheel
10. Spindle binding clamp
11. Dead center
12. End of tailstock screw
13. Tailstock clamp nut
14. Tailstock set-over
15. For oiling
16. Tailstock clamp bolt

28.75X

Figure 9-15.—Cross section of a tailstock.



28.87X
Figure 9-16.—Quick-change gearbox.



28.69
Figure 9-17.—Front view of carriage assembly.

gear in the cluster has a different number of teeth and produces a different gear ratio when it is connected in the train To increase the range, other changes in the gear train can be made by sliding gears, which multiply the number of different ratios obtainable with the cone of change gears just described. All changes are made by shifting appropriate levers or knobs An index plate, or chart, mounted on the gearbox indicates the position for placing the levers to obtain the necessary gear ratio to cut the thread or to produce the feed desired

Carriage

The primary duty of the carriage assembly is to support the cutting tool and move it with extreme accuracy in whatever direction required to machine a piece of work. The accuracy of cuts made parallel to the lathe bed is 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 9-17 shows the construction of a carriage and the major components of the carriage: saddle, cross slide, apron, and compound rest.

SADDLE.—The saddle, when viewed from the top, is shaped like the letter H. The two arms have inverted V's machined in them which fit over the ways and guide the movement of the carriage along the ways.

CROSS SLIDE.—The cross slide of the carriage moves the cutting tool at right angles to the ways The cross slide is mounted to the top of the saddle by a dovetail which allows movement across the carriage but prevents side play.

APRON.—The apron is attached to the front of the carriage. 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. You should thoroughly understand the purpose of the apron before attempting to operate the lathe. Study figure 9-17 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 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 cross-feed.

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 cross-feed, while some lathes have a single clutch for both.

There is a feed change lever for selecting power cross-feed, longitudinal feed or, in the center position, for cutting threads.

A HALF-NUT CLOSURE LEVER engages and disengages the lead screw for cutting threads. The half-nuts fit the thread of the lead screw, which turns in them when they are clamped over it.

COMPOUND REST.—The compound rest (fig. 9-18) is fitted on the top of the cross slide on a swivel for cutting small tapers and feeding the cutting tool at any angle desired. The top of the compound rest also moves on a dovetail like the cross slide.

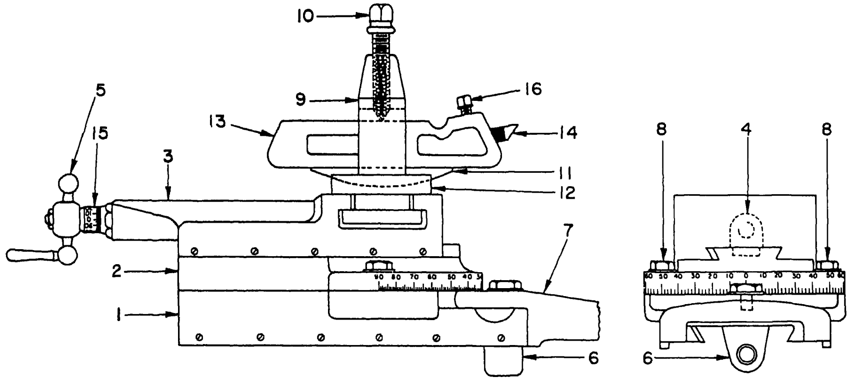
The tool post, which holds various toolholders, is held in the compound rest by a T-slot.

ATTACHMENTS AND ACCESSORIES

The variety of accessories, or attachments, 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 this section we will describe the most common parts that an Opticalman uses.

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



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 rocker
12 Toolpost ring
13 Toolholder
14 Cutting tool
15 Micrometer collar
16 Tool clamp bolt

28.88X

Figure 9-18.—Compound rest.

on the sides of the work. The jaws are moved in and out by screws turned by a chuck wrench applied to the sockets at the outer ends of the slots.

The four-jaw independent lathe chuck (fig. 9-19, view A) is the most practical chuck for general work. It provides the most clamping power. 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 for inside or outside clamping.

The three-jaw universal, or scroll, chuck (fig. 9-19, view B) can be used only for holding round or hexagonal work. It has matched sets of inside and outside jaws. All three jaws are moved in and out together in one operation as the chuck wrench is turned. This chuck is easier and faster to operate than the four-jaw type, but when its parts become worn its accuracy in centering cannot be relied upon. Runout is quite often from 0.001 to 0.030 inch. Proper lubrication and constant care in use are necessary to ensure reliability.

When you need 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 9-20 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.

The drill chuck is used to hold center drills and straight shank drills in the tailstock for drilling operations on a lathe.

Collets

The best way to accurately hold small work in a lathe is with the draw-in collet.

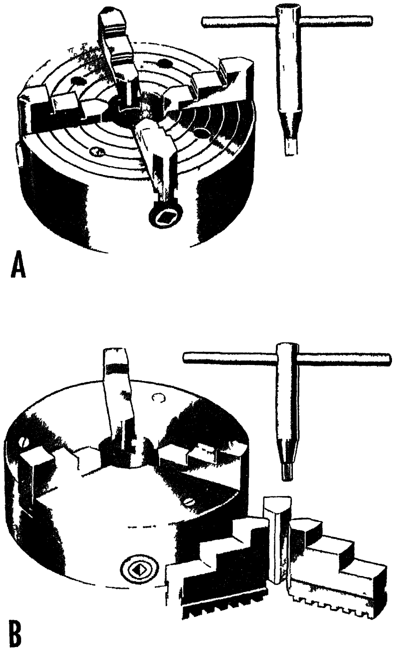


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Figure 9-19.—A. Four-jaw chuck; B. Three-jaw chuck.

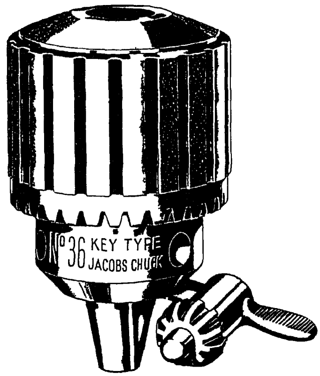

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Figure 9-20.—Drill chuck.

Figure 9-21 shows the collet assembled in place in the lathe spindle. The collet is a self-centering holding device that is very accurate and most often used for precision work in the optical shop. The collet 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 handwheel 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 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 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 a draw-in collet, be sure the contact surfaces of the collet and closing sleeve are free of chips, dirt, and burrs.

Taper Attachment

The taper attachment (fig. 9-22) is used for turning and boring tapers. It moves the cross slide laterally as the carriage moves longitudinally, causing the cutting tool to move at an angle to the axis of the work to produce a taper

The angle of the taper desired is set on the guide bar of the attachment. One end of the bar is marked in degrees; the other end is marked in inches of taper per foot. The guide bar support is clamped to the lathe bed. Since the cross slide is connected to a shoe that slides on the guide bar, the tool follows along a line parallel to the guide bar at an angle to the work axis corresponding to the desired taper

The operation and application of the taper attachment will be explained further in the section on taper turning

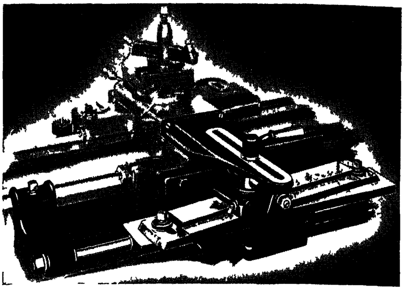

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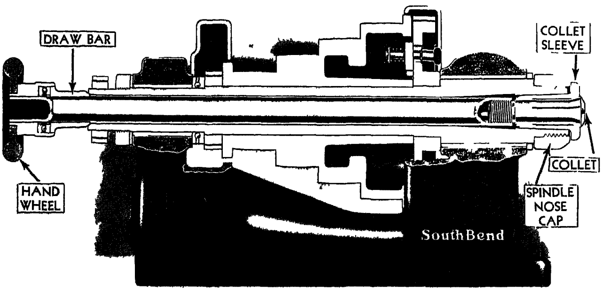
Figure 9-22.—A taper attachment.

Center Rest

The center rest, also called the steady rest, is used for the following purposes

1 Provides an intermediate support or rest for long slender bars or shafts being machined



28.91X

Figure 9-21.—Draw-in collet chuck.

between centers. It prevents them from springing while being cut or sagging as a result of their otherwise unsupported weight.

2. Supports and provides a center bearing for one end of the work 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 bed on which it is properly aligned by the ways, as illustrated in figure 9-23. The jaws (A) must be carefully adjusted and lubricated 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 (C) for easy positioning without removing the work from the centers or changing the position of the jaws. To set up a center rest, turn a short piece of stock to the same diameter as the work to be supported. Adjust the jaws to bear evenly on the stock, then chuck the actual workpiece and move the rest to the desired location on the lathe bed.

Follower Rest

The follower rest backs up work of small diameter to keep it from springing under the stress of cutting. It is named for its function—it follows the cutting tool along the work. As shown in figure 9-24, 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. As with the center rest, lubrication is necessary to prevent marring of the work.

Thread Dial Indicator

The thread dial indicator (fig. 9-25) eliminates the need to reverse the lathe to return the carriage to the starting point to catch the thread at the beginning of each successive cut. The dial, which is geared to the lead screw, indicates when the half

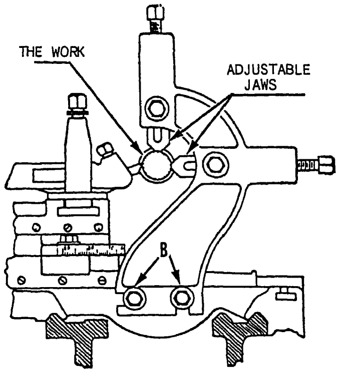


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Figure 9-24.—Follower rest.

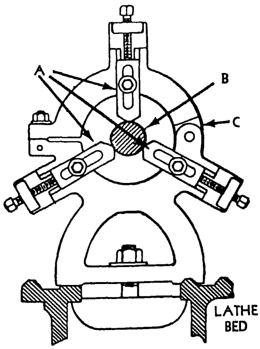

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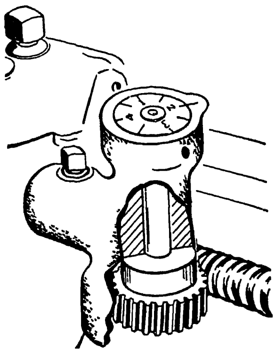
Figure 9-23.—Center rest.



28.99X

Figure 9-25.—Thread dial indicator.

nuts are to be clamped on the lead screw for the next cut.

The threading dial consists of a worm wheel attached to the lower end of a shaft and meshed with the lead screw. The dial is the upper end of the shaft. As the lead screw revolves, the dial turns 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 you want the carriage to stop. It is used mainly for turning, facing, or boring duplicate parts, and eliminates repeated measurements of the same dimension. In operation, you set up the stop at the point where you want to stop the feed. Just before reaching this point, shut off the automatic feed and carefully run the carriage up against the stop. Carriage stops come with or without a micrometer adjustment. Figure 9-26 shows a micrometer carriage stop.

NOTE: Some carriages have a stop that will automatically stop the carriage by disengaging the feed or stopping the lathe. This type of stop is referred to as an AUTOMATIC CARRIAGE STOP and is usually a built-in feature of the lathe design.

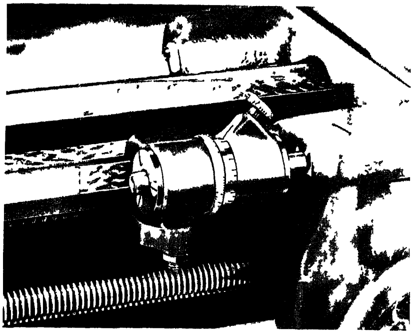


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Figure 9-26.—Micrometer carriage stop.

Lathe Centers

The 60-degree lathe centers, shown in figure 9-27, hold 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. A dead center, mounted in ball bearings, is available for most lathes. This center does turn with the work. 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 rotates with the work, and it is usually left soft. The dead center and live center must never be interchanged.

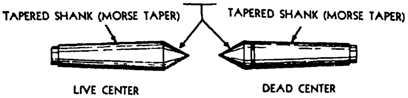
NOTE: There is a groove around the hardened tail center to distinguish it from the live center.

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; you can then pick it out with your 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 be forced out of the tapered hole.

Mandrels

As an Opticalman, very often you will machine a part that must have all its finished



28.93

Figure 9-27.—60-degree lathe centers.

external surfaces running true with a hole that extends through it. You can best accomplish this operation by holding the part to be machined on a mandrel. There are several types of mandrels used by machinists, but the most common mandrel used in the optical shop is the expansion mandrel (fig. 9-28). The expansion mandrel is composed of two parts: a tapered pin, which is turned between centers, and a split shell, which is tapered on the inside to fit the tapered pin. As the tapered pin is pressed into the split shell, the shell expands evenly to grip the work firmly. Be very cautious when pressing in the tapered pin. You do not want to exert too much pressure on the work.

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 cutting tool greatly affects the quality of the work done on a lathe. 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 functions connected with operating a lathe are automatic features built into the design of the machine. The cutting tool is not one of these features. You must acquire the knowledge to design the proper tool and the skill to grind cutting tools from tool blanks. The major factors in designing and grinding a cutting tool are the properties of the material to be cut, the type of cut to be taken, and the composition of the cutting tool

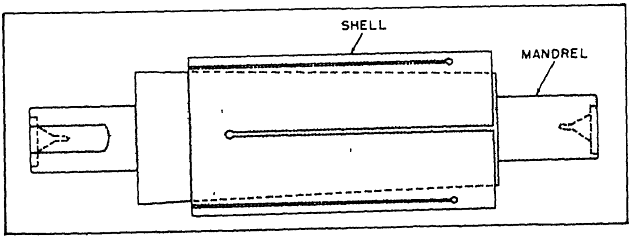
The majority of machine work in optical shops is done as a special setup/one-piece operation, so the cutting tools are usually made of high-speed steel.

You should remember that a metal cutting tool usually "pushes" the metal apart. 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, which in turn causes heat to be generated.

The pressure exerted on the cutting tool is necessary because it makes the cutting action possible. The objective, therefore, is to produce a cutting tool with an edge that will require a minimum amount of pressure to force it through the metal and still withstand the cutting pressure without breaking or wearing. To follow this discussion on grinding cutting tools, you must understand the terminology used to describe cutting tools.

Cutting Tool Nomenclature

A tool blank is an unground piece of toolstock. After it is ground, it is called a tool bit Tool blanks are available in sizes from 1/8 to 1 inch square and in proportional lengths from about 2 to 8 inches. The part of the tool behind 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 right to left (as you see it, standing in front of the machine), it is a right-hand tool. A left-hand tool is just the opposite.



28.116

Figure 9-28.—A split-shell expansion mandrel.

Figure 9-29 shows the application of angles and surfaces used in discussing single-edge or single-point cutting tools.

Side rake (fig. 9-29, view A) 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 chip to "flow" to the side of the tool and away from the cutting edge. For cutting aluminum, increasing the side rake angle will produce better results. Steel is easier to machine when the side rake is decreased.

The side relief (fig. 9-29, view A) is the angle at which the side or flank of the tool is ground so that the cutting edge leads the flank surface during cutting. The total of the side rake and side relief subtracted from 90° equals the angle of keenness. A tool with proper side clearance concentrates the side thrust on the cutting edge rather than on the flank of the tool.

The end relief (fig. 9-29, view B) is the angle at which the end surface of the tool is ground so that the end face edge of the tools clears the work being turned.

The back rake (fig. 9-29, view B) 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 and away from the work. Back rake may be positive or negative; it is positive if it is sloped downward from the nose of the tool toward the shank, and negative if the angle is reversed. When you grind a tool bit, you must hold the tool blank against the grinding wheel so that you form the side rake and back rake at the same time.

Most toolholders you will use position the tool bit at a 16 1/2-degree angle from horizontal. You must take this factor into account when grinding back rake. In some cases you will have to grind a negative back rake on the tool bit to achieve the correct overall rake.

The side cutting edge angle (fig. 9-29, view C) is ground to prevent the point of the tool from digging into the workpiece, which would probably result in pulling the tool 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.

Note the radius on the tool nose in figure 9-29, view C. For rough turning, a radius of 1/64 inch is effective for most optical shop applications, a

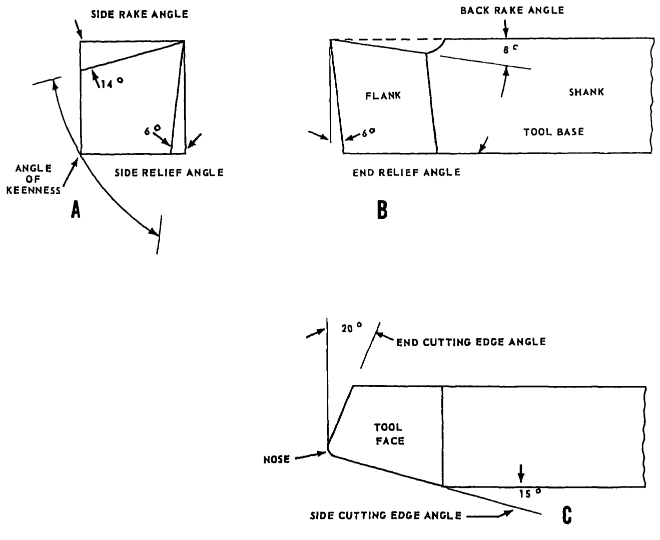


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Figure 9-29.—Applications of tool terminology.

radius of 1/32 inch for both rough and finish work is quite satisfactory.

Tool Grinding Procedure

The following steps apply to all types of lathe tool bits:

1. Form the side cutting edge angle and side relief.
2. Grind the end cutting edge angle, nose radius, and end relief.
3. Grind the side rake and back rake angles.

NOTE: Tool bits are extremely hard, so considerable grinding will be necessary. Quench the tool frequently to prevent overheating.

4. After carefully grinding all faces of the tool bit, hone the cutting surfaces with an oilstone. This step ensures smoother cutting action and prolongs tool life.

Figure 9-30 shows a variety of commonly used lathe tool bits and their applications. The tool design preferred for most turning operations, however, is one similar to that shown in figure 9-29.

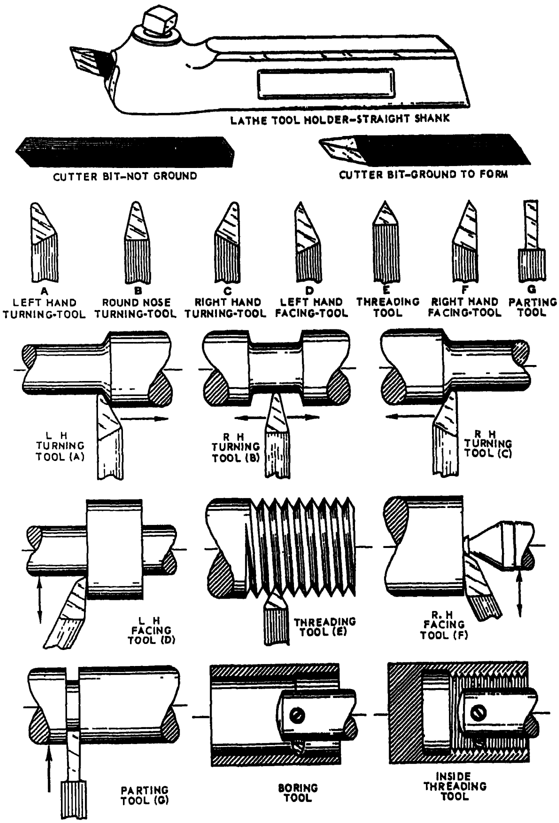

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Figure 9-30.—Lathe tools and their applications.

Figure 9-31 shows the toolholders used in ıcal shops. Either left-hand or right-hand tool and threading tools can be held in the straight ık toolholder. The left-hand toolholder is used right-hand bits, the right-hand toolholder is d with left-hand bits.

ning Tools

The next paragraphs will discuss the most ular shapes of ground lathe cutter bits and r application.

LEFT-HAND TURNING TOOL.—This tool round for machining work when fed from left ight, as indicated in view A, figure 9-30. The ing edge is on the right side of the tool, and top of the tool slopes down away from the ing edge.

ROUND-NOSED TURNING TOOL.—This l is for general all-round machine work and sed for taking light roughing cuts and finishing s. Usually, the top of the cutter bit is ground 1 side rake so that the tool may be fed from ıt to left. Sometimes this cutter bit is ground on top so that the tool may be fed in either ection (view B, fig. 9-30).

RIGHT-HAND TURNING TOOL.—This is the opposite of the left-hand turning tool and esigned to cut when fed from right to left (view fig. 9-30). The cutting edge is on the left side.

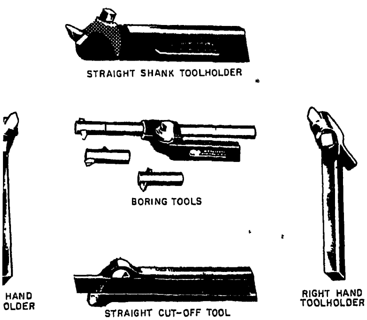

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Figure 9-31.—Common types of toolholders.

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 view D, figure 9-30. 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 the shoulder. (See view F, fig. 9-30.)

Thread-Cutting Tools

The thread-cutting tool has a different design as compared to the turning tool. It is a special tool used only for thread cutting In the following paragraphs, each type of threading tool is described.

THREADING TOOL.—The point of the threading tool is ground to a 60-degree included angle for machining V-form screw threads (view E, fig. 9-30). 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 view E, figure 9-30, except that it is usually much smaller Boring and internal-threading tools may require larger relief angles when used in small diameter holes

Square-Nosed Parting (Cut-off) Tool

The principal cutting edge of this tool is on the front. (See view G, fig 9-30) 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, and squaring corners and for cutting off

Boring Tools

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.

KNOWLEDGE OF OPERATION

Before attempting to operate any lathe, read all of the operating instructions that come with it. Learn the location of the various controls and how to operate them. When you know how they work, check to see that the spindle clutch and the power feeds are disengaged and start the motor. 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. Try to get the feel of this operation.
2. Before engaging either of the power feeds, operate the hand controls to be sure that the 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. Be careful not to run the carriage too near the limits of its travel, and NEVER allow the compound rest to run into a rotating chuck. Learn how to reverse the direction of feeds, how to disengage them quickly, and how to stop the spindle quickly
3. Try out the operation of engaging the lead screw for thread cutting. Remember that you must disengage the carriage feed mechanism before you can close the half nuts 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 you can make changes in the gearbox with the lathe running slowly, but you must stop the lathe for spindle speed changes.

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.

5. Always wear eye protection when operating a lathe.

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 × 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

$$\frac{(2 \times 3.1416) \times 100}{12} = 52.36 \text{ fpm}$$

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 gearbox 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 a variety of methods: the hardess 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 practical and efficient speed and feed consistent with the finish desired.

If the cutting speed is too slow, the job will take longer than necessary and often the work produced will be 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 fpm can be turned at about 80 fpm when flooded with a good cutting lubricant

Some of the recommended, approximate cutting speeds for various metals, using high-speed steel bits, are shown as follows:

Metal	Roughing cut (fpm)	Finishing cut (fpm)	Thread-cutting (fpm)
Cast iron	60	80	25
Machine steel	100	150	35
Tool steel	50	75	20
Brass	150	200	50
Bronze	90	100	25
Aluminum	250	400	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 practical speed. On many pieces, when 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 that the metal removed is much greater. This will prolong tool life. Consider this example: the depth of cut is 1/4 inch, the feed is 0.020 inch per revolution, and the speed is 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 0.040 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. You can usually use a fine feed, making it possible to run at a higher surface speed. A 50 percent increase in speed over the roughing speed is commonly used. In any event you should run the work as fast as the tool will withstand to obtain the maximum speed in this operation. Be sure to use a sharp tool when finish turning.

Lubricants

A cutting lubricant serves two main purposes—it cools the tool by absorbing a portion of the friction heat produced by the cutting action, and it lubricates the cutting edge to prevent a buildup of metal A cutting lubricant also keeps the chips flushed away from the tool

The best lubricants for cutting metal must often be determined by experiment. Ordinary petroleum base oil is often used, but soluble oil mixed with varying amounts of water are usually suitable for most metals—especially when coolant action rather than lubrication is desired. Other cutting lubricants 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 metals are as follows:

Metal	Lubricant
Cast iron	Usually worked dry
Mild steel	Oil or 5% solution of soluble oil
Hard steel	Mineral lard oil or 10% solution of soluble oil
Monel	Mineral lard oil or 20% solution of soluble oil
Bronze	Dry or 5% solution of soluble oil
Brass	Dry (kerosene is sometimes used on the hard composition)
Aluminum	Dry or kerosene or a 5% solution of soluble oil

Use of a lubricant is more critical for threading than for straight turning. Mineral lard oil is recommended for threading steel and cast iron; kerosene mixed with oil is recommended for aluminum and brass.

Maintenance

Maintenance is an important part of operational procedure for lathes The primary 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 to preserve its accuracy A worn lead screw lacks precision in thread cutting. Be 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 has an automatic oiling system for some parts, be sure all of those parts are getting oil Make it a habit to CHECK frequently for proper lubrication of all moving parts.

Do NOT neglect the motor At times the motor is hard to see, but it must be checked for proper lubrication. If it does not run properly, notify an Electrician's Mate. It is his duty to care for it. He should cooperate with you to make sure it is kept 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 good maintenance. Dirt and chips on the ways, lead screw, and cross-feed screws can cause serious wear and impair the accuracy of the machine. When you polish work on a lathe with emery cloth, protect the ways with rags or paper.

- NEVER put wrenches, files, or other tools on the ways.

- NEVER use the bed or carriage as an anvil. Remember that a lathe is a precision machine, and you must try to maintain its accuracy.

LATHE OPERATION

The basic function of a lathe is to remove metal, by means of a suitable cutting tool, from a piece of work that 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 makes it the most valuable machine tool available. Up to this point, you have studied the construction of a lathe, the accessories, and the various tools used on it. Now you will be given additional information 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 to determine the best procedure. Be sure that the stock you intend to use is large enough for the job.

Mounting Work

Accurate machining cannot be performed if work is improperly mounted. Requirements for proper mounting are as follows:

- The work center line must be accurately centered with the axis of the lathe spindle.
- The work must be rigidly held while it is being turned.
- The work must not be sprung out of shape by the holding device.
- 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 three general methods for holding work in the lathe for optical shop purposes: (1) between centers, (2) on a mandrel, and (3) in a chuck. The most common chuck used for general optical shop machining is the three-jaw universal. When accurate centering or holding power is not critical, and a rapid setup is desired, the three-jaw chuck will be satisfactory for all applications.

Whenever you change chucks, threads and mating surfaces must be perfectly clean and free of chips. Always use a block of wood to cover the ways when installing or removing a chuck.

If a chuck is to be used for holding work, be sure enough stock extends so you do not have to rechuck the work.

Centering the Work

When additional machining is to be done on round stock that is turned to finished size, the most practical method of holding the work is to use a collet. Collets are extremely accurate and need no centering adjustments. If the stock is an odd size or if it will not fit any available collet, use a four-jaw chuck and dial indicator as shown in figure 9-32.

Place copper or aluminum shims between the stock and chuck jaws to prevent marring of the

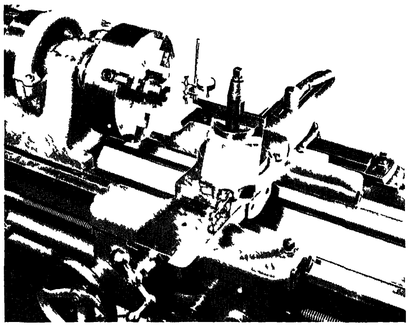

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Figure 9-32.—Centering work with a dial indicator.

work, then lightly tighten the jaws. (NOTE: Never operate a lathe until you remove the chuck wrench.)

Be sure the end of the stock is resting on the face of the chuck if the stock is larger than the center hole in the chuck. Place the point of the indicator on the stock, and spin the chuck slowly to note the amount and direction of runout. The chuck jaws are numbered to make this task easier. When you determine which way to move the stock, remember to loosen the jaw on one side before tightening the opposing jaw, and then check runout again.

Centering work in a four-jaw chuck is generally by trial and error, but with a little practice you can usually eliminate runout with just a few adjustments.

Once the work is running true, take up evenly on all four jaws and check runout again. The work must be chucked tightly, but not so tightly as to distort it.

Center Drilling

A center hole must be drilled if the end of a piece of stock is to be drilled or if it is to be held in a center. Figure 9-33 shows the method for center drilling a short shaft. Figure 9-34 shows a long shaft supported with a center rest.

A correctly formed center hole must support the center and allow clearance for the center point, as shown in figure 9-35, view A. The dead center

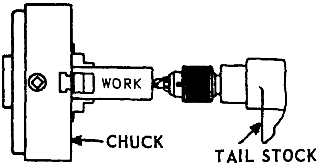

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Figure 9-33.—Drilling a center hole.

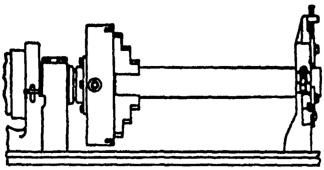

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Figure 9-34.—Work mounted in a chuck and center rest.

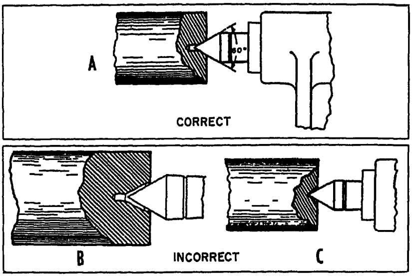

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Figure 9-35.—Examples of center holes.

is subjected to considerable friction and pressure so it must be properly lubricated. If center drilling is too deep (fig. 9-35, view B) or incorrectly shaped (fig. 9-35, view C), the work will not be adequately supported.

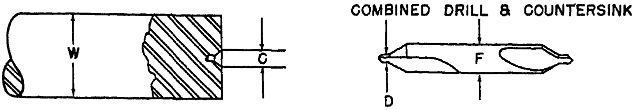
Figure 9-36 shows the correct size center drills to use for various stock diameters.

Turning Between Centers

When it is not practical or desired to clamp work in a chuck, or if you are machining a piece held on a mandrel, turning between centers will be necessary. Always align the centers as shown in figure 9-37 prior to mounting the work NEVER assume that the centers are already aligned. Even a slight amount of misalignment will produce a taper rather than a consistent diameter

Notice the setup in figure 9-38 A lathe dog is clamped to the shaft near the headstock A projection on the dog rests in a slot in the faceplate, thereby turning the shaft Also notice that a follower rest is used to prevent the shaft from springing away from the cutting tool

Before turning accurate work, you should test the mandrel on centers before placing any work on it. The best test for runout is made with an indicator. The indicator is mounted on the tool post and applied to the mandrel as it is turned slowly between centers. Any runout will then be registered on the dial which is graduated in thousandths of an inch. If there is runout and you cannot correct it by cleaning the live center and headstock spindle, 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 may have been bent by careless handling. Be sure to always



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 9-36.—Correct size of center holes.

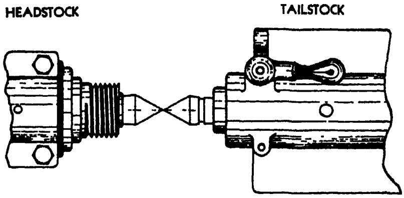


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Figure 9-37.—Aligning lathe centers.

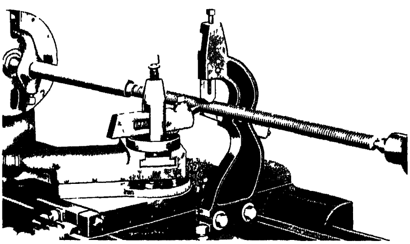

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Figure 9-38.—Follower rest supporting work turned between centers.

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, you must have a tighter press fit than for finishing. Therefore, you should remove thin-walled metal from the mandrel after the roughing cut and reload it lightly on the mandrel before taking the finish cut.

Setting the Cutting Tool

The first requirement for setting the tool is to have it rigidly mounted. Be sure the tool sets squarely in the tool post 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 damage to both the tool and the work The distances represented by A and B in figure 9-39 show the correct overhang for the tool bit and the holder.

The point of the tool must be correctly positioned on the work. Place the cutting edge slightly above the center for straight turning of

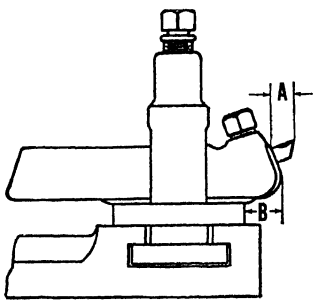

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Figure 9-39.—Tool overhang.

steel and cast iron, and exactly on the center for all other work and metals. To set the tool at the height desired, position the rocker under the toolholder. By placing the tool point opposite the tailstock center point, you can adjust the setting accurately.

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, that causes 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 hardest 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, or you may need to regrind the tool bit. Also, you should support the work with a center rest or follower rest.

Machine adjustment may be the cause of chatter. Gibs may be too loose or bearings may be worn after a long period of heavy service. If the machine is in perfect condition, the fault will be in the tool or tool setup. Grind the tool nose to a smaller radius and avoid a wide, round leading edge on the tool. 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 is the first thing you should correct when chatter occurs.

Turning

Turning is the machining of excess stock from the periphery of the workpiece to reduce the diameter. In most machining operations that require removal of large amounts of stock, a series of roughing cuts is taken to remove most of the excess stock. A finishing cut is then taken to accurately "size" the workpiece. The proper tool should be selected for taking a heavy cut. 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 scale on 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.

Figure 9-40 shows the position of the tool for taking a heavy cut on large work. The tool should be set so that if anything occurs during machining to change the position of the tool, it will not dig into the work, but will move in the direction of the arrow—away from the work. Setting the tool in this position sometimes prevents chatter.

Regardless of how the work is held in the lathe, the tool should feed toward the headstock. In this way most of the pressure of the cut will be 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.

The work should be rough machined to almost the finished size; so be careful when measuring.

Bear in mind that the diameter of the work being turned is reduced by an amount equal to twice the depth of the cut; thus, if you want to reduce the diameter of a piece by

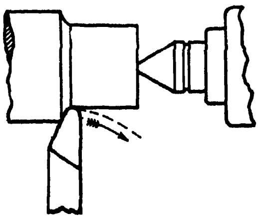

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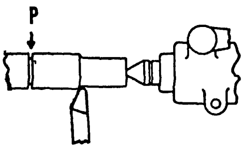
Figure 9-40.—Position of the tool for a heavy cut.



28.133X

Figure 9-41.—Machining to a shoulder.

0.010 inch, you must remove 0.005 inch from the surface.

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 you are measuring.

Where very close limits are to be held, be sure that the work is not hot when you take the finish cut. Cooling of the piece will leave it undersized if it was turned to the exact size while hot.

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 use 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 as shown at P in figure 9-41. Insert the parting tool about 1/32 inch from the shoulder line, and enter the work to within 1/32 inch of the finished diameter of the work. Then, machine the stock by taking heavy cuts up to the shoulder thus made. Shouldering eliminates repeated measuring and speeds up production. Then you can take a finishing cut to an accurate measurement.

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 needed as the work will have been cut to the approximate length or rough machined to the shoulder.

Figure 9-42 shows the methods of facing the end of a shaft. A right-hand tool is used as shown, and a light cut is taken on the end of the work, feeding the tool (by hand or power cross-feed) from the center toward the outside. One or two cuts are taken to remove sufficient stock to true the work.

Figure 9-43 shows the application of a turning tool in finishing a shouldered job that has a fillet corner. A finish cut is taken on the smaller diameter, and the fillet is machined with a light cut. The tool is then used to face from the fillet to the outside diameter of the work.

In facing larger surfaces, the carriage should be locked in position, since only cross-feed is needed to transverse 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 one-half of a thousandth of an inch. (In a 30° to 60° right triangle, the length of the side opposite the 30° angle is equal to one-half the length of the hypotenuse.)

Boring

Boring is the same as turning, except that cuts are taken from the inside surface of the work. If the outside surface is running true, a bored hole will be perfectly concentric. Stock to be bored can

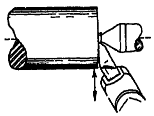


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Figure 9-42.—Facing the end of a shaft.

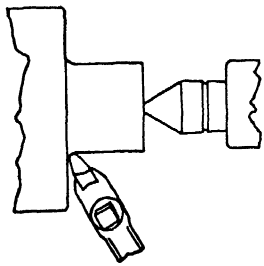

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Figure 9-43.—Facing a shoulder.

The terms training manual (TRAMAN) and nonresident training course (NRTC) are now the terms used to describe Navy nonresident training program materials. Specifically, a TRAMAN includes a rate training manual (RTM), officer text (OT), single subject training manual (SSTM), or modular single or multiple subject training manual (MODULE); and a NRTC includes nonresident career course (NRCC), officer correspondence course (OCC), enlisted correspondence course (ECC) or combination thereof.

Although the words "he," "him," and "his" are used sparingly in this manual to enhance communication, they are not intended to be gender driven nor to affront or discriminate against anyone reading this text

Example 2: Find the taper per foot of a piece 2 inches in diameter at the large end, 1 inch in diameter at the small end, and 6 inches in length. (See fig. 9-45.)

$$\frac{2 - 1}{6} \times 12 = 2\text{-inch TPF}$$

In the preceding examples, notice that the actual amount of taper in both pieces is 1 inch (difference in size of large and small ends). The degree of taper in a certain length is important in establishing the TPF.

Tapers are also expressed as an angle. The included angle of a tapered piece is twice the angle that a cutting tool must make with the axis of a lathe to produce that taper. For instance, if you want to cut a 60° lathe center, you must set the compound rest at 30°.

There are several standard tapers in common usage for machine tools (Morse, Jarno, and Brown & Sharpe). This standard usage makes it possible to interchange parts and attachments. Taper pins have a 1/4-inch TPF and pipe threads have a 3/4-inch TPF.

If you are ever required to make a special fitting for a machine, simply refer to the *Machinist's Handbook* for all necessary dimensions

To produce a taper, you must either cause the cutting tool to move at an angle in relation to the axis of the lathe (taper attachment-compound rest), or you must mount the work at an angle (tailstock setover).

As stated earlier, adjusting screws allow you to move the tailstock top laterally on its base In straight turning, you will recall that you used these adjusting screws to align the dead center with the live center by moving the tailstock to bring it on the center line In taper turning, you deliberately move the tailstock off center, and the amount you move it determines the taper produced You can set the approximate amount of setover by using the zero lines inscribed on the base and top of the tailstock. Then, for final adjustment, measure the setover with a rule between center points, as illustrated in figure 9-46.

In turning a taper by this method, the distance between centers is of utmost importance. To illustrate, figure 9-47 shows two very different tapers produced by the same amount of setover of the tailstock. The closer the dead center is to the live center, the steeper the taper produced. Tapers produced by this method are less accurate than by other methods because you cannot completely seat the centers in the center holes.

The compound rest is generally used for short, steep tapers. Such jobs are often referred to as working to an angle rather than as taper work. The length of taper that can be machined by this method is necessarily short because of limited travel of the compound rest.

The graduations marked on the compound rest allow you to set the angle you need quickly. When set at zero, the compound rest is perpendicular to the lathe axis. When set at 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 center line, the setting of the compound rest corresponds to the complement of that angle. (The complement of an angle is that angle, which, when added to it, makes a right angle.) For example, to machine a 50° included angle (25° angle with the center line), set the compound rest at 90° − 25°, or 65°.

When you must make a very accurate setting of the compound rest to a fraction of a degree, run the carriage up to the chuck, and set the compound rest with a vernier bevel protractor set to the required angle. Hold the blade of the protractor on the flat surface of the chuck, and hold the base against the finished side of the compound rest.

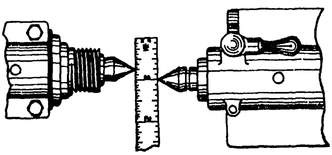

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Figure 9-46.—Measuring setover of dead center.

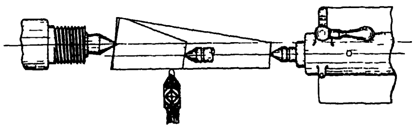

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Figure 9-47.—Setover of tailstock showing importance of considering length of work.

For turning and boring long tapers with accuracy, the taper attachment is indispensable. It is especially useful in duplicating work; you can turn and bore identical tapers with one setting on the taper guide bar.

When preparing to use the taper attachment, position the carriage approximately in the middle of the length of the work to be tapered, and move the cutting tool nearly up to the work with the cross slide handwheel. Set the desired taper on the guide bar. (NOTE: You must set the tool bit exactly on center for taper turning.)

Now remove the chip guard from the cross slide and disengage the cross-feed nut (fig. 9-18). Position the taper guide bar even with the ends of the saddle, and clamp the holding bracket to the ways (fig. 9-22). Attach the slotted guide to the cross slide; then tighten the hand clamp on top. Lateral movement of the tool bit is now controlled by the taper attachment. Adjustments for depth of cut will be made with the compound rest.

Carefully eliminate any mechanical backlash in the setup for each cut you take by moving the carriage so the cutting tool goes past the end of the work prior to engaging longitudinal feed. If you neglect this step, a short section of the work will be turned straight, rather than tapered, until slack is taken up.

In 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 having to remove metal at the extreme bottom of the bore, which is rather difficult, particularly in small, deep holes.

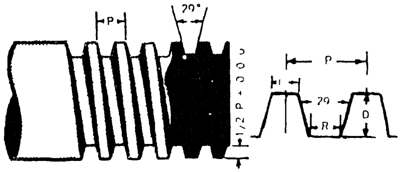
Precision plug and socket gauges (fig. 9-48) are used to test the size and accuracy of standard tapers. For nonstandard tapers, the mating part is used. After taking several cuts, remove chips from the work and make a chalk mark the full length of the male taper. Then fit the parts together and twist slightly to mark the chalk. If the parts do not bear evenly the full length of the chalk mark, you must make a slight adjustment on the taper guide bar. Take another cut, chalk and fit the parts, and make another adjustment until the taper is correct before turning to required size.

Threading

Most of the machine work done by an Opticalman is limited to V-form threads, even though normal duties will bring you in contact with acme threads (fig. 9-49) and square threads (fig. 9-50).

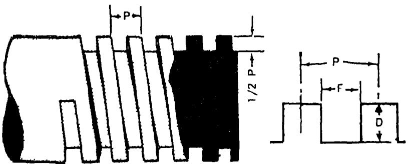
Each of these thread forms is used for specific applications. Fastening devices, such as bolts, nuts, and machine parts, usually have V-form threads. Acme screw threads are generally used for transmitting motion, such as that between the lead screw and lathe carriage. Square threads are used to increase mechanical advantage and to provide good clamping ability as in the screw jack or vise screw

There are many terms used in describing screw threads and screw thread systems that you must know before you can calculate and machine screw



28.147

Figure 9-49 —Acme thread



28.149

Figure 9-50.—Square thread.

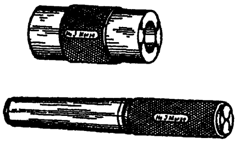


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Figure 9-48.—Morse taper socket gauge and plug gauge.

threads. Figure 9-51 illustrates the application of some of the following terms:

EXTERNAL THREAD: A thread on the external surface of a hollow cylinder.

INTERNAL THREAD: A thread on the internal surface of a hollow cylinder.

RIGHT-HAND THREAD: A thread that, when viewed axially, winds in a clockwise and receding direction.

LEFT-HAND THREAD: A thread that, when viewed axially, winds in a counterclockwise and receding direction.

LEAD: The distance a threaded part moves in one complete revolution.

PITCH: The distance between corresponding points on adjacent threads.

SINGLE THREAD: A single (single start) thread that has a lead equal to the pitch.

MULTIPLE THREAD. A multiple (multiple start) thread that has a lead equal to the pitch multiplied by the number of starts.

CLASS OF THREADS: Classes of threads 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 a shrink fit (class 5) through a loose fit (class 1).

THREAD FORM: The cross-sectional profile of a thread.

FLANK: The side 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.

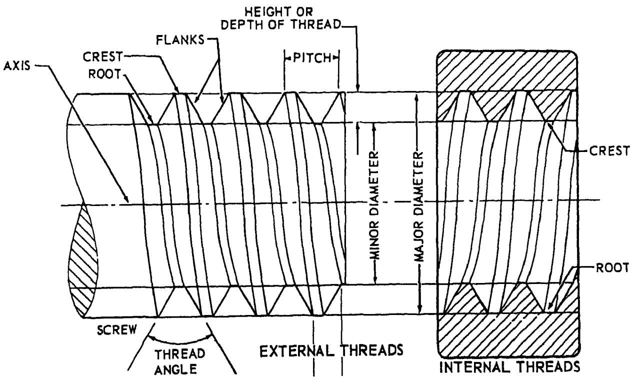
MINOR DIAMETER: The diameter of a cylinder that bounds the root of an external thread or the crest of an internal thread.

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.

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).



28.145

Figure 9-51.—Screw thread nomenclature.

SLANT DEPTH: The distance from the crest to the root of a thread measured along the flank 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 (1/4-20nc) and the fine series (1/4-28nf).

The Naval Sea Systems Command and naval procurement activities use American Standard Unified threading systems whenever possible; this system is recommended for use by all naval activities. The American Standard thread is a unified series of threads that permits the United States to interchange standard thread fastening devices manufactured in the United States, Canada, and the United Kingdom.

V-FORM SCREW THREAD.—To cut a V-form 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.

Pitch.—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.

Straight Depth.—Twice the straight depth of an internal thread subtracted from the outside diameter of the externally threaded part determines the bore diameter of a mating part to be threaded internally.

Slant Depth.—When the thread-cutting tool is fed into the workpiece at one-half of the included angle of the thread, the slant depth determines how far to feed the tool into the work.

Width of the Flat.—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 formulas will provide you with the information you need to know for cutting V-form American Standard Unified threads.

Pitch $= 1 \div$ number of threads per inch, or $\frac{1}{n}$

Depth of external thread $= 0.61343 \times$ pitch

Depth of internal thread $= 0.54127 \times$ pitch

Width of flat at point of tool for external threads $= 0.166 \times$ pitch

Width of flat at point of tool for internal threads $= 0.125 \times$ pitch

Slant depth of external thread $= 0.708 \times$ pitch

Slant depth of internal thread $= 0.625 \times$ pitch

To produce the correct thread profile, the cutting tool must be accurately ground to 60° with 0° back rake (fig. 9-52, view A) Also the cutting tool must be set in the correct position.

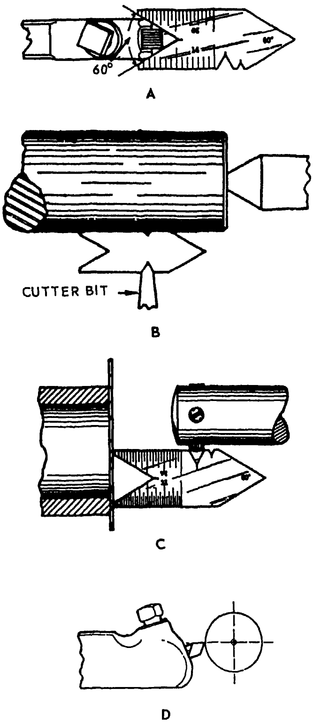
Use a center gauge or a thread-tool gauge to check the exact angle. The top of the tool is usually ground flat However, for cutting threads in steel, side rake is sometimes used.

Set the threading tool square with the work, as shown in views B and C of figure 9-52. Use the center gauge to position the point of the threading tool. Of course, if you do not set the threading tool perfectly square with the work, the angle of the thread will be incorrect

For cutting external or internal threads, place the top of the threading tool exactly on center as shown in view D of figure 9-52 Note that the top of the tool is ground flat and is in exact alignment with the lathe center

The size of the threading tool used 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 as possible in diameter and as short as possible to prevent its springing away from the work during cutting.

USING A LATHE FOR CUTTING THREADS.—For cutting screw threads, the headstock spindle of the lathe is connected to the lead screw by a series of gears to obtain a positive carriage feed; the lead screw is driven at the



28.146X
Figure 9-52 —Threading tool setup for V-form threads.

required speed with relation to the headstock spindle. The gearing between the headstock spindle and lead screw can be arranged to cut any desired pitch 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. The quick-change gearbox allows you to make the proper gearing arrangement quickly and easily by placing the levers, as indicated on the index plate, for the thread desired.

Until you become very proficient at threading, always put the lathe in back gear and turn the headstock at approximately 60 rpm.

When threading work in the lathe, 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.

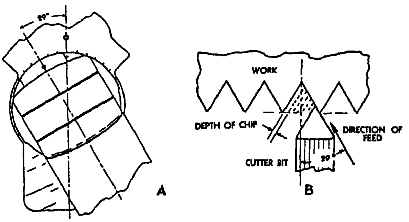
When threading long slender shafts, use a follower rest. Use the center rest to support one end of long work that you are threading on the inside.

To cut external V-form threads, it is customary to place the compound rest of the lathe at an angle of 29°, as shown in view A of figure 9-53. With the compound rest set in this position and the compound rest screw adjusted to the depth of cut, most of the metal will be removed by the left side of the threading tool (view B of fig. 9-53). The chip will curl out of the way better than if the tool is fed straight in. Also, the thread will not tear. 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.

To cut internal V-form threads, set the compound rest at 29° in the opposite direction and back the tool into the work for each cut.

To prepare for the first threading cut, position the carriage so you can feed the tool in with the cross slide handwheel to contact the work. Then, loosen the locks on the cross slide and compound rest micrometer collars and set the collars to zero. Be sure to tighten the micrometer collar lock screws. Move the carriage so the threading tool is approximately 1/2 inch from the end of the work.

To cut threads on a lathe, clamp the half nuts (threading lever) over the lead screw to engage the threading feed. At the end of the cut, release the threading feed with the threading lever. Use the



28.150X
Figure 9-53.—Compound rest set at 29°.

threading dial (fig. 9-25), discussed earlier in this chapter, to determine the time to engage the threading lever so that the cutting tool follows the same path during each cut. Align the index mark on the threading dial with the witness mark on the housing, and then engage the threading lever. For some thread pitches, however, the threading lever can be engaged only when certain index marks are aligned with the witness mark. You can engage the threading lever on most lathes as follows:

1. For all even-numbered threads per inch, close the threading lever at any line on the dial.
2. For all odd-numbered threads per inch, close the threading lever at any numbered line on the dial.
3. For all threads involving one-half of a thread in each inch, such as 11 1/2, close the threading lever at any odd-numbered line.

With the lathe set up as previously explained, you are now ready to take a very light trial cut. Start the lathe, watch the threading dial, and engage the threading lever. When the threading tool comes to the end of the length of thread desired, you must do two things at once: (1) disengage the threading lever, and (2) back the cross-feed out one revolution. This is particularly important in threading to a shoulder or the bottom of a hole.

Now stop the lathe and check the thread produced with a screw pitch gauge. The gauge consists of a number of sheet metal plates in which are cut the exact form of threads on the various pitches. Each plate is stamped with the number of threads per inch for which it is to be used.

Compare the appropriate gauge with the thread you just cut to be sure you have the quick-change gearbox set properly.

If the thread is correct, proceed with the threading. Move the carriage past the start of the work, return the cross-feed to zero, feed the compound rest in a few thousandths, and take another cut. (NOTE: Always use the correct cutting lubricant when threading.)

You do not have to stop the lathe after each cut. After you disengage the threading lever and back out the cross-feed, move the carriage past start, reset the cross-feed, feed the compound rest a few more thousandths, apply lubricant, and continue until you reach the predetermined depth for your thread.

Make the final check for fit, using the mating part for which you are machining the thread. You will usually want a snug fit without binding. If the thread is too tight, take another light cut. If the fit is too loose, you have made some incorrect calculations or adjustments and have wasted time and material. Do not be discouraged if your first attempts at threading are not perfect. Try to prevent the same mistakes again.

If the threading tool must be sharpened during operation or if you are chasing a previously cut thread, you can reset the lathe to catch the thread in the following manner:

Use a center gauge to check the angle of the tool and to set the tool square with the work. Also be sure the tool is again on center. Then with the tool a few thousandths of an inch away from the workpiece, start the machine and engage the threading mechanism; then stop the lathe.

Adjust the compound rest slide forward or backward so that the tool moves along 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, use the cross-feed screw to bring the tool point directly into the groove. When you get a good fit between the cutting tool and thread groove, set the micrometer collar on the cross-feed screw on zero Set the micrometer collar on the compound rest feed screw to the depth of cut previously taken or to zero, as required. Now back the cross slide out, move the carriage past the start of the thread, and proceed with the cutting

SAFETY PRECAUTIONS

You have studied the lathe and its operating procedures, but before you can apply this knowledge, you must understand and observe the principles of safety 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 greatly increases. Treat a machine with respect, and there will be no need to fear it.

When operating a lathe or any machine tool, be sure the area is free of personnel and objects that could make the job more hazardous. Your responsibility, as the operator, is to look out for others as well as yourself when chips are flying and your machine is in motion.

Safety precautions for all machinery in the shop are posted in the work area, so never begin an operation without reading these precautions. The posted precautions give detailed instructions that apply to the machine you are operating. Following are some general safety rules that apply:

- Always protect your eyes and your limbs from chips and moving parts by wearing safety goggles. Do not wear any loose clothing that can 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.

- Be 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.

MILLING MACHINES

A milling machine removes metal with a revolving cutting tool called a milling cutter. With various attachments, milling machines can be used for boring, broaching, circular milling, dividing, and drilling, for cutting keyways, racks, and gears; and for fluting taps and reamers.

To advance in rating you must demonstrate the ability to set up and perform basic milling machine operations 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 have both manual and power feed systems, a selective spindle speed range, and a coolant system.

KNEE AND COLUMN MILLING MACHINES

The knee and column milling machine is the type most commonly used by the Navy. 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 can be adjusted to raise or lower the table to accommodate various sized pieces of work.

You can take vertical cuts by feeding the table up or down. You can move the table 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. Therefore, you can mount work at practically any location on the table.

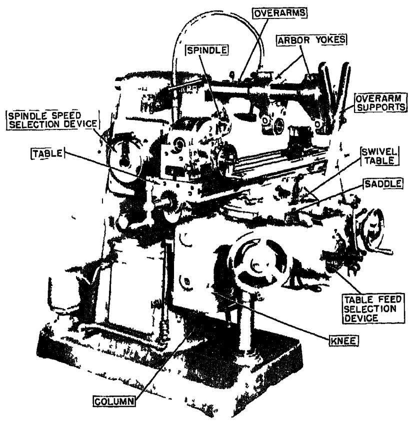
Knee and column milling machines are made in three designs: plain, universal, and vertical spindle.

Plain Milling Machine

As in all milling machines of this type, you can move the table of the plain milling machine in three directions: longitudinal (at right angles to the spindle), transverse (parallel to the spindle), and vertical (up and down). The machine's chief value results from its rigid construction—it can take heavy cuts at fast speeds with coarse feeds.

Universal Milling Machine

A universal milling machine (fig. 9-54) has all the principal features of the other types of

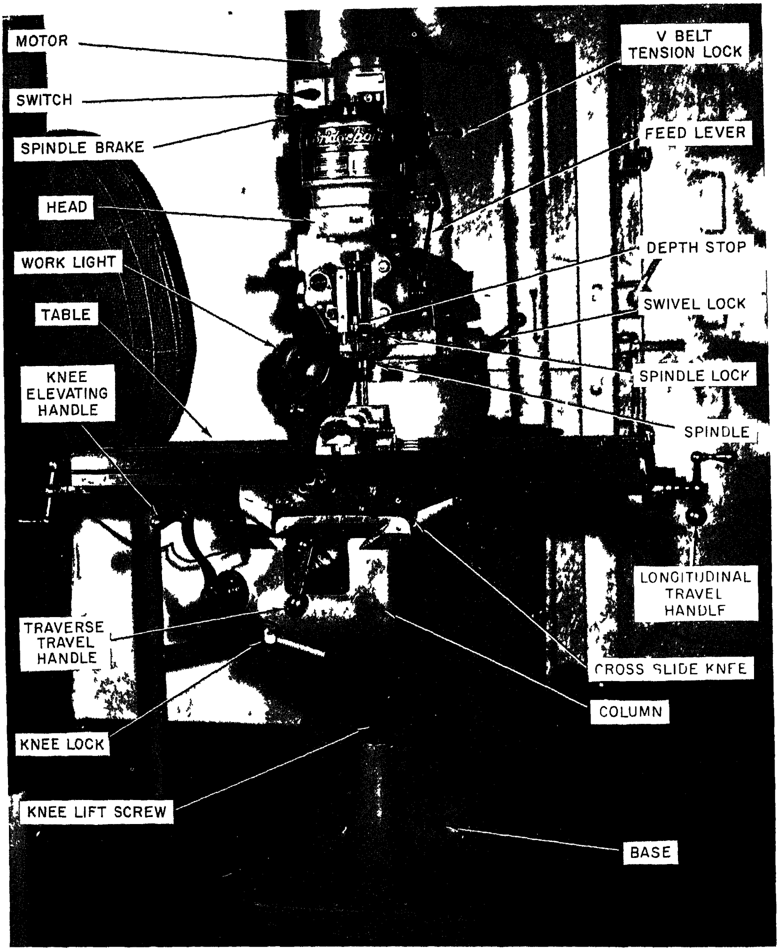


28.197X

Figure 9-54.—Universal milling machine.

milling machines. It can handle practically all classes of milling work. Its main advantage over the plain mill is that you can swivel the table 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.

A vertical milling attachment can be mounted in place of the overarms so that the spindle is vertical, rather than horizontal as shown. The basic design of the universal mill, coupled with



28.198(28D)

Figure 9-55.—Small vertical spindle milling machine.

a variety of attachments, makes this the most versatile of all milling machines.

Vertical Spindle Milling Machine

The vertical spindle milling machine (fig. 9-55) has the spindle in a vertical position and is similar in design and operation to the plain and universal milling machines. The vertical spindle can also be positioned up to 90° left or right of vertical. Since you can see both the cutter and the surface being cut, you can do face milling and end milling 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. You can use this type of machine for face milling, profiling, die sinking, and various odd-shaped jobs; you can also use it for boring holes.

Although knee and column milling machines vary slightly in design, depending on the manufacturer, the components labeled in figure 9-54 are common to most milling machines.

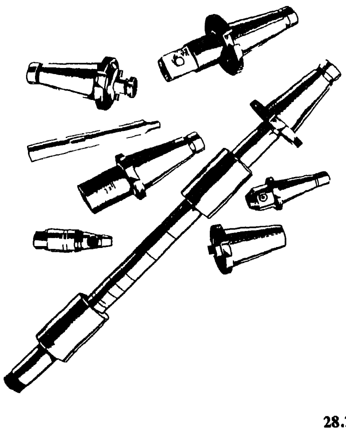
The spindle nose of all milling machines has a standard internal taper. Driving keys, or lugs, on the face of the spindle nose drive the cutter directly, or drive an arbor or adapter on which the cutter is mounted (fig. 9-56). The overarms, yokes, and overarm supports are used for accurate alignment and to support arbors. You can retract or extend the overarms from the column to any length needed to support the arbor The overarm supports are extremely helpful in supporting the cutter for taking heavy cuts. The overarm supports are used with the yokes and overarms.

STANDARD EQUIPMENT

Standard equipment for milling machines in Navy ships includes work-holding 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 found in Navy repair work.

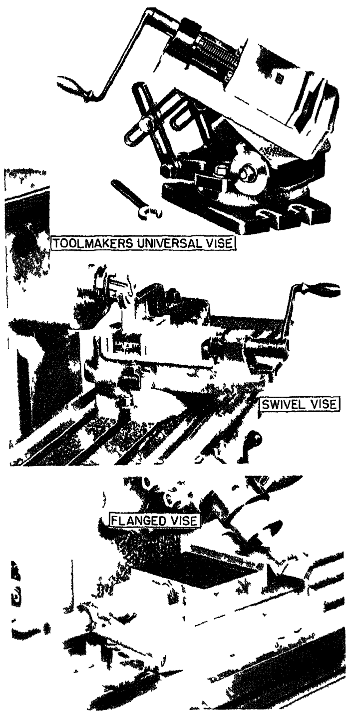
Vises

The vises commonly used on milling machines are the flanged plain vise, swivel vise, and toolmakers universal vise (fig. 9-57).



28.204X

Figure 9-56.—Arbors, sleeves, and special adapters.



28.199X

Figure 9-57.—Milling machine vises.

A flanged vise provides a rigid work-holding setup when the surface to be machined must be parallel to the surface seated in the vise.

A swivel vise is used similarly to a flanged vise, but the setup is less rigid, allowing the workpiece to be swiveled in a horizontal plate to any required angle.

A 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.

Index Head

Indexing equipment (fig. 9-58) is used for holding and turning the workpiece to make a number of accurately spaced cuts (gear teeth, for example). The workpiece is held in a chuck, attached to the index head spindle. The center rest can be used to support long slender work. The center of the footstock may be raised or lowered to set up tapered workpieces.

The basic components of an index head are shown in figure 9-59. The ratio between the worm and gear is 40:1. One turn of the worm rotates the spindle 1/40 of a revolution. The index plates, which have a series of concentric circles of holes, permit accurate gauging of partial turns of the worm shaft and allow the spindle to be turned accurately in amounts smaller than 1/40 of a revolution. It is also easy to convert spindle rotation to an angular value in degrees and minutes. The index plate may be secured to the index head housing or to the worm shaft. You can adjust the crankpin radially for use in any circle of holes. You can set the sector arms to span

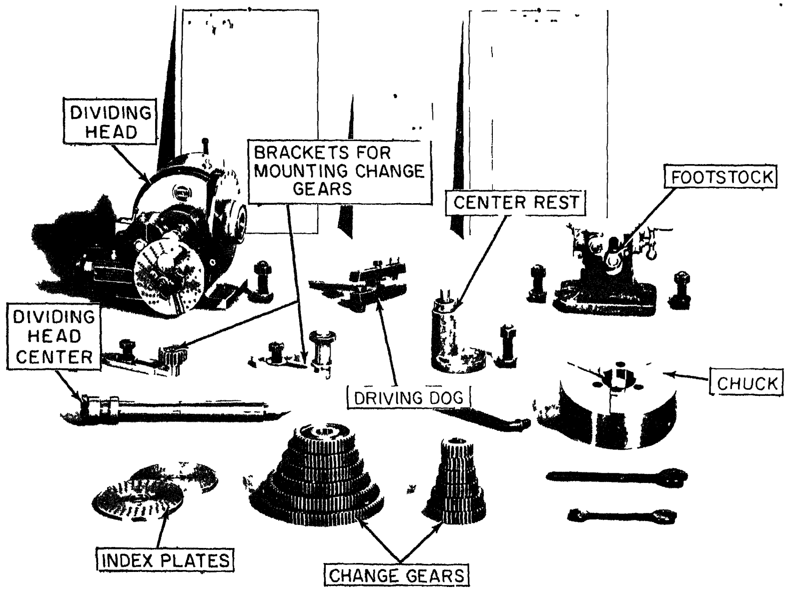


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Figure 9-58.—Index head and associated fittings.

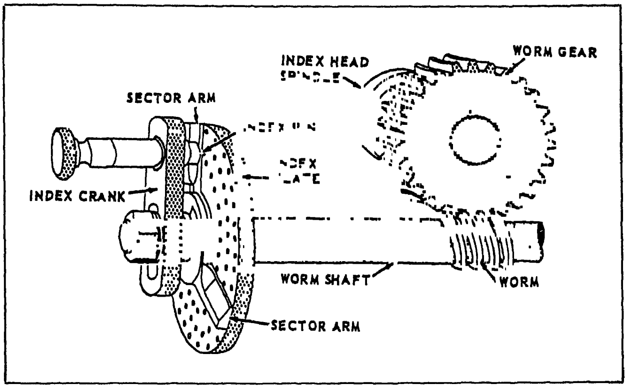

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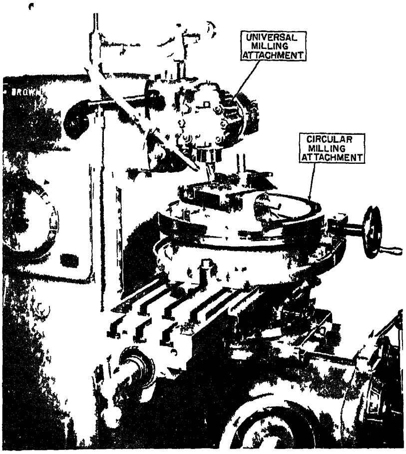
Figure 9-59.—Index head mechanism.

any number of holes in the index plate to provide a guide for rotating the index crank for partial turns.

You can turn the index head spindle 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 for indexing, while the third is for rotating the workpiece (while it is being cut) to make helical cuts

Universal Milling Attachment

The universal milling (head) attachment (fig. 9-60) is clamped to the column of the milling machine The cutter can be secured in the spindle of the attachment and set by two rotary swivels so that it will cut at any angle to the horizontal or the vertical plane The spindle of the attachment is driven by gearing connected to the milling machine spindle

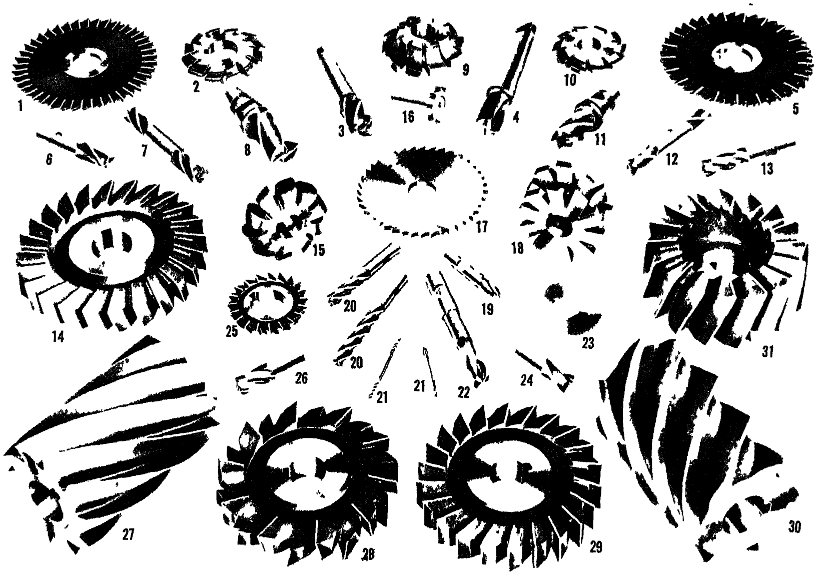


28.202X

Figure 9-60.—Circular milling attachment and universal (head) attachment.

Circular Milling Attachment

The circular milling attachment, or rotary table, shown in figure 9-60, is used to set up work that must be rotated in a horizontal plane. The worktable is graduated (1/2° to 360°) around its circumference. You can turn the table by hand or by the table feed mechanism through a gear train. An 80:1 worm and gear drive in the rotary table and index plate arrangement makes this device useful for accurate indexing of horizontal surfaces.



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 keyseat 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 mill for use with shell end mill arbor.

28.205X

Figure 9-61.—Milling machine cutters.

Milling Cutters

The variety of cutters used with milling machines adds to the versatility of the mill. Figure 9-61 shows a small sample of cutters commonly used. The cutters, used with other attachments, provide an endless list of applications.

End mills are used for facing, slotting, boring, and cutting various angles on work. Formed cutters (2 and 10 in fig. 9-61) are used for cutting gears and racks. The other cutters shown are used for slitting, heavy facing or slotting, and heavy slab cuts.

End mills are held in the milling machine spindle either in collets or special adapters. The other cutters are mounted on an arbor (fig. 9-62) and are usually prevented from turning on the arbor by a key and keyway. You can mount a single cutter on the arbor, as shown, or you can mount several cutters and spacers to take multiple cuts with one setup.

Figure 9-63 shows how a dovetail or T-slot for holddown bolts is cut. First, rough out the hole with an end mill, and then use the appropriate formed cutter. In fact, with a milling machine, if you ever need a specially shaped cutter, you can make it yourself.

A word of caution concerning end mills. You can use two-lip end mills carefully to bore holes since the cutting edge extends the full width of the end (8 in fig 9-61) Four-lip mill ends are relieved in the center, so only the outer half of each lip can cut (11 in fig. 9-61). Do NOT use a four-lip end mill for boring; it could shatter, causing serious injuries.

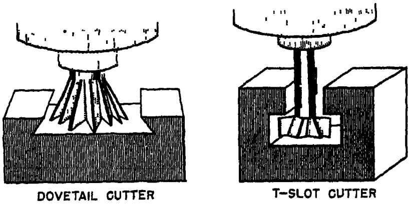


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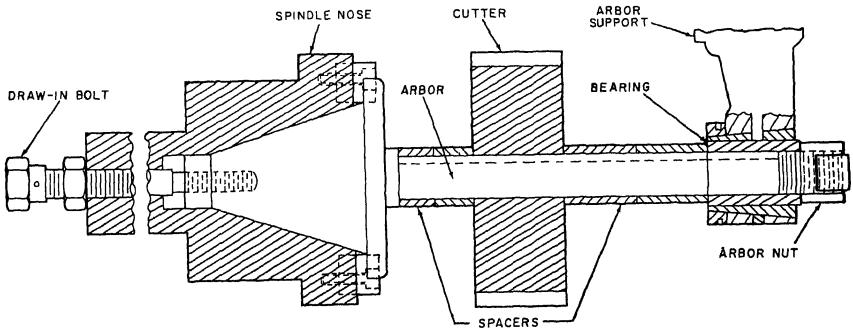
Figure 9-63.—Application on T-slot and dovetail cutters.

As a general rule, the more teeth a cutter has, the smoother the finished surface will be. Helical teeth will also produce a very smooth cut. Coarse cutters and stagger-tooth cutters are normally used for roughing cuts The distance between teeth allows ample room for chip clearance and coolant flow so heavy feeds can be used efficiently.

MILLING MACHINE OPERATION

A mill is more complicated to operate than a lathe, mainly because of the various attachments, applications, and planes of movement available. If you plan your work carefully, appreciate the limitations of the machine, and use reasonable caution, no one will get hurt, and the job should be successful.



28.211

Figure 9-62.—Standard arbor.

You must become thoroughly familiar with the controls for table feeds. Since the table moves in six directions, engaging the wrong lever could be disastrous.

Setup Procedures

Cutting tools and work-holding devices must be TIGHT. With all components held securely, you avoid the possibility of vibration or of launching a piece of work across the shop. Mating surfaces must be absolutely clean and free of chips so that you can properly mount the work, cutter, and attachments.

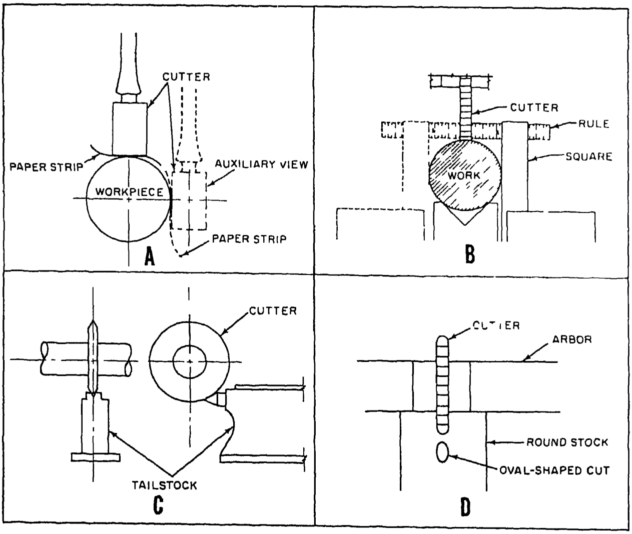
A dial indicator is absolutely necessary for most setups. It is used (1) for squaring the table of a universal mill or the jaws of a swivel vise, (2) for trueing the spindle of a vertical mill or vertical attachment, (3) for checking runout of work held in an index head, and (4) for leveling other setups.

Once you are sure the cutter and work are properly mounted and are true and square, proceed with positioning the cutter. Figure 9-64 shows various methods for positioning cutters to mill round stock. These same methods are also used for all other shapes.

On a milling machine, the cross-feed, longitudinal feed, and vertical feed handles have micrometer collars to allow very precise positioning.

The most accurate method to position a cutter is shown in figure 9-64, view A. The following steps should be used when possible:

1. Move the workpiece into position, as shown in the auxiliary view of figure 9-64, view A, 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 it 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 side of the workpiece. (NOTE: Be very careful to keep your hands clear of the cutter when using the paper.)



28.212

Figure 9-64.—Methods of positioning cutter.

4. If you intend to slot the top of the work, lower the table 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. The cutter is now centered on the axis of the shaft.

The method just described works equally well with end mills or arbor-type cutters.

If the cutter is so small that the arbor or spindle nose touches the workpiece, you can align the cutter with some degree of accuracy by using squares on each side of the work and centering the cutter with a 6-inch rule (fig. 9-64, view B).

Figure 9-64, view C, shows the method for aligning a cutter with the footstock center, if the work is to be held between centers.

Figure 9-64, view D, shows a light trial cut taken with a perfectly centered cutter.

Direction of Cutter Rotation

In selecting the direction of cutter rotation and table travel, the conventional milling practice is to make the cutter revolve against the advancing table to cut up into the work (fig. 9-65) 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 rotate the cutter with the direction of table feed, making the cutter cut down into the work With the latter system there is less chance of the cutter being drawn to one side, producing crooked slots

When the work moves with the cutter, you must carefully eliminate any looseness and lost motion in the table by setting the table gibs snugly.

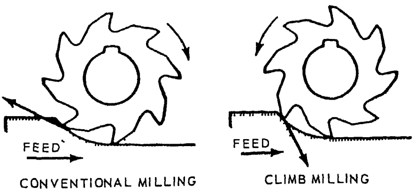


Figure 9-65.—Conventional and climb milling.

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 personnel injury.

Before you start any cutting, be sure the spindle is rotating in the proper direction. You will not remove much metal if the cutter is revolving backwards.

Feeds and Speeds

The spindle speed of milling machines usually ranges from 25 to 2,000 rpm, and the feed ranges from 1/4 inch to 30 inches per minute (ipm). Since the feed is independent of the spindle rotation, a workpiece can be fed at any rate in the feed range regardless of the spindle speed. Some of the factors concerning the selection of appropriate feeds and speeds for milling are discussed in the following paragraphs.

SPEEDS.—You can regulate the heat generated by friction between the cutter and work by using the proper speed, feed, and cutting coolant. Heat regulation 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 to govern cutting speeds because conditions vary from job to job Generally speaking, you should select a cutting speed which gives the best compromise between maximum production and longest life of the cutter. In any particular operation, consider the following factors in determining the proper cutting speed:

- Hardness of the material being cut: The harder and tougher the metal being cut, the slower should be the cutting speed.

- 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 often be made at a speed 40 percent to 80 percent higher than that used in roughing since the depth of cut is less.

- Cutter material. Carbide tool cutters may be operated from 50 percent to 100 percent faster than high-speed cutters because carbide cutters have better heat-resistant properties.

- Type of cutter teeth: Cutters with undercut teeth cut more freely than those with a radial face (gear cutters and concave and convex cutters); therefore, cutters with undercut teeth may be run at higher speeds.

- Sharpness of cutter: A sharp cutter may be run at a much higher speed than a dull cutter.

- Thickness of the cutter: Cutters like 27 and 30 in figure 9-61 put considerable strain on the machine; consequently, they should turn a little slower.

- Use a coolant: Sufficient coolant will usually cool the cutter so that it will not overheat even at relatively high speeds. The same coolants used for lathe work are appropriate for milling.

Use the approximate cutting speeds in the following list as a guide in selecting the proper cutting speed for high-speed steel cutters. If you find that the machine, the cutter, or the work cannot be suitably operated at the suggested speed, make an immediate readjustment. It is usually advisable to reduce the spindle speed and decrease the depth of cut.

	Rough (ft/min)	Finish (ft/min)
Cast iron:		
Malleable	90	100
Hard castings	15	20
Annealed tool steel	40	50
Low carbon steel	60	70
Brass	200	250
Aluminum	700	900

The proper cutting speed (fpm) for various diameter milling cutters turned at available spindle speeds (rpm) is as follows:

$$\text{fpm} = \frac{\pi D \times \text{rpm}}{12}$$

This formula should be familiar to you by now, since you used it to compute drilling speeds and lathe cutting speeds.

Example: What spindle speed should you use to turn a 1/2-inch end mill to produce a cutting speed of 45 fpm?

$$45 \text{ fpm} = \frac{3.14 \times 0.5 \times \text{rpm}}{12}$$

or

$$540 = 1.57 \times \text{rpm}$$

$$\text{rpm} = \frac{540}{1.57} = 344$$

Example: What is the cutting speed of a 2 1/4-inch end mill turning at 204 rpm?

$$\text{fpm} = \frac{3.14 \times 2.25 \times 204}{12}$$

$$\text{fpm} = \frac{1441}{12} \approx 120$$

FEEDS.—The rate of feed is the rate at which the workpiece travels past the cutter When selecting the feed, you should consider the following factors:

- Forces 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, are 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

- 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 will 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.

- 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.

● The desired degree of finish affects the amount of feed. When a fast feed is used, metal is removed rapidly and the finish will not be very smooth. However, a slow feed rate and a high cutter speed will produce a finer finish. For roughing, you should use a comparatively low speed and a coarse feed. More mistakes are made by overspeeding the cutter than by overfeeding the work. Overspeeding produces a squeaking, scraping sound. If chatter 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.

Indexing

Direct indexing, sometimes called rapid indexing, is done with the 24-hole direct index plate which is mounted just back of the work on the index head spindle (fig. 9-66). Disengage the index crank worm from the index head spindle so you can rotate simultaneously by hand the direct index plate, spindle, and work. An indexing pin, entering the index plate from the rear, locks the assembly and prevents unwanted rotation. You can produce any number of divisions, evenly divided into 24 (2, 3, 4, 6, 8, 12, 24), by this method. If you need to divide a piece of work into 6 equal parts, for instance, divide 6 into 24 The result, 4, is the number of holes to advance the index plate for each cut.

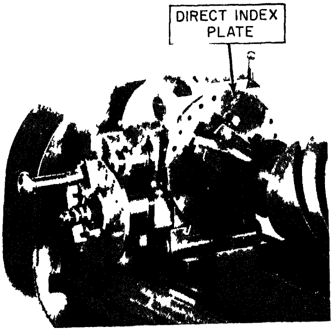


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Figure 9-66.—Direct index plate.

In any indexing operation, ALWAYS start counting from the hole adjacent to the crankpin. During heavy cutting operations, lock the spindle with the clamp screw to relieve strain on the index pin.

Plain indexing, 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. Index heads are available with ratios of 4:1, 5:1, and 40:1. The 40:1 index head is most common, so formulas based on this ratio are explained next. If you encounter an index head with a different ratio, just substitute that ratio for 40.

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, divide 40 by 40, indicating that one complete turn of the index crank is required for each division. If 10 divisions are required, divide 40 by 10; 4 complete turns of the index crank will be required for each division. 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.

Suppose you need to make 9 divisions:

$$\frac{40}{9} = 4\frac{4}{9}$$

or 4 turns and 4 holes in a 9-hole circle.

You will not be able to find a 9-hole circle, so you must multiply the numerator and denominator of the above fraction by the same factor to correspond with an available plate If you have a plate with a 24-hole circle, your problem is solved since 9 divides into 27 three times, therefore:

$$\frac{40}{9} \times \frac{3}{3} = \frac{120}{27} = 4\frac{12}{27}$$

or 4 turns and 12 holes in a 27-hole plate.

Occasionally, you may make a number of divisions that may lead to some complications, 52 for instance. It is doubtful that you will be able to find a plate with a 52-hole circle, so you could reduce your fraction:

$$\frac{40}{52} = \frac{20}{26}$$

This will work if you have an available 26-hole circle. If not, you will need some further manipulation of the basic problem. Try dividing by a common factor:

$$\frac{40}{52} \div \frac{4}{4} = \frac{10}{13}$$

No 13-hole plate either? Then multiply the result by a common factor:

$$\frac{10}{13} \times \frac{3}{3} = \frac{30}{39}$$

You have a 39-hole plate so, as odd as it may seem, 30 holes in a 39-hole circle will produce 52 graduations.

When indexing is necessary, do not become discouraged by strange looking fractions. You can divide the numerator and denominator by a number that divides evenly into both to find an appropriate index plate with a smaller number of holes, or you can multiply both by a common factor to correspond with an index plate with a larger number of holes.

To avoid the confusion of counting holes each time you index your work, be sure you set the sector arms (fig. 9-59) before starting. Advance the rear arm up to the index pin; then set the lead arm to span the correct number of holes. You can now lock the sector arms so they move together, but not independently. When you index your work and set the index pin next to the lead arm, simply slide the back arm up to the pin in preparation for your next indexing

Angular indexing, although quite similar to plain indexing, is applied differently. Rather than dividing a workpiece into a number of evenly spaced sections, index your work to achieve a certain angular relationship between surfaces. Since the index head rotates at a 40:1 ratio, one turn of the index crank revolves the work 1/40 of 360°, or 9°. Therefore, 9° becomes the basis for computing required angles.

Suppose you need to produce several surfaces at an angle of 15° to each other. Simply divide the angle desired by 9:

$$\frac{15}{9} = 1\frac{6}{9}$$

You need to rotate the index crank one revolution and 6 holes in a 9-hole circle. You will not find a 9-hole circle, but an index plate with 54 holes is common. Therefore, multiply by a common factor to correspond with an available plate:

$$\frac{6}{9} \times \frac{6}{6} = \frac{36}{54}$$

One turn and 36 holes in a 54-hole circle will result in a 15° advance of the index head.

Now try this one: You need to produce some surfaces at 85° to each other, and you want to use a 27-hole circle:

$$\frac{85}{9} = 9\frac{4}{9} = 9\frac{12}{27}$$

or 9 turns and 12 holes in a 27-hole circle

What will happen if a rotation of 25°10′ is called for? First of all, convert the 9° basic figure to minutes

$$9 \times 60 = 540'$$

Then convert 25°10′ to minutes 25 × 60 = 1500′ plus 10′ = 1510′ Now proceed as in previous examples

$$\frac{1510}{540} = 2\frac{430}{540}$$

You may have already guessed that an index plate with 540 holes is going to be rather rare How about reducing the fraction by a common factor?

$$\frac{430}{540} \div \frac{10}{10} = \frac{43}{54}$$

There it is. Two turns and 43 holes in a 54-hole circle.

MILLING MACHINE PRECAUTIONS

A milling machine operator's first consideration should be for safety, and you should attempt nothing that may endanger yourself or others. CARELESSNESS and IGNORANCE are the two great hazards to personal safety. Milling machines are not playthings and must be accorded the respect due any machine tool.

For everyone's safety, observe the following precautions:

- NEVER attempt to operate a machine unless you are sure you thoroughly understand it.

- Do NOT throw an operating lever without knowing in advance the outcome. 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.

- Do NOT play with control levers or idly turn the handles of a milling machine, even though it is not running.

- Do NOT take a cut without being sure that the work is secure in the vise or fixture and that the holding member is rigidly fastened to the machine table.

- 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.

- ALWAYS protect your eyes with goggles and keep them out of line of the cutting action. There is always danger to your eyes from flying chips.

- ALWAYS remove chips with a brush or other suitable agent—NEVER with your fingers or hands.

- Above all, KEEP CLEAR OF THE CUTTERS. Do NOT touch a cutter even when it is stationary, unless there is a good reason for doing so. If you must touch it, be very careful.

REFERENCE

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

CHAPTER 10

OPTICAL AND NAVIGATION EQUIPMENT MAINTENANCE

This chapter covers most of the small instruments that you will be working on as an Opticalman. We will explain the complete repair procedures for some of the optical instruments that do not have supporting technical manuals Because technical manuals should be available at your duty station, we will describe some of the other instruments only briefly

PARALLEL MOTION PROTRACTOR

The parallel motion protractor (PMP) (fig 10-1) is a mechanical device used by navigators to plot positions and courses A scale is attached to a protractor head (360° graduations), which can be rotated a full 360° and locked in any position Regardless of where you position the protractor head, the two arms, or the elbow joint, the scale will remain parallel to the original position as you move it over a chart This parallel motion is obtained by single pulleys at the head and bracket and a double pulley at the elbow, fitted with steel bands (shown removed in fig 10-1)

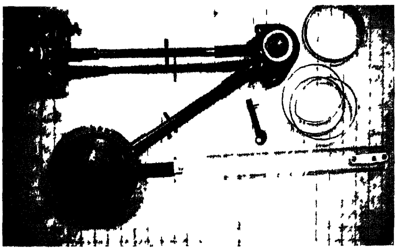

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Figure 10-1.—Parallel motion protractor (bands removed).

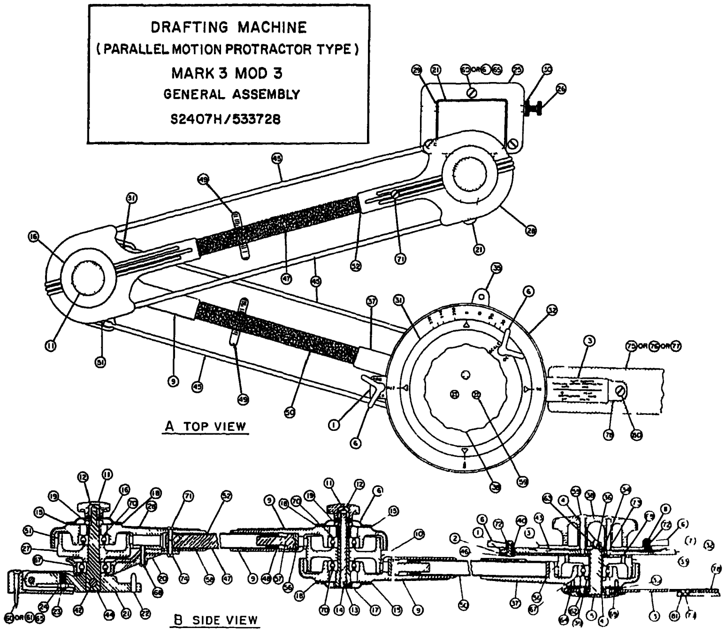
The Mk 3 Mod 3 PMP (fig. 10-1) is quite large. Each arm is approximately 18 inches long, and the protractor head is 7 inches in diameter. The fleet also uses smaller instruments that are similar. The repair procedures that follow will generally apply to most types of PMPs.

DISASSEMBLY

Prior to disassembling a PMP, or any other instrument, thoroughly inspect the mechanical operation, function, and appearance, and note defects on an inspection sheet. Although we will cover some complete overhaul procedures in this manual, it is not practical to disassemble an instrument further than what is necessary to restore the device to its normal operating condition Refer frequently to the numbered items in figure 10-2 as we explain the disassembly procedure.

1 Remove the three screws (59) from the handle (38), and lift off the handle. Now unscrew the scale lock L nut (6) and remove the spring (8) While holding the baseplate (3), remove the nut (63) with a socket wrench; then lift the head off the bench and tap the end of the spindle unit (4) with a fiber mallet to drive it out of the head. Notice that a pin through the spindle engages a slot in the witness plate (31), so when the scale is unlocked, the baseplate (3) turns the witness plate. Remove the protractor lock (1) and L nut shim (4). Now you can remove the brake screw (46) from the protractor (2) and the witness plate (31). Slip the scale lock screw (7) away from the friction plate riveted to the protractor. (NOTE: Do not mix up the component parts of the scale lock and protractor lock.)

2. Remove the four band covers (45) (if so equipped). These covers are made from thin formed steel and are friction fitted between the upper and lower elbow brackets (9) and the fork bracket (28) and head bracket (37). The covers are U-shaped (open on the bottom). Grasp the



C PARTS LIST

PC NO	NAME	BUSHIPS DWG NO
1	PROTRACTOR LOCK	S2407/533729
2	PROTRACTOR LOCK PLATE	
3	BASE PLATE	
4	SPINDLE UNIT	
5	SKID BUTTON	
6	"L" NUT	
7	SCALE LOCK SCREW	
8	"L" NUT SPRING	
9	ELBOW BRACKET	
10	ELBOW PULLEY	
11	BRAKE KNOB	
12	BRAKE KNOB INSERT	S2407/533730
13	LOWER BRAKE SHAFT	
14	LOWER BRAKE PLATE	
15	BRAKE LINING	
16	UPPER BRAKE	
17	ELBOW SPINDLE	
18	BRAKE DISC	
19	ELBOW NUT	
20	BRACKET SUPPORT	
21	HINGE MOUNTING	
22	PIN	
23	SET SCREW (COMM HEADLESS)	¼ 28 X $\frac{5}{6}$ LONG
24	JAM NUT	¼ 28
25	ANCHOR PLATE	S2407/533732
26	ANCHOR SCREW	S2407/533731
27	MAST PULLEY	
28	FORK BRACKET	
29	ANCHOR PIVOT	
30	LOCK NUT	
31	WITNESS PLATE	
32	PROTRACTOR	
33	HEAD PULLEY	
34	SPINDLE BUSHING	S2407/533732
35	BRACKET PLATE	
36	SPINDLE PIN	
37	HEAD BRACKET	
38	HANDLE	
39	LOCK NUT	
40	"L" NUT SHIM	
41	SPINDLE BUSHING SHIM	"
42	HINGE MOUNTING MAST SCREW	"
43	FRICTION PLATE	"
44	MAST	"
45	BAND COVER	"
46	BRAKE SCREW	
47	UPPER TUBE	S2407/533733
48	TUBE BUSHING	
49	TUBE TIGHTENING PIN	
50	LOWER TUBE	
51	BAND	
52	THRUST WASHER	
53	HINGE MOUNTING WRENCH	
54	CHUCK WRENCH	
55	CHUCK WRENCH PIN	
56	THRUST PLUG	
57	THRUST SCREW	
58	SUPPORT STEEL TUBE	
59	MACH SCREW (OVAL PHILLIPS)	8 32 X 1¼ LONG
60	WOOD SCREW (OVAL HD)	10 X 1½ LONG
61	MACH SCREW (OVAL HD)	10 32 X 2 LONG
62	RIVET	$\frac{3}{32}$ X $\frac{5}{16}$ RD HD
63	HEX NUT	¼ 28
64	MACHINE SCREW (FILLISTER HD)	2 56 X $\frac{3}{16}$ LONG
65	HEX NUT	10 32
66	ALLEN WRENCH (NO 18)	S2407/533733
67	BEARING	FAFNIR T 202-C2 KDD-$\frac{12}{MM}$
68	MACH SCREW (RD HD)	8 32 X 1 LONG
69	LOCK PLATE SCREW	S2407/533733
70	BEARING	FAFNIR T 201-C2 KDD-$\frac{12}{MM}$
71	MACH SCREW (OVAL HD)	8 32 X ½ LONG
72	"L" NUT BUSHING	S2407/533733
73	RIVET	"
74	MACH SCREW (RD HD)	8 32 X ½ LONG
75	SCALE (32ND & 50TH)	S2407/533734
76	SCALE (16TH & 20TH)	"
77	SCALE (32ND & 40TH)	"
78	SCALE CHUCK	"
79	SCALE CHUCK SCREW	"
80	SCALE SCREW	
81	SCALE CHUCK BUSHING	
82	NAMEPLATE (CARRYING CASE)	
83	PIN (ESCUTCHEON)	18 X $\frac{3}{8}$ LONG
84	CARRYING CASE	S2407/533734

137.568

Figure 10-2.—Parallel motion protractor parts identification.

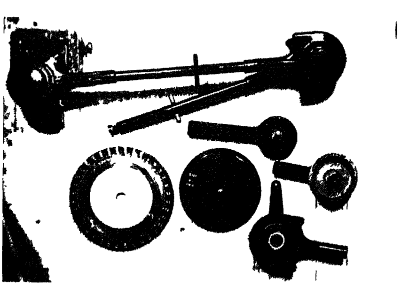
cover several inches from the elbow bracket, squeeze slightly, and slide the cover into the elbow bracket until the other end clears the head or fork bracket. Then lift the cover free and slide it out of the elbow bracket (NOTE: Do not crimp or bend the covers.)

3. Remove tension on the bands by turning the upper (47) and lower (50) tubes clockwise. The pins (49) provide a finger hold. Thrust screws (57) in the tubes are slotted, so you can insert a pin punch or small screwdriver in the holes in the upper and lower elbow brackets (9) to hold the screws while rotating the tubes.

4. Remove the head pulley band. If the band is not loose enough to slip over the pulley (33), repeat step 3. Once the band is removed, pull the head bracket (37) away from the lower tube (50) and remove the tube Do not lose the two thrust plugs (56). Use a socket to remove the nut (39) from the spindle bushing (34), and tap out the spindle bushing from the bottom with a fiber mallet (This will separate the head into the major components shown in fig 10-3)

5 Remove the band from the mass pulley (27) See step 3 if the band is too tight to slip off Pull the elbow bracket (9) away from the upper tube (47) and remove the tube and thrust plug (56) Notice that the upper and lower tubes are not interchangeable

6 To disassemble the elbow bracket, remove the brake knob (11) This will free the lower brake shaft (13) and plate (14) and the upper brake (16) With two socket wrenches, unscrew the elbow nut (19) from the elbow spindle (17) This will free the upper and lower elbow brackets (9), the upper and lower brake linings (15) and disc (18), and the elbow pulley (10) (See fig 10-4)



137.569

Figure 10-3.—Parallel motion protractor head components.

(NOTE: Protect all components from possible damage from nicks and bending.)

7. Remove the brake knob (11) and brake (16) from the fork bracket (28). Unscrew the elbow nut (19) with a socket, freeing the brake disc (18) and lining (15). Now remove the screws (68, 71, and 74) to remove the tube support (58) and fork bracket (28). Remove the hinge mounting mast screw (42) from the hinge mounting (21), and pull out the mast (44). The disassembled components are shown in figure 10-5.

8. It is usually unnecessary to disassemble the PMP any further unless it is to be stripped and painted or unless damaged bearings are to be replaced. Check the bearings by rotating them with your fingers. They should roll smoothly without catching, jumping, or binding. If you note any defects, the bearings must be replaced.

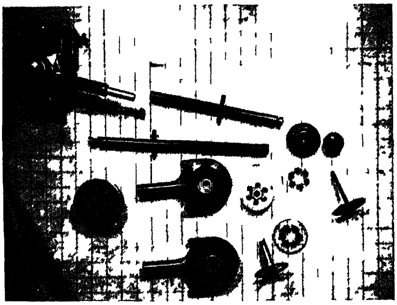


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Figure 10-4.—Parallel motion protractor elbow components.

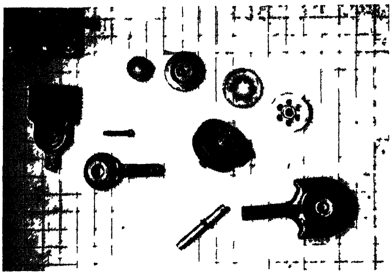

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Figure 10-5.—Parallel motion protractor fork components.

You can carefully press out and replace bearings either by using a bench vise and two sockets, as shown in figure 10-6, or by using an arbor press.

INSPECTION, CLEANING, REPAIR, AND REASSEMBLY

Most defects in the PMP can be detected during the predisassembly inspection and verified upon disassembly. The most serious casualty is a damaged pulley. There can be no nicks, burrs, or eccentricity, and all pulleys must be exactly the same diameter to provide parallel motion of the scale attached to the baseplate.

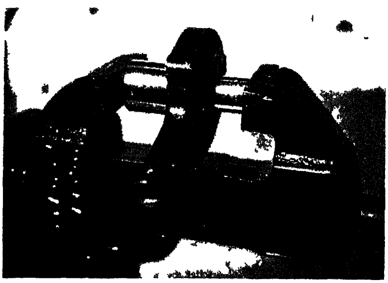

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Figure 10-6.—Parallel motion protractor bearing removal.

45.595

Figure 10-7.—U.S. Navy 7 1/2-inch magnetic compass.

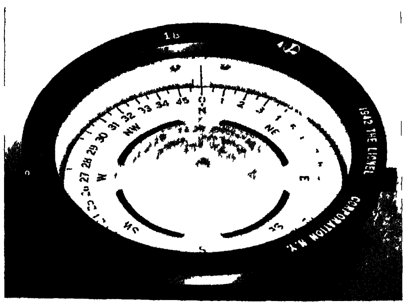
Carefully mask parts that require repainting or touch up so that no paint touches bearing surfaces, brake components, threads, or spindles. Black wrinkle finish is preferred, and most durable, for all parts except those that are engraved. Semigloss enamel is used on these components, followed with a Monofil application on markings.

Clean PMP parts with paint thinner or a similar solvent to remove oil and dirt. Blow dry the cleaned parts and wipe them with a clean lint-free cloth. The pulleys, bands, and brakes must remain absolutely free of oil or grease.

Occasionally, a PMP will be sent to the shop with a broken or kinked band. Kinks are not easy to remove, but you can work them out on a surface plate or other smooth surface with a fiber mallet. If the kink is severe, cut out the damaged portion and grind the ends square. (The same procedure is used for a broken band.) Once the ends are squared, weld the band together, using the welding attachment on a bandsaw. After welding, dress the seam down with a fine sharpening stone. The bands used on a PMP do not need to be the same length to function properly. They do have to be long enough to allow installation, removal, and tension adjustment.

Prior to assembly, check all threads for damage. Restore damaged areas or, if necessary, replace the parts. Also check brake components for damage, and replace unsuitable parts.

Reassembly of the PMP is done in the reverse order of disassembly. Bearings, spindles, and threads should be lightly lubricated. (NOTE: Do not allow any grease on brakes, bands, or pulleys.)



45.23

Figure 10-8.—Standard 4-inch boat compass.

When you adjust the PMP bands, they should be tight enough to "ping" when plucked. They must be tight enough to prevent slipping on the pulleys, but not so tight as to be strained. After the bands have the proper tension, turn the tube tightening pins (49) so they are parallel with the work bench.

After the PMP is assembled, the scale lock and protractor lock should be in the position shown in figure 10-2 when they are locked. If this condition is not met, remove the L nuts (6) and turn a 10-32 screw into the L nut to remove the threaded bushing. Turn the bushings snugly back on the brake screw (6) and/or scale lock screw (7), then tap the L nuts onto the bushings, in the proper position, with a fiber mallet. (NOTE: Support the protractor directly under the L nut with a block of wood while reseating the L nuts.)

The brakes on the elbow bracket and fork bracket are merely friction brakes to prevent unwanted movement while the PMP is in use—they do not lock these brackets

For final adjustment of the PMP, mount the hinge mounting (21) on the anchor plate (25), and tighten and lock the anchor screw (26). Mount any convenient scale on the baseplate (3) and swing the scale to see if it passes freely under the elbow bracket To make this adjustment, turn the setscrew (23) and lock the adjustment with the jam nut (24) If the top of the elbow pulley (10) is not aligned with the mast pulley (27), alternately loosen and tighten the screws (71 and 74) to raise or lower the tube support (58), then recheck the scale clearance under the elbow bracket

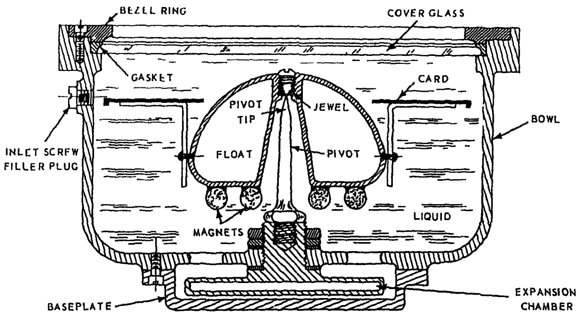
Place a large sheet of clean paper on your workbench under the PMP scale. With the PMP in the position shown in figure 10-1, draw a line on the paper along the scale. Manipulate the PMP so the elbow bracket is on the left side and the scale is in the approximate original position. Using the rule, now draw another line parallel to the first line. If the two lines are parallel, the scale lock may be loose, the bands may not be tight enough, they may be dirty, or there may be some misalignment or looseness in the PMP. Another common cause of nonparallelism is that the bands may not be seated in the pulley grooves. Recheck all phases of assembly and adjustment until parallel lines are produced.

MAGNETIC COMPASS

The Navy has equipped all of its ships with GYROCOMPASSES, but the large ships also have MAGNETIC COMPASSES similar to that shown in figure 10-7. Ships' boats depend entirely on the magnetic compass shown in figure 10-8.

The size of a compass is designated by the diameter of the compass card. The large 7 1/2-inch compass shown in figure 10-7 is complete with gimbal ring, and the 4-inch boat compass in figure 10-8 has the gimbal ring removed. When a magnetic compass is mounted in a ship or boat, the gimbal ring arrangement keeps the compass level regardless of the motion of the vessel.

For a complete examination of compass nomenclature, refer to figure 10-9. The compass bowl is completely filled with varsol (mineral



137.286

Figure 10-9.—Nomenclature of a magnetic compass.

spirits) or a mixture of 45 percent alcohol (190 proof) and 55 percent distilled water. For obvious reasons, the compass fluid must not freeze. By using a fluid-filled compass, the float assembly (float, compass card, and magnets) is stabilized against vibration, pitching, and rolling. Also since the float assembly is lighter when it is submerged, it is more sensitive to the magnetic attraction of the Earth's poles. (The float assembly of a 7 1/2-inch compass weighs 3,060 grains in air and 90 grains submerged.)

The compass bowl is made of cast brass or bronze (nonmagnetic). The top is machined to accept a thick cover glass, a gasket recess, and a bezel ring to hold the glass and compress the gasket. The bezel ring is secured with 8 to 12 screws, depending on the size of the compass. (NOTE: Except for the magnets, a compass must be constructed of nonmagnetic materials.)

The float is a hollow, sealed chamber with magnets soldered to the bottom, a synthetic sapphire pivot jewel held in the center, and a compass riveted to the outside. The compass card is very thin and fragile. Markings on the compass card (fig. 10-8) are stamped out of the card.

Rather than having four bar magnets, the compass has magnets that are actually bundles of small magnetic wires This arrangement provides more magnetic attraction than solid bars

A tough metal pivot is attached to the expansion chamber to support the float assembly and to hold it in the center of the compass bowl The pivot tip is formed with a very small radius to reduce friction against the pivot jewel. The float assembly must be balanced in order to function properly. Balancing is accomplished by adding or removing solder on the bottom of the float

An expansion chamber is secured to the bottom of the compass bowl and protected by a baseplate. The expansion chamber is a thin metal bellows that compensates for expansion and contraction of the compass liquid caused by temperature changes. The compass in figure 10-9 uses a sealed, hollow chamber that is surrounded by liquid. You will also see compasses that have the expansion chamber surrounded by air but are open to the compass bowl liquid.

INSPECTION AND DISASSEMBLY

When a compass is sent to the optical shop, a careful inspection will usually indicate probable defects prior to disassembly The following list of defects/causes should be beneficial

- If the compass card is level and there is a large bubble under the glass cover, liquid is leaking around the cover glass or filler plug, 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, 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, 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 (vertical line in the bowl) With a

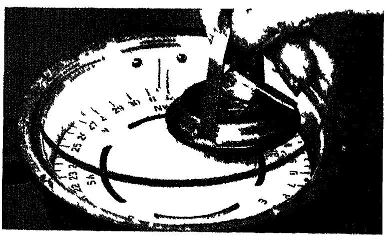


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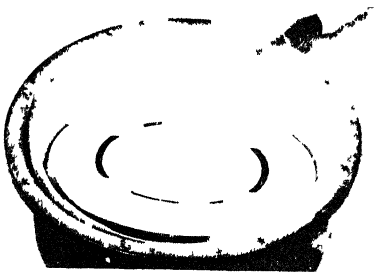
Figure 10-10.—Removing the cover glass.



137.289

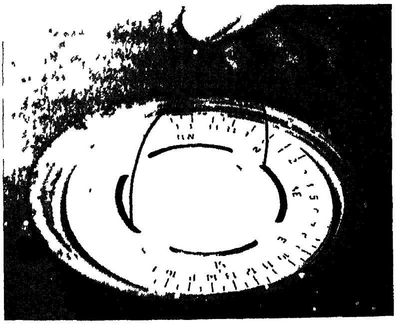
Figure 10-11.—Testing the float for leaks.

magnet, deflect the compass card exactly 11°, and then quickly remove the magnet. The card will then swing back; as the zero mark crosses the lubber's line, start a stopwatch. The zero mark will reach the end of its swing and start back; 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 when 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, because you must put the bezel ring back in the same position it occupied before removal.
3. Remove 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 and possible breakage of the glass.)



137.290
Figure 10-12.—Removing the float assembly.

4. Lift off the bezel ring, and then remove and discard the rubber gasket.

5. With a suction gripper (fig. 10-10), 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 figure 10-11, hold it down for several seconds, and release it. Repeat this test at three different points around the card. If the float stays down at each of the three positions, it contains liquid. If the float stays down at only one position, the problem is caused by loss of balance.

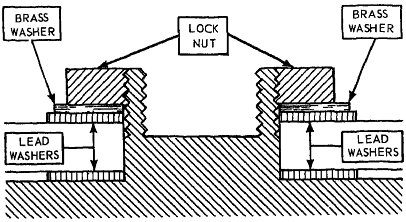
7. With a piece of wire bent to form two hooks (fig. 10-12), lift the float out.

8. Pour the remainder of the liquid from the bowl.

9. To remove the pivot, fit a socket wrench over its hexagonal base and turn it counterclockwise. (CAUTION: Be sure the center of the 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 baseplate to guide you in reassembling the baseplate in its original position. Remove the screws from the baseplate and lift it off.

11. Figure 10-13 shows a typical method of securing the expansion chamber to the compass bowl. Beneath the lock nut is a



137.292
Figure 10-13.—Expansion chamber secured to the bottom of the compass bowl.

brass friction 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. Turn the bowl over and remove the expansion chamber lock nut with a socket wrench. (CAUTION: Do not set the compass down on the expansion chamber.)

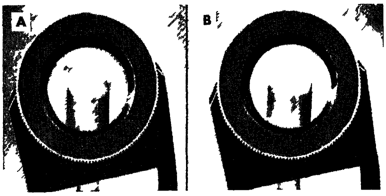
12. Remove the expansion chamber from the bowl, and inspect it for leaks or other damage.

REPAIR AND ASSEMBLY

Inspection of parts, repair, and reassembly of a magnetic compass are discussed together, step by step, as follows:

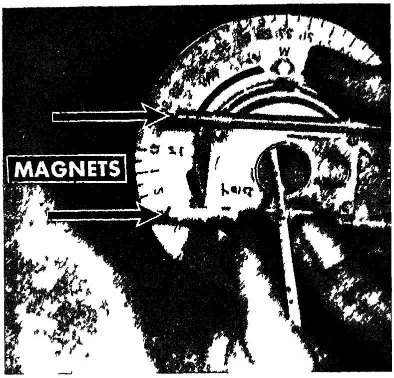
1. If the expansion chamber is in good condition, reassemble it. (CAUTION: Do NOT forget the lead washer between the expansion chamber and the bottom of the bowl. If this washer is not in perfect condition, replace it.)

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 extension to seal the lead washers.)



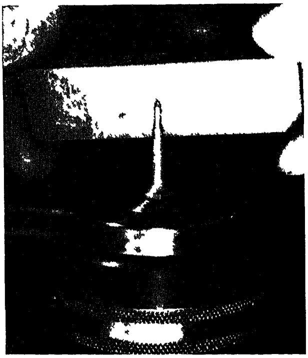
137 293

Figure 10-14.—Pivot points



137 295

Figure 10-16.—Removing the jewel from the float



137.294

Figure 10-15.—Shaping a worn pivot point.

137.296

Figure 10-17.—Testing a needle for sharpness.

3. Put the baseplate back into position; then replace the baseplate screws and tighten them. (CAUTION: Be sure to line up the 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 figure 10-14. The magnified pivot in part A is badly worn and rounded. The pivot in part B is properly shaped. (NOTE: A badly worn pivot point will cause a compass to be sluggish.)

5. If the pivot point is worn, put it in a lathe and reshape it with a fine carborundum stone (fig. 10-15). Then polish the pivot point with a hard Arkansas oilstone, and inspect it again for correct shape. The tip of the pivot should have a radius of 0 005 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 figure 10-16. (CAUTION· Be extremely careful at all times when handling the float to avoid damage to the compass card) Hone a steel needle to a sharp point on an oilstone and rest it on your thumbnail (fig 10-17) If it slides under its own weight, it is NOT sharp enough; if it catches on your thumbnail, it has correct sharpness Now slide the needle under its own weight over the whole bearing surface of the jewel, as shown in figure 10-18. 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.)

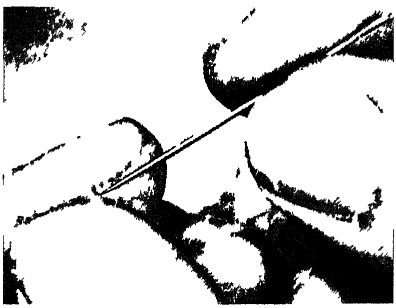
7. Test the float for leaks by submerging it in warm water (120°F). The heat will expand the air inside the float; if there are leaks in the float air will bubble out. Use a pencil to mark the position of each leak.

To fix a leak in a float, drill a small vent hole in it, drain out the liquid, and dry it in an oven at 150°F. 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 it for leaks. (NOTE: Leaks in the cone section of the float are difficult to close; if you cannot seal them, replace the float.)

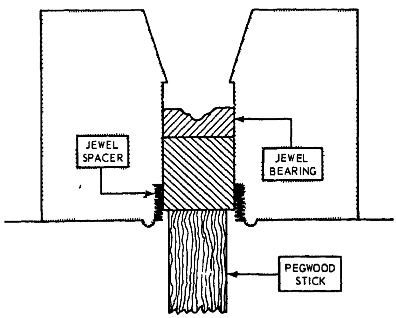
8. Use a pegwood stick with a flat end to press the jewel and its spacer back into the float, as shown in figure 10-19 Then replace the retaining screw and tighten it. (CAUTION· Do NOT use force, too much pressure will crack the jewel.)

9. When you repair a float or replace a jewel, you generally destroy the balance of the bloat and must rebalance it Materials



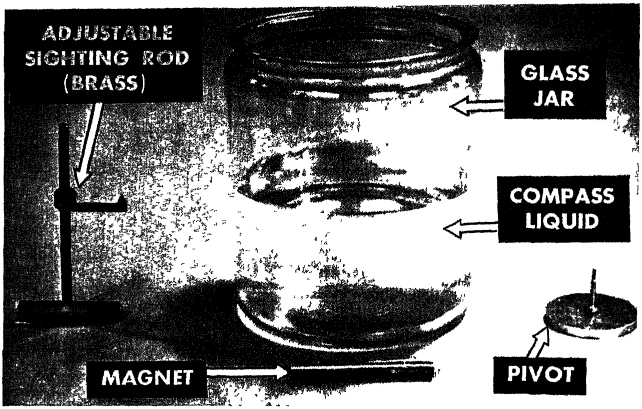
137.297

Figure 10-18.—Testing a pivot jewel with a needle.

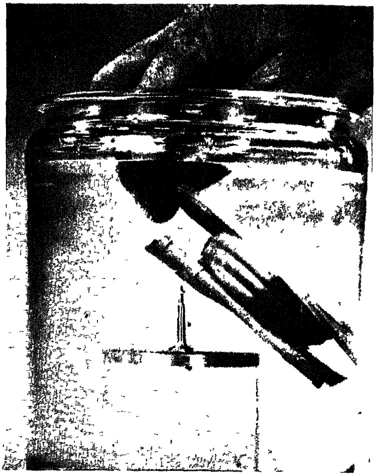


137.298

Figure 10-19.—Replacing the pivot jewel and spacer.



137.299
Figure 10-20.—Equipment for testing float balance.



137.300
Figure 10-21.—Mounting the float for a balance test.

137 301
Figure 10-22 —Making the balance test.

required for making a float balance test are shown in figure 10-20.

10. To remove bubbles from under the compass card and the cone section of the float, immerse the float edgewise in the compass liquid in the jar, as illustrated in figure 10-21. 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 a magnet. See figure 10-22. 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, it will wobble as it turns.

Remove the float and scrape a clean spot on its edge at the high point. Then apply a small amount of solder at this spot. Put the float back on the pivot and retest for balance. Keep adding solder and retesting until you have the float in perfect balance. (NOTE: If you apply too much solder, scrape some of it off with a knife.)

12. Inspect the cover glass and rubber gasket seats. If they are corroded, scrape them by hand or remove the corrosion on a lathe. Then clean the surfaces thoroughly with an approved cleaner. (NOTE. These surfaces must be perfectly flat and smooth)

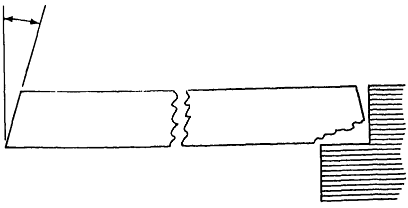
13. Inspect the beveled edge of the glass cover. (NOTE· The side that seats against the bowl has the larger diameter) If there are any chips on this edge, as shown in figure 10-23, replace the cover glass

14 Clean the compass bowl with a soft brush to remove lint or other foreign particles; then blow it out with low-pressure air.

15 Fill the expansion chamber with compass liquid, using a rubber syringe When the chamber is filled in this manner, trapped air will be forced out

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, bend the pivot with a pair of pliers Be careful to avoid damaging the pivot point)



137.305

Figure 10-23.—Inspection of a cover glass.

18. With wire hooks, lower the float onto the pivot. Check 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.

19. Remove the float and fill the bowl with compass liquid to a level one-half inch below the cover glass seat.

20. Replace the float and, with a pegwood stick sharpened to a chisel point, carefully place the glass in position. Be sure the inside of the glass is clean.

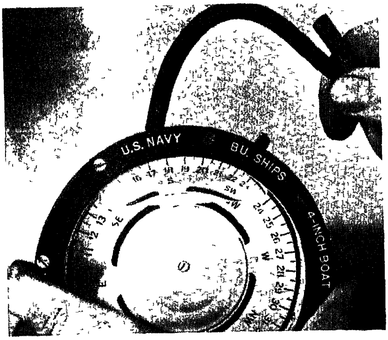
21. Fit a new rubber gasket around the edge of the cover glass. The gasket material comes in a roll, and it must be cut to size for each compass. Cut the ends square with a razor blade so the ends butt perfectly together when properly installed.

22. Replace the bezel ring, and insert the screws. Turn them until they are finger tight. Then use a screwdriver to tighten all screws, one-half turn at a time in rotation, until the ring is secure.

TEST AND ADJUSTMENT

The procedure for testing and adjusting your reassembled compass is as follows:

1. To test for leaks around the bezel ring, or expansion chamber, make a screw to fit the filler hole, and drill a small hole through the center of the screw. Insert the screw in the hole filler, and fit a piece of rubber tubing over the screw. Suck on the tube to pull a slight vacuum, and then pinch it off (fig 10-24). Roll the compass slowly from



137.309

Figure 10-24.—Testing for leaks around the bezel ring.

side to side to see if any bubbles appear around the bezel ring. Set the compass on its base to see if any bubbles rise from the bottom. All leaks must be repaired before you fill the compass.

2. With a rubber bulb syringe, finish filling the bowl with liquid; then replace the filler 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 as explained at the beginning of the inspection and disassembly section.

5. Balance the compass using the equipment shown in figure 10-25. The compass must balance on its lugs, and the compass and gimbal ring must balance as a unit. When you place the spirit level on the compass cover glass, be sure it is centered so you do not get a false balance.

If your compass does not balance, file the lugs to move the bearing edge over toward the heavy side (fig. 10-26). Make a light cut with your file, and test the balance. Repeat this process until the balance is perfect on the compass and the compass and gimbal ring. See figure 10-27.

137.310

Figure 10-25.—Equipment for testing compass balance

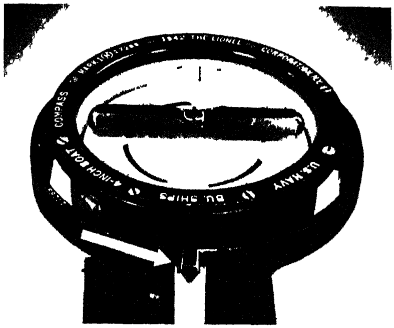


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Figure 10-27.—Final balance test

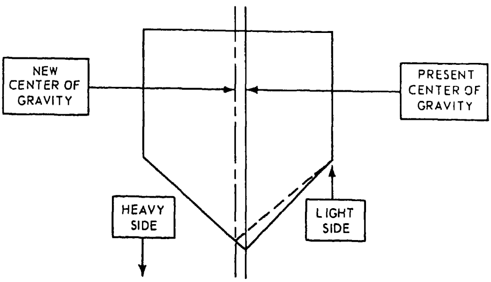

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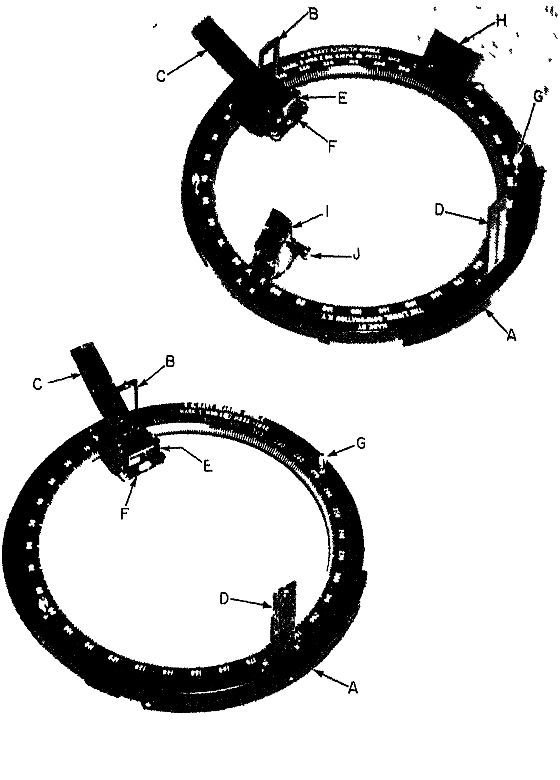
Figure 10-26.—Restoring compass balance.

AZIMUTH AND BEARING CIRCLES

The azimuth and bearing circles, shown in figure 10-28, are used on the bridge of ships to aid in navigation. These instruments are constructed entirely of nonmagnetic materials since they are used on gyrocompass repeaters or 7 1/2-inch magnetic compasses.

True and relative bearings of terrestrial objects and the azimuth of celestial objects can be measured with the sights mounted at 0° and 180° on both instruments. The movable mirror and right-angle prism assembly on the azimuth circle (90°–270°) are used to measure the azimuth of the sun.

The graduations on the bearing ring of both instruments run counterclockwise. To measure a



A. Counterweight
B. Front sight
C Black mirror
D. Rear sight
E. Penta prism
F. Penta spirit level
G. Hand knob
H. Curved mirror
I Right-angled prism assembly
J Right-angled spirit level

65.122

Figure 10-28.—Mk 3 Mod 2 azimuth circle and Mk 1 Mod 2 bearing circle.

relative bearing when the sights are aligned with an object, merely read the bearing aligned with a lubber's line engraved on top of the compass or repeater. If the true bearing is needed, read it directly from the compass card.

Notice the spirit levels on the 0°-180° and 90°-270° sights. If the instruments are not level when a sighting is made, the azimuth or bearing reading will be inaccurate. Since these instruments are basically a small mechanical sighting device, you must adjust them perfectly during overhaul to obtain accurate readings.

CONSTRUCTION FEATURES

The azimuth or bearing circle ring (fig. 10-29) is common to both instruments. The only difference is the additional set of sights (90°-270°) on the azimuth circle. The ring must be perfectly flat and concentric; otherwise, accurate readings would be impossible. Three spring detents (120° apart) hold the ring firmly on a compass or repeater.

The rear sight assembly, shown in figure 10-28, consists of a bracket held to the bearing ring with screws aligned with dowel pins. The

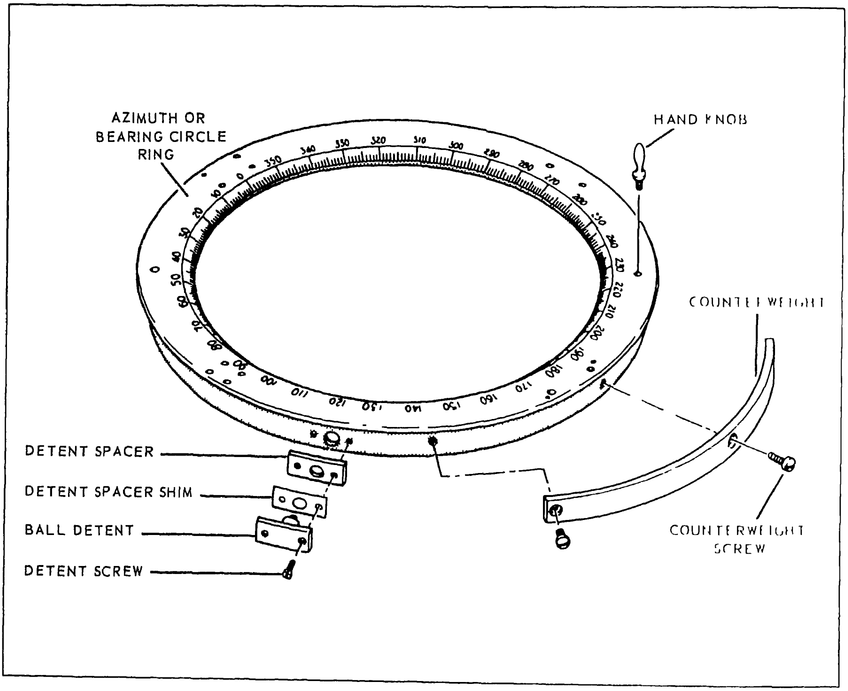


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Figure 10-29.—Azimuth or bearing circle ring.

vertically slotted sight leaf pivots on a friction pin through the sight and bracket.

The complete front sight assembly (fig. 10-30) consists of various subassemblies. Due to the nature of the construction of this assembly, numerous adjustments can be made to align components during collimation. The front sight wire is made from 0.011-inch brass. If loose, it can be tightened; when kinked or broken, it must be replaced. The pins that the front sight and black mirror pivot on should be tight enough to hold these elements in any position, but still allow them to be moved. During collimation, you must adjust the black mirror, front sight, bottom sight wire, and spirit level to align perfectly with a plane passing through the 0°-180° graduations and perpendicular to the collimator stand.

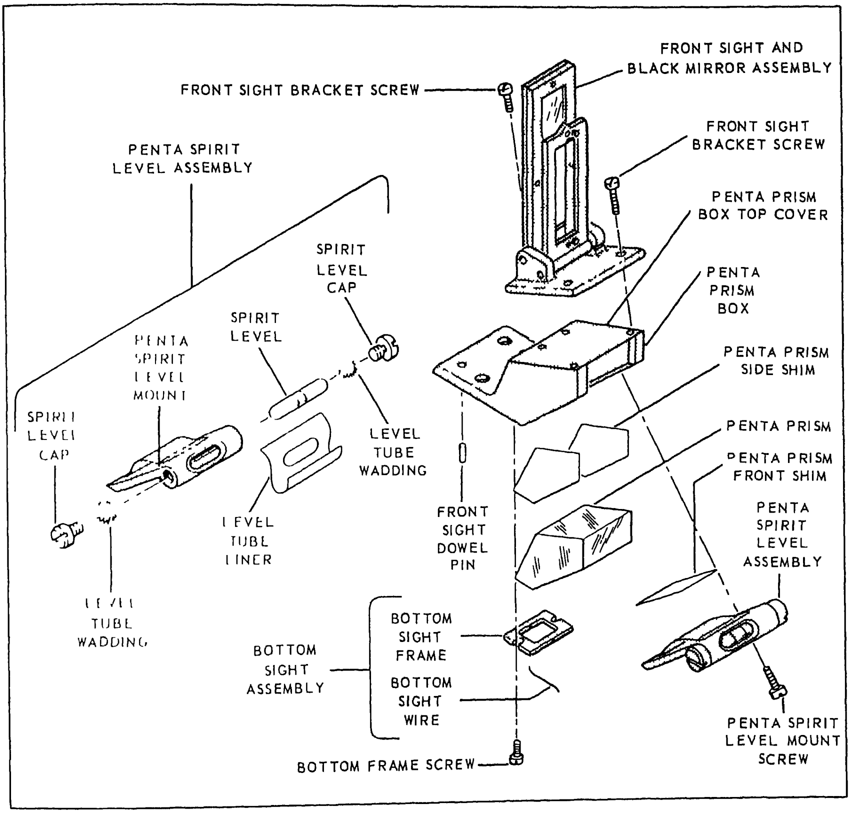

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Figure 10-30.—Front sight assembly.

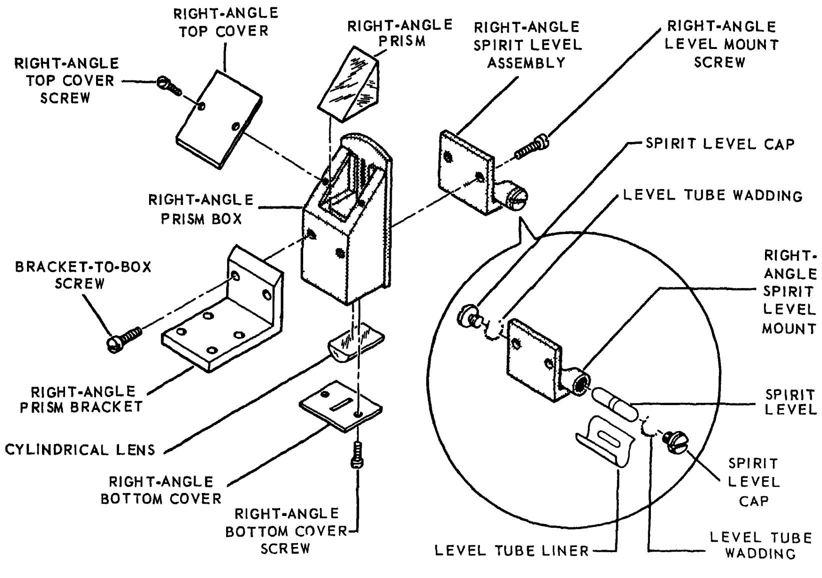

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Figure 10-31 —Right-angle prism housing assembly

An exploded view of the right-angle prism assembly is shown in figure 10-31 Alignment adjustments are provided on the spirit level assembly, prism bracket, and slotted bottom cover. This assembly, located on the azimuth circle ring at 90°, is used in conjunction with the curved mirror (fig 10-32) mounted at 270° on the azimuth circle ring. When properly adjusted, the reflection of the sun is directed toward the slot in the front of the right-angle prism box The prism reflects this wide band of light to the cylindrical lens, which focuses a narrow band of light onto the compass card. The spirit level must indicate a true level, and all reflection and refraction must take place in a plane passing through the 90°-270° graduations and perpendicular to the collimator stand.

REPAIR AND ADJUSTMENT

A thorough predisassembly inspection will usually pinpoint areas where work is needed. Check all optics for chips, scratches, and, where

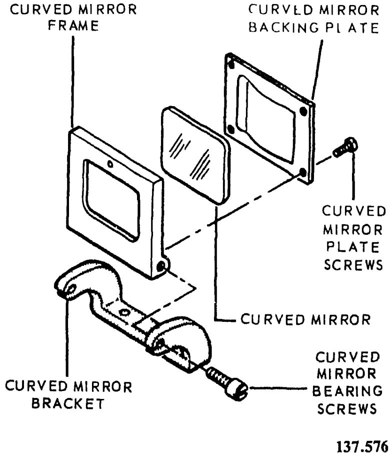

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Figure 10-32.—Curved mirror assembly.

appropriate, deteriorated silvering. Look for missing paint and corrosion on metal surfaces, and be sure the graduation marks are readable. Check the action of movable components to detect binding or looseness.

Obvious damage to sights caused by carelessness or accidental dropping is easy to detect, but a warped bearing ring can only be checked and straightened on a special circle repair ring (which you can manufacture if necessary).

A typical collimation setup is shown in figure 10-33. First, level the collimator stand. Then place a machinist's square on the stand with its vertical edge touching one of the dumb lines engraved on the stand. Turn on the artificial sun, and rotate the stand until the shadow cast by the machinist's square falls on the dumb line. Then lock the stand in position.

When collimating the azimuth or bearing circle, check all adjustments by observing the light

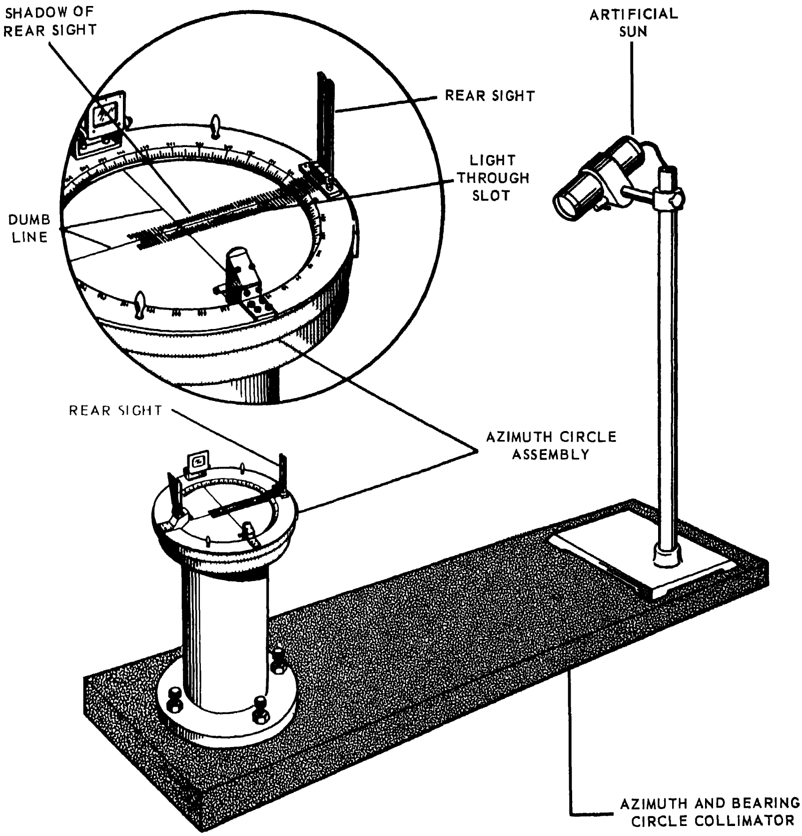

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Figure 10-33.—Azimuth and bearing circle collimator.

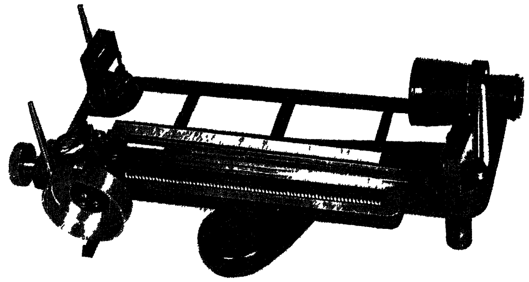

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Figure 10-34.—The Fisk stadimeter.

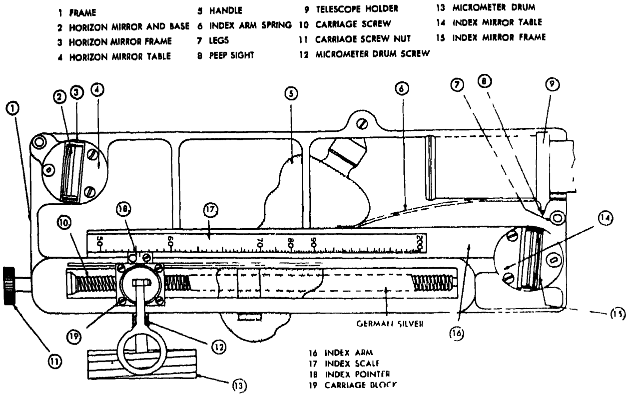

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Figure 10-35.—Construction of a Fisk stadimeter.

or shadow cast on the collimator stand by the artificial sun. NAVSHIPS 250-624-7 contains complete overhaul information for the azimuth and bearing circle.

STADIMETER

The stadimeter is a small, hand-held navigation instrument shown in figures 10-34 and 10-35. It is used to measure range between ships or to prominent landmarks (from 200 to 10,000 yards) when the height of an object is known (between 50 and 200 feet). When a stadimeter is properly adjusted and carefully used, you can measure the distance to objects up to 2,000 yards with an accuracy of ± 2 percent. Beyond 2,000 yards, accuracy rapidly decreases.

CONSTRUCTION FEATURES

A two-power Galilean telescope is screwed into a bracket attached to the frame. With this slight magnification, there is a better view of the target.

A rectangular index mirror (1 1/4 by 1 1/1 inch) is mounted on, and turns with, the index arm. The horizon mirror (1 by 3/4 inch) is held in the lower half of the open frame, which is mounted on a turntable attached to the stadimeter frame. Both the index and horizon mirror can be tipped slightly fore and aft from vertical, and the rotating base of the horizon mirror allows for parallelism adjustment of the two mirrors.

Since the stadimeter is a split-image range finder, one line of sight from the target passes through the open half of the horizon mirror frame directly to the telescope. The other line of sight from the target strikes the movable index mirror, reflects to the horizon mirror, and is directed to the telescope.

The index arm with height scale pivots on a tapered male bearing within a matching female bearing held in the stadimeter frame. To maintain the limited accuracy of this instrument, the pivot axis must be perpendicular to the plane of the frame. A leaf spring bears against the index arm to hold it in position. Wear or damage to the index arm will reduce accuracy of ranges taken.

The complete carriage assembly is shown in figure 10-36. The carriage is held snugly in the stadimeter frame with just enough clearance to allow it to move smoothly up and down the frame when the carriage screw is turned. Looseness between the carriage and carriage screw is unimportant, but looseness of the carriage in the frame or between the drum screw and split halves of the carriage will cause inaccurate range readings.

REPAIR AND ADJUSTMENT

The most serious casualties that can occur to a stadimeter are as follows:

- Any shifting of the male and female index arm bearings from an axis perpendicular to the frame.
- Bending of the index arm.
- Bending or warping of the stadimeter frame.

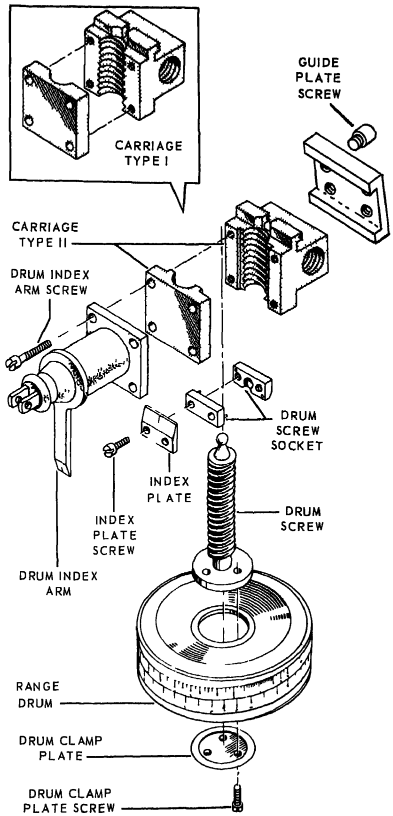
The index arm, with a matched set of bearings, can be replaced. However, if the frame is warped, you may have to survey the instrument.

For this instrument to function properly, the frame must be perfectly flat and true, the mirrors must be properly aligned, slop between the carriage and frame and between the carriage and drum screw must be eliminated, and the index arm must be parallel with the slot in the frame when the range drum is set at infinity. Parallelism between the index arm and carriage guide slot is measured with a dial indicator. Allowable error is ±0.0005 inch. Any variation over this tolerance is corrected by scraping the high spots on the index arm.

Complete overhaul procedures for the stadimeter are contained in NAVSHIPS 250-624-6.

SEXTANT

The sextant is a hand-held navigation instrument somewhat larger, and much more accurate, than the stadimeter. As you can see in



137.577

Figure 10-36.—Stadimeter carriage assembly.

figure 10-37, the sextant and stadimeter share some basic features. Namely, the application of two mirrors, a movable index arm, and a low-power telescope. There the similarity ends. The stadimeter measures a range, when the height of the object is known, with limited accuracy; the sextant measures the angle above the horizon of a celestial body. The angle is read in degrees, minutes, and tenths of minutes, and the exact time of the sighting is recorded. Then the navigator

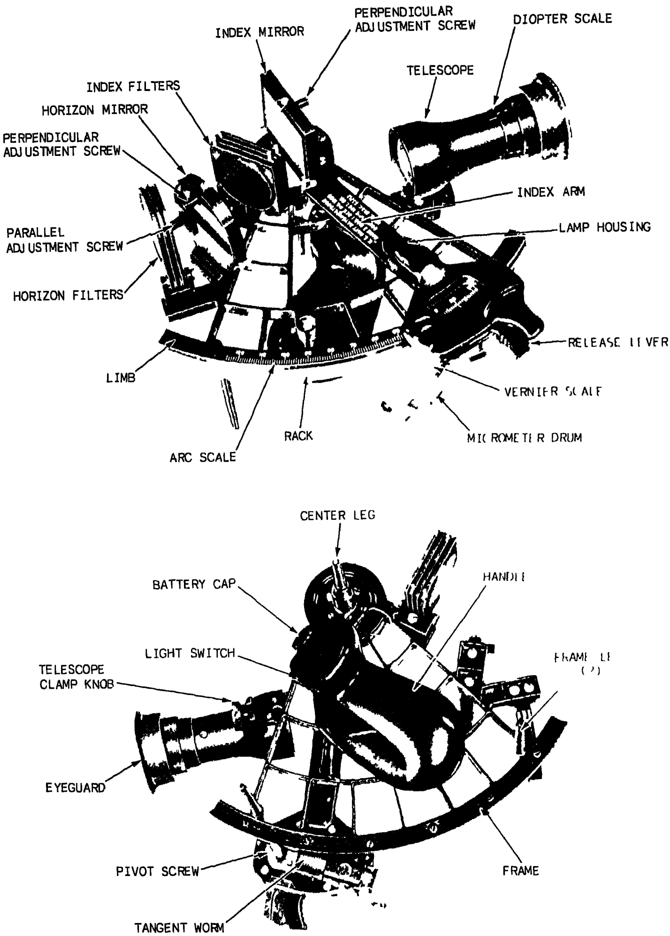


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Figure 10-37.—Sextant controls and components.

consults a nautical almanac to plot the ship's position. A good navigator, with a properly adjusted sextant, can pinpoint a ship's position anywhere on the surface of any existing body of water within one-quarter mile.

The Mk III marine sextant (fig. 10-37) is representative of other sextants manufactured by Pioneer, Bendix, and Weems & Plath. All perform similar functions with slight mechanical variations. Once you have overhauled one type, you will have no difficulty with the others.

CONSTRUCTION FEATURES

The heart of a sextant is the index arm female center bearing, mounted in the frame. This bearing must be perpendicular to the frame and located at the exact geometric center of the arc of the frame. The manufacturer positions the female center, using some very sophisticated equipment. You should NEVER remove the female center from a sextant because you will not be able to replace it in the correct position.

Also mounted on the frame is an adjustable telescope holder and a bracket that holds the filters and the adjustable horizon mirror mount.

The edge of the frame arc is machined with a guide rack groove to allow free movement, without play, of the index arm—and a series of gear teeth, one for each degree marked on the arc.

The mechanism that holds and moves the index arm is shown in figure 10-38. The male

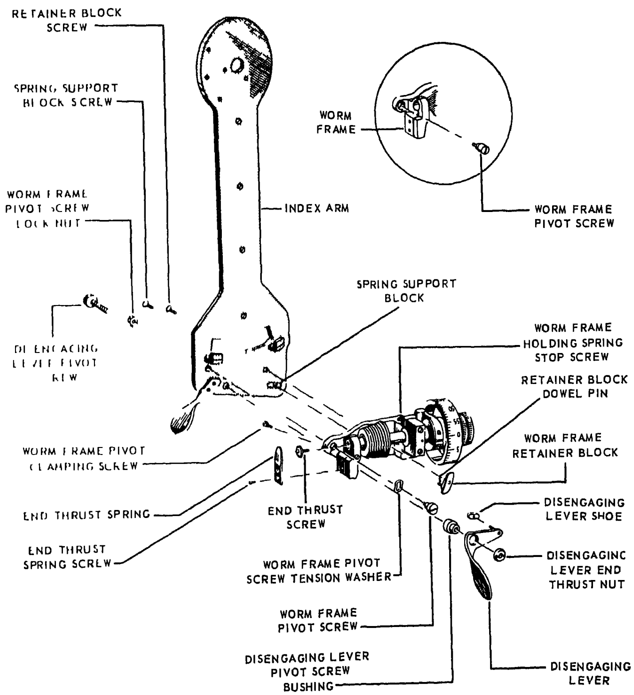

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Figure 10-38.—Index arm and worm frame assembly.

center bearing is not shown. All components of the index arm and worm frame assembly are carefully lapped and fitted to provide smooth action and to eliminate slop.

You can move the index arm to any position on the arc by grasping the disengaging lever to pivot the worm screw away from the gear teeth on the sextant arc. Then swing the index arm to the rough position desired, and release the disengaging levers. Spring tension holds the worm screw in mesh with the rack teeth. A flat spring bears against the end of the worm shaft to prevent end thrust.

Study figure 10-39. It gives two sample extant readings. In part A, 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 that coincides with a mark on the drum is 7 on the vernier scale. This gives us a reading of 13°16.7′. The reading in part B of figure 10-39 is 5°25.2′.

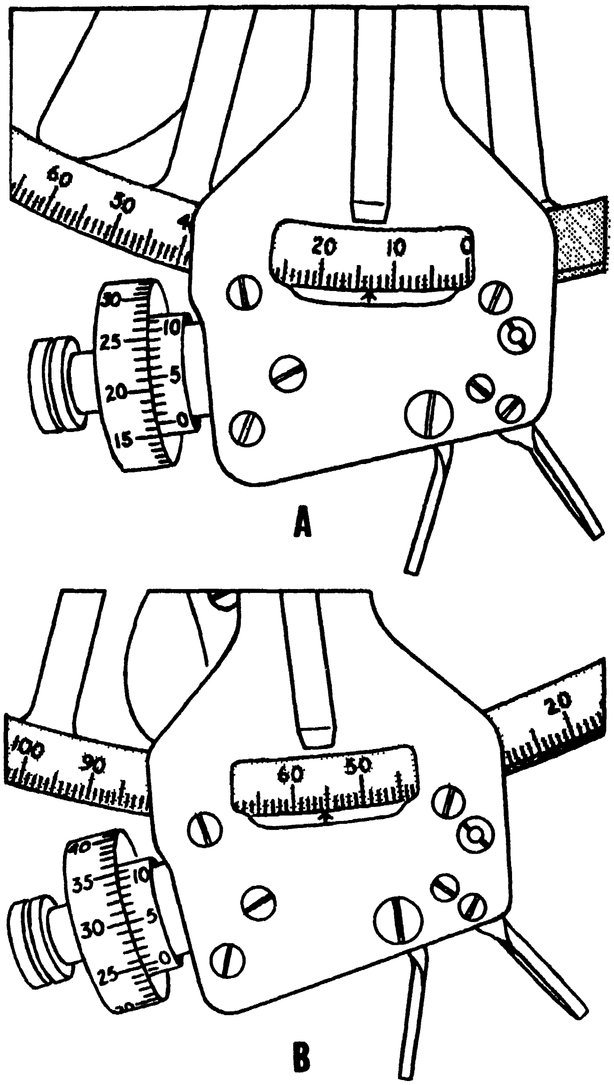

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Figure 10-39.—Examples of sextant readings.

REPAIR AND ADJUSTMENT

A preliminary decision must always be made concerning the feasibility of repair of an instrument. The purpose of a predisassembly inspection is 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 you should check when giving a sextant a predisassembly inspection include the following:

- 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 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.

- Rack guide slot. The index arm should move freely over the entire sextant frame. If you feel any binding, examine the guide slot with an eye loupe to check for burrs.

● Endless tangent worm and arc gear teeth. The accuracy of a sextant depends upon faultless engagement of the worm thread with the arc gear teeth. Carefully dress down any burrs or nicks to prevent binding and incorrect readings.

NOTE: Do NOT lubricate the worm thread and arc gear teeth. Lubricants pick up dust and other foreign particles which destroy accuracy.

Collimation of the sextant is relatively easy. The index arm and micrometer drum are mechanically set to read 0°0′; then the index and horizon mirrors are adjusted until they are perpendicular to the plane of the arc and parallel to each other. Complete overhaul information for the sextant is contained in NAVSHIPS 0924-059-5010.

STRAIGHT LINE TELESCOPES

The OOD and QM spyglasses are hand-held, straight line of sight, simple terrestrial telescopes. Figure 10-40 shows two variations of the QM glass and one of the OOD glass. These instruments are basically the same, except for the larger, longer focal length objective used in the QM glass. To account for varying focal lengths between replacement objective lenses, the objective mount of the QM glass has various spacers on each side of the lens. The objective lens of the OOD glass uses no spacers. Characteristics of the two instruments are as follows:

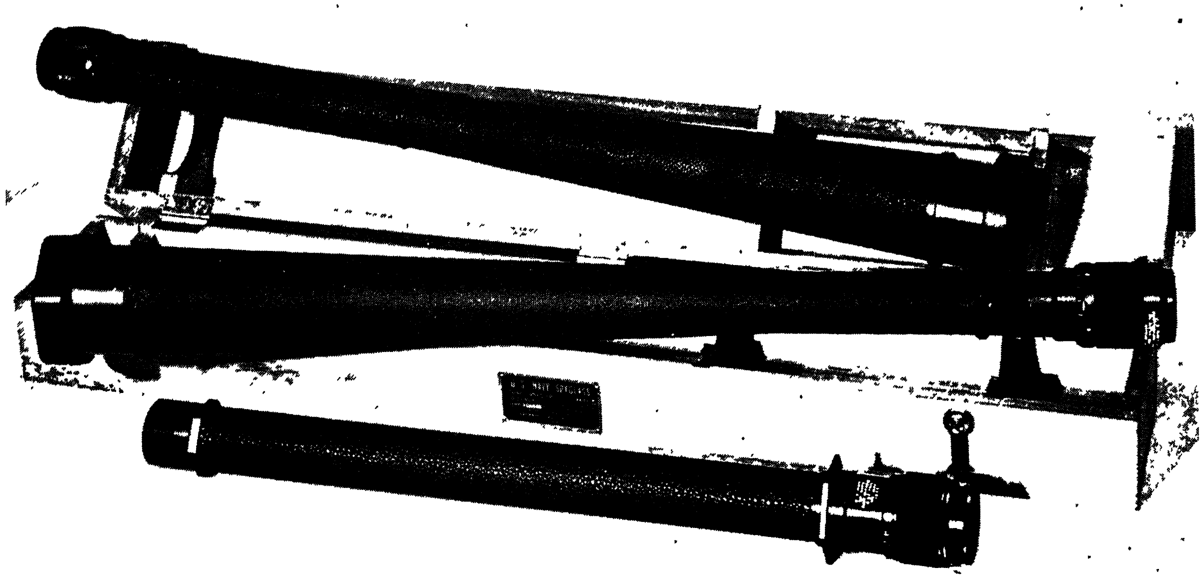
	OOD	QM
Magnification	10×	16×
True field	5°30′	3°30′
Apparent field	55°	56°
Eye distance	29.0 mm	28.0 mm
Exit pupil	3.5 mm	4.0 mm

CONSTRUCTION FEATURES

The eyelens, objective lens, threaded external tube sections, and setscrews are sealed with sealing compound to prevent moisture from getting inside the instrument. Focusing is by a spiral keyway arrangement, which is lubricated with medium-heavy grease to assist with sealing.

A series of diaphragms is located permanently in the body tube to control aberrations and to prevent stray light. An adjustable diaphragm is mounted in the eyepiece drawtube to control aberrations and to frame the final image plane.

Except for the objective lens, all optics are mounted in tube sections, which thread together.



37.3

Figure 10-40.—An OOD spyglass and two QM spyglasses.

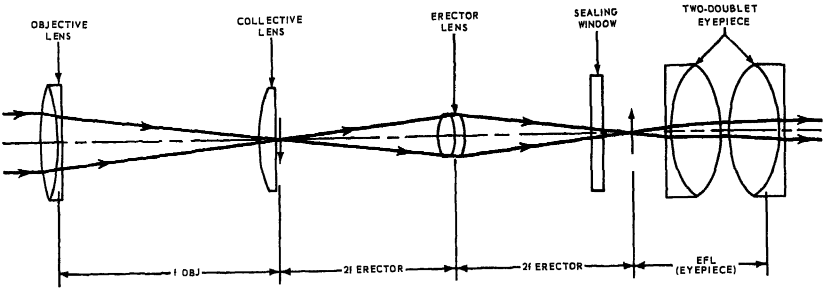


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Figure 10-41.—Optical elements for OOD and QM spyglasses.

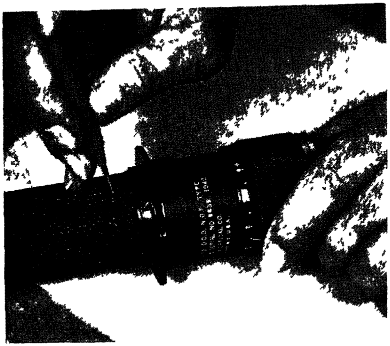

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Figure 10-42.—Releasing the eyepiece mount support tube setscrew.

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Figure 10-43.—Removing the eyepiece mount from the eyepiece mount support tube.

Figure 10-41 shows a schematic of the optical system (not drawn to scale).

The positive achromatic doublet objective lens forms a real, inverted, diminished image, just beyond the rear surface of the collective lens.

The convex-plano collective lens gathers marginal rays of light, which would otherwise be lost, and directs them to the erector. By using a collective lens in this position, you can obtain a fairly good field of view with a bright image.

A doublet erector lens is located approximately two focal lengths from the objective image plane. The greatest curvature of this lens is on the outer surface of the negative element, which faces the eyepiece. The erector forms a real, diminished, erect image within the focal length of the eyepiece.

A plano-parallel sealing window is shown in figure 10-41, located within the back focal distance of the erector. Most spyglasses you will work on have had this window removed.

Spyglasses use a two-doublet eyepiece. The eyelens is slightly smaller than the field lens, and the rear edge is beveled to provide space for the sealing compound. The eyepiece presents a virtual, enlarged, erect image of a target to the observer.

Two gassing screws on the telescope body are used to purge these instruments, since they are not designed to hold pressure. One screw is located at the forward end of the eyepiece mount support tube, the other is behind the objective.

DISASSEMBLY

Prior to disassembly, check and inspect the QM and the OOD spyglasses in the same manner as for any other optical instrument. Write your findings on an inspection sheet and proceed with the disassembly, or consult your shop supervisor for advice concerning overhaul of the instruments. A straight line telescope should be disassembled in the following manner:

1. Remove the setscrew that secures the eyepiece mount support tube in the body tube (fig. 10-42). Then unscrew the eyepiece mount support tube and pull it from the body tube.
2. Remove the setscrew that secures the eyepiece mount support tube in the body tube (fig. 10-43).
3. The knurled focusing ring is held on the eyepiece mount so it can be rotated to focus, but unwanted end play is prevented 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. 10-44). Unscrew the lockring and then the retainer ring from the eyepiece mount Notice that these two rings are not identical The lockring has a bevel on each side, and the retainer ring has only one bevel You may need to use a grip wrench to remove the lockring
4 Unscrew the eyepiece cap from the eyepiece drawtube, and slip off the lock and retainer rings

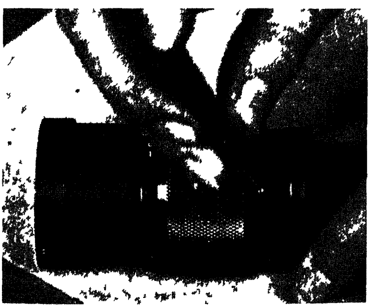

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Figure 10-44.—Removing the focusing ring lockring screw.

5. Remove the knurled focusing ring by rotating it counterclockwise to disengage it from the focusing key, then slide it from the eyepiece mount.
6. Remove the focusing key. It is aligned with two dowel pins and secured with two screws. After removing the screws (fig. 10-45), 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.
7. With an adjustable retainer ring wrench, loosen the diaphragm lockring (fig. 10-46) just

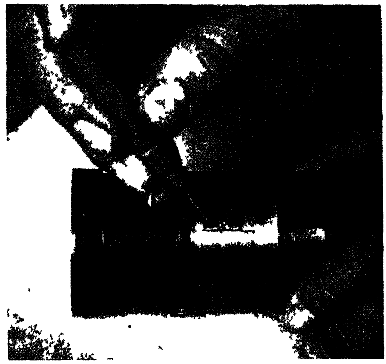

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Figure 10-45.—Removing the focusing key screws.

137.252

Figure 10-46.—Removing the diaphragm lockring.

enough so that it turns freely. Do not use the wrench to remove the lockring completely from the drawtube; the wrench may damage the fine threads on the inner wall of the drawtube. Use a pegwood stick to remove the lockring. Measure and record the distance the diaphragm is in the drawtube. (NOTE: The position of the diaphragm is very important; it controls chromatic aberration.) Remove the diaphragm in the same manner you remove its lockring.

8. Remove the lockring that secures the eyepiece lenses and their spacer. (CAUTION: When you remove the lockring, the field lens and spacer are loose and can easily fall out. This lockring is almost the same diameter as the diaphragm lockring; do not get these rings mixed.)

9. With a piece of lens tissue on the plano surfaces of the field lens and the eyelens, turn the eyepiece drawtube over and let the field lens and spacer 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. The clearance between the lenses and the inner wall of the drawtube is so small that you need to press out the lenses. When you remove the lenses and spacers from the drawtube, mark them to indicate the direction they face in the drawtube. There is only one correct way for them to 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 screw that secures the collective-erector mount support tube in the eyepiece mount tube (fig. 10-47), 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 lockring and the collective lens. Then wrap it in lens tissue. (NOTE: If this lens has pits, scratches, or chips, replace it. The lens is near the focal plane of the objective lens; any defect on the collective lens is very apparent in the field.)

12. Remove the erector lens mount lockring from the support tube. Be careful 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 10-48. To facilitate collimation, this mount can be mounted either way.) Remove the erector lens lockring, and then remove 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 lockring in the eyepiece end of the eyepiece mount support tube. 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 of the OOD spyglass with a grip wrench, and remove the mount. Now remove the objective lockring and the objective lens from the inside of the mount (NOTE: No setscrew secures the objective mount

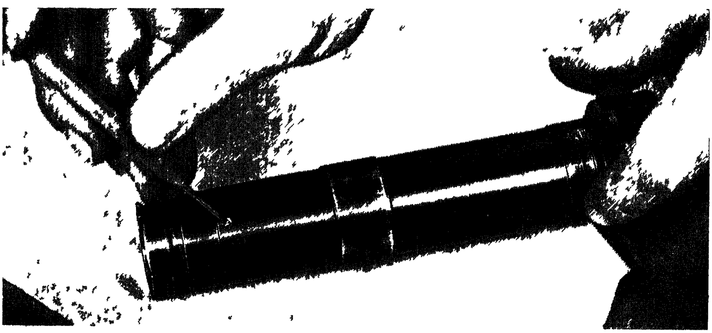

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Figure 10-47.—Removing the collective-erector support tube setscrew.

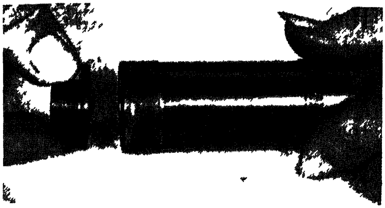

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Figure 10-48.—Removing the erector lens mount from its support tube.

to the body tube. The objective mount of a QM spyglass is part of the body tube and cannot be removed. The lockring, spacers, and objective lens are removed from the front of the body tube.)

15. Remove the two gassing screws, and be sure both gassing screw orifices are free of obstructions.

You have now completed disassembly of the QM or OOD spyglass

REPAIR, REASSEMBLY, AND COLLIMATION

OOD and QM spyglasses usually need refinishing due to mistreatment and salt damage. Follow the procedures outlined in chapter 7 of this manual if you repaint or cement lenses

Correct defects noted during disassembly that were not apparent when you inspected the instrument Pay particular attention to threaded support tube sections, locking threads, and retainer ring threads Remove any nicks or damage with thread chasers Clean these components with a clean brush, and fit them together to be sure they turn smoothly before cleaning and mounting optics.

Before replacing the lenses in the eyepiece drawtube, assemble the focusing mechanism to set zero diopters at mechanical midthrow. At this time you should also remove any play between the focusing key and spiral keyway

With the focusing ring, retaining ring, and lockring properly tightened to allow the focusing ring to turn without end play, turn the focusing ring slightly in both directions and observe the drawtube. If the drawtube moves when the focusing ring is turned, the focusing key is correct. If any play is evident, you will have to spread the ends of the focusing key by tapping lightly with a prick punch (peening). A very slight amount of peening is usually sufficient; do not overdo it. Fit and try until the focusing action is smooth and positive.

To check mechanical midthrow, turn the focusing ring to move the drawtube all the way in; then measure the height of the assembly. Now turn the drawtube all the way out and measure again. Position the drawtube halfway between these two measurements, and observe the alignment between the zero mark on the diopter ring and the index mark on the focusing ring. If they are not perfectly aligned, you will have to carefully drill and tap a new hole for the diopter ring lockscrew.

Disassemble the focusing mechanism again, and be sure the components are clean. Place a thin bead of sealing compound around the eyelens seat and replace the two lenses, spacer, and lockring. Tighten the lockring enough to ensure that the eyelens is sealed and seated properly. Replace the diaphragm in its original position. To check for proper placement of the diaphragm, look through the eyelens and look at the edge of the diaphragm. You will notice a fringe of yellow around this edge if the diaphragm is located correctly when the eyepiece is set to zero diopters. If not, turn the diaphragm in or out until this condition is met, and then install the diaphragm lockring.

Now reassemble the collective and erector lenses and the various internal tube sections. Lubricate and reassemble the focusing mechanism, and then seal and install the eyepiece mount on the eyepiece mount support tube. (NOTE: If a sealing window is used, replace and seal it prior to installing the eyepiece mount.)

Replace and seal the objective lens and mount of the OOD spyglass. Do not seal the objective of the QM glass at this time You may need to reposition this lens during collimation by shifting spacers.

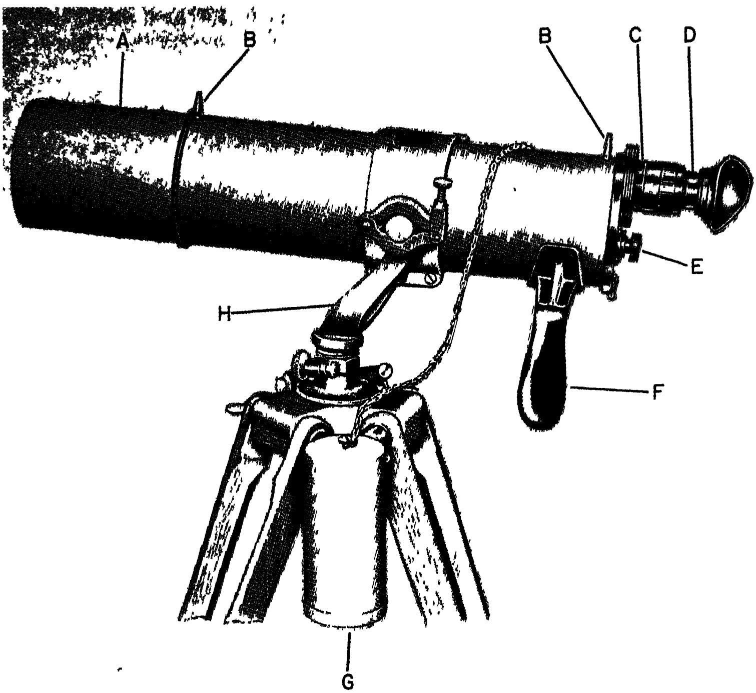
Place a piece of fine wire through the holes behind the collective lens, pull the wire tight, and twist the ends together to hold it tightly in position. Now screw the eyepiece mount support tube into the telescope body. (NOTE: Do not seal the joint at this time.)

Place the assembled telescope in V-blocks on any convenient collimator, and use an auxiliary telescope set to your eye correction to check for parallax between the collimator target and auxiliary wire. Remove parallax by screwing the collective lens mount in or out of the support tube.

When you assemble the eyepiece mount support tube and telescope body after each adjustment, be sure the joint is tight. If you do not have enough movement on the collective lens mount of a QM glass, now is the time to shift objective spacers. Move the lens the same direction you want the collimator image to move; then seal the QM glass objective.

After eliminating parallax, set optical zero diopters by adjusting the erector lens mount. Use an auxiliary telescope to determine which way the final image plane must move so the image will be in sharp focus at mechanical zero diopters.

These are single-erector telescopes, and you must move the erector in the opposite direction you want the image plane to move. Remember, you can reverse the erector lens and mount if necessary. Just be sure the lens is facing the right way, or you will introduce unwanted aberrations.



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 10-49.—Mk 1 Mod 0 ship telescope.

With parallax removed and zero diopters set, make sure the collective mount lockring, erector lockring, and collective-erector support tube setscrew are tight. Make a final check for parallax, and then remove the auxiliary wire. Now you can seal the eyepiece mount support tube and replace and seal the setscrew in the telescope body.

When the instrument passes a final inspection for cleanliness, collimation, focusing action, and appearance, your work is finished.

SHIP TELESCOPE

The ship telescope (fig. 10-49) is a change of power observation instrument with a porro prism erecting system. It is mounted on the open bridge of ships in a yoke that allows it to be elevated within practical limits and trained in any direction Change of power is provided by four interchangeable eyepieces of 13×, 21×, 25×, and 32×. The 21× eyepiece is orthoscopic, while the others are Kellner types. Since this instrument is exposed to salt spray and all types of weather, all joints and lenses are sealed with sealing compound to prevent moisture from entering the instrument There is no provision to gas or purge a ship telescope.

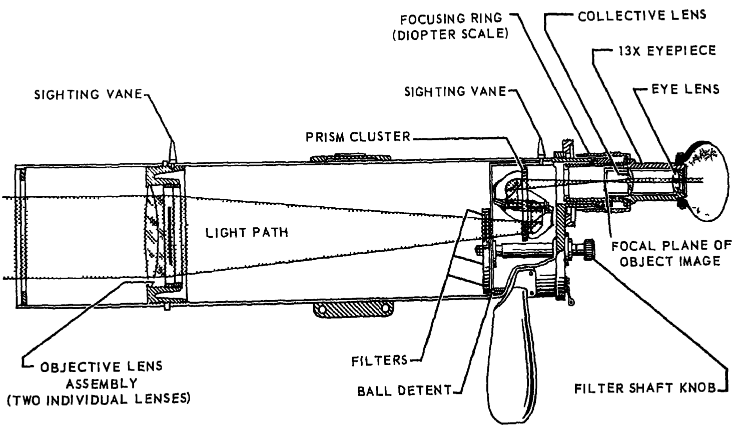
CONSTRUCTION FEATURES

The optical system and basic mechanical assembly are shown in figure 10-50. These are relatively simple telescopes with few adjustments. However, you will come across some instruments in such poor condition that they will tax your skill as an Opticalman.

The objective mount is threaded externally so it can be attached to and positioned in the body tube. A lockring holds the mount in position, and a sunshade screws on to the outboard side of the mount. The front sight vane functions as a lock screw for the objective mount.

Since the objective lens is too large to cement, the elements are separated by three equally spaced tin foil shims 0.001 to 0.002 inch thick. A spring ring backed by a retainer ring holds the lens in the mount.

All other components of the ship telescope are mounted on a prism box that threads into the



37.5

Figure 10-50.—Optical system of a Mk 1 Mod 0 ship telescope.

body tube (fig. 10-51). A lockring holds this prism box in position, and the rear sight vane serves as a setscrew.

A filter plate, controlled by a shaft through the prism box, is located within the objective focal length. A clear plano parallel compensator (to eliminate a change in objective focal distance), a light blue filter, and a single dark Polaroid filter are mounted in the filter plate. The Polaroid filter is oriented to reduce glare when it is in the line of sight.

The porro prism cluster, as usual, can be adjusted to remove lean. Finally, the multiple lead focusing mechanism is secured to the outside of the prism box. The four matched eyepieces screw into the focusing tube so the operator can easily change them without tools.

REPAIR AND ADJUSTMENT

The ship telescope is mostly constructed from aluminum. Even your best efforts to seal joints may eventually fail and allow salt corrosion, making disassembly difficult. Since the sunshade and body are quite thin, you will need to make fitted wooden clamp blocks to hold the telescope securely without crushing during disassembly.

Complete overhaul and collimation instructions are found in NAVSHIPS 250-624-3. The only unusual departure from normal repair and collimation procedures is parfocalizing the four eyepieces. Each eyepiece must focus within ± 1/4 diopter of the others. To do this, machine a predetermined amount of metal from the mounting shoulder of the eyepiece(s) in error.

TELESCOPE ALIDADE

The telescopic alidade is a portable navigational 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 a magnified image of the target (6×) aligned with a vertical wire, combined with an image of a level vial and compass card in the upper part of the field.

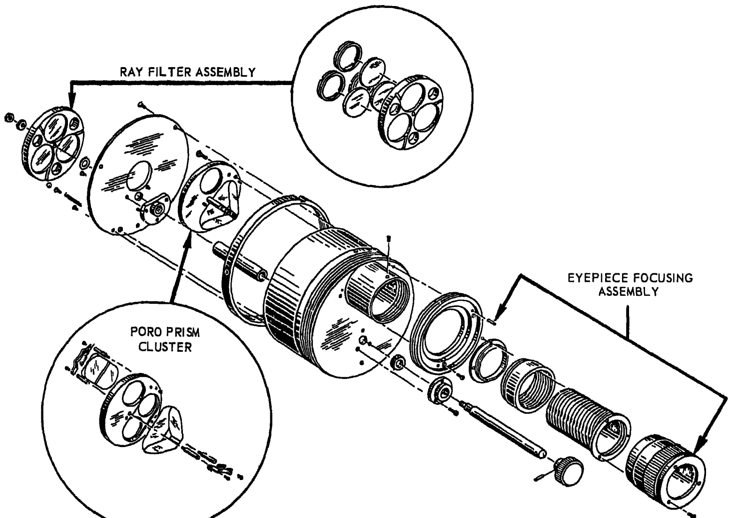


Figure 10-51.—Prism box, filter, and eyepiece focusing assembly—exploded view.

The two instruments shown in figure 10-52 are identical, except for the size of the adapter ring, which fits different gyro repeaters or compasses.

CONSTRUCTION FEATURES

The Mk 6 and Mk 7 alidades are gastight, aluminum-bodied, dual line of sight instruments with an internal focusing eyepiece that focuses the main and auxiliary optical systems. The optical schematic is shown in figure 10-53.

The main optical system consists of an objective lens, a filter assembly, a Schmidt prism (erects the image and directs it toward the eyepiece at a 45° angle), and the eyepiece system. The filter assembly consists of a fixed and movable Polaroid and a clear compensator. A large knob on the right side of the alidade drives the filter assembly (in or out of the line of sight), while a smaller knob through the center of the large knob controls Polaroid density.

The objective lens is adjustable along the optical axis to correct for parallax between the target and crosswire

The Schmidt prism is bonded to a post that is held to the prism mounting plate with three screws The screws have enough clearance so the prism post can be adjusted up or down, fore and aft, or rotated slightly in a vertical plane.

The auxiliary optical system consists of a sealing window (9), a front surface aluminized mirror (13), an inner and outer objective (11 and 12), two identical erector lenses (10), and the auxiliary system prism

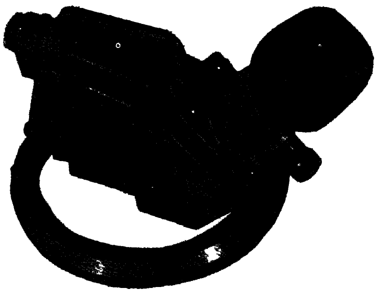
The auxiliary mirror is bonded to a threaded plug that screws in or out of the alidade body. This allows you to raise or lower the compass card image in the auxiliary field of view and to correct for tilt or lean in the auxiliary field

The two objectives share a common cell, as do the erectors, and both cells are threaded for adjustment along the auxiliary axis.

The auxiliary prism (5) is mounted and adjusted in the same manner as the main prism.

A metal plate and fine crosswire are mounted at the common image plane of the main and auxiliary optical systems.

The image of the level vial (14) will always be slightly out of focus since it is positioned approximately 1 inch above the compass or repeater.



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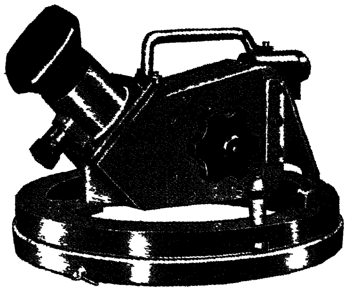

MARK 7 MOD 0

45.39

Figure 10-52.—Mk 6 and Mk 7 telescopic alidades.

REPAIR AND ADJUSTMENT

After you have acquired some experience repairing optical instruments, you will probably discover that the Mk 6 and Mk 7 alidades are made to be replaced, rather than repaired. This is unnecessarily expensive and frustrating to a good repairman.

The complete overhaul procedure, as well as drawings and parts lists, is contained in NAVSHIPS 324-0488. Basically, collimation consists of aligning a collimating stand on the collimator (Mk 4), adjusting the main optical system, and adjusting the auxiliary optical system.

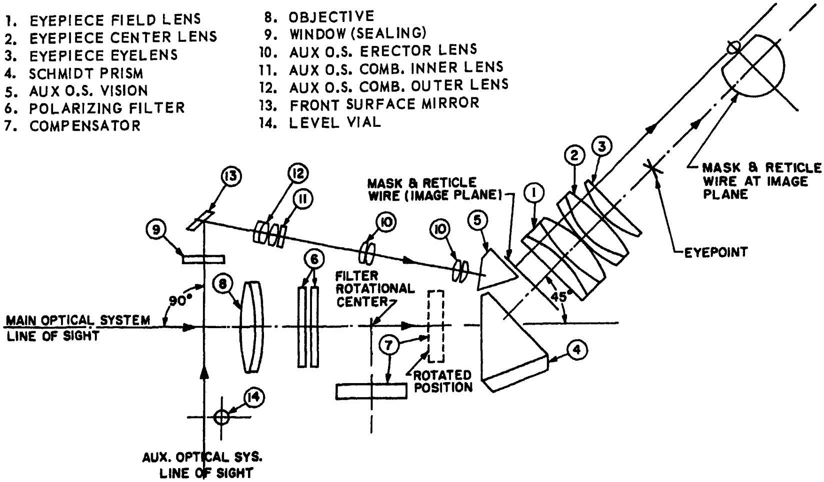

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Figure 10-53.—General optical arrangement of the Mk 6 and Mk 7 alidades.

Once the instrument is collimated and sealed, you must test for leaks, dry the interior with nitrogen, and charge it to 4 psi

BINOCULARS

Most people know basically what binoculars are, but now you will learn more about them. We will discuss two basic types, the hand-held 7 × 50 and the mounted 20 × 120. The numbers 7 and 20 refer to magnification, and 50 and 120 indicate the size of the objective lens opening in millimeters.

7 × 50 BINOCULARS

The optical system and mechanical arrangement shown in figure 10-54 are generally common to all current hand-held binoculars. In effect, there are two separate prism-erected telescopes joined by a hinge so people with different eye separations can use the instruments comfortably. The 7× has been determined to be about the highest practical magnification for hand-held binoculars. Any more power would cause excessive target motion, and any less would not bring out sufficient detail on the target The 50-mm objective lens has very good light gathering ability under all weather conditions In fact, binoculars used by the Navy can be used effectively half an hour before sunrise and half an hour after sunset The wide separation between the objective lenses increases your effective interpupillary distance, thereby increasing your range of stereoscopic vision. (Stereoscopic vision is directly related to your ability to judge relative distance between objects)

Construction Features

The Mk 28 and Mk 39 binoculars are practically identical, except that the Mk 39 has a reticle mounted on the right prism plate (fig. 10-55). These two instruments are sealed against moisture by sealing compound in lens mounts and joints between body and covers, and by heavy grease on the eyepiece cell. The prism plates are mounted on lugs inside the body, and

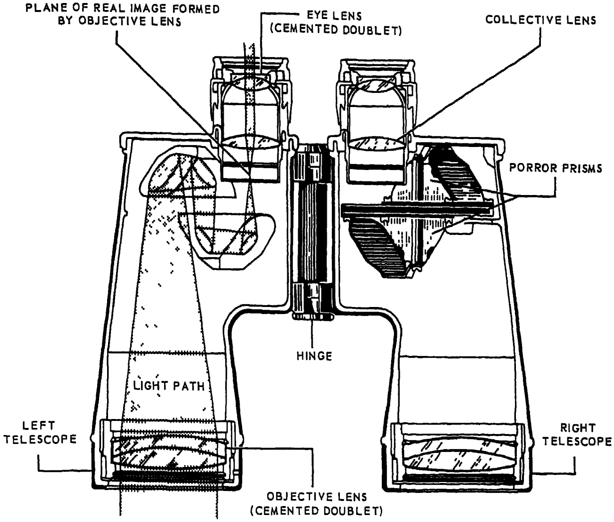

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Figure 10-54.—Cross section of a binocular system.

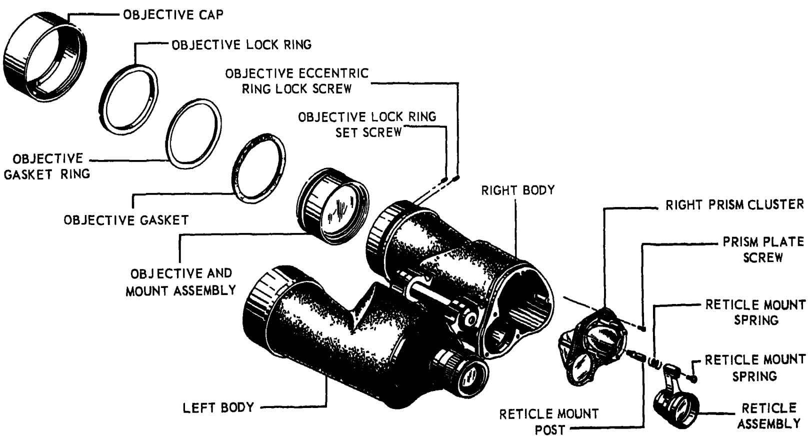

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Figure 10-55.—Mk 28 binocular objective and prism cluster and Mk 39 reticle assembly.

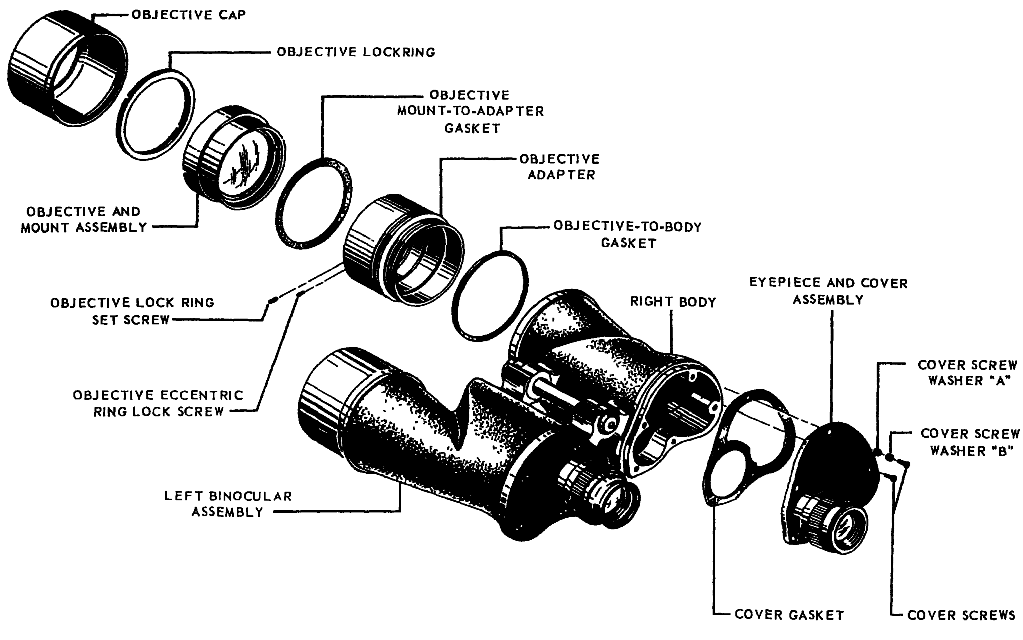
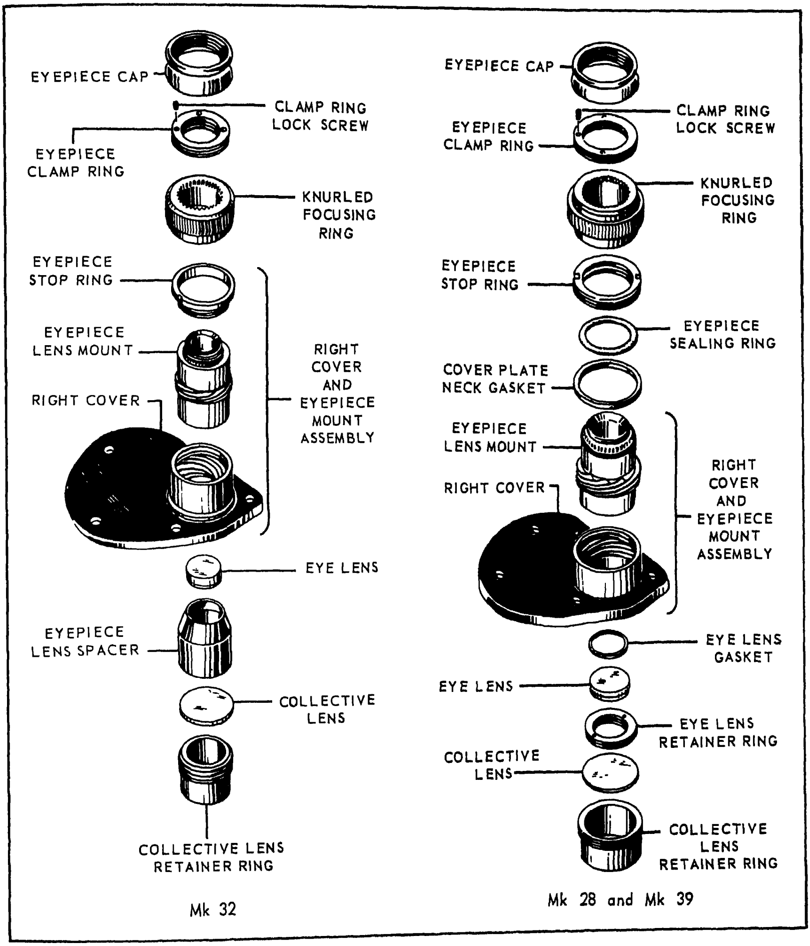


Figure 10-56.—Mk 32 binocular—exploded view.

the objective assembly slips into a recess in the front of the body.

The Mk 32 has several changes, mainly to improve sealing the instrument. It also has an objective adapter that screws into the binocular body. See figure 10-56.

Two types of eyepiece assemblies are shown in figure 10-57. Again the major difference



137.580

Figure 10-57.—Mk 32 and Mk 28 and 39 eyepiece and cover assemblies.

between the Mk 28 and Mk 39 and the Mk 32 is in the provision for sealing the instruments.

An exploded view of a prism cluster, common to the Mk 28, Mk 32, and Mk 39 is shown in figure 10-58.

The hinge is the heart of a pair of binoculars. It must operate smoothly but provide enough tension to hold the two bodies in

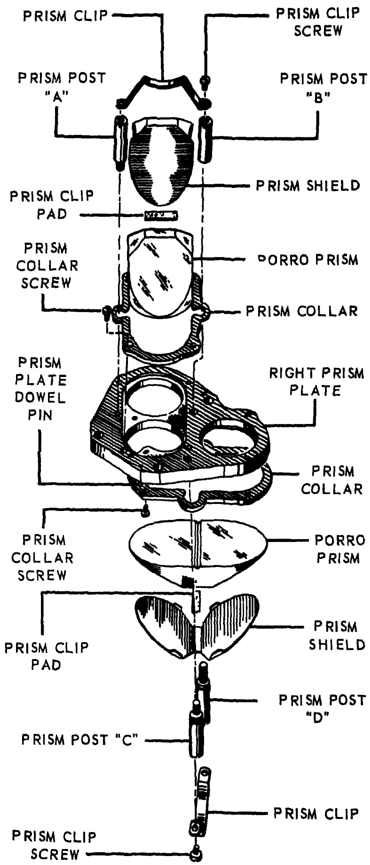


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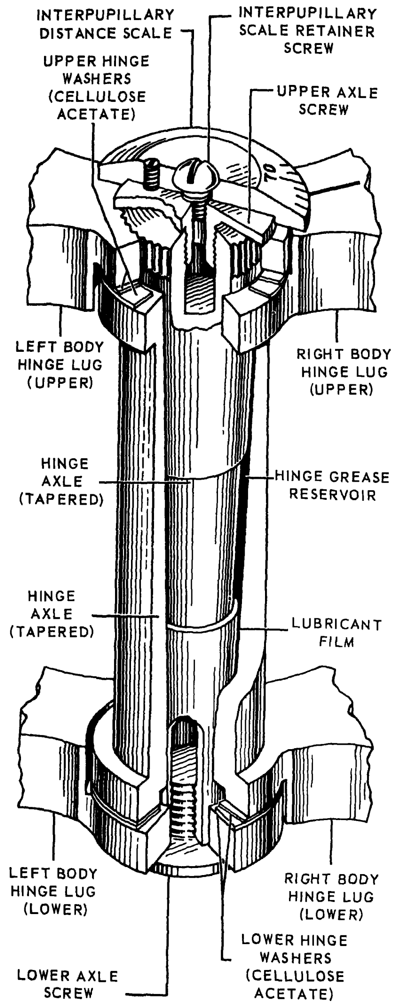
Figure 10-58.—Mk 28, Mk 32, Mk 39 porro prism cluster.



137.464
Figure 10-59.—Mk 28, 32, and 39 binoculars hinge mechanism.

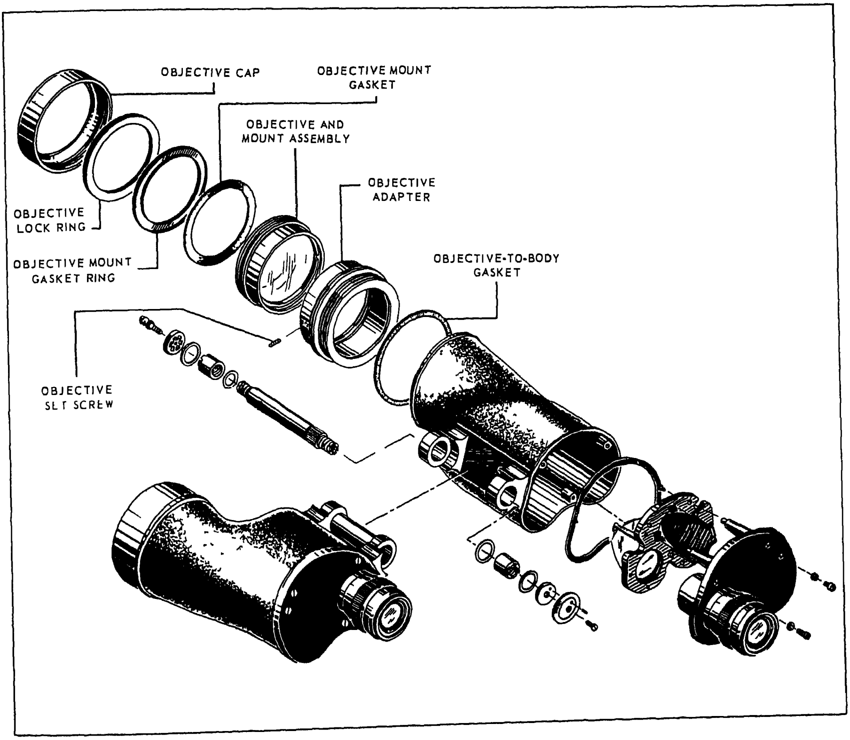
position. It forms the mechanical axis of the instrument.

Figure 10-59 shows the hinge mechanism used on the binoculars discussed so far. The tapered hinge axle is kept from turning by splines that mate with the upper left body lug. You will encounter some variations that use two dowel pins rather than splines between the hinge axle and the body lug.

When a hinge is properly assembled, the height of the two bodies must be equal. There must be 0.004-inch grease clearance between the hinge axle and the tapered hinge tube (right body). These factors are controlled by the seating depth of the axle in the left body lug (upper) and various thickness hinge washers between the body lugs. The seating depth of the hinge axle is determined by the upper and lower axle screws.

Improper lubrication, incorrect adjustment, or grit and burrs on hinge components can cause problems with the hinge action.

Although the Mk 28, Mk 32, and Mk 39 binoculars share some common mechanical features, the Mk 45 binocular is completely different in construction (fig. 10-60). The design of the Mk 45 makes it practically waterproof. There are many reported instances when these instruments were submerged to depths of 100 feet and did not leak.



137.541

Figure 10-60.—Mk 45, 7 × 50 binocular assembly—exploded view.

The Mk 45 eyepiece assembly (fig. 10-61) is somewhat similar to the Mk 32, but the prism cluster (fig. 10-62) is entirely different. Also notice that the prism cluster of the Mk 45 mounts on posts on the underside of the cover plates. Four prism locating shoes are used to locate and adjust each prism.

The hinge assembly of the Mk 45 is also very different (fig. 10-63). Instead of using a tapered hinge axle, split bronze bearings screw onto each end of a straight hinge axle. As those bearings contact brass hinge thrust washers, further rotation forces them to expand and contact bearing surfaces machined in the right hinge lugs. Correct lubrication, tension adjustment, and corrosion prevention are essential to smooth operation of the Mk 45 hinge.

Overhaul

As an Opticalman, you will work on more binoculars than all other instruments combined. Some binoculars will be sent to the optical shop in excellent condition, others will be basket cases. A good casualty analysis will indicate the extent of repair and disassembly necessary. Do not disturb the binoculars any more than necessary to do a typical outstanding overhaul. It does not make any difference whether you disassemble the objectives or the eyepiece and cover assemblies first, but save the hinge for last. Likewise, if you must completely disassemble a pair of binoculars, reassemble and adjust the hinge before installing optics. (NOTE: The hinge of hand-held binoculars receives considerable wear; therefore the hinge of each pair of binoculars sent to the shop should be checked, lubricated, and readjusted.)

Always replace gaskets, and never interchange optics or mechanical parts between bodies. Binoculars can be temperamental if you start switching parts. You should use a compartmented parts box to keep the parts separated. Even with excellent quality control, dimensions of mechanical components will vary slightly, lenses will have minor focal length differences, and prisms will not always be identical. Use a lens centering instrument to check focal lengths of lenses, and make a side visual inspection to determine variations between mechanical components. The seating depth of objective lenses in their mounts can be troublesome at times, especially if different size prisms are used in each telescope.

To compare prisms for size, place them in a V-block protected by a sheet of lens tissue. The

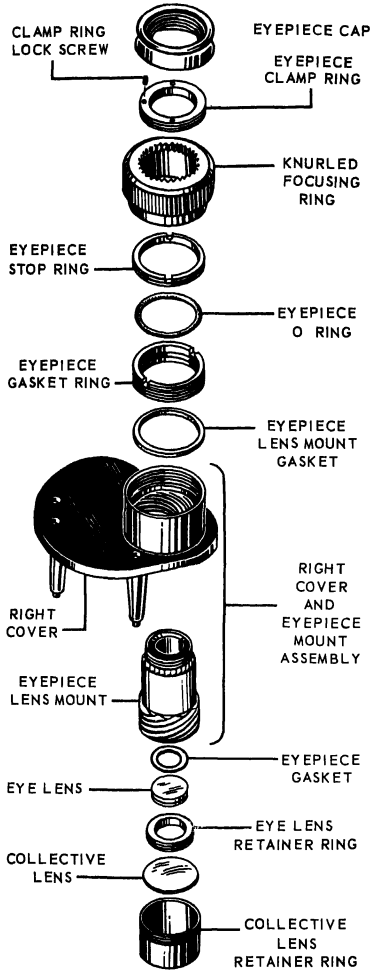
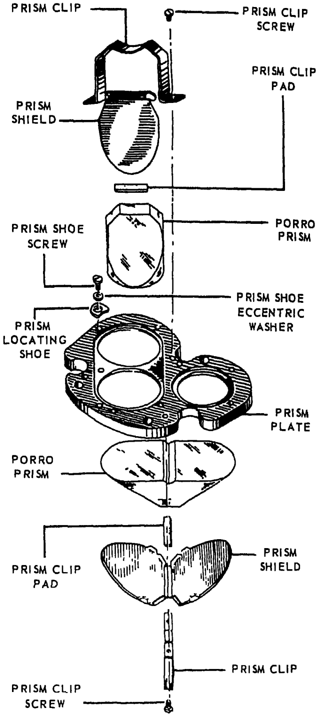


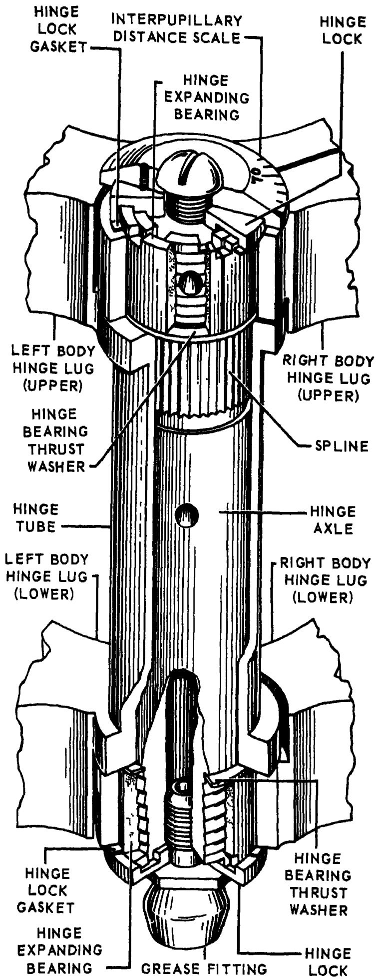
Figure 10-61.—Mk 45 binocular eyepiece and cover assembly.



137.583
Figure 10-62.—Mk 45 binocular prism cluster.

entrance/emergence face of the larger prism will be higher than the corresponding surface of the other prism Replacing any prism in a pair of binoculars, with one of larger size, will lower the eyepiece in that telescope. The converging light from the objective has to travel further in the larger prism; therefore, it comes to a focus farther from the eyepiece (see fig. 10-54), and you have to turn the eyepiece in to focus the image.

Cleanliness is just as important in binoculars as it is in any other instrument. Dust or grease smudges will reduce light transmission, and these defects can be seen on the optics. The collective lens is very close to the objective image plane so



137.540
Figure 10-63.—Mk 45 hinge mechanism.

any specks or lint will be magnified and very obvious. Remove grease from all lens mounts before you attempt to replace the lenses.

When you remove the eyepiece cells from the cover plates, mark the relationship between these parts so you can reassemble them in the same position—especially if focusing action is equal between them. If focusing action is not equal, try a different lead on the multiple lead thread. Eyepiece cells of the Mk 28, 32, and 39 are removed from the top. The Mk 45 should be removed from the bottom.

Apply lubrication to the eyepieces and objective eccentric rings during final assembly. Likewise, use antiseize on cover screw threads, objective cap threads, and the objective adapter threads (where appropriate).

Collimation

Prism cluster assembly is a very important part of binocular collimation. If this is not done properly, you may not be able to collimate your binoculars without disassembling one or both clusters to find the problem. Porro prism cluster adjustments were discussed in chapter 8 of this manual

The assembled binocular (except for objective seals, lockrings, and objective caps) is mounted on a Mk 5 collimator, as shown in figure 10-64. Notice that the binocular is mounted upside down, and the right hinge lug is clamped in the fixture so the left body is free to move.

Using an auxiliary telescope with rhomboid attachment, focus both eyepieces on the collimator target and set the focusing rings to zero diopters (within $\pm 1/4$ diopter of each other). At this time, the eyepieces should be of equal height within 1/16 inch (check with a straightedge). Also check for lean by comparing the magnified collimator target, seen through the eyepieces, with the smaller collimator target picked up by the rhomboid attachment. Correct any problems noted before proceeding.

To align both lines of sight with the hinge axis, use the tail-of-arc method, explained next.

First swing the left body all the way up to show approximately 58 mm on the IPD scale. Using the auxiliary telescope, adjust the screws on the collimator fixture to align the normal and magnified target image (fig. 10-65).

Now swing the left body down to obtain the widest separation between eyepieces (74 mm). What you see through the auxiliary telescope should be similar to figure 10-66 The smaller

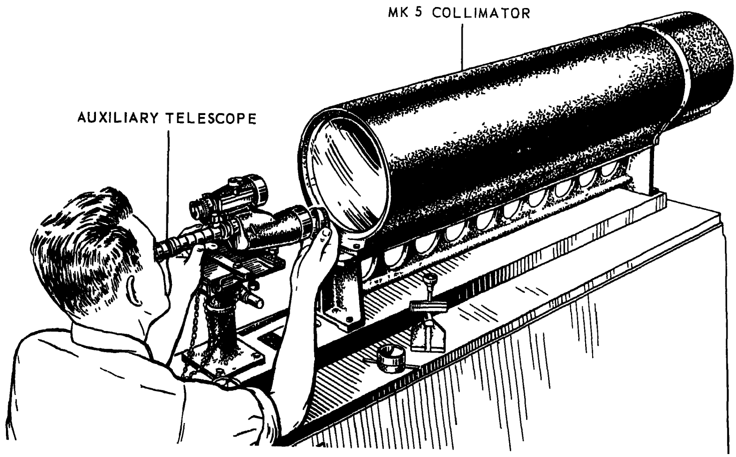


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Figure 10-64.—Mk 5 binocular collimator.

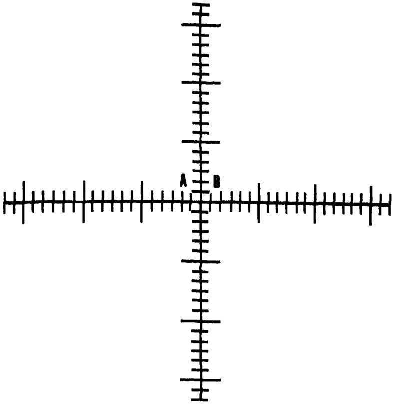

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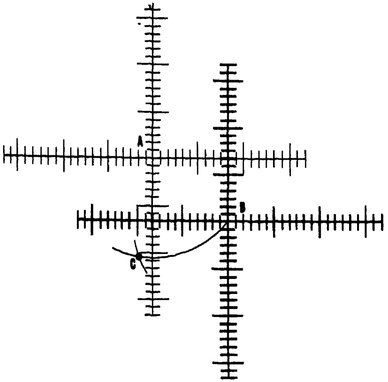
Figure 10-65.—Collimator crosslines superimposed at 58 mm interpupillary distance.



137.492
Figure 10-66.—Preliminary step in binocular tail-of-arc collimation.

target (A) is a stationary reference picked up by the rhomboid The magnified target (B), seen through the left barrel, shows how far the line of sight deviates from parallelism with the hinge (NOTE. To make collimation easier, the objective eccentric rings should be set for maximum displacement when assembled)

To adjust the line of sight, construct an imaginary equilateral triangle, shown by points A, B, and C in figure 10-66. Point C must always be figured in a clockwise direction from point B, regardless of where the magnified crossline ends up after swinging the left body (NOTE: The small crossline may appear to move)

With the left telescope still at 74 mm IPD, manipulate the objective eccentrics to place the magnified target image (B) in the area of imaginary point (C). Try to make this adjustment without disturbing the binocular on the collimator fixture. (NOTE: First, rotate the entire objective assembly (inner and outer eccentric). If this does not move the magnified target to point C, throw some eccentricity into the objective and rotate the complete assembly again.)

After you are satisfied that the crossline is near point C, swing the left body back to 55 mm IPD and adjust the collimator fixture to superimpose the two crosslines (fig. 10-65). Repeat steps 2 through 5 until there is no displacement of the magnified crossline when you swing the left barrel from 54 mm to 74 mm.

If you find there is not enough eccentricity in the left objective to satisfy collimation requirements, you will have to shift prisms. After shifting prisms, check zero diopters, equal eyepiece height, and lean again before recollimating.

Once the left body is collimated, swing that body down to approximately 64 mm, realign the two crosslines by adjusting the collimator fixture, and adjust the right objective to superimpose the two crosslines seen through the auxiliary telescope. Recheck the left and right bodies to be sure you have perfectly superimposed the crosslines. (NOTE: If you cannot superimpose the line of sight with the right objective eccentrics, shift prisms.)

Tighten the eccentric lock screws, replace gaskets and rings, replace and lock the objective lockring, and replace the objective caps. (NOTE: Tightening the eccentric lock screws and the objective lockrings may throw collimation off. Recheck and adjust as necessary.)

Collimation tolerance for both lines of sight in a binocular are specified as (1) 2′ step (vertical displacement), (2) 4′ divergence (outward separation), and (3) 2′ convergence. These tolerances represent government performance standards for binoculars. You will not find an optical shop supervisor who will accept these sloppy tolerances. If your collimation is not perfect, it is not good enough.

Complete overhaul information for Navy hand-held binoculars is found in NAVSHIPS 250-624-2.

SHIP-MOUNTED BINOCULARS

A completed ship binocular is shown in figure 10-67. The optical arrangement is similar to hand-held binoculars except that Polaroid filters and clear compensators are provided, and the ship binocular uses an internal focusing eyepiece. Characteristics of the ship binocular are as follows:

Magnification ....20 power
Clear aperture.................120 mm
True field of view ....3°30′
Eye distance at zero diopters....22.5 mm
Apparent field (approx.)........70°
Exit pupil ....6 mm
Interpupillary distance ....56-74 mm
Overall binocular length
(sunshade extended).........20.375 inches
Overall binocular width ....22.5 inches

The Navy uses four similar types of ship binoculars, the Mk 3 Mod 1, the Mk 3 Mod 2, the Mk 3 Mod 4, and the Mk 3 Mod 5. An exploded view of the Mk 3 Mode 4 is shown in figure 10-68. This instrument may look like

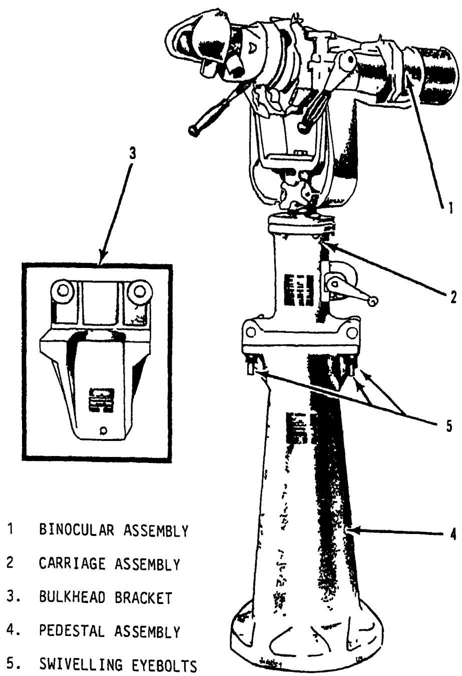


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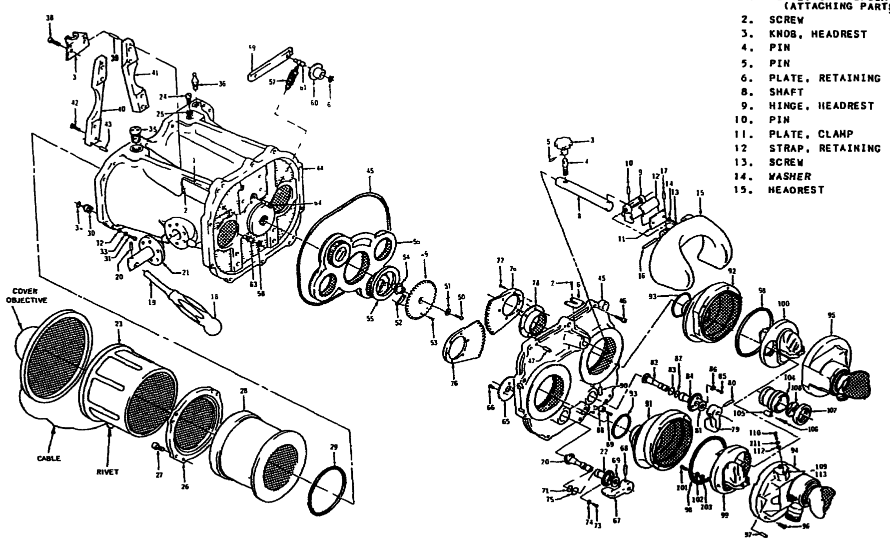
Figure 10-67.—Ship binocular.



1. PLATE, IDENTIFICATION (ATTACHING PARTS)
2. SCREW
3. KNOB, HEADREST
4. PIN
5. PIN
6. PLATE, RETAINING
8. SHAFT
9. HINGE, HEADREST
10. PIN
11. PLATE, CLAMP
12 STRAP, RETAINING
13. SCREW
14. WASHER
15. HEADREST
16. PIN, HINGE
17 PIN
18. GRIP
19. HANDLE
20. PIN
21 SHAFT, PIVOT
22. SCREW
23. VISOR, BINOCULAR
24. SCREW
25. WASHER
26. CLAMP, OBJECTIVE
27. SCREW
28. CELL, OBJECTIVE
29. SEAL
30. SHAFT, ECCENTRIC
31. SCREW
32. WASHER
33. WASHER
34. PACKING
35. VALVE, GAS
36. SIGHT, FRONT
37. BRACKET, CARRIAGE
38. SCREW
39. PIN
40. DOVETAIL LH
41. DOVETAIL RH
42. SCREW
43. PIN
44. HOUSING, MAIN
45. HOUSING, FILTER
46 SCREW
47. PIN
48. SEAL
49. GEAR, IDLER, FILTER
50 SCREW
51. WASHER
52. PLATE, ACTUATOR
53. SCREW
54. SHAFT, IDLER GEAR
55 RING, RETAINING
56. FILTER ASSEMBLY
57. SPRING, DETENT ARM
58. RING, RETAINING
59. ARM, DETENT
60. ROLLER, DETENT
76. GEAR, SECTOR
77. SCREW
78. BEARING SLEEVE
79. KNOB, INTEROCULAR ADJUST
80. PIN, SPRING
81. SHIM, WASHER
82. GEARSHAFT, INTEROCULAR
83. PACKING
84. BEARING, SLEEVE
85. SCREW
86 WASHER
87. PACKING
88. SPACER, STOP
89. SCREW, FIL HD, SLOT
90. BUTTON, STOP
91. HOUSING, PRISM LH
92. HOUSING, PRISM RH
93. SEAL
94. HOUSING, EYEPIECE LH
95. HOUSING, EYEPIECE RH
96. SCREW
97. PIN
98. PACKING
99. PRISM ASSEMBLY LH
100. PRISM ASSEMBLY RH
101. SCREW
102. WASHER
103. WASHER
104. SPACER, SLEEVE, RETICLE
105. CLAMP, RIM
106. SCREW
107. HOUSING, RETICLE
108. WINDOW, COMPENSATOR
109. PLUG, ACCESS
110. SCREW
111. WASHER
112. WASHER
113. PACKING

148.110

Figure 10-68.—Mk 3 Mod 2 ship binocular assembly.

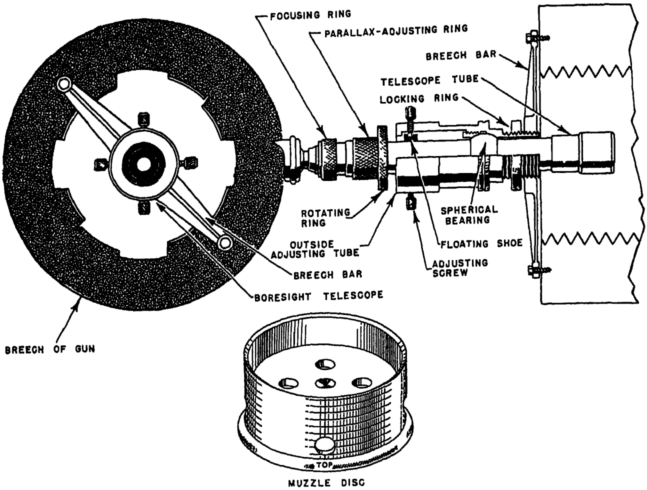


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Figure 10-69.—Typical boresighting equipment.

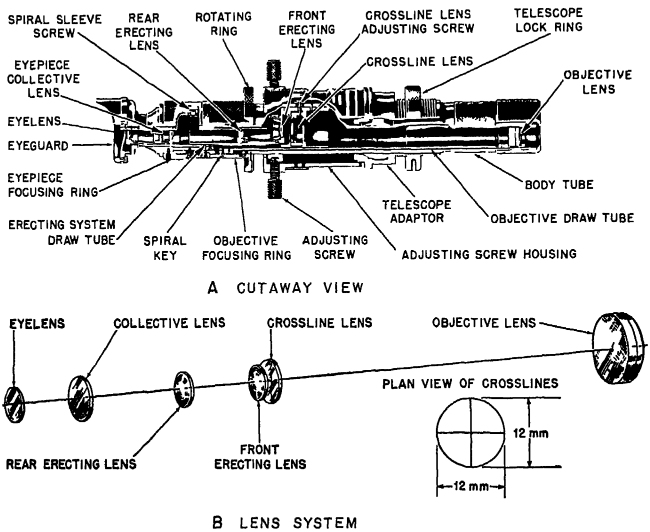

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Figure 10-70.—Optical and mechanical system of a Mk 8 Mod 6 boresight.

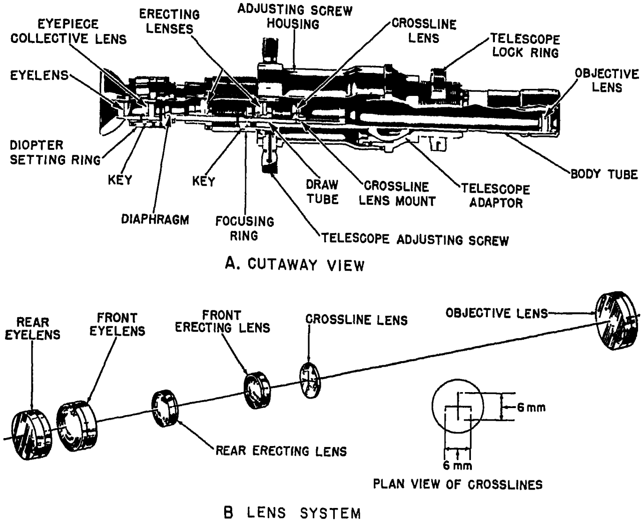

Figure 10-71.—Optical and mechanical system of a Mk 75 Mod 1 boresight.

a nightmare, but it really is not very complicated

Most ship binoculars are sealed with O-rings, packing, and sealing compound to maintain an internal pressure of 2 psi Two shafts extend through the eyepiece housing One controls the filter assembly, the other moves both eyepieces to set the user's IPD (NOTE: As you can see in figure 10-68, there is no hinge connecting the two telescopes of a ship binocular The two eyepieces are gear driven to move in opposite directions)

The two elements of each objective are separated by a spacer. Various spacers, seals, and lockrings fit into the objective tube to complete the objective assembly. The major difference between the Mk 3 Mod 1 and Mk 3 Mods 2, 3, 4, and 5 is the means for adjusting the objectives during collimation. In the Mk 3 Mod 4 (illustrated), eccentric buttons (30) are used to shift the objective assembly. The Mk 3 Mod 1 uses eccentric rings. Complete information on overhaul, adjustment collimation, sealing, and drying drying can be found in NAVSHIPS 324-0516 and NAVSEA S9421-AA-MMA-010.

BORESIGHT TELESCOPES

As the name implies, a boresight is used to accurately align the point of aim of a naval gun with associated sighting equipment. A typical setup is shown in figure 10-69 The boresight is mounted on a breech bar, which centers it in the breech, and a fitted muzzle disc, with centered peep hole, is placed in the muzzle. The boresight can be adjusted to center a crossline on the muzzle disc. The boresight can then be focused on a selected external target so associated equipment can be aligned to the gun bore on the same target.

CONSTRUCTION FEATURES

Two similar instruments are shown in cutaway form in figures 10-70 and 10-71. Even though there are some optical and mechanical differences, the boresights function alike.

Optical characteristics of the two boresights are as follows:

Mk 8 Mod 6		Mk 75 Mod 1	
Magnification	9 6×	Magnification	8×
Field	2°30′	Field	3°20′
Exit pupil	2.3 mm	Exit pupil	2.5 mm
Eye distance	11 0 mm	Eye distance	19.4 mm

Notice that these boresights have a small field angle and a tiny exit pupil. Considering that they are used only for infrequent alignment purposes, these features are not objectionable.

Another requirement for a boresight is the ability to focus on objects at various distances. The Mk 8 Mode 6 can focus on objects from 6 feet to infinity. This is accomplished by mounting the objective lens in a drawtube so it can be moved in relation to a fixed crossline to provide a parallax-free view of the target. The eyepiece system of the Mk 8 Mod 6 is also in a fixed position. Focusing is provided by mounting the erecting system in a drawtube.

The Mk 75 Mod 1 boresight is capable of focusing on objects between 10 feet and infinity. In this telescope, the objective is fixed and the crossline and erectors are mounted in a drawtube. It is also a focusing eyepiece.

As you can see in figures 10-70 and 10-71, both telescopes have a spherical bearing on the body tube that fits a socket in the telescope adapter. When the telescope adapter is screwed into a fixture and secured with the telescope lockring, the four telescope adjusting screws can be manipulated to accurately position the line of sight.

The Mk 8 Mod 6 boresight has a rotating ring and crossline adjusting screws. This feature allows you to remove eccentricity between the target and crossline. The Mk 75 Mod 1 does not have this feature because the crossline lens is accurately ground to be perfectly concentric with the crossline and the mounts and body tubes.

REPAIR AND ADJUSTMENT

Boresight telescopes are sturdy but delicate. They are stored in a protective box most of the time. However, accidents do happen. Usually, they are sent to the optical shop only for cleaning and lubrication.

In a boresight, screws are small, threads are very fine, the lenses are small, and mating parts are closely fitted. You must be very careful when disassembly is necessary. Parts can be easily damaged or deformed. It would be advisable to make some special tools for removing lockrings.

The complete description and overhaul procedures for the Mk 8 Mod 6 and Mk 75 Mod 1 boresights is contained in OP 1449.

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Manual for Overhaul, Repair and Handling of Mark I Mod 0 Ship Telescope, NAVSHIPS 250-624-3, Department of the Navy, Washington, D.C., 1953.

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Type 1 Technical Manual Ship Binocular, 20 Power, Mark III Mod 4 and Mod 5, NAVSEA S9421-AA-MMA-010, Naval Sea Systems Command, Washington, D.C., 1977

Technical Manual, Alidade, Telescopic, Marine, Mark 6 Mod 1, and Mark 7 Mod 0, NAVSHIPS 324-0488, Bureau of Ships, Washington, D.C., 1961.

CHAPTER 11

NIGHT VISION SIGHTS AND GUNSIGHTS

You might think it strange to combine two seemingly different types of instruments in one chapter, but there are some similarities to justify this action. First, several of the night vision sights being discussed are actually used as gunsights. Second, both categories of instruments combine conventional optics with some electrical or electronic application.

This chapter, therefore, is an introduction to electro-optical instruments.

NIGHT VISION SIGHTS

Up to this point, we have only discussed optical instruments that function in bright light or rely on a luminous or illuminated target to form a useful image. We will now discuss night vision sights. They are electro-optical devices and are designed for use when there is not enough light for a conventional telescope to form an image.

We will discuss three passive instruments that emit no light during operation, consequently, they cannot be detected. These devices electronically amplify available light 35,000 to 50,000 times so the operator can clearly distinguish objects. We will also describe an infrared telescope, considered an active instrument since it generates a beam of infrared to illuminate targets. Infrared is not visible to the unaided eye, but it can be detected by the use of infrared-sensitive instruments.

COMPONENTS

A night vision sight (NVS) consists of three optical assemblies: the objective elements, the image intensifier tube (ITT), and the eyepiece system. The objective assembly, consisting of multiple lenses (or mirrors), focuses available light on the first stage of a three-stage IIT. The IIT amplifies the light through a process of electron emissions from phosphor screens and then presents this light to a focusing eyepiece for final magnification. A very basic schematic of a typical NVS system is shown in figure 11-1.

Two types of IIT are currently being used. They can be used in all three of the night vision sights being discussed. The older type of IIT could not tolerate bright light without overloading. Too much exposure would burn out the unit. A new automatic brightness control (ABC) IIT can

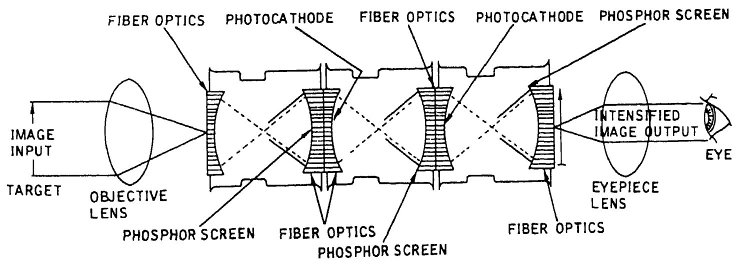

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Figure 11-1.—Image intensifier diagram.

accept higher light levels and will also turn itself off to prevent damage.

MK 36 NVS

The Mk 36 NVS (fig. 11-2) is a lightweight (6 pounds) 4-power instrument that can be hand held or mounted on various light rifles or machine guns. It has an objective assembly that can be focused on objects from 4 yards to infinity.

MK 37 NVS

The Mk 37 NVS (fig. 11-3) is a bridge-mounted sight with a power of 5.5 or 7.5, depending on the eyepiece used. The objective assembly can focus on objects from 50 yards to infinity.

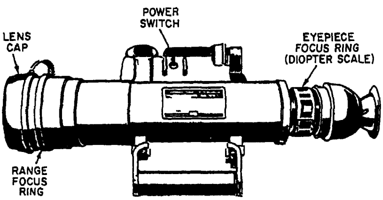

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Figure 11-2.—Mk 36 night vision sight.

CREW SERVED WEAPON SIGHT (CSWS)

The CSWS (fig. 11-4) is a 7-power instrument with two types of illuminated reticles. This NVS is mounted on heavy machine guns, recoilless rifles, and 20-mm cannons. The objective focus range is the same as the Mk 37. The boresight mount assembly shown is also used on the Mk 36 NVS.

A representative power supply assembly is shown in figure 11-5. A mercury battery (6.8 volts dc) powers an oscillator, which converts the low dc voltage to 2,800 volts ac. This higher ac voltage is further boosted by the IIT to approximately 45,000 volts during the process of light amplification. The Mk 36 and Mk 37 are also supplied with a converter so that 115-volt ac power can be used in place of the battery.

METASCOPE

The infrared telescope (metascope) is shown in figure 11-6 The receiver portion, which detects other infrared sources, is a 1.1× telescope, with

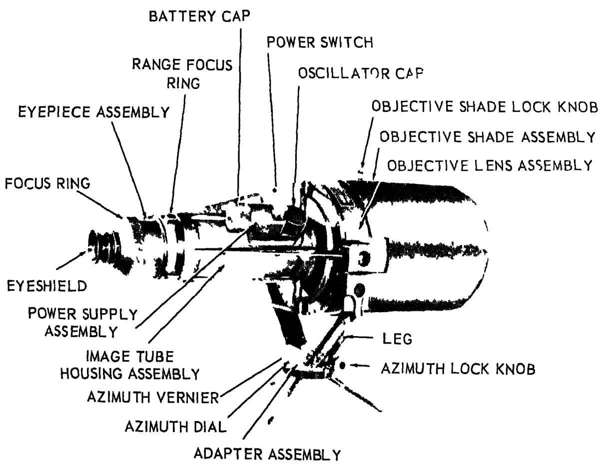

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Figure 11-3.—Mk 37 night vision sight.

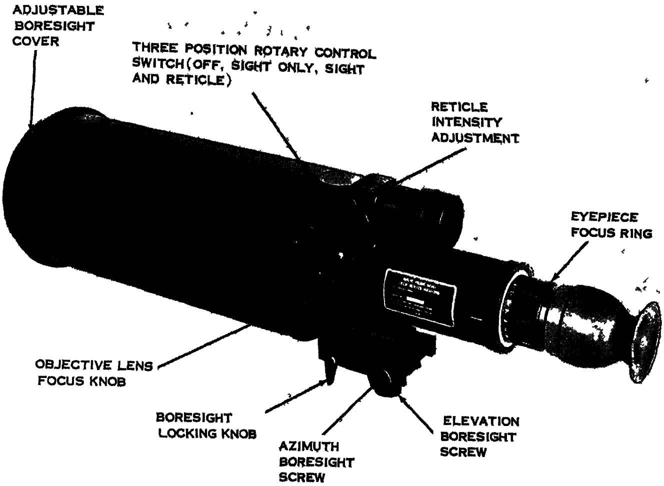

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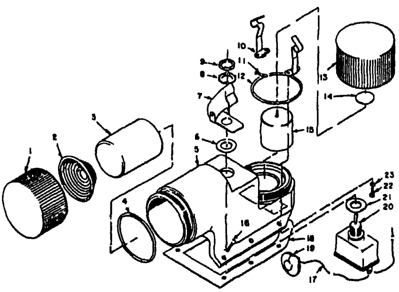
Figure 11-4.—Crew served weapon sight.



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

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Figure 11-5.—Power supply assembly, exploded view.

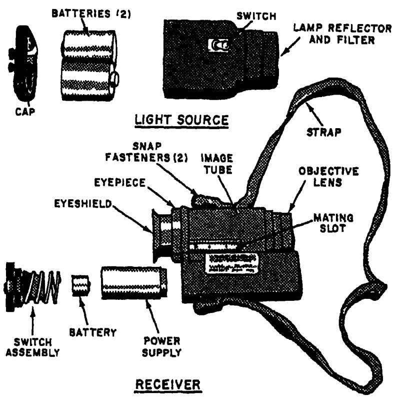

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Figure 11-6.—Metascope components.

a focusing eyepiece and an objective lens, (adjustable for target distances from 12 inches to infinity). A mercury battery (1.34 volts dc) activates a power supply that steps the voltage up to 11,500 volts dc. The power supply output energizes a single-stage image tube, which functions similarly to the IIT in a NVS. The light source of the metascope is nothing more than a two-cell flashlight with an infrared filter over the reflector. With the light source attached to the receiver, and activated, the target is bathed in invisible infrared light, which is converted to a visible image by the image tube in the receiver.

REPAIR AND ADJUSTMENT

The primary safety consideration in working with an NVS is the high voltage in the IIT assembly. This voltage must be discharged, as specified in OP 4067, BEFORE you attempt any internal repairs. It is also important to avoid damaging the IIT. The coating on the phosphor screen is toxic. You must not inhale it nor allow it to come in contact with your mouth or any open wounds.

Repairs to night vision sights are limited to checking the continuity of switches and wiring, replacing defective electrical components, cleaning external optics, replacing various seals, and replacing (turn-in) damaged or unserviceable optical components. Further repair or disassembly is not normally authorized.

Limited repair procedures for night vision sights are contained in OP 4067.

GUNSIGHT TELESCOPES

Gunsight telescopes vary from small, fixed line of sight instruments to large servo-controlled tilting prism sights. The small sights are mounted on open gun mounts, the larger sights are found in closed twin mounts, and the modern instruments are mounted on gunfire directors or in gun mounts.

Older gunsights were designed so one person could sight the target and control elevation while another person, using a similar sight, could train the gun. Range to a target was determined by a rangefinder or radar. The pointer and trainer would observe the effect of gunfire and adjust train and elevation accordingly.

Large guns, in closed mounts, used several different types of sights which were mechanically connected to the elevation/train mechanism. With this arrangement, the operators could observe the effects of gunfire without changing position. Aiming of the guns and sights was normally controlled from the director, but local control could be used if necessary.

This section will deal with only one type of older gunsight If additional information is needed, refer to OP 582.

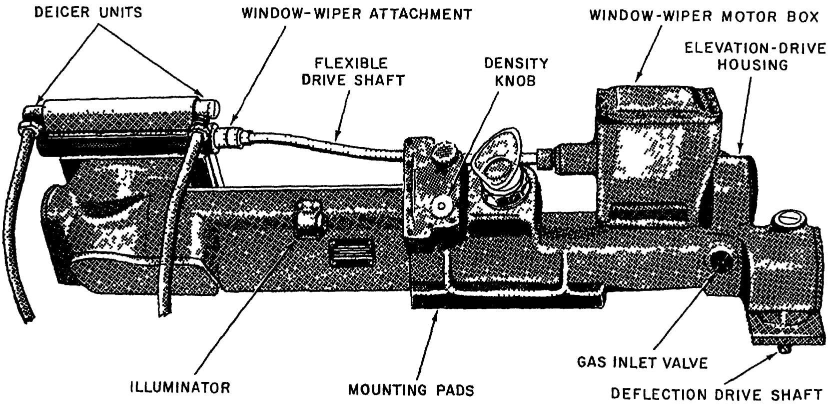

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Figure 11-7.—Mk 67 telescope.

MK 67 AND MK 68 GUNSIGHTS

The Mk 67 gunsight (fig. 11-7) is a 6×, tilting prism gunsight about 4 feet long and weighing approximately 180 pounds. The Mk 68 telescope is essentially a mirror image of the Mk 67. The optical system is shown in figure 11-8.

Three of these instruments are found in a 5"/38 caliber twin gun mount—one each for the pointer and checker (Mk 67) and one for the trainer (Mk 68).

The line of sight, controlled by suitable shafts and gears, is movable from +85° to −15° in elevation, with maximum deflection of 20° left or right.

Various cover plates and windows, sealed by flat gaskets, allow access to the optical and mechanical components for disassembly and adjustment. It is very important that you use scribe lines and punch marks (bench marks) during disassembly and reassembly of the Mk 67 and Mk 68 telescopes

The crossline and rear erector are mounted in an inner optical tube which is secured in the outer optical tube. The objective lens is threaded into the outer end of the outer optical tube. The rear erector is secured in a mount threaded into the body casting. Notice that the filter assembly is located between the erecting lenses; consequently, no clear compensator is necessary.

Collimation of a gunsight must be very accurate for obvious reasons. Accuracy is possible only if you properly adjust the Mk 9 collimator and follow the collimation steps outlined in OP 582 in sequence.

There is no tolerance for parallax. Deflection backlash must be held to 30 seconds and elevation backlash must be no more than 1 minute. The line of sight, in full left or right deflection, must be in a horizontal plane within 2 minutes (vertical separation of the horizontal crosslines). Elevation of the line of sight can vary from a true vertical plane by no more than 2 minutes at 90° (horizontal separation of the vertical crosslines).

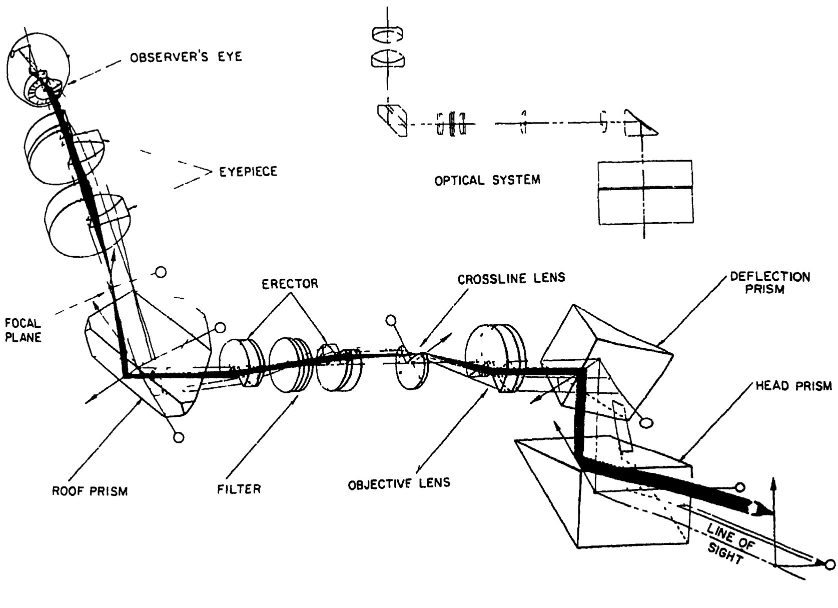

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Figure 11-8.—Mk 67 optical system.

NOTE: Horizontal or vertical displacement is determined by comparing the telescope crossline with the collimator crossline. Any variation from perfect superimposition is displacement.

MK 97 TELESCOPE

The Mk 97 is the first of a line of roughly similar director-mounted sights. Although it is much smaller than the Mk 67 or Mk 68, it weighs 190 pounds. The Mk 97 is an 8× terrestrial binocular with a front surface aluminized mirror which provides elevation of the line of sight from −25° to +95°. A reticle, consisting of two concentric circles, is located in the right eyepiece system (internal focusing).

The optical system (fig. 11-9) is somewhat unusual, especially the shape of the roof prisms, but easy to understand. You can rotate the left rhomboid prism and eyepiece assembly for interpupillary adjustment.

Figure 11-10 shows an exploded view of the major components of the Mk 97 telescope. The mirror tilt drive assembly is very precise for such a bulky looking instrument; one degree of input shaft rotation must move the mirror.

Reference surfaces for collimation of the Mk 97 consist of the bottom surfaces of the mounting feet and the left vertical edges of the left mounting feet. Once you have mounted the collimator fixture on the Mk 9 collimator and adjusted the collimator, all other adjustments you make are made to these surfaces. Needless to say, you must handle the instruments carefully to avoid marring the mounting feet.

Collimation of the Mk 97 telescope consists of leveling the mirror, setting zero diopters, and adjusting the objective eccentrics to align both lines of sight with the collimator.

To level the mirror, install the mirror tilt drive assembly and the mirror in the telescope body. Then clean the mounting feet and set the telescope on a large surface plate. Use a surface gauge and sensitive dial indicator (0.0001-inch graduations) to establish parallelism between the surface plate and mirror. (NOTE: Since this mirror is front-surface aluminized, use extreme caution when cleaning and leveling. The dial indicator should contact the mirror only at the extreme edges.)

Operate the mirror tilt drive input shaft to establish parallelism between the surface plate and front-rear mirror surfaces. If you note any error between the left-right surfaces, you must carefully

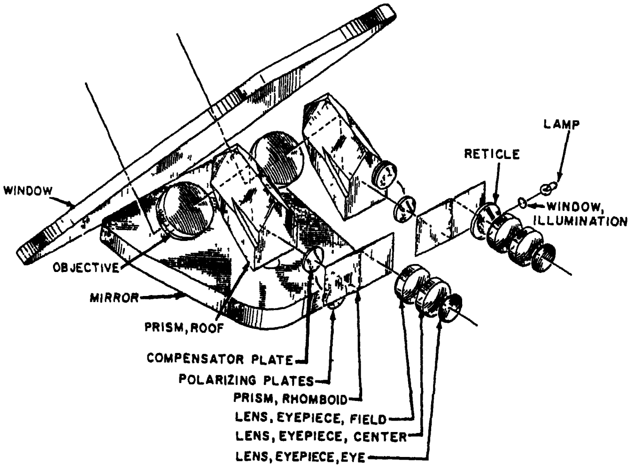

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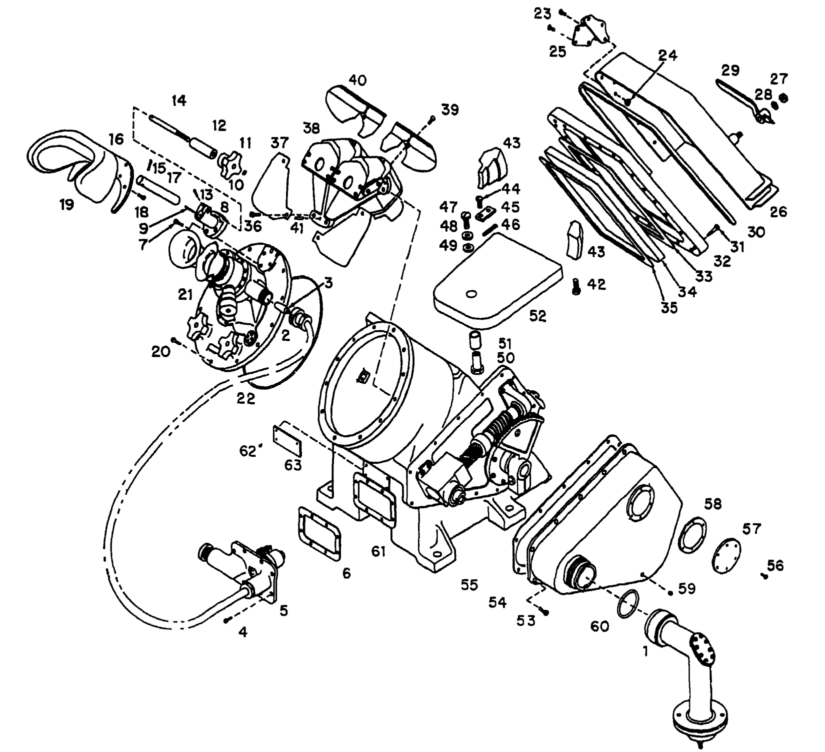
Figure 11-9.—Mk 97 optical system.



1. Input Drive Shaft Assembly
2. Lamp Socket Mk 9 Mod 0
3. Lamp
4. Screw
5. Illumination Rheostat Subassembly
6. Gasket
7. Screw
8. Headrest Support Bracket
9. Pin
10. Retaining Ring
11. Headrest Knob
12. Headrest Spacer
13. Pin
14. Headrest Clamping Shaft
15. Pin
16. Headrest Support
17. Headrest Adjusting Shaft
18. Screw
19. Headrest
20. Screw
21. Faceplate
22. Gasket O-ring and Cover Assembly
23. Screw
24. Nut
25. Hinge
26. Cover
27. Nut
28. Washer
29. Handle
30. Packing, strip
31. Screw
32. Bezel
33. Gasket
34. Window
35. Gasket
36. Screw
37. Light Shield
38. Objective Mount Assembly
39. Screw
40. Shield Riveting Assembly–Left/Right
41. Pin and Mirror Assembly
42. Screw
43. Counterweight, left
43. Counterweight, right
44. Screw
45. Clamp
46. Gasket
47. Screw
48. Spacer
49. Washer
50. Bolt
51. Packing
52. Mirror
53. Screw
54. Cover
55. Cover Gasket
56. Screw
57. Cover Plate
58. Gasket
59. 1/8-inch Drain Plug
60. Gasket, O-Ring
61. Body Casting (Mirror Tilt Drive is attached; not part of 61)
62. Screw
63. Name Plate

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Figure 11-10.—Mk 97 Mod 1 telescope, exploded view.

scrape the mirror mount to eliminate the error. The tolerance for mirror parallelism is 0.00075 inch.

Use standard techniques to set zero diopters and equal focusing of both eyepieces. Use a stereo comparator when adjusting the objectives to align both lines of sight with the collimator.

Complete procedures for overhaul, collimation, and sealing/drying of the Mk 97 telescope are found in OP 1857.

MK 100 TELESCOPE

The Mk 100 telescope is similar to the Mk 97, except that it has a change of magnification feature (6× and 10×). In the 10× position, shown in figure 11-11, the auxiliary lenses are out of the line of sight. When the auxiliary lenses are in the line path, overall magnification is reduced to 6×.

NOTE: The rear and middle auxiliary objectives are eccentric-mounted so the 6× line of sight can be made to correspond with the 10× line of sight. The front auxiliary objectives are in threaded cells for focus adjustment.

For more detailed information on the Mk 100 telescope, refer to OP 1959.

MK 102 AND MK 116 TELESCOPES

You may have thought that just when you have things figured out, we throw something new into the game. The Mk 116 and various Mods of the Mk 102 fall into this category. These 8×, single-eyepiece sights are located on single, rapid-fire gun mounts. Depending on the gun mount and fire control system involved, one or two sights could be used.

In these sights, elevation (from $-20°$ to $+85°$) and deflection ($30°$ left or right) of the line of sight is controlled by a synchroservo mechanism fed by signals from the gun director. There is no mechanical connection between the gun position and the line of sight. In an emergency, or when desired, the gun mount can be locally controlled electrically.

The optical system of the Mk 116 and Mk 102 Mods 5 and 6 is shown in figure 11-12. The optical system of the Mk 102 Mod 3 is shown in figure 11-13. These telescopes perform the same function, but the optical systems are quite different. For more data on the Mk 102 Mod 3, consult OP 1858.

Functionally, the Mk 102 Mods 5 and 6 and the Mk 116 are interchangeable. You will notice some mechanical and electrical differences when overhauling these instruments

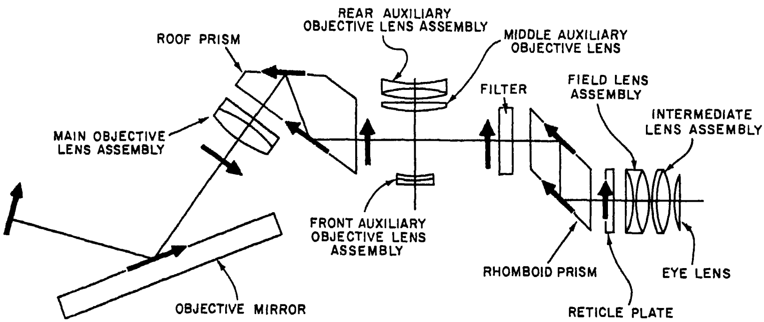

Figure 11-11.—Mk 100 telescope, optical schematic.

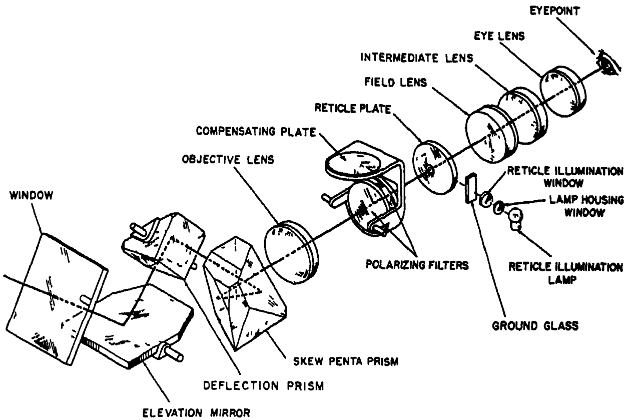

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Figure 11-12.—Mk 102 Mods 5 and 6 and Mk 116 telescopes, optical diagram.

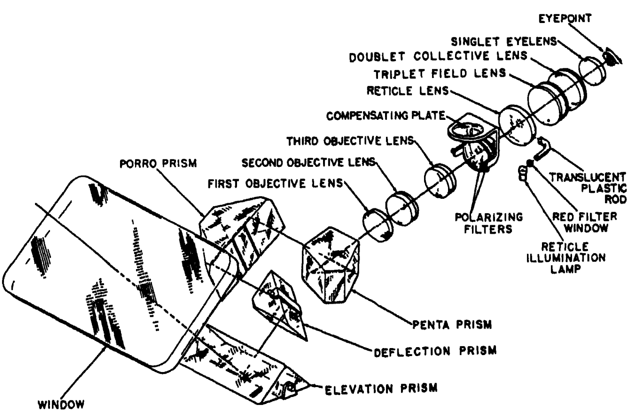

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Figure 11-13.—Mk 102 Mod 3 telescope, optical diagram.

Figure 11-14 shows a cutaway view of a representative telescope. The optical chamber and servo chamber are separated by an airtight bulkhead, with suitable penetration provided for elevation and traverse shafts. The optical chamber is sealed and pressurized with nitrogen; the servo chamber is sealed but not charged. This arrangement allows access to the servo chamber for adjustment and replacement of components, without disturbing the seal of the more durable optical system. As with the Mk 97 telescope, mounting surfaces machined on the body of these telescopes establish reference surfaces for optical and mechanical adjustments.

Although you follow a prescribed collimation procedure during overhaul, you can make minor adjustment to the line of sight on the gun mount, using the autocollimator (fig. 11-15).

Each telescope has an autocollimator, located on the inside of the servo chamber cover. The autocollimator consists of a front-surface

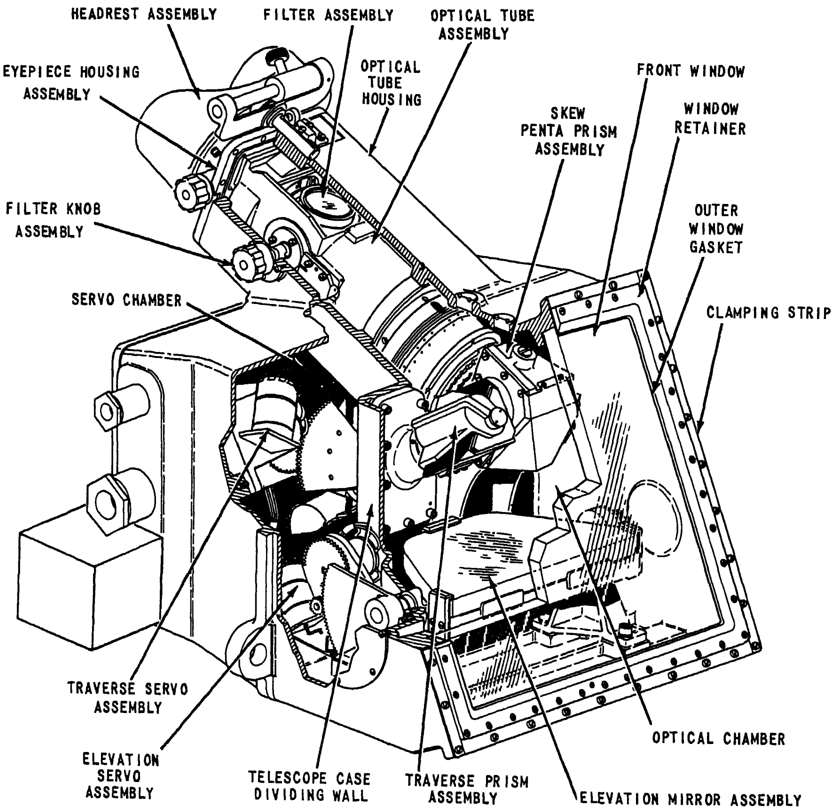

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Figure 11-14.—Telescope cutaway view, typical.

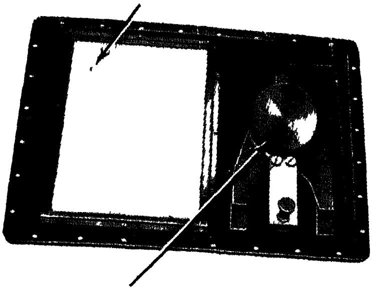

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Figure 11-15.—Rear cover, inside view.

aluminized mirror and a suitably shaped mount, which fits over the optical chamber window.

To use the autocollimator, attach it to the telescope, energize the telescope, and turn on the reticle illumination (NOTE: It may be necessary to cover the telescope with a dark cloth to exclude bright light.)

When you look into the telescope eyepiece, you will see the illuminated reticle and a reflected image of the reticle, which was transmitted through the optical system, to the autocollimator, and back

If the reflected image is superimposed on the reticle, there is no problem If the reflected image is slightly displaced in any direction, you will need to adjust the elevation or traverse (or both) mechanism to establish coincidence

Complete coverage of technical data concerning the Mk 102 Mods 2, 5, and 6 and the Mk 116 can be found in one or more of the following publications: OP 1858, OP 3651, and OP 4239.

These OPs are updated periodically, and the trend seems to be to change the number of the OP. Even though the information contained in the older OP may be valid, you should always try to use the most recent edition.

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Night Vision Equipment, OP 4067, Naval Sea Systems Command, Washington, D.C., April 1975.

Opticalman 3 & 2, NAVEDTRA 10205-C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

Telescope Mark 97, NAVSEA OP 1959, Naval Sea Systems Command, Washington, D.C., July 1976.

Telescope Mark 102 Mods 5 and 6 and Mark 116 Mod 0, OP 3651, Naval Sea Systems Command, Washington, D.C., October 1976.

Telescope Mark 102 Mod 3, OP 1858, Naval Sea Systems Command, Washington, D.C., April 1976.

Telescope Mark 102 Mod 2, OP 4239, Naval Sea Systems Command, Washington, D.C., October 1976.

Telescope Mark 100 Mods 1 and 2, OP 1959, Naval Sea Systems Command, Washington, D.C., July 1975.

Telescope Mark 67 and 68, OP 582, Naval Sea Systems Command, Washington, D.C., August 1976.

CHAPTER 12

SUBMARINE PERISCOPES

Since the first attempts to build and operate underwater craft, there has been a need for the occupant(s) to have some way to observe surface craft from these watertight vessels. Various names have been used for the devices, but we will use the term *periscope* in this manual.

The first periscope, developed in 1854, was nothing more than a pipe with mirrors at each end to allow the operator to see out. As the science of optics became more exact and the technical means to produce precision lenses were developed, periscopes became more sophisticated. By the time of the first world war, periscopes were quite efficient, and during the 1930's some real progress was realized These periscopes contained a split image rangefinder and a change of power mechanism. Radar was added a few years later.

In 1958, communication antennas and several improved radar antennas were added, along with a synchroservo mechanism which allowed the periscope to be used for astral navigation like a sextant At the present time, electronics are an integral part of all periscopes

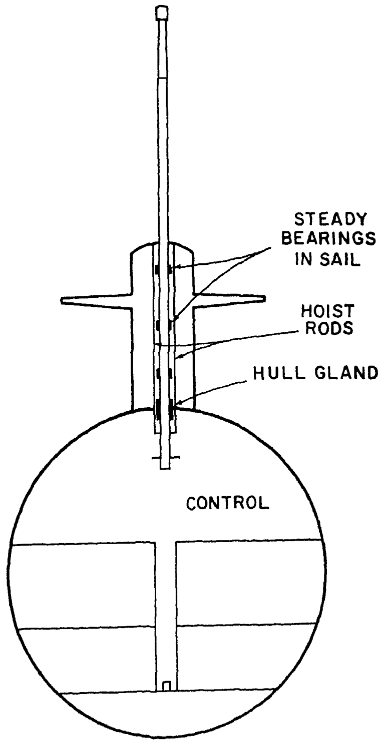

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Figure 12-1.—Vertical section through a submarine, with periscope elevated.

THEORY AND DESIGN

Basically, a 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 designer must solve several special problems brought about by the design of other optical instruments. Compromises must be made between conflicting requirements. Following are some of the problems:

First of all, the periscope has to be relatively long, as you can see in figure 12-1. 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 run from 36 to 43 feet.

Another important requirement is that the upper head section—the part that sticks out of the water—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. The main outer tube must also be of sufficient size to contain the optics and inner tube sections. Our periscopes are 7 1/2 inches in diameter with an outer tube wall thickness of 1/4 inch.

When a periscope is not in use, it is lowered for protection into a well (fig. 12-1). But when the submarine is maneuvering into attack position, it will use the periscope fully raised. The periscope, despite its slender construction, must be rigid enough to resist the bending effect of the water pressure that results from its own drag, and the optical system must be designed so the bending effect will not distort or displace the target image.

Another requirement is that the periscope have some means for sweeping through 360° and for elevating the line of sight to check for aircraft. With a modern periscope, the submarine captain sweeps the horizon by rotating the entire instrument. Elevation is provided by a movable right angle prism in the head section.

Since the periscope must be raised, lowered, and rotated, it must pass through an opening in the hull. The design and packing of that opening creates another serious problem. The packing must admit no water into the submarine, even under tremendous pressures, yet it must allow the periscope to be freely raised, lowered, and rotated within it.

The periscope itself must be completely waterproof. 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, so the possibility of leakage through them must be zero. Since the submarine is so dependent on its periscope, the internal optical surface must not fog up. A pressure of 7 1/2 psi of dry nitrogen in the periscope maintains a fog-free condition.

The problem of image orientation is not too difficult. Since we need a prism at each end of the optical system to see out, one prism inverts and the other reverts. Then by using a suitable combination of terrestrial and astronomical telescope systems in the periscope, the final image will be normal and erect.

Obtaining a suitable field of view is a major problem, especially when you consider the desired length of a periscope in relation to the entrance pupil, which is usually only several inches wide. This obstacle was overcome by placing an upper astronomical telescope in the system backwards with a lower telescope in the normal position (objective toward the target).

Suppose the upper telescope is 4X, but the telescope is backward. Its actual power is 1/4X. If an 8° cone of light were able to enter the upper telescope, the 8° field would be reduced to 2° by the reversed telescope

$$\text{mag} = \frac{\text{app}}{\text{True}}.$$

A 2° cone of light can pass through the periscope tube for a considerable distance—approximately 12 feet. The objective of the lower telescope must be placed to take advantage of this cone of light if the light transmission of the periscope is to be effective.

If the power of the lower telescope is 24X, the 2° true field becomes a 48° apparent field

$$24X = \frac{48^\circ}{2^\circ}.$$

Now to determine the overall power of the periscope, combine the magnification of the upper and lower telescopes.

$$1/4X \quad 24X = 6X$$

The periscope has fairly good magnification (6X) and a reasonably true field (8°)

The length of a periscope is usually figured as three times the distance between the upper and lower telescope objectives (12 feet):

$$12 \times 3 = 36 \text{ feet.}$$

Thirty feet is an impressive length for an optical instrument, but for an attack periscope it should be a little longer to give the submarine a better margin of safety. One way to increase length is to increase the power reduction of the upper telescope, thereby reducing the true field so it can pass through the tube for a greater distance. This was not considered practical because of several other design considerations: (1) the head section of the periscope must be very small; and (2) there must be some means to determine target range. Both problems were solved by adding two more astronomical telescopes above the upper telescope.

Those two telescopes were small in diameter (about 1 inch) and were 1X. (In a 1X telescope, the objective and eyepiece focal lengths are the same, and they have no effect on the true field of the periscope.) A crossline was placed in the upper auxiliary telescope to assist with ranging. (NOTE: In a periscope, the crossline lens is called a telemeter. Lines are etched on the telemeter with a known angular separation so ranges can be estimated.)

Now we have a periscope about 42 feet long, with a telemeter and a small head section. With the telemeter placed in the upper auxiliary telescope, even though the tube vibrates when the submarine is moving, the target image and telemeter will move in unison.

We are not finished yet. Range estimation using a telemeter is fine if either the target or observer is reasonably stationary and if there is plenty of ammunition. A submarine can carry only a limited number of torpedos, and the submarine and target are usually moving at angles to each other. Each shot must count.

The accurate ranging problem was solved by splitting the objective of the lower main telescope vertically so both halves would move equally in opposite directions The observer now has two images of the same object. Figure 12-2 shows the optical principle involved.

The ranging mechanism of a periscope is called a stadimeter. It is attached to the bottom of the scope and consists of a range dial, height scale, and suitable gearing to drive the range dial and split lens gear To take a range, set the height of the target (waterline to masthead) on the height scale, and then operate the stadimeter drive to split the target image. When the masthead of one image is displaced to the waterline of the other image, read the target range opposite the height scale pointer.

As you recall from the beginning of this section, the main portion of the outer tube of a periscope is 7 1/2 inches in diameter. Taking into account the tube thickness and the need for inner tube sections to hold the optics, the diameter of the upper objective is about 5 1/2 inches. Since the lower objective is split and must move in opposite directions to provide ranging, the lens can be only about 4 inches in diameter. Some light is lost as a result, but you still have a reasonably bright image.

The designer has one more small problem to solve; namely, the addition of a change of power mechanism. This is achieved by adding a Galilean telescope above the upper auxiliary telescope. This Galilean telescope is 4X, but, when it is in the line of sight, it is backwards. In high power (6X) the Galilean telescope is out of the line of sight. When rotated into the line of sight, the overall power of the periscope becomes

$$1/4 \times 6 = 1.5X$$

which also provides a true field of 32° in the low power position.

Our submarine now has a long attack periscope with a very small head section, an accurate range mechanism, and a choice of

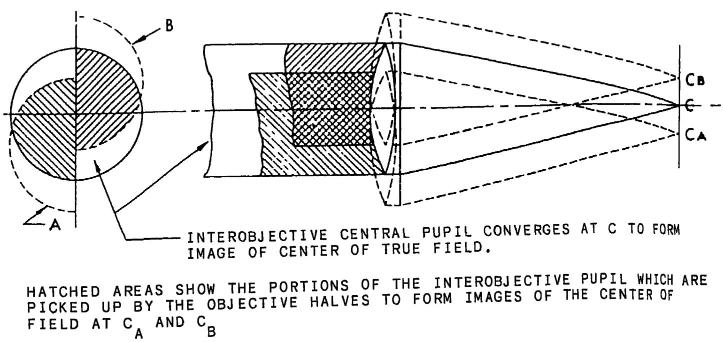

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Figure 12-2.—Lower (split) objective lens ray diagram.

1.5X or 6X. Low power is always used to quickly scan the horizon and air space above, while high power is used to make the attack.

Another factor of periscope design and theory that affects the repairman, and contributed to designer headaches, is that a periscope is charged with nitrogen. Nitrogen has a different index of refraction than air; consequently, light comes to a focus further from a lens when it is in a nitrogen atmosphere.

To repair a periscope, you have to take it apart. Before you take it apart, you have to release nitrogen pressure. When you reassemble and collimate a periscope, it is done in air, not nitrogen. Therefore, you must make all collimation adjustments carefully on suitable targets so the completed instrument will perform as designed, when it is charged to service pressure.

The optical system common to modern periscopes (fig. 12-3) is a general-purpose periscope with no ranging mechanism. Attack periscopes use the same optical arrangement except for a different mounting for the 5th erector and the absence of a sun filter. (NOTE: Modern attack periscopes use a solid lens and split lens mounted in a cube so the split lens can be rotated in or out of the line of sight when needed.)

Instead of using either three or five telescopes to transmit light and provide an erect image, modern design uses a series of optical relays composed of erectors and collectors. Parallel light passes between the erectors, and the collectors control aberrations and focus available light to the various image planes or erectors. By varying the separation between erectors, a periscope of any desired length can be produced.

These periscopes still use a Galilean telescope for change of power (1.5X and 6X), but this new design will not adapt to the very small head sections required for older periscopes. Since submarines are much faster than before and weapons systems are more accurate, the small head section is no longer necessary.

The 6th erector, shown in alternate position in figure 12-3, has a dual purpose. It can be moved along the optical axis approximately 10 inches. In the upper position, shown by solid lines, it is moved up and down slightly to focus the periscope. When photographs are taken through a periscope, the eyepiece is removed and the 6th erector is moved down to the camera position, shown by dash lines. This moves the image plane outside the periscope to correspond with the film plane of a camera.

PERISCOPE IDENTIFICATION

Periscopes are not identified by Mark and Mod as other optical instruments. They all have individual serial numbers (called registry numbers), but major identification between different types is by a design designation, as shown here.

121 KN 36 or 123KA43.3/HA

The first set of numbers (121 or 123) is an identifying number pertaining to the type of periscope (121 = 8B, 123 = 2D). The first letter (K) refers to the manufacturer, in this case Kollmorgen. The second letter designates the use of the periscope (N for night or observation, A for attack use). The second set of numbers (36 or 43.3) refers to the optical length of the system. The HA in the type 2D design designation means high angle (with the periscope in low power, at the edge of the field you can see directly above you).

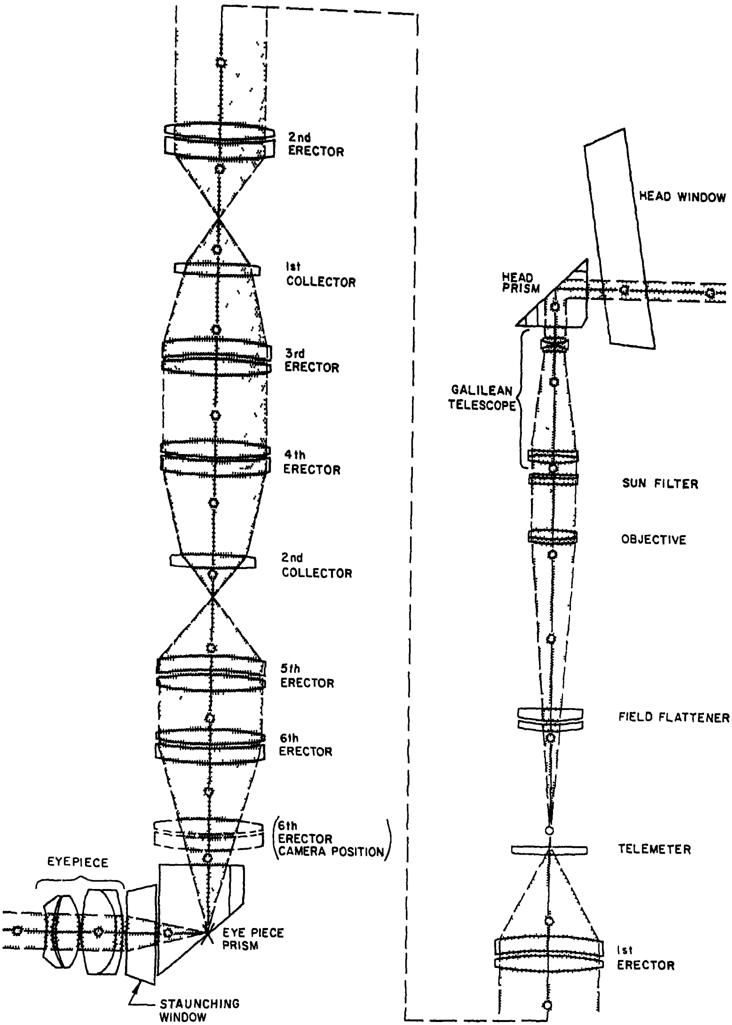
The periscopes you will encounter are as follows:

8B
8C
8D
8L
15B
15D
15L
18B
18D

Observation periscopes (radar, ECM, communications antennas)

2D
2E
2F

Attack periscopes (with stadimeter)



148.353

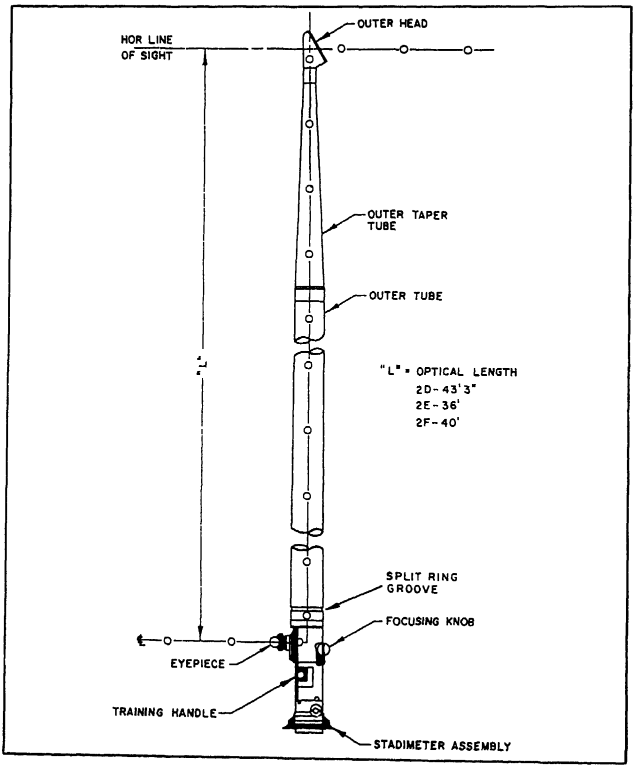
Figure 12-3.—General arrangement of optics.

All submarines use two periscopes, one for general observation or night use and the other for attack purposes. They may be mounted fore and aft or side by side, depending on the class of submarine. The number one periscope (usually the attack scope) is either nearer the bow or on the starboard side. The number two scope (observation) is second in line or on the port side.

PERISCOPE HANDLING

As an Opticalman, you will be responsible for preparing periscopes for removal, pulling them from the submarine, transporting them to your shop, performing necessary repairs, returning them to the submarine, and installing and hooking them up. Considering that a periscope is a 2,000-pound, 40-foot long, greased pole that costs anywhere from 90 thousand to half a million dollars, that is a lot of responsibility, and a challenging job. In this section we will discuss the correct methods for handling periscopes.

Before getting into any detail, look at figures 12-4 and 12-5 to become familiar with some characteristics of attack and general-purpose periscopes.



134.101

Figure 12-4.—Attach periscope.

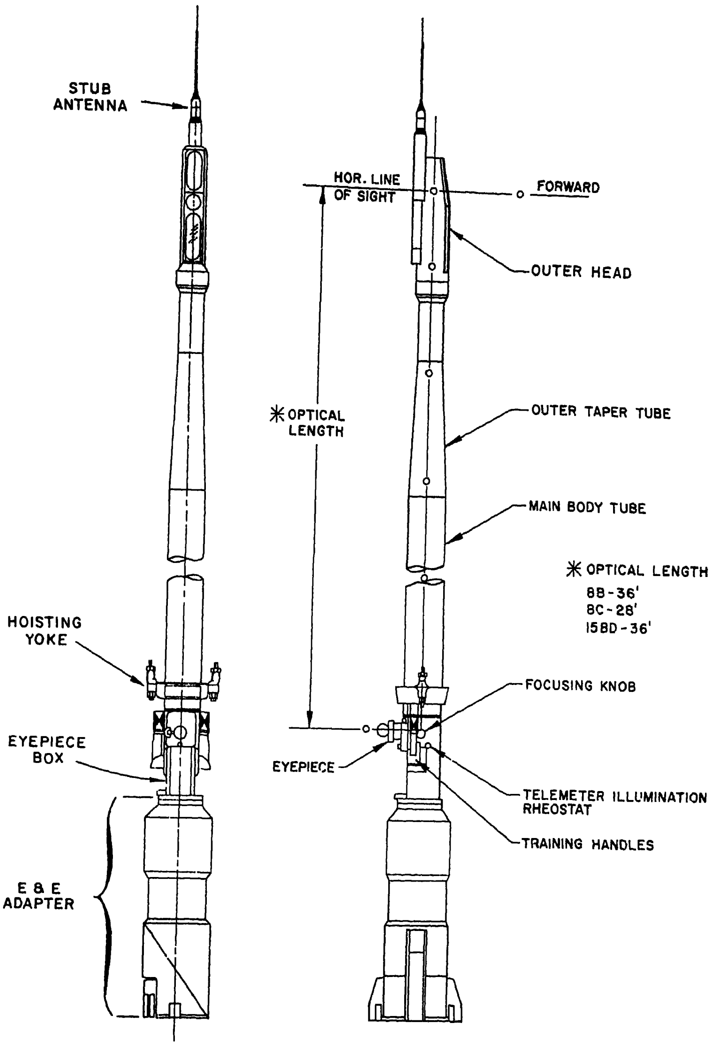


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Figure 12-5.—General-purpose periscope.

Before pulling a periscope from a submarine, remove all fittings or accessories that project beyond the 7 1/2-inch diameter of the outer tube. While you are doing this, tools, cap screws, and even the fittings themselves tend to be easily lost or misplaced. You do not want that to happen and should carefully maintain accountability of these parts.

The weight of a periscope is supported by a hydraulic system and hoisting yoke similar to that shown in figure 12-6. (The hoisting yoke is shown in position in fig. 12-5.) Type 2D, 2E, and 2F periscopes use a larger yoke which has a mechanism that transmits target beaming information as the periscope is trained. The yoke is basically a housing for a bearing and race assembly. Split rings fit in a split ring groove in the outer tube (fig. 12-4). A shoulder in the upper race fits tightly around the split rings, holds them around the scope, and, in conjunction with the yoke and lower race, holds the scope up. A cover screws into the top of the yoke to lock in the assembly. (NOTE: You need a special wrench to install or remove the yoke cover. Notice the setscrew. Always check for setscrews.)

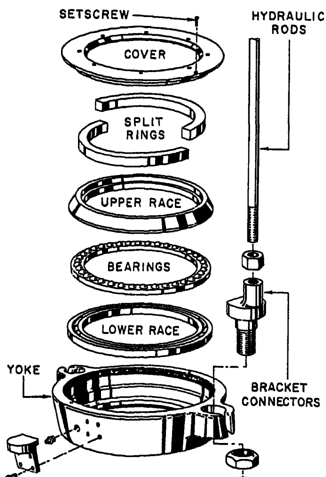

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Figure 12-6.—Hoisting yoke.

The hydraulic rods are secured in eccentric bracket connectors which are locked into the yoke. The bracket connectors are eccentric to allow for minor variations in the separation of hydraulic cylinders installed in some submarines.

Although it is not shown in any of the illustrations in this section, some submarines have a streamlined casing which surrounds the periscope to reduce drag when the scope is raised. This wing-shaped casing is called a FAIRING.

Fairings are approximately 12 to 15 feet long, and they can either be attached to the periscope (dependent) or raised and lowered separately (independent). Inside both types are cylindrical bearings to prevent rattling. Teflon bearing blocks fore and aft, located at various points in the sail, cushion the fairing externally. The bearing blocks allow the fairing to be raised and lowered quietly and still take the full force of water pressure when the scope and fairing are raised while the submarine is submerged and underway.

Independent fairings will not usually cause you any difficulties. Dependent fairings, since they are secured to a scope, take special handling when you remove or replace a scope

PERISCOPE REMOVAL

All operations dealing with the removal or installation of periscopes must be done in a sheltered harbor. Movement of the submarine, while a periscope is partially supported by the steady bearings in the sail, can cause severe damage to both the scope and the submarine. If a tender is doing the job, the sub can sometimes be moved to the lee side. If it is not possible to offer protection in this manner, the job may have to wait for more favorable conditions However, many times it is absolutely necessary to pull or install a scope, regardless of wind or water conditions. When this situation comes up, a very experienced person must be in charge.

You must follow the sequence of events listed here when removing a periscope

- Notify the submarine duty officer that you are going to pull the scope. When a periscope is removed, there is a 7 1/2-inch hole in the hull, putting the submarine out of commission until the hole is filled. Also, the hydraulic power may be temporarily secured. The duty officer will take steps to provide hydraulics so the scope can be raised and will solve any other problems hindering your scope job.

● Be sure the fairwater area is clear before raising the scope; you do not want to startle or injure anyone. Cycle the scope up and down several times to be sure the hydraulic system is functioning smoothly; then stop the scope in the observing position. (NOTE: Pulling a scope is usually a two- or three-person job; therefore, several of the following steps can be performed at the same time. One or two people can be on the fairwater clamping the scope, while one or two more are in the control room stripping external fittings from the scope. Teamwork and communication between the fairwater and control room are essential to prevent errors or omissions.)

CAUTION

You must wear an approved safety harness when working on top of the fairwater. Attach the short, heavy line on the harness to any convenient permanent fixture on the fairwater. This will prevent you from falling.

● With the periscope eyebox approximately chest high, enough outer tube extends above the fairwater to provide a suitable area for clamping Remove any grit or dirt by lightly sanding with 180-grit sandpaper After sanding, reclean all traces of foreign matter from the outer tube in the area to be clamped

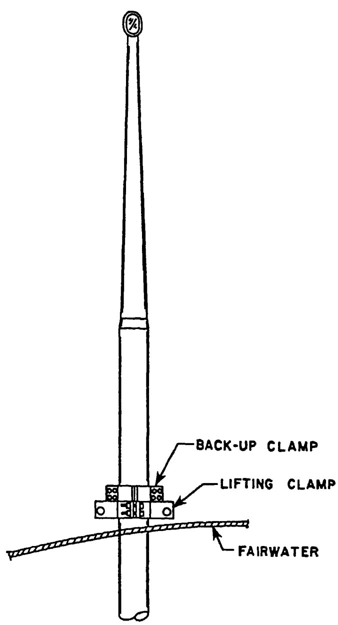

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Figure 12-7.—Clamps and slings attached to the outer side.

Figure 12-7 helps to explain the next step Securely bolt the steel hoisting clamp to the scope about 1 inch above the fairwater with the lifting lugs parallel to the head window Torque each of the four nuts on the clamp sequentially. A suitable chock should be placed between the top of the fairwater and the lug of the lifting clamp not contacting the fairwater This will distribute the weight evenly and prevent binding at the lower end of the periscope

After the lifting clamp has been assembled on the periscope, place the hydraulic controls in the DOWN position This position allows the full weight of the periscope to be restrained by the lifting clamp.

If no slippage occurs, attach the backup clamp above and snugly against the lifting clamp. NEVER disconnect the lifting and backup clamp before first ensuring that the periscope hydraulic hoist system is reenergized or that some other suitable means of temporary support, such as chain falls or shoring support, is in place.

All equipment used in handling periscopes (shackles, slings, clamps, and so on) must be regularly inspected and weight tested to verify safety and condition. After inspection, it is tagged to certify that it passed test and inspection. NEVER use periscope handling gear that does not have a current inspection sticker and NEVER attempt to use any piece of handling gear that you suspect may be defective. Always check each piece of gear before you use it.

When you have finished clamping the scope, notify the control room. At this time the hydraulic control can be moved to the lower position and the clamps will support the weight of the scope.

On many occasions, you will be called upon to clamp a periscope, but not pull it, so work can be done on associated components. You will use the same clamps and procedures, but you will wrap and seal the clamps and about 1 foot of the scope above them in plastic to prevent the entry of moisture.

- Removing external fittings from periscopes is relatively easy. Be careful and do not drop anything down the periscope well. If a type 8 is being pulled, remove the stub antenna before the scope is fully elevated and clamped. On general-purpose periscopes (fig. 12-5), you must also disconnect the E&E adapter before the scope is fully elevated. (NOTE: Be sure all power to the scope is secured before removing the E&E adapter and electrical and antenna connections. The adapters weigh from 450 to 700 pounds, and a sturdy support must be provided to hold them up.)

You must remove an access cover from the E&E adapter before you can disconnect the various connectors between the scope and adapter. Then remove the cap screws holding the adapter to a flange on the bottom of the scope. Last, elevate the scope to the observing position and remove the E&E adapter flange.

On all periscopes, the registry number (serial number) is stamped on the focus knob and training handles, and also on the stadimeter of type 2 periscopes. This is done because each periscope is hand-fitted at assembly, so these components are not readily interchangeable.

Set the right handle to low power, the left handle to zero elevation, and the focus knob to + 1.5 diopters before removing them. Switch the illumination control knob to OFF before removal. (NOTE: Do not drop the woodruff key when you pull the illumination knob off.)

WARNING

PERISCOPE HANDLES HAVE VERY POWERFUL SPRINGS, WHICH HOLD THEM UP WHEN THE SCOPE IS NOT BEING USED. THE HANDLES ARE SWUNG DOWN FOR REMOVAL. THEREFORE, THE HANDLE BRACKETS ARE UNDER ENOUGH SPRING TENSION TO BREAK YOUR FINGERS IF YOU HANDLE THEM CARELESSLY.

To remove the stadimeter from a type 2 periscope, first set the in-out lever to the IN position and turn the range knob clockwise to the stop. Now the four captive bolts in the bottom of the stadimeter can be loosened and the stadimeter can be lowered slightly from the scope. Then disconnect the electrical connection between the scope and stadimeter. (NOTE: The stadimeter is too heavy for one person to support and remove bolts at the same time. GET SOME HELP.)

Eyepieces are attached to periscopes with opposed spring-loaded plungers at the top and ball detents at the bottom. To remove an eyepiece, simply pull the plunger knobs out, tip the eyepiece back, and pull it away from the scope.

Keep all external fittings from each individual periscope separated from those of other scopes. Tag each piece and indicate the registry number of the scope you removed it from. It is not uncommon to have fittings from 6 to 10 periscopes in the shop at the same time. Under such conditions, parts could be interchanged. This could cause problems when the fittings are reinstalled.

With all fittings off and the scope resting on the clamps, remove the hoisting yoke (fig. 12-6). On general-purpose scopes, unscrew the yoke cover, and then slowly lower the yoke away from the scope hydraulically. The upper race will usually remain in place and must be tapped off the split rings with a fiber mallet Carefully pry the split rings away from the scope, and then lower the yoke cover off the scope. The bearings and races should now be taken to the shop for cleaning and inspection.

Removing the yoke/target bearing transmitter (TBT) from an attack scope is similar to the above procedure with the following exception:

A keyway is milled in the outer tube of the scope just below the split ring groove. A key is inserted which drives the TBT when the scope is trained. You must remove this key after you lower the yoke/TBT away from the scope.

After the hoisting yoke is lowered away from the scope, hydraulic power to the system must be secured and the controls must be tagged to prevent operation. If the scope is an attack type, the yoke is usually secured level with the top of the periscope well. For general-purpose scopes,

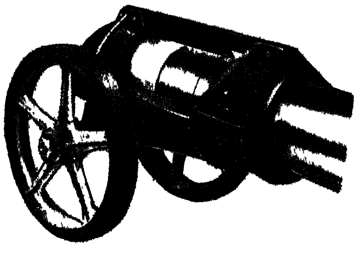

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Figure 12-8.—Hinge carriage at horizontal position.

the yoke is either secured in a raised position or lowered to the E&E adapter. Where the yoke is secured depends on whether or not the E&E adapter needs work.

- The scope is now free to be pulled from the submarine. The submarine must be on an even keel so the periscope will be as nearly vertical as possible to avoid damage to the scope or steady bearings in the sail Spot the crane hook directly over the scope, with slings and spreader attached, as shown in figure 12-7 As the crane pulls the scope, one person should remain on the sail to attach a steady line around the split ring groove when the scope clears the sail Someone on the pier or tender should handle the other end of the steady line to keep the scope from swinging as the crane moves

AUXILIARY HANDLING EQUIPMENT

You already know that periscopes are long, heavy, and expensive. You should also know that they are precision instruments and must be carefully handled to avoid bumps, shocks, or bending. It takes a lot of moving around to haul a periscope between the submarine and your shop or from storage to the submarine. Coordination, training, and proper equipment are necessary.

At some point in the handling procedure, a periscope must be shifted from the vertical to the horizontal position or vice versa. A hinge carriage, similar to that in figure 12-8, is used to make this transition. The carriage can be clamped on a scope when it is in a horizontal position, as shown, or as the scope is lowered vertically toward the deck or pier.

The bottom of the carriage is merely a cushioned socket to protect the eyebox. The rigid frame has provision for a split, hinged clamp which fits around the scope at the split ring groove. When the clamp is tightened around the scope, a split ring or other suitable device keeps the carriage in position. With the hoisting clamp attached and slings and spreader in position, the scope can be lowered to horizontal or raised to vertical by the crane without damaging the eyebox.

Whenever a periscope is in the horizontal position, it should be resting on at least two V-blocks located at the quarter points. (Quarter points are one-fourth the length of the periscope outer tube, measured from each end.) The V-blocks can be plain wood, padded metal, or special wheeled dollies. The blocks must be tall enough so the wheels of the hinge carriage will clear the deck when the scope is in the horizontal position.

To move a periscope in or out of the shop, or storage boxes, a strongback similar to that shown in figure 12-9 is used. The strongback is a rigid I-beam approximately 10 feet long with sturdy split clamps at each end. In the figure, the strongback is shown attached to chain hoists at

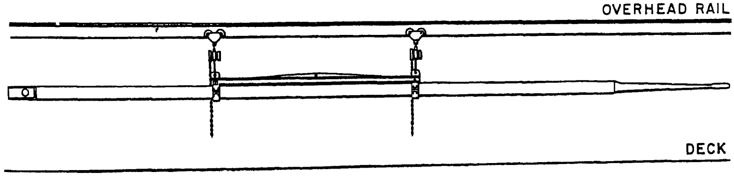

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Figure 12-9.—Periscope supported by strongback and chain hoists.

each end. Normally, a single hoist or crane hook is attached to an eye in the middle of the strongback. When a strongback is used, all other clamps should be removed and the scope should be balanced before tightening the strongback clamps.

If a periscope is to be moved any distance with the strongback, from pier to tender for instance, steady lines must be attached to both ends of the scope to control movement.

While on the subject of handling periscopes, we must comment on storage or shipping boxes. When scopes are transferred, or in some cases stored, special shipping containers should be used.

These shipping containers are constructed of heavy gauge aluminum, stiffly braced, and should have heavy wooden skids on the bottom. A tightly sealed lid, composed of two to four interlocking sections, protects the periscope from dust or moisture. The periscope rests on five or six rubber-padded semicircular brackets built into the box. A padded clamp, bolted to each bracket, prevents the scope from bouncing or sliding during transport.

Padeyes for lifting scope boxes with slings are welded at the quarter points of the boxes. Two areas for using forklifts are prominently marked on the boxes. To prevent damage to the boxes and periscopes, never move a shipping container by any method other than those provided.

Periscopes are often transported by flatbed truck. Since the shipping container is longer than most truck beds, the eyebox end of the container must be to the front of the truck to allow the lighter taper section of the scope to hang over the end If the truck driver exercises reasonable care and misses bumps, the scope should be safe.

When a periscope is shipped, the design designation and registry number of the scope should be marked on the outside of the box at the eyebox end. Also, all external fittings for the scope should be wrapped and secured in the box (except for the E&E adapter on general-purpose periscopes).

PERISCOPE PACKING

The method for sealing a periscope and hull opening is shown in figure 12-10. By using this particular arrangement, the periscope can be raised, lowered, and trained while the submarine is submerged—with little possibility of leakage. In fact, if all components are properly arranged and perfectly aligned, more water will enter the boat if it is on the surface in a rainstorm than if it were deeply submerged.

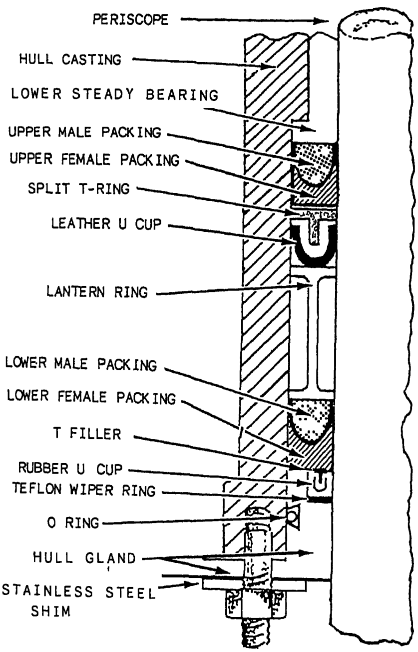

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Figure 12-10.—Periscope packing assembly

Leather U-cup packing is preformed (molded) natural leather. The U-cup conforms well to the variations in the inside diameter of the hull casting. To provide the necessary seal, there can be no cracks or other blemishes on the surface of the ring of packing.

Other factors which affect the seal of the packing assembly are concentricity of the packing rings, filler ring, and lantern ring; alignment of the lower steady bearing with all other sail steady bearings; and the clearance between the top packing ring and the bottom of the lower steady bearing. Seawater pressure acting on the top of the top packing ring compresses the entire packing assembly. The deeper you go, the more the pressure; the higher the pressure, the tighter the seal. If any of the bronze rings in the packing assembly are out of round, however, high pressure will distort the packing and probably cause a leak.

When a periscope is pulled, the packing must be removed. Otherwise, the scope would tear up the assembly when it is reinstalled. With the scope and packing removed, you have an excellent opportunity to check alignment of the steady bearings and the condition of the hull casting.

Many problems with periscope leakage or difficulty with training are blamed on the packing. The real culprit, however, is usually misalignment of sail steady bearings. The optical shop usually performs this alignment.

Packing can be removed with the scope in place, but it is difficult. You have to raise the scope to the observing position, clamp and strip it, and then loosen and carefully drop the hull gland. The metal components of the packing assembly are fairly easy to remove; the U-cup packing causes the problems. If it will not slide out easily, you must dig it out with a tool similar to a corkscrew.

PERISCOPE INSTALLATION

Replacing a periscope is NOT the reverse of removing it. In this description we will skip all the steps involved with moving the scope out of the shop and on deck or on the pier. The equipment used has been explained in this chapter; the methods to use vary with conditions present on different tenders.

The first step in replacing a periscope is coordination between the shop, crane crew, and submarine. It takes no more than 15 minutes to get a scope out of your shop and ready to install. Proper scheduling is necessary to be sure the boat is ready to receive the scope and to assure uninterrupted use of the crane. Due to various drills, other priority crane usage, and work by other shops on the submarine, it is often necessary to replace scopes early in the morning or after normal working hours. The important consideration is to finish the job once it is started.

With all necessary preparations made (submarine personnel informed, external fittings assembled, yoke and packing components ready), the periscope is lifted to a vertical position by the hoisting clamp. (NOTE: Location of the hoisting clamp is critical. Different types of periscopes vary in length, and the distance between the control room and the sail varies between classes of submarines. You have to know exactly where to clamp the scope so the eyebox will extend the proper distance into the control room.)

When the periscope is held vertically, a specially made tapered guide called a BULLET is bolted to the bottom of the eyebox. The bullet guides the scope through the sail or fairing bearings. At the same time, a steady line is secured around the split ring groove and passed to a person on the sail. (NOTE: If you are on the sail, do NOT forget your safety harness.)

The person on the sail has an important job—to help the crane operator spot the scope directly over the hole in the sail, to guide the scope in, and to apply a medium coat of approved grease to the outer tube as the scope is lowered. As you may suspect, this part of your job is dangerous. You do not have any place to stand, the boat is usually moving, and your hands will be covered with grease. That is why you must wear a safety harness.

Once the scope is lowered completely and resting on the clamp, unhook the slings and go to the control room to help out.

REPACKING THE PERISCOPE

Repacking the periscope is the next task. The procedure is the same whether you just replaced a scope or are renewing packing in place. At this point, all of the metal rings have been cleaned and checked for concentricity and dings. The packing has been inspected, and the height of the assembled packing has been measured. (NOTE: When the packing assembly is in place, there must be 0.010- to 0.020-inch compression. The compression is the difference between the depth of the hull gland and the stack height of the packing assembly. To obtain this compression, vary the thickness of the shimstock spacers.)

At least two people are needed to repack a periscope, and you will need several packing sticks. The packing sticks are about 3 or 4 feet long, 1 inch wide, and 3/4 inch thick. Without packing sticks, there is no way you can slip the metal rings or the U-cup packing into the cavity between the scope and hull casting.

First, slip the upper male and female packing rings around the scope, followed by the split T-ring and leather U-cup. Then use the packing sticks to slide these components into the hull casting. (NOTE: When you slip the U-cup packing into place, be sure it does not hang up on the lower lip of the hull casting. The lip could be sharp enough to damage the packing. Now coat the cavity of the lantern ring with grease and slide it into position.)

Next, slip the lower male and female rings into the hull gland. There will not be enough friction between the scope, packing, and hull casting to keep the partial packing assembly in position. You will have to support it with packing sticks while you slip the lower male and female packing rings and hull gland into place.

After bolting the hull gland into place, use a long 0.006-inch feeler gauge to check the clearance between the scope and hull gland. If the feeler gauge will not pass freely around the scope, something is wrong. You may need to drop the packing to find the difficulty, or, if you are lucky, you can install the yoke and raise and lower the scope several times to properly seat the packing assembly. In any event, the minimum clearance of 0.006 inch is necessary to provide proper alignment of the scope, packing assembly, and steady bearings.

The final step in repacking a scope is to hydrostatically test the hull gland. To make this test, one person must crawl into the sail and attach a cofferdam around the scope and upper part of the hull casting. (NOTE: The cofferdam is a special fitting about 18 inches tall and made in two halves. A groove is machined in all mating surfaces to accept a quick-drying sealant.)

When the halves of the cofferdam are bolted together, a small amount of water is poured in. A high-pressure airhose can then be attached. This air pressure, acting on the water in the cofferdam, duplicates the action of seawater pressure on the periscope packing when the boat is submerged.

EXTERNAL FITTINGS REPLACEMENT

After the ship's force has restored hydraulic power, very slowly move the control lever to LOWER, and cycle the yoke down and up several times to remove trapped air in the hydraulic system. (NOTE: Perform this step just before replacing a periscope.)

Now slip the yoke cover on the outer tube, above the split ring groove, and replace the split rings. With a conventional yoke, slip the upper race on the scope and tap it onto the split rings. Pack the lower race and bearings with approved grease, and replace these components in the yoke. Very slowly, raise the yoke into position on the scope until the scope is raised several inches. (NOTE: When raising the yoke, you may have to guide it over the bottom of the eyebox. If the yoke hits the eyebox, it could bend a hoist rod. With the yoke in position, pack the yoke cavity with grease and secure the yoke cover.)

On a TBT, you do not need to be concerned about bearings or grease, but you must be sure the keyway on the scope is aligned with the TBT so the key can be reinstalled. Once the yoke is up, tighten the yoke cover the same as a conventional yoke.

Now, remove the bullet from the eyebox and clean all traces of grease from the eyebox and visible area of the outer tube. Then carefully clean the eyepiece window with acetone. Also, remove the clamps at this time.

As you recall from a previous section of this chapter, the external fittings of a periscope were set at specific positions when they were removed (except for the eyepiece). The scope control shafts and external fittings must likewise be matched to facilitate replacement. Be sure the fittings are from the scope you are working on; then replace, secure, and test the fittings.

PERISCOPE REPAIR

As a junior OM, you will be responsible for the maintenance of all periscope external fittings We will not go into the detailed procedures for completing an overhaul, but we will explain some of the finer points of construction and adjustment.

EXTERNAL FITTING OVERHAUL

The repair and adjustment of external fittings are just as important as the maintenance of internal optics and mechanical systems If external components are out of adjustment or damaged, the periscope is essentially useless

The external fittings for type 2, 8, and 15 periscopes are practically identical—left training handles, eyepieces, blinder attachments, variable density filter assemblies, pressure gauge and valve assemblies, and focusing knobs The right training handles of type 2 periscopes are so similar to left training handles they do not need explanation Right training handles of type 8 and 15 scopes are identical.

External fittings receive considerable handling and some abuse. Adequate lubrication is essential for proper performance Durable paint is necessary for appearance and protection. The preferred lubricant for moving parts is Lubriplate. It is available in several grades.

Your shop supervisor will specify the type and amount of lubricant to use on various fittings. The recommended paint is a good grade of semigloss baking enamel. If properly applied, this paint is very durable and will provide an attractive finish.

Periscope Eyepieces

An exploded view of an eyepiece and faceplate assembly is shown in figure 12-11. The eyeguard adapter is free to rotate on the faceplate. Three screws keep the adapter from coming off, and a detent assembly holds it in position.

A spring-loaded plunger assembly holds the faceplate on the scope eyebox. (Only one plunger is shown.) A self-contained, spring-loaded detent (only one shown), holds the faceplate snugly to the eyebox. This arrangement allows the bottom of the faceplate to be pulled away from the eyebox, while pivoting on the detent plungers, so the eyepiece window can be cleaned.

Not shown in figure 12-11 is an eyepiece heater which is built into the faceplate. The heater consists of an electrical contact, which receives power from a power supply pin on the eyebox, and eight turns of resistance wire, which are wound inside the faceplate lens cell and sealed with epoxy resin. The heater prevents moisture from condensing on the eyepiece optics.

The two eyelens and the field lens are held in the faceplate by retainer rings. When it is necessary to remove the lenses, new shims must be placed between the two eyelens elements. Four shims of 0.001- to 0.002-inch tin foil evenly spaced around the edge provide the required 0.037-inch spacing of the elements.

When the eyepiece and faceplate assembly is ready for reassembly, use a drop of Locktite on all threads. This compound prevents the threaded parts from backing out but does not make future disassembly difficult. Also, when you replace the three screws that retain the eyepiece adapter, screw them in tightly, and then back them out one-eighth of a turn to provide freedom of rotation without binding.

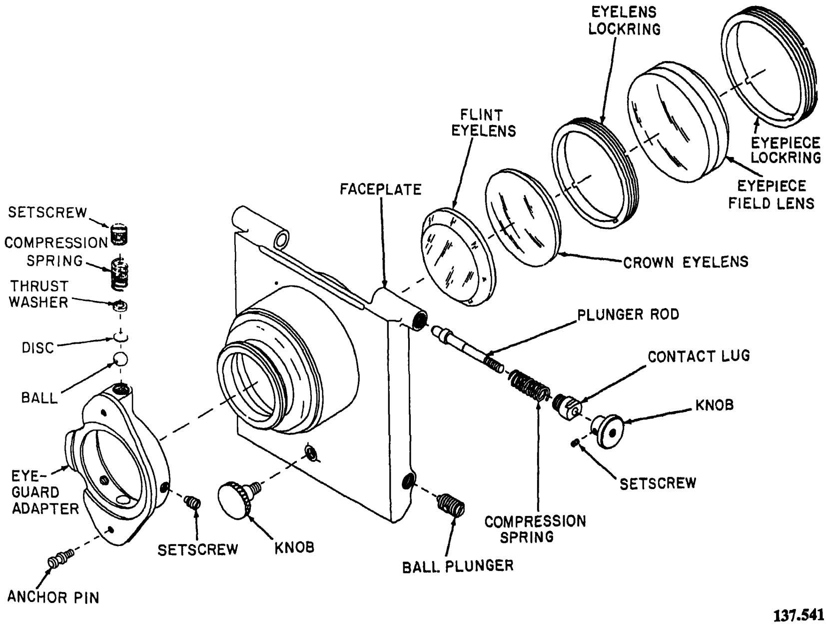

Figure 12-11.—Eyepiece and faceplate assembly.

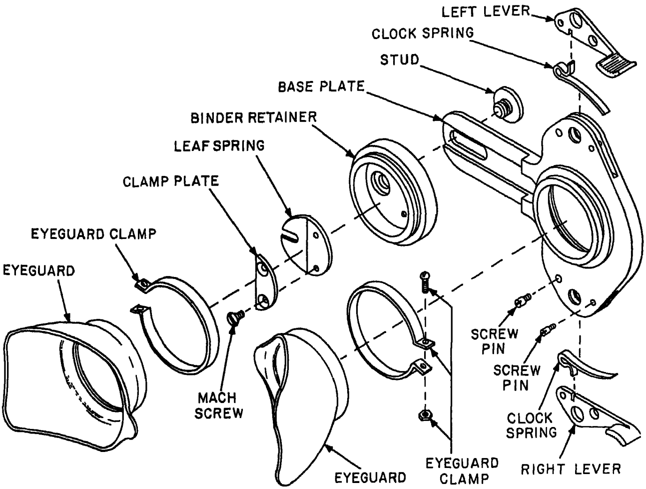

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Figure 12-12.—Blinder attachment assembly.

Blinder Assembly

The blinder assembly (fig. 12-12) is an attachment that fits over two studs on the eyeguard adapter shown in figure 12-11. The rubber eyeguards provide the proper eye distance for viewing through the periscope, and one eyeguard is mounted on a slide to accommodate the viewer's interpupillary distance. Since the eyepiece adapter is rotational and detented, simply by turning the blinder assembly 180° the user can view through the periscope with either the left or right eye.

The most common defects found with blinder assemblies are missing, immovable, or deteriorated eyeguards, or frozen or broken finger lever springs. Since this assembly is quite simple, disassembly and function of components can be easily understood by studying the illustration.

Proper lubrication of the finger levers and springs and between the base plate and blinder retainer will usually result in longer trouble-free service.

Variable Density Filter Attachment

As you can see from comparing figures 12-12 and 12-13, the arrangement of finger levers and the method of attachment of the blinder assembly and variable density filter are identical Since the construction and operation of the filter assembly is more complicated, however, it can cause you problems if you are not careful

One way or another, most of the components of the filter assembly are attached to or move around the socket housing (18). The fixed filter (20) and its retainer (19) screw into the front of the socket housing. The movable filter (17) and its retainer (16) are screwed into the cradle (15), which slips into the socket housing A screw (13) passes through the slot in the socket housing and is attached to the cradle. The slot in the socket housing allows the filter (17) to be rotated 90° to change light transmission from minimum to maximum.

The actuator sleeve (1) is free to rotate when the socket housing is screwed into the base plate (10). When the actuator sleeve is slipped over the

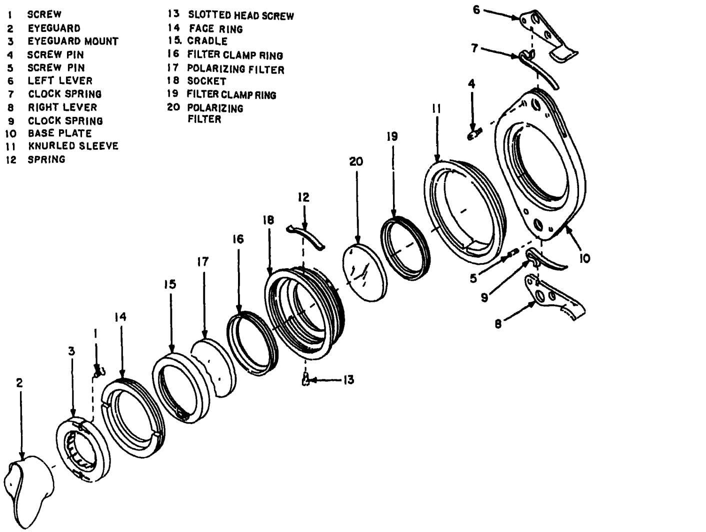

Figure 12-13.—Variable density filter attachment assembly.

socket housing, the head of the screw (13) must engage the slot in the actuator sleeve, and the friction spring (12) must be depressed slightly to allow the parts to mate

The face ring (14) screws into the rear of the socket housing and retains the cradle and movable filter, but allows the cradle to rotate. The eyeguard mount (3) and eyeguard, when they are secured in the face ring, complete the assembly

If an eyeguard is in poor condition, remove it by pulling it away from the eyeguard mount To replace an eyeguard, carefully pry open (toward the center) the equally spaced clips before inserting the new eyeguard (NOTE: The clips, which are an integral part of the eyeguard mount, are made of brass Therefore, they can be bent only once or twice before breaking. You should pry the clips apart just enough to accept a new eyeguard, and then press it in place in the eyeguard mount.)

As you can see in figure 12-13, there is a horizontal and a vertical slot at the top and bottom of the eyeguard mount (3). At the intersection of the slots, there are tapped holes to accept bevel head friction screws (1). These screws are installed from the rear, as shown in figure 12-13, but are not tightened until the eyeguard mount is slipped into the face ring. The shoulder on the face ring prevents access to the screwheads, so the ends of these screws are slotted for a jeweler's screwdriver. When the eyeguard is properly oriented, turn the friction screws counterclockwise from the front to spread the slots in the eyeguard mount. This will lock the eyeguard mount in the face ring.

Now that you are familiar with the function and relationship of the filter assembly parts, you need a few more hints to properly assemble the filters. Both the fixed and movable filters have short lines scribed at the top and bottom to indicate the proper orientation of the axis of polarization. Both filters should be assembled with these marks toward the periscope eyebox. When the filter assembly is completely assembled and the index marks of both filters are aligned vertically, maximum light transmission will be realized and glare will be reduced. Turn the actuating sleeve clockwise. The movable filter should rotate 90° and reduce light transmission to zero. Proper orientation of the fixed filter is quite easy, but you may need to partially disassemble the whole filter assembly to establish the proper relationship between the movable filter, cradle, and socket housing.

The moving parts of the filter assembly are quite closely fitted. Any burrs or distortion would be detrimental to smooth operation. Apply just enough lubricant to mating parts to provide smooth operation, but not so much that it will contaminate the filters.

Pressure Gauge and Valve Assembly

The pressure gauge and valve assembly (fig. 12-14) is common to all modern scopes except for some of the earlier type 8 periscopes. The assembly is secured to the inside of the lower door on the eyebox (to be shown later). Not shown in the figure are the 12 screw holes which are factory drilled through the flanged portion of the gauge housing.

This assembly is quite sturdy and usually trouble free, but the gauge does eventually wear out, and leaks can develop around the various O-rings. The most common source of leakage is from the shutoff valve.

The pressure gauge reads from 0 to 30 psi, but periscopes are pressure tested to 50 psi. Therefore, the shutoff valve must be used quite often to secure pressure to the gauge before it is damaged by excessive pressure.

Whenever you must disassemble this assembly, replace all O-rings. You must also be extremely careful during disassembly and in removing old O-rings to avoid damage to O-ring seating surfaces.

Focusing Knob Assembly

The focusing knob (fig. 12-15) is more complicated than you might expect, but it does more than provide a focus range of +1.5 to −3 diopters. Since the 6th erector (focusing erector) of a periscope can be moved about 10 inches, the focusing knob must be able to provide the necessary movement, with suitable internal stops to prevent overtravel or damage to related components.

As a starting point in understanding this assembly, you will need to know the limits of travel available. With the focus knob turned all the way to the stop, clockwise, the diopter scale should read +1.5 diopters. With the knob turned approximately 260° counterclockwise, the diopter scale should read −3 Now pull out the detent plunger (2 through 7) to disengage the focusing stop; turn the focus knob counterclockwise to a stop, which cranks the 6th erector down to camera position. (NOTE· From

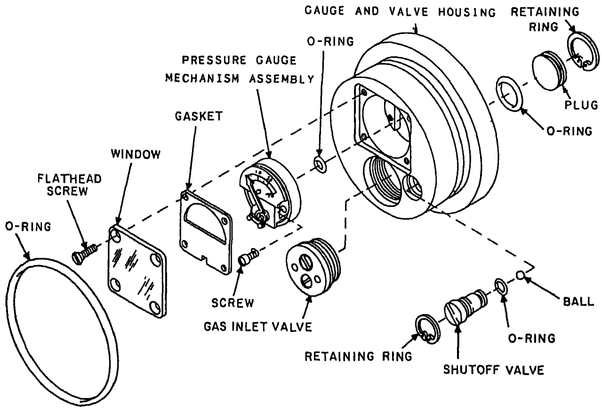

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Figure 12-14.—Pressure gauge and valve assembly.

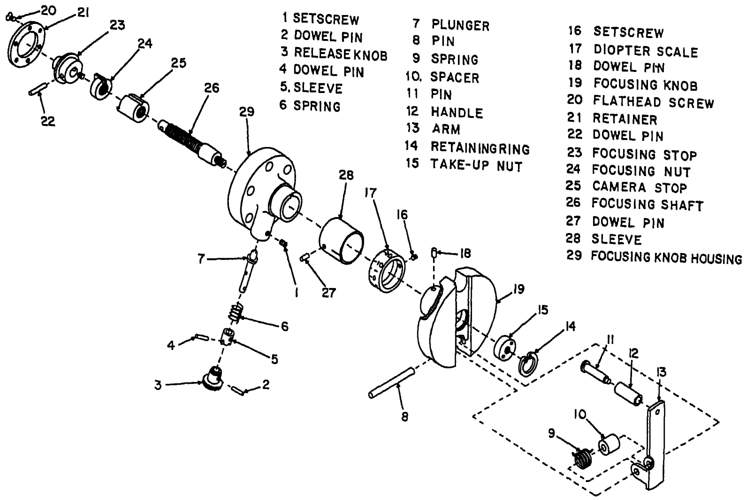


Figure 12-15.—Focusing knob assembly.

the + 1 5 diopter stop to the camera stop takes approximately 6 1/2 to 6 3/4 turns The spring-loaded handle (shown in dash lines) can be extended to provide rapid action for this operation)

To disassemble the focusing knob, there is no specified starting point Use the following steps as a guide

1 Remove the detent plunger assembly by backing out screw 1, which also secures bushing 5 in the focusing knob housing (29) Further disassembly of the plunger assembly, if necessary, is apparent in figure 12-15.

2 Turn the focusing knob clockwise to the stop, extend the handle (13), and back the nut (15) out to contact the retainer ring (14). The inside of the focusing knob has a tapered socket that matches the tapered end of the focusing shaft (25). Backing nut 1 out against the retainer should separate the focusing knob from the focusing shaft. If not, tap the focusing knob with a fiber mallet to release it.

3. Remove the six screws from the retainer (21) and withdraw the focusing shaft and stops as a unit (22, 23, 24, 25, and 26). Do not disturb the relationship of these parts unless repair is necessary.

The focusing shaft (26) is machined with a left-hand thread. The focusing stop (23) is pinned to the focusing shaft The camera stop (25) is positioned against the shoulder on the focusing shaft When this assembly is all together, pin 18 in the focusing knob engages the slot in the camera stop. Consequently, when the focusing knob is turned, parts 23, 25, and 26 turn together. The focusing nut (24) rides up and down the focusing shaft and is prevented from turning by a tab which engages a slot in the focusing knob housing (29).

For the stops to function properly, the length of the camera stop (25) is critical, as is the initial placement of the focusing nut (24). If you replace any component of the focusing shaft or stops, you will need to do some machining to obtain the proper travel and engagement of the focusing nut. Also, machine the tab on the focusing nut to provide at least 0.040-inch engagement with the lip on the camera stop.

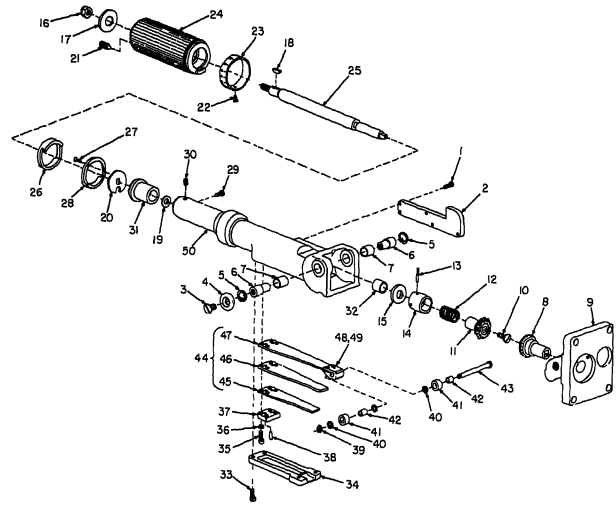
Notice that the short threaded section of the focusing shaft (26) is slotted for a screwdriver. This feature allows you to make some external adjustment of the stops when the focus knob is attached to the periscope. Simply by backing nut 15 against stop ring 14 to release the focus knob, you can hold the knob and turn the focusing shaft with a screwdriver to properly place the stops. Then reseat the focusing knob. If the diopter ring (17) does not align with the index mark after the previous adjustment, loosen setscrew 15 and reset the diopter ring. (NOTE: Anytime you make repairs to any portion of the focusing mechanism, either in the periscope or focusing knob assembly, you must make the focus knob adjustment, just explained as part of the scope collimation procedure.)

Left Training Handle Assembly

The training handle shown in figure 12-16 is generally representative of left training handles found on type 2, 8, and 15 periscopes. Any differences between handles used on the various periscopes are found in pivot bushings (3 through 7) and in the handle stops and detents (26, 28, and 31). (NOTE: The handle shown is from the type 15 periscope.)

Complete disassembly of the training handle is seldom necessary. It is much more sensible to disassemble only to the extent necessary to make needed repairs. Common wear points include the inner and outer bevel gears (8 and 11), the pivot pins and bushings (6 and 7), and the elevation stops and detent bushing (26, 28, and 31).

If it is necessary to separate the hinge (50) from the handle bracket (9), you must release tension on the spring leaf assembly (44). Remove the cover (34) and back off evenly on the four screws (35)



1. SCREW, SELF-LOCKING
2. COVER, LEFT TRAINING HANDLE
3. SCREW
4. CAP
5. RING, RETAINING
6. PIN, PIVOT
7. BUSHING
8. GEAR, CLUTCH BEVEL (INNER)
9. BRACKET, L.H. TRAINING HANDLE
10. SCREW
11. GEAR, CLUTCH BEVEL (OUTER)
12. SPRING, CLUTCH
13. TAPER PIN
14. COLLAR, SHAFT
15. WASHER, THRUST
16. NUT, SELF-LOCKING
17. WASHER
18. KEY, WOODRUFF
19. WASHER, THRUST
20. WASHER
21. BALL PLUNGER
22. SCREW, ROUND HEAD
23. BAND, GRADUATED, LEFT HAND
24. GRIP, LEFT TRAINING HANDLE
25. SHAFT, CONTROL
26. STOP RING, INTERMEDIATE
27. SCREW, FLAT HEAD
28. STOP RING
29. SCREW, SELF-LOCKING
30. SETSCREW
31. DETENT BUSHING
32. BEARING, NYLINER
33. SCREW, SELF-LOCKING
34. COVER, TRAINING HANDLE
35. SCREW, SPECIAL
36. WASHER, LOCK
37. BLOCK, SPRING RETAINER
38. PIN, DOWEL
39. RING, RETAINING
40. WASHER, THRUST
41. ROLLER
42. BEARING
43. SHAFT, CAM FOLLOWER
44. SPRING LEAF ASSEMBLY
45. LEAF SPRING, BOTTOM
46. LEAF SPRING, MIDDLE
47. LEAF SPRING, TOP
48. BRACKET, LEAF SPRING
49. RIVET
50. HINGE, LEFT TRAINING HANDLE

137.546

Figure 12-16.—Training handle assembly.

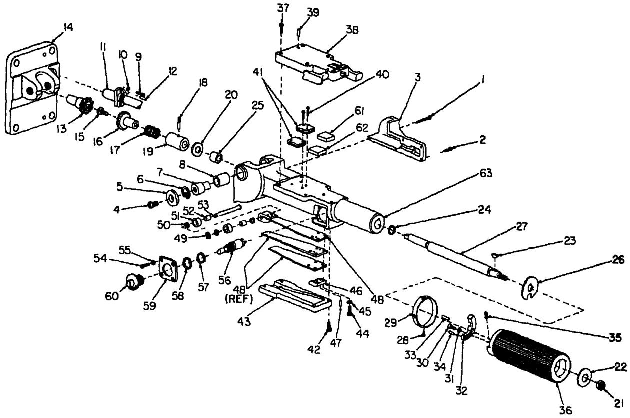
that secure the spring retainer block (37). When replacing the leaf spring assembly, you must torque the special screws (35) to no more than 40 inch-pounds. (NOTE: When working on a periscope handle with the leaf spring assembly in place, be extremely careful that the handle bracket does not snap shut on your fingers.)

The relationship of parts in the left training handle and disassembly sequence is readily apparent in figure 12-16. If you replace the inner or outer bevel gears, or any component of the elevation stops, you will need to replace the handle on the periscope to check for proper operation and adjustment as needed.

Right Training Handle Assembly

Because right training handles of type 2 periscopes are so similar to left training handles, no illustration is presented. After making repairs to the right handle, you must be sure that shafts and gears are properly aligned and that stops are set. The periscope must shift properly between high and low power. The stops are very important. Overtravel of the handle can stretch the steel tapes that shift the Galilean lens cubes, and undertravel can partially shift the cubes and block out part of the field of view.

The right training handle, common to type 8 and 15 periscopes, is shown in figure 12-17. This



1 SCREW, SELF LOCKING
2. SCREW, SELF LOCKING
3 COVER, RIGHT TRAINING HANDLE
4 SCREW, FLAT HEAD
5 CAP
6 RING, RETAINING
7 PIN, PIVOT
8 BUSHING
9 SCREW, CAP
10. WASHER, LOCK
11 WIRING HARNESS ASSEMBLY with PLUG, FEMALE
12. PIN, DOWEL
13. GEAR, CLUTCH BEVEL (INNER)
14 BRACKET, TRAINING HANDLE, RH
15 SCREW
16 GEAR, CLUTCH BEVEL (OUTER)
17 SPRING, CLUTCH
18 TAPER PIN
19 COLLAR, SHAFT
20. WASHER, THRUST
21 NUT, SELF-LOCKING
22. WASHER
23. KEY, WOODRUFF
24 WASHER, THRUST
25 BEARING, NYLINER
26. WASHER
27 SHAFT, CONTROL
28. SCREW
29 BAND, GRADUATED, POWER CHANGE
30 SCREW, CAP
31. WASHER
32. STOP, INDEXING
33 PIN, DOWEL
34 PIN, DOWEL
35 SETSCREW, SELF LOCKING
36 GRIP, RIGHT TH
37 SCREW, SELF-LOCKING
38 SWITCH ACTUATOR ASSEMBLY
39 PIN, DOWEL
40 SCREW, PAN HEAD
41 SWITCH, MICRO
42. SCREW, SELF-LOCKING
43 COVER, TRAINING HANDLE
44 SCREW, SPECIAL
45 WASHER, LOCK
46 BLOCK, SPRING RETAINER
47. PIN, DOWEL
48 SPRING, LEAF
49 RING, RETAINING
50 WASHER, THRUST
51 ROLLER
52 BEARING
53 SHAFT, CAM FOLLOWER
54 SCREW, FILL HEAD
55 WASHER, LOCK
56 SWITCH, PUSH
57 NUT (Part of 56)
58 WASHER, LOCK (Part of 56)
59. PLATE, SWITCH
60 HOUSING, SWITCH (Part of 56)
61. FILTER, MARK SWITCH
62. FILTER, FORWARD AND REVERSE SWITCHING
63 HINGE, RIGHT TRAINING HANDLE

137.547

Figure 12-17.—Right training handle assembly.

handle does more than change power. A sextant mark switch (60) activates a remote recorder to record the elevation of celestial objects, and two switches on the switch actuator assembly (38) activate a torque motor in the E&E adapter to assist with training the periscope. Pushing one switch with your thumb turns the scope to the right, pulling the other switch with your index finger turns the scope left.

Also included on the switch actuator assembly is the high-power filter release. When the scope is in high power, the release can be pushed toward the scope, and the grip can be turned slightly to drop a very dark filter into the line of sight. The filter enables the operator to use the sun as a navigation aid.

A wiring harness assembly (11), secured to the handle bracket, contains a receptacle and all the necessary wiring to connect the various switches in the handle to a mating plug on the periscope eyebox.

The mechanical portion of the right training handle is essentially the same as a left handle and should not be a problem. However, you will need a multimeter to check wiring and switch functions. If you are not familiar with multimeters, ask your shop supervisor to explain their function. After learning how to use a multimeter, you will be able to troubleshoot a variety of problems in a short time.

Stadimeter Dial and Drive Assembly

A very simplified schematic of the stadimeter, attached to the bottom of type 2 periscopes, is shown in figure 12-18. The stadimeter is heavy but very precise. Shafts and gears are supported by preloaded thrust bearings to prevent end shake, and the special couplings between the stadimeter and eyebox compensate for misalignment between the shaft axes. An adjustable stop on the stadimeter drive shaft allows full travel of the split lens and range dial and also prevents overtravel.

A wiring harness in the stadimeter provides illumination to the dials, but the stadimeter is strictly mechanical. The inside of the stadimeter is packed with grease to provide lubrication and to prevent the entry of moisture. If repairs are necessary, this grease can be quite messy.

Since clearances and adjustments to the stadimeter and split lens cube (5th erector) are very critical, you should follow the repair procedure outlined in NAVSHIPS 324 0487 when you work on either the 5th erector assembly or the stadimeter. During periscope collimation, you must attach the stadimeter to the scope to be absolutely certain that all components of the ranging mechanism are functioning properly.

PERISCOPE MAINTENANCE

The maintenance of submarine periscopes is similar to that of other optical instruments. The same steps are followed—premaintenance inspection, disassembly and repair, reassembly and collimation, and charging.

A premaintenance inspection is the first step in periscope repair This inspection determines the condition of the optical, mechanical, and electrical systems and establishes the extent of disassembly.

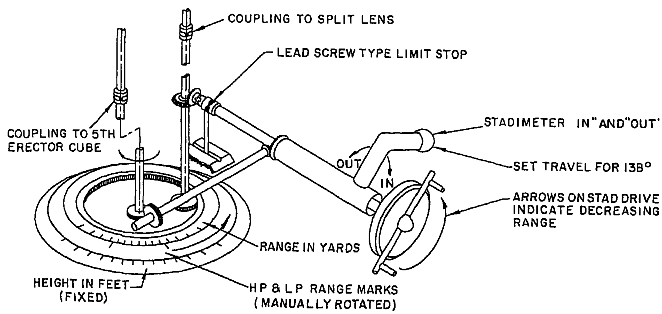


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Figure 12-18.—Stadimeter dial and drive assembly.

The essential factor in maintenance and repair is cleanliness. Because of the large number of elements in the line of sight, cleanliness of optical surfaces is extremely important.

Periscopes seldom wear out; they are too well made. Entry of moisture, careless maintenance, dirty optics, failure of components, and misuse in service are causes for overhaul. Discounting problems caused by these failures, periscopes require an annual overhaul as a preventive measure.

The methods used for cleaning optical and mechanical components of optical instruments, discussed in earlier chapters, also apply to periscope maintenance. The difference is that more care must be taken when a periscope is being worked on. Periscopes are much more difficult to remove, disassemble, repair, reassemble, and install than other optical equipment. Your objective is to do the job correctly and carefully the first time. You must use the same degree of care and skill in your work as the manufacturer used in designing and manufacturing the instruments.

PERISCOPE EVACUATION AND CHARGING

After a periscope has been reassembled, it must be tested to make certain there is no leakage in any of the hermetically sealed areas. When a leak develops in any of the sealed areas, gas leakage and breathing of the periscope will occur during temperature changes This enables water vapor to enter the periscope, which causes fogging of the internal optics To correct this condition, you must locate and repair any leaks. After a leak has been located and repaired, you must evacuate the periscope by removing the moisture-laden nitrogen and refilling it with dry nitrogen A dew-point test is made to make sure that the moisture content in the periscope is sufficiently low so that the optics will not become fogged When these actions have been accomplished, the periscope is ready for installation in the submarine. In this section, the state-of-the-art of periscope evacuation will be discussed. This discussion describes the use of equipment found aboard submarine tenders. This equipment is not available in all optical shops.

PRESSURE LEAK TEST

Soap tests, previously used to detect gas leaks, are no longer authorized. Small amounts of freon pressurized with nitrogen are now used because they give better test results. The following items are used to detect gas leaks:

Flow meter
Pressure gauge (2)
Regulator (2)
Freon
Nitrogen, technical
Halogen leak detector

To test for gas leaks you should use the following procedure:

1. Connect test equipment as shown in figure 12-19.
2. Open the freon filling valve and maintain the flow rate to less than 5 cubic feet per hour.
3. Pressurize the mast to approximately 2 psig of freon.
4. Close the freon filling valve and remove the pressure gauge and freon filling system.
5. Open the nitrogen filling valve and maintain the flow rate to less than 5 cubic feet per hour.
6. Pressurize the mast to approximately 7.5 psig of dry nitrogen and remove the charging system.
7. Using a calibrated halogen leak detector with an H-2 detector probe, monitor all hermetic seals.

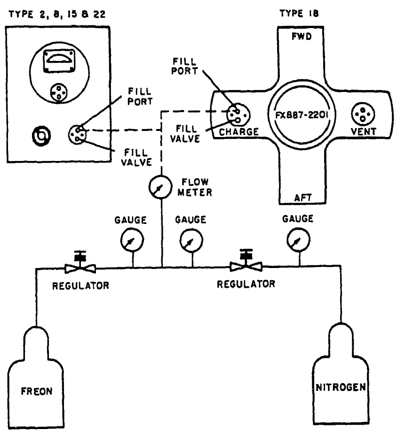

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Figure 12-19.—Internal low-pressure test setup.

8. If the halogen leak detector indication is within the specifications, replace the charging system and continue to slowly increase total pressure inside the periscope mast to +5 psig with nitrogen. Repeat step 7 at 10 psig increments to continue checking for leakage.

9. When 50 psig is reached, maintain for 30 minutes. Then repeat step 7 every 10 minutes.

10. Depressurize the mast of all residual nitrogen. Check for leaks at 10 psig increments as per step 7.

11. Close the air valve inlet plug when the flow of gas stops and the pressure gauge indicates 0 psig.

12. Purge for 30 minutes (minimum) prior to performing periscope evacuation.

EVACUATION

This procedure is used to remove the moisture-laden nitrogen present in the mast assembly and to refill it with dry nitrogen. The following evacuation/charging procedures must be performed prior to the dew-point test.

1. Remove the plug retainer from the quick evacuation port on the lower door of the eyepiece box. Place an O-ring (fig. 12-20, view A) in the lower door recess.

2. Connect the valve adapter and vacuum lock actuator to the evacuation port as shown in view A of the figure. The handle of the vacuum lock actuator should be pulled back to provide maximum free passage of gas during evacuation.

3. Turn the handle of the vacuum lock actuator 20° counterclockwise.

4. Start the vacuum pump (1) and energize the vacuum gauge (2).

5. Set the pressure regulator (3) to 15 psi.

6. Continue pumping until the pressure is reduced to less than 0.1 millibar.

7 Connect the periscope fitting (4) to the air valve inlet.

CAUTION

The periscope charging equipment must be connected at this point, otherwise the operator might open the charging valve and allow outside air to enter the periscope. This would further contaminate the periscope with wet air.

8. Attach three heat sensors to the periscope mast. Space them evenly along the tube.

9. Wrap the periscope mast with three heater blankets. Strap the blankets in place to provide uniform heating along the mast outer tube. Blankets should cover at least 70 percent of the periscope length.

10. Set the thermocoupler to 120°F (40°C). Then energize the heater blankets.

(NOTE: The periscope mast assembly is to be heated throughout the entire evacuation procedure.)

11. Open the air valve inlet screw and allow the pressure to rise to between 25 to 50 millibars. Continue to cycle for 30 minutes. Close the air valve inlet screw.

12. Continue the evacuation until the vacuum gauge reads less than 0.02 millibar. The total time to reach this condition should be less than 8 hours.

13. Remove the heater blankets and sensor equipment.

CHARGING

To charge the periscope, perform the following steps:

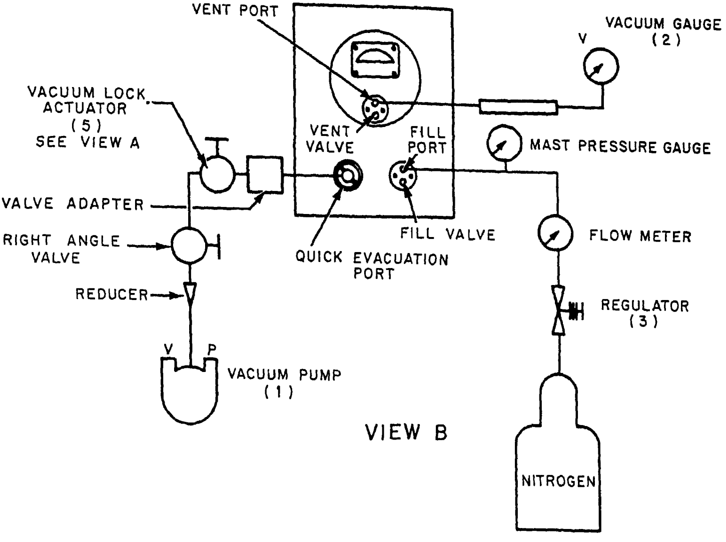
1. Open the air valve inlet screw to allow a flow of nitrogen through the periscope. The flow rate should not exceed 5 cubic feet per hour

2. Close the evacuation port by pushing in the vacuum lock actuator handle. Turn the handle clockwise to lock the sealing plug of the evacuation port in place. De-energize the vacuum gauge (2).

3. Remove the valve adapter (4), the O-ring (6), and the vacuum lock actuator (5) from the evacuation port.

4. Screw the retaining ring into the evacuation port to secure the retaining plug. Store the O-ring with the valve adapter.

5. Continue filling with nitrogen until the pressure reaches 15 psi as indicated on the pressure gauge of the eyepiece box. Then close the air valve inlet screw.



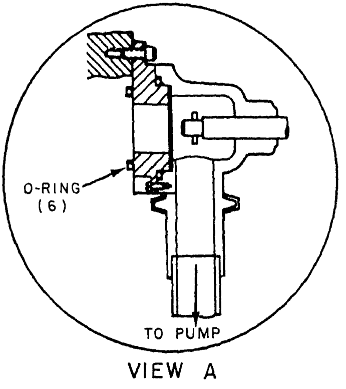


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Figure 12-20.—Type 2, 8, 15, and 22 evacuation and charging setup.

DEW-POINT TEST

After the periscope has been filled for a minimum of 1 hour, perform a dew-point test as follows:

1. Connect the direct-reading dew-point meter to the dew-point sampling valve port (fig. 12-20, view B).
2. Open the dew-point sampling valve to permit nitrogen to be bled from the periscope through the meter.
3. Let nitrogen flow for about 5 minutes to bleed moisture from the line and meter.
4. Take the dew-point reading from the meter and record it for future reference.
5. Disconnect the meter from the periscope.

PREPARATION FOR INSTALLATION

After all procedures described have been completed, use the following steps to prepare the periscope for installation in the submarine:

1. Vent the pressure of the periscope until the internal pressure is 7.5 psi.
2. Reinstall any of the antennas that were removed for pressure testing, and make sure all QA forms are completed.

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Opticalman 3 & 2, NAVEDTRA 10205C, Naval Education and Training Program Development Center, Pensacola, FL, 1979.

Type 18, Submarine Periscope Systems, NAVSEA 0924-LP-062-3020, Naval Sea Systems Command, Washington, D.C., September 1976.

Type 2, Submarine Periscope, NAVSEA 0324-LP-018-7000, Naval Sea Systems Command, Washington, D.C., June 1961.

APPENDIX I

GLOSSARY

ABBERRATION.—Generally, any deviation from an ideal path of the image-forming rays passing through an optical system that causes the image to be imperfect. Specific abberrations are spherical abserration, coma, curvature of field, astigmatism, longitudinal chromatic aberration, lateral chromatic aberration, and distortion.

ABERRATION, CHROMATIC.—Image imperfection caused by light of different wavelengths following different paths through an optical system due to dispersion in the optical elements of the system.

ABERRATION, SPHERICAL.—An optical defect of lenses and spherical mirrors where light rays that come from a common axial point, but strike the lens at different distances from the optical axis, do not come to a common focus.

ABSORPTION, SELECTIVE.—The act or process by which a substance "takes up" or "soaks up" all the colors contained in a beam of white light, except those colors it reflects or transmits Some substances are transparent to light waves of certain frequencies, allowing them to be transmitted, while absorbing waves of other frequencies Some reflecting surfaces will absorb light of certain frequencies and reflect others. The color of a transparent object is the color it transmits, and the color of an opague object is the color it reflects

ACCOMMODATION.—A function of the human eye where its total refracting power is varied in order to clearly see objects at different distances.

ACCOMMODATIONS, LIMITS OF.—The distances of the nearest and farthest points which can be focused clearly by the eyes of an observer. Usually varies from 4 to 5 inches to infinity. (See ACCOMMODATION.)

ACHROMAT.—A contraction of achromatic lens.

ACHROMATIC.—Having the quality of being free of chromatic aberration.

ACHROMATISM.—The absence of chromatic aberration.

ACUITY, VISUAL.—The degree of sharpness of vision.

ACUTANCE.—Edge sharpness and high edge contrast.

ADAPTATION, DARK.—The ability of the human eye to adjust itself to low levels of illumination.

ADAPTATION LIGHT.—The ability of the human eye to adjust itself to a change in the intensity of light.

ADJUSTMENT, INTERPUPILLARY.—The adjustment of the distance between the eyepieces of a binocular instrument to correspond to the distance between the pupils of the observer's eyes.

ANGLE, CRITICAL.—The angle of incidence in a denser medium, at an interface between the denser and less dense medium, at which all of the light is refracted along the interface; that is, the angle of refraction is 90°. When the critical angle is exceeded, the light is totally reflected back into the denser medium. The critical angle varies with the indices of refraction of the two media.

ANGSTROM.—A unit of measurement of the wavelength of light equal to 10^{-8} centimeters.

ANNEALING.—The process of relieving unwanted stresses by suitable heat treating.

APERTURE.—An opening or hole through which light or matter may pass. In an optical system, it is equal to the diameter of the largest entering beam of light that can travel completely through the system. This may or may not be equal to the aperture of the objective. (See APERTURE, CLEAR; APERTURE, RELATIVE.)

APERTURE, CLEAR (Abbreviated CA).—The opening in the mount of an optical system or any component thereof that limits the extent of the bundle of rays incident on the specific surface. It is usually circular and specified by its diameter. Clear aperture is sometimes referred to as free aperture or objective aperture.

APERTURE, EFFECTIVE.—Equivalent to the diameter of the largest bundle of rays that can be imaged by the optical system.

APERTURE, FREE.—A term sometimes used as a synonym for clear aperture.

APERTURE, RELATIVE.—The diameter of the entrance pupil of a lens or optical system measured in terms of the equivalent focal length of that lens or system. It is written as a fraction in which f, the equivalent focal length, is the numerator and is symbolized by f/ followed by a numerical value. For example, f/2 signifies that the diameter of the entrance pupil is equal to 1/2 the equivalent focal length. Relative aperture is applicable for determining exposure time only when the object is at infinity.

ASTIGMATISM (Abbreviated ASTIG).—An aberration that causes an off-axis point to be imaged as a pair of lines at right angles to each other. Each line is at a different distance from the image-forming element along the main ray of the image-forming bundle of rays. The image-forming element thus has two foci, one radial and the other tangential to the optical axis. A sharp image of a point cannot be obtained

ASTIGMATIZER.—A cylindrical lens that can be introduced into the line of sight of a rangefinder to transform point light sources into line images.

AXIS, OPTICAL.—The line formed by the coinciding principal axes of a series of optical elements. It is the line passing through the centers of curvatures of the optical surfaces, also known as the optical centerline.

AXIS, PRINCIPAL.—A straight line connecting the centers of curvature of the refracting surfaces of a lens. In a mechanical sense, a line joining the centers of a lens as it is placed in a mount. The principle axis is the optical axis of a lens.

BALSAM, CANADA.—An adhesive used to cement optical elements.

BEAM.—A shaft or column of light; a bundle of rays. It may consist of parallel, converging, or diverging rays.

BINOCULAR.—Vision with both eyes. A term applied to instruments consisting of two telescopes.

BLISTERS.—Elongated bubbles or seeds, elliptical in shape and longer than one-quarter inch.

BORESIGHT.—To adjust the line of sight of the sighting instrument of a weapon parallel to the axis of the bore. Also applied to the process of aligning other equipment, such as radar mounts and directors. It is also the name of an optical instrument used for checking alignment.

BUBBLE.—A gaseous inclusion in glass

BURNISHING.—The process of turning a thin edge of metal over the beveled edge of a lens to hold it in its cell.

CANDLE/CANDELA.—A unit of luminous intensity.

CANDLEPOWER —A unit of measure of the illuminating power of any light source. The number of candles in the luminous intensity of a source of light.

CENTER, OPTICAL.—The point, generally within a lens, but sometimes exterior to it, at which the optical axis intersects the optical path of a ray.

CENTIMETER.—A unit of metric measurements:

100 centimeters equal 1 meter.

10 millimeters equal 1 centimeter.

2.54 centimeters equal 1 inch.

CHARACTERISTICS, OPTICAL.—The qualifications an optical system possesses by reason of its optical nature, such as field of view, magnification, brightness of image, image quality, and correction for aberrations.

CHART, FOUCAULT.—A test target containing groups of alternate black and white bars spaced at various intervals, which is used to measure the resolving power of telescopes and lenses. This chart is placed at a distance from the site of observation such that the angular separations between the centers of adjacent black bars in the various groups have precalculated values. The most closely spaced group whose bars as imaged by an optical instrument can be resolved, determines the resolving power of that instrument.

COLLIMATE.—To render parallel.

COLLIMATION.—The process of aligning the optical axis of optical systems to the reference mechanical axes or surfaces of an instrument, or the adjustment of two or more optical axes with respect to each other The process of making light rays parallel

COLLIMATOR —An optical device that renders diverging or converging rays parallel It may be used to simulate a distant target or to align the optical axes of instruments

COMA —An aberration of a lens that causes oblique pencils of light rays from an object point to be imaged as a comet-shaped blur

COMPARATOR —An inspection instrument, usually a projection device, that presents a composite of a reference contour and the image of the actual contour for comparison More commonly called an optical comparator

COMPENSATOR —An optical element used to correct for mechanical or optical displacement.

CONCAVE.—A term denoting a hollow, curved surface.

CONCENTRIC.—The characteristic of having the same center. Circles differing in radius, but inscribed from a single center point.

CONFUSION, LEAST, CIRCLE OF.—A circle whose perimeter defines the area, for any point in the field of view, covered by the smallest image (usually of a point source formed by the lens).

CONVERGENCE.—The bending of light rays towards each other, as by a convex or plus lens.

CONVERGENCE, ANGLE OF.—The angle formed by the lines of sight of both eyes in focusing on any line, corner, surface, or part of an object. It is also referred to as convergent angle.

CONVEX.—A term denoting a surface like the outside of a sphere or ball.

COOLANT.—A fluid used to reduce the temperature rise produced by friction or other causes.

CORD.—A large strai in glass.

CORRECTION.—The process of compensating for or adjusting the aberration in the optical design stage.

CRYSTAL.—A natural or artificial substance, such as fluorite, quartz, calcite, or lithium fluoride, used for optical construction.

CURVATURE.—The amount of departure from a flat surface, as applied to lenses. The reciprocal of the radius of curvature.

CURVATURE, CENTER OF.—The center of the sphere of which the surface of a lens or mirror forms a part.

CURVATURE, FIELD.—A synonym for the aberration known as curvature of field.

DEVIATION, ANGLE OF.—The angle through which a ray of light is bent by reflection or refraction.

DEVIATION, CONSTANT.—That property of certain optical devices, such as a penta prism, that preserves the angular relationship between the entering and emerging rays passing through the device, regardless of the orientation of the device in the plane of deviation.

DIALYTE.—A type of compound lens in which the inner surfaces of the two elements are ground to different curvatures to correct for aberrations. The dissimilar faces cannot be cemented together.

DIAPHRAGM.—A fixed or adjustable aperture in an optical system. Diaphragms are used to intercept scattered light, to limit field angles, or to limit image-forming bundles of rays.

DIAPHRAGM, ANTIREFLECTION (OR GLARE).—A diaphragm for eliminating internal reflections and glare in the field of view of the instrument.

DICHROISM.—As applied to certain crystals, this term refers to the selective absorption of light rays vibrating in one particular plane relative to the crystalline axes, but not those vibrating in a plane at right angles.

DIFFUSION.—The scattering of light by reflection or transmission. Diffuse reflection results when light strikes an irregular surface, such as a frosted window or the surface of a frosted or coated light bulb. When light is diffused, no definite image is formed.

DIOPTER (Abbreviated DIOPT).—A unit of refractive power of a lens or prism. In a lens or lens system, it is numerically equal to the reciprocal of the focal length measured in meters. For example, if a lens has a focal length of 25 centimeters, or 1/4 meter, its power is 4 diopters.

DIOPTER, PRISM.—A unit of measure of the reflecting power of a prism. One diopter is the power of a prism that deviates a ray of light by 1 centimeter at a distance of 1 meter from the prism.

DISTANCE, EYE.—The distance from the vertex of the last optical surface of the visual optical system to the exit pupil. Also called eye relief.

DISTANCE, IMAGE.—The axial distance between the image and the second principal point of a lens.

DISTANCE, INTERPUPILLARY (Abbreviated IPD).—The distance between the two eye pupils when the observer is viewing distant objects.

DISTANCE, OBJECT.—The distance from the object to the observer's cornea or to the first principal point of the objective in an optical system.

DISTORTION.—Also called radial distortion. An aberration of lens systems characterized by the imaging of an extra-axial straight line as a curved line, without necessarily affecting the definition. Unsymmetrical, or otherwise irregular distortions of the image can also be caused by imperfect centration or irregularity of optical surfaces.

DISTORTION, BARREL.—A form of radial distortion.

DISTORTION, PINCUSHION.—A form of radial distortion.

DISTORTION, RADIAL.—A charge in magnification from the center of the field to any other point in the field, measured in a radial direction to the center of the field. It is an inherent aberration of lens systems, but can be eliminated or minimized by proper design. Barrel distortion results when the magnification decreases with field angle; pincushion distortion results when the magnification increases with the field angle.

DIVERGENCE.—The bending of rays away from each other, as by a concave or minus lens or by a convex mirror. In a binocular instrument, divergence is the horizontal angular disparity between the images of a common object, as seen through the left and right systems. Divergence is defined as positive when the right image is to the right of the left image.

DOUBLET.—A compound lens consisting of two elements. If there is an air space between the elements it is called an air-spaced doublet. If the inner surfaces are cemented together, it is called a cemented doublet.

ELEMENT, OPTICAL.—An optical part constructed of a single piece of optical material; usually single lenses, prisms, or mirrors.

ELEVATION, ANGLE OF.—The angle between the line of sight (imaginary line from weapon to target) and the line of elevation (formed by axis of bore when a weapon is in a firing position).

EMERGENCE.—A term referring to the trigonometric relation between the emergent ray and the surface of the medium.

EMERGENCE, NORMAL.—A condition in which a ray emerges along the normal to the emergent surface of a medium.

ENERGY, RADIANT.—The energy of electromagnetic waves.

ERECTOR.—A term used as a synonym for erecting system.

EYE.—The organ of vision. Also a term used in the optical industry as follows: assume that a fine ground convex or flat surface is being polished to make it more steeply convex. The polishing then will proceed from the edges and work toward the center, which is not yet polished, but remains fine ground. This central area becomes smaller and smaller as the polishing proceeds and is called the eye. The polishing continues until the eye just disappears. In this way the thickness is controlled, and by keeping the eye centered, the centering is also controlled

EYEGUARD.—A shield of rubber, plastic, or metal used to protect the eyes of the observer from stray light and wind and to maintain the proper eye distance.

EYELENS —The lens of an eyepiece that is nearest to the observer's eye. Various types of lenses are used for this purpose

EYEPIECE —An optical system used to form an enlarged virtual image of the image formed by the objective and to direct the light into the eye of the observer The optical system of an eyepiece usually consists of two lenses, an eyelens and a collective or field lens, but may consist of only one lens or of more than two lenses. Erfle, Ramsden, Huygenian, Kellner, Plossl, and Bertele are various types of eyepieces.

EYESHIELD.—A term used as a synonym for eyeguard.

FIELD, APPARENT.—The size of the field of view in the image space of an optical instrument, as differentiated from the size of the field of view in the object space.

FIELD, CURVATURE OF.—An aberration of actions that causes the image of a plane to be focused into a curved surface instead of a plane.

FIELD, TRUE.—The size of the field of view in the object space of an optical instrument as distinguished from the size of the field of view in the image space (see APPARENT FIELD). More specifically, it is the maximum cone or fan of rays subtended at the entrance pupil that is transmitted by the instrument to form the usable image.

FILTER.—Often referred to as ray filter. It is a device with the desired characteristics of selective transmittance. Usually special glass, gelatin, or plastic optical parts with plane parallel surfaces, which are placed in the path of light through the optical system of an instrument to selectively absorb certain wavelengths of light, reduce glare, or reduce light intensity. Colored, ultraviolet neutral density, and polarizing filters are in common use. Filters are provided as separate elements or as integral devices mounted so that they can be placed in or out of position, as desired.

FILTER, POLARIZING.—A filter that polarizes the light passing through it.

FILTER, RAY.—A synonym for filter.

FIXATION, POINT OF.—An object on which the observer's eye is concentrated.

F-NUMBER —The ratio of the equivalent focal length of an objective to the diameter of its entrance pupil.

FOCUS.—Often used as a synonym for focal point. The term is also used to describe the process of adjusting the eyepiece or objective of a telescope so that the image is clearly seen by the observer. The term is also used to denote the adjustment of the lens, plate, or film holder of a camera so that a sharp, distinct image is registered.

FOCUS, FIXED.—A term used to denote instruments that are not provided with a means of focusing.

FOCUS, PRINCIPAL.—A term used as a synonym for principal point of focus.

FOCUS, PRINCIPAL, POINT OF.—The point to which incident parallel rays of light converge, or from which they diverge when they have been acted upon by a lens or mirror. A lens has a single point of principal focus on each side of the lens. A mirror has but one principal focus. A lens or mirror has an infinite number of image points, real or virtual, one for each position of the object.

FOOT-CANDLE.—A unit of illuminance equal to one lumen incident per square foot. The illuminance (formerly called illumination) of a surface placed one foot from a light source having a luminous intensity of one candle.

FREQUENCY.—The number of crests of waves that pass a fixed point in a given unit of time, as in light or other wave motion.

GLASS, BARIUM.—A term commonly used in reference to a type of glass of which one of the ingredients is barium oxide, which is added for the purpose of increasing the index of refraction, while maintaining a relatively low dispersion.

GLASS, BARYTA.—A type of glass containing lead for increasing the index of refraction, together with barium, which further increases the index while maintaining a relatively low dispersion.

GLASS, COMPENSATING.—Also called clear glass or clear filter. Where a filter is used in converging or diverging light, a change of focus would occur upon removing the filter. To avoid this, a clear glass plate of equivalent optical thickness, called a compensating glass, is substituted for the filter.

GLASS, CROWN.—A type of optical glass of the alkali-lime-silica type. It usually has an index of refraction in the 1.5 to 1.6 range. Since the positive element of an achromatic lens is almost always made of crown glass, it is often referred to simply as the crown, as differentiated from the negative element, the flint (see GLASS, FLINT).

GLASS, FIELD,—A hand-held binocular telescope, usually of the Galilean type.

GLASS, FLINT.—A type of optical glass to which lead or other elements are added to produce generally a higher index of refraction 1.6 to 1.9.

GLASS OPTICAL.—A glass which during manufacture is carefully controlled with respect to composition, melting, heat treatment, and other processing in order that its optical characteristics, such as its index of refraction, dispersion, transmittance, and spectral transmittance, have the values required for the optical application for which it is to be used.

HEIGHTFINDER.—An instrument used to determine the height of altitude of aerial targets by optical triangulation. The instruments used employ the stereoscopic principle.

ILLUMINANCE.—Luminous flux incident per unit area of a surface. Widely known as illumination.

ILLUMINATED.—A surface or object is said to be illuminated whenever luminous flux is incident upon it.

IMAGE.—A representation of an object produced by light rays. An image-forming optical element forms an image by collecting a bundle of light rays diverging from an object point and transforming it into a bundle of rays that converges toward, or diverges from, another point. If the rays converge to a point, a real image of the object point is formed; if the rays diverge without intersecting each other, they appear to proceed from a virtual image.

IMAGE, ERECT.—An image, either real or virtual, that has the same special orientation as the object. The image obtained at the retina with the assistance of an optical system is said to be erect when the orientation of the image is the same as with the unaided eye.

IMAGE, REAL.—See IMAGE.

IMAGE, REVERTED.—An image, the right side of which appears to be the left side, and vice versa.

IMAGE, VIRTUAL.—If 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 distance of the virtual image is inversely proportional to the divergence of the rays. Since there is no physical intersection of rays, there is no real image that can be focused on a screen. The image of any real object produced by a negative lens or convex mirror is always virtual. The image produced by a positive lens of an object located within its focal length is also virtual.

INCIDENCE.—The act of falling upon, or affecting, as light upon a surface.

INCIDENCE, ANGLE OF.—A term used to denote light incident at 90° to the surface.

INDEX, ABSOLUTE.—A synonym for index of refraction

INDEX, REFRACTIVE.—A term used as a synonym for index of refraction.

INFINITY —In the optical industry, a term used to denote a distance sufficiently great so that light rays emitted from a body at the distance are practically parallel.

INFRARED —The visible electromagnetic radiation beyond the red end of the visible spectrum The wavelengths range from 768 millimicrons to the region of 30 or 40 microns Heat is radiated in the infrared region

INVERTED —Turned over; upside-down. Usually refers to the effect of a prism or lens upon the image. Inversion is the effect of turning upside-down.

JUMP, IMAGE.—The apparent displacement of an object due to an erroneous prismatic condition in an optical system.

LENGTH, FOCAL.—In a lens, focal length is synonymous with equivalent focal length. In a mirror or single refracting surface, it is the distance measured from the focal point to the mirror or surface.

LENGTH, FOCAL, BACK (Abbreviated BF).—The distance measured from the vertex of the back surface of the lens to the rear focal point.

LENGTH, FOCAL, EQUIVALENT (Abbreviated EFL).—The distance from a principal point to its corresponding principal focal point. The focal length of the equivalent thin lens. The size of the image of an object is directly proportional to the equivalent focal length of the lens forming it.

LENGTH, FRONT, FOCAL (Abbreviated FFL).—The distance measured from the principal focus located in the the front space to the first principal point.

LENS.—A transparent optical element, usually made from optical glass, having two opposite polished major surfaces of which at least one is convex or concave in shape and usually spherical. The polished major surfaces are shaped so that they serve to change the degree of convergence or divergence of the transmitted rays.

LENS, ACHROMATIC.—A lens consisting of two or more elements, usually made of crown and flint glass, which has been corrected so that light of at least two selected wavelengths is focused at a single axial point (see LENS, COMPOUND).

LENS, APLANATIC.—A lens that has been corrected for spherical aberration and departure from the sine condition freedom from coma. It may also be corrected for color.

LENS AXIS OF.—A term used as a synonym for principal axis.

LENS, COLLECTIVE.—A lens of positive power (a field lens, for example) used in an optical system to refract the chief rays of image-forming bundles of rays so that these bundles will pass through subsequent optical elements of the system. If all the bundles do not pass though an optical element a loss of light ensues, known as vignetting.

LENS, COMPOUND.—A lens composed of two or more separate pieces of glass or other optical material. These component pieces or elements may or may not be cemented together. A common form of compound lens is a two-element objective, one element being a converging lens of crown glass and the other a diverging lens of flint glass. The combination of suitable glasses or other optical materials (plastics, minerals) properly ground and polished reduces aberrations normally present in a single lens.

LENS, CONCAVE.—A term used as a synonym for diverging lens.

LENS, CONVEXO-CONCAVE.—A synonym for meniscus.

LENS, CYLINDRICAL.—A lens with a cylindrical surface. Cylindrical lenses are used in rangefinders to introduce astigmatism in order that a point light source may be imaged as a line of light. By combining cylindrical and spherical surfaces, an optical system can be designed that gives a certain magnification in a given azimuth of the image and a different magnification at right angles in the same image plane. Such a system is designated as being anamorphic.

LENS, DIVERGENT-MENISCUS.—A lens with one convex surface and one concave surface, the latter having the greater curvature or power. A negative meniscus. Also called a diverging meniscus lens.

LENS, DIVERGING.—Also known as divergent lens, negative lens, concave lens, dispersive lens. A lens that causes parallel light rays to spread out. One surface of a diverging lens may be concavely spherical and the other plane (plano-concave), both may be concave (double concave), or one surface may be concave and the other convex (concave-convex, divergent-meniscus). The diverging lens is always thicker at the edge than at the center

LENS, DOUBLE-CONCAVE.—A minus lens having both surfaces concave.

LENS, DOUBLE-CONVEX.—A plus lens having both surfaces convex.

LENS, FIELD.—A positive lens used to collect the chief rays (field rays) of image-forming bundles so that the entire bundles or sufficient portions of them will pass through the exit pupil of the instrument. A field lens is usually located at or near the focal point of the objective lens. The field lens increases the size of the field that can be viewed with any given eyelens diameter.

LENS, PLANO.—A lens having no curved surface, or whose two curved surfaces neutralize each other so that it has no refracting power.

LENS, PLANO-CONCAVE.—A lens with one surface plane, the other concave.

LENS, PLANO-CONVEX.—A lens with one surface plane, the other convex.

LENS, THICK.—A lens whose axial thickness is so large that the principal points and the optical center cannot be considered as coinciding at a single point on the axis.

LENS, THIN.—A lens whose axial thickness is sufficiently small that the principal points, the optical center, and the vertices of the two surfaces can be considered as coinciding at the same axial point.

LIGHT, COLLIMATED.—A light bundle in which the rays emanating from any single point in the object are parallel to one another. Light from an infinitely distant real source, or apparent source, such as a collimator reticle, is collimated light.

LIGHT, PARALLEL.—A synonym for collimated light

LIGHT, PENCIL OF —A narrow bundle of light rays diverging from a point source or converging toward an image point.

LIGHT, POLARIZED.—A light beam whose electric vectors vibrate along the same direction, that is in a single plane containing the line of propagation, is said to be plane polarized (often called linearly polarized).

LIGHT, VELOCITY OF.—This term usually refers to the speed of monochromatic light waves.

LIGHT, WHITE.—Radiation having a spectral energy distribution that produces the same color sensation to the average human eye as average noon sunlight.

MAGNIFICATION.—Magnification is best defined by the following conditions: (1) Lateral magnification is the ratio of the linear size of the image to that of the object, as used in enlarging lenses. (2) Angular magnification is the ratio of the apparent size of the image seen through an optical element or instrument to that of the object viewed by the unaided eye, when both the object and image are at infinity (telescopes), or when both the object and image are considered to be at the distance of distinct vision (microscopes). Angular magnification is often used as a synonym for magnifying power.

MAGNIFIER.—A lens or lens system forming a magnified virtual image of an object placed near its front focal point. Magnifiers are also referred to as loupes, simple microscopes, or magnifying glasses. The magnifications of magnifiers range from approximately 3× to 20×.

MEASURE, LENS.—A mechanical device for measuring surface curvature in terms of dioptric power.

MENISCUS.—A lens having surfaces, one of which is convex and the other concave.

METER.—A unit of metric measurement.

1000 millimeters equal 1 meter

100 centimeters equal 1 meter

1 meter equals 39.37 inches

MICRON (μ).—A unit of length in the metric system equal to 0.001 millimeter.

MILLIMETER.—A unit of metric measurement:

1000 millimeters equal 1 meter,

10 millimeters equal 1 centimeter,

25,400 millimeters equal 1 inch.

MILLIMICRON (mμ).—A unit of length in the metric system equal to 0.001 micron. It is also equivalent to 10 angstroms.

MIRROR.—A smooth, highly polished surface for reflecting light. It may be plane or curved. Usually a thin coating of silver or aluminum on glass constitutes the actual reflecting surface. When this surface is applied to the front face of the glass, the mirror is termed a front surface mirror.

MIRROR, PARABOLOIDAL.—A concave mirror that has the form of a paraboloid of revolution. Sometimes the paraboloidal mirror may consist of only a portion of a paraboloidal surface through which the axis does not pass and is known as an off-axis paraboloidal mirror. All axial parallel light rays are focused at the focal point of the paraboloid without spherical aberration, and conversely all light rays emanating from an axial source at the focal point are reflected as a bundle of parallel rays without spherical aberration. Paraboloidal mirrors are free from chromatic aberration.

MIRROR, SURFACE, FRONT.—An optical mirror on which the reflecting surface is applied to the front surface of the mirror instead of to the back, that is, to the first surface of incidence.

MONOCHROMATIC.—Composed of one color.

MONOCULAR.—Pertaining to one eye.

MOUNTING, ECCENTRIC.—A type of lens mounting consisting of eccentric rings that may be rotated to shift axis of the lens to a prescribed position.

N, n.—A symbol used to indicate index of refraction. It is usually used with a subscript to indicate the wavelength of light; for example, N_p, n_p indicates the index of refraction for sodium light.

NORMAL.—Sometimes called the perpendicular. An imagninary line forming right angles with a surface or other lines. It is used as a basis for determining angles of incidence, reflection, and refraction.

OBJECT.—The figure viewed through or imagined by an optical system. It may consist of natural or artificial structures or targets, or may be the real or virtual image of an object formed by another optical system. In the optical field, an object should be thought of as an aggregation of points.

OBJECTIVE.—The optical component that receives light from the object and forms the first or primary image in telescopes and microscopes. In cameras, the image formed by the objective is the final image. In telescopes and microscopes, when used visually, the image formed by the objective is magnified by use of an eyepiece.

PERISCOPE.—An optical instrument designed to displace the line of sight in a vertical direction. It is used to permit observation over the top of a barricade or out of a tank or submarine.

PLANE, FOCAL.—A plane through the focal point perpendicular to the principal axis of a lens or mirror. The film plane in a camera focused at infinity.

PLANE, IMAGE.—The plane in which the image lies, or is formed. It is perpendicular to the axis of the lens. A real image formed by a converging lens would be visible upon a screen placed in this plane.

PLANE, OBJECT.—The plane that contains the object points lying within the field of view.

PLANES, PRINCIPAL.—Planes of unit magnification; that is, a ray directed at the first principal plane appears to leave the second principal plane at the same height.

PLATE, SURFACE.—A plate having a very accurate plane surface, used for testing other surfaces, or to provide a true surface for accurately locating a testing fixture.

POINT, FOCAL.—The point at which a bundle of rays from a sharp image of an object; alternatively, the point at which the object must be placed for a sharp image. The term is also used as a synonym for principal point of focus.

POINT, PRINCIPAL, FIRST.—The principal point related to the object space.

POINT, PRINCIPAL, SECOND.—The principal point related to image space.

POINTS, PRINCIPAL.—The points of intersection of the principal planes and the optical axis.

POLARIZER.—An optical device for converting unpolarized or natural light into polarized light.

POWER.—A measure of the ability to bend or refract light in a mirror or lens. It is usually measured in diopters. In a telescope, it is the number of times the instrument magnifies the object viewed. For example, if with a 6-power (6×) instrument an object 600 yards away is enlarged six times, it appears as it would to the naked eye if it were at a distance of only 100 yards.

POWER, MAGNIFYING.—Synonymous with magnification, magnifying power is the measure of the ability of an optical device to make an object appear larger than it appears to the unaided eye. For example, if an optical element or system has a magnification of 2-power (2×) the object will appear twice as wide and high. The magnification of an optical instrument is equal to the diameter of the entrance pupil divided by the diameter of the exit pupil. For a telescopic system, the magnification is also equal to the focal length of the objective divided by the focal length of the objective divided by the focal length of the eyepiece.

POWER, RESOLVING.—A measure of the ability of a lens or optical system to form separate and distinct images of two objects close together Because of diffraction by the aperture stop, no optical system can form a perfect image of a point, but produces instead a small disk of light (airy disk) surrounded by alternately dark and bright concentric rings. When two object points are at that critical separation from which the first dark ring of one diffraction pattern falls upon the central disk of the other, the points are just resolved or distinguished as separated, and the points are said to be at the limit of resolution.

PRISM.—A transparent body with at least two polished plane faces inclined with respect to each other, from which light is reflected or through which light is refracted. When light is refracted by a prism whose refractive index exceeds that of the surrounding medium, it is deviated or bent toward the thicker part of the prism.

PRISM, AMICI.—Also called roof prism and right-angle prism with roof. A form of roof prism consisting of a roof edge formed upon the long reflecting face of a right-angle prism. It is used as an erecting system in elbow and panoramic telescopes. It erects the image and bends the line of sight through a 90° angle.

PRISM, COINCIDENCE.—A compound prism, consisting of a system of small prisms cemented together, used in a coincidence rangefinder to bring the images from the two objectives to a single eyepiece for viewing.

PRISM, DOVE.—Also known as rotating prism. It is used to invert the image in one plane without deviating or displacing the axis. It is used as the rotating prism in the conventional type of optical system of panoramic telescopes. Dove prisms and double dove prisms are also used in scanning systems.

PRISM, PENTA.—A five-sided prism used to bend light through a constant angle, usually 90°, without producing inversion. A penta prism can be rotated about an axis parallel to its faces without producing a change in its deviation of 90°.

PRISM, PORRO.—A 45°—90°—45° reflecting prism with the surfaces forming the 90° angle reflecting the light beam through a total angle of 180°.

PRISM, RHOMBOIDAL.—A reflecting prism whose unpolished side faces are rhomboidal in shape. It has two parallel transmitting faces, and two parallel reflecting faces; the latter are oblique to the former (usually but not necessarily at 45°). This prism has the property of offsetting the optical axis without changing the aspect of the image. By rotating the rhomboidal prism around an axis normal to the entrance surface, the offset emergent axis can be moved parallel to itself in a circular arc; hence pairs of these prisms are often used to provide interpupillary adjustment of the eyepiece of binocular instruments, such as stereoscopic rangefinders and heightfinders.

PRISM, RIGHT ANGLE.—A type of 45°—90°—45° prism used to turn a beam of light through a right angle (90°) with the surfaces forming the 90° angle acting as transmitting faces.

PRISM, ROOF-ANGLE OR ROOF.—A synonym for Amici prism.

PUPIL, ENTRANCE.—The image of the limiting aperture stop formed in the object space by all optical elements preceding the limiting aperture stop; also used as a term to denote the aperture of the objective when there are no other limiting stops following it in the system.

PUPIL, EXIT.—The image of the limiting aperture stop in an optical system formed by all lenses following this stop. In telescopes the image is real and can be seen as a small bright, circular disc by looking at the eyepiece of the instrument directed toward an illuminated area or light source. In telescopes its diameter is equal to the diameter of the entrance pupil divided by magnification of the instrument. In Galilean telescopes the exit pupil is a virtual image between the objective and eyepiece and acts as an out-of-focus field stop.

QUARTZ.—A natural mineral composed of silicon dioxide (SiO_2). Quartz is used as an optical medium in scientific apparatus because of its transparency over a wide interval of the electro-magnetic spectrum, particularly the ultraviolet.

QUARTZ, FUSED.—A vitreous (glassy) material resulting from the fusion of crystalline quartz. It has a much lower index of refraction than crystalline quartz.

RANGEFINDER.—An optical instrument used to determine the distance of an object or target by triangulation.

RANGEFINDER, COINCIDENCE.—A self-contained distance-measuring device operating on the principle of triangulation. Two images of the same object, simultaneously observed from two points a known distance apart, are matched to determine the range.

RAY, EMERGENT.—A ray of light leaving, or emerging, from a medium as contrasted to the entering or incident ray.

RAY, INCIDENT.—A ray of light that falls upon, or strikes, the surface of an object, such as a lens or mirror. It is said to be incident to the surface.

RAY, LIGHT.—The term applied to the lines perpendicular to the wavefronts of waves of light to indicate their direction of travel.

RAY, PRINCIPAL.—In the object space, the principal ray is one directed at the first principal point, and hence in the image space this ray, projected backward, would intersect the axis at the second principal point.

RAY, REFLECTED.—The ray of light leaving a reflecting surface, representing the path of light after reflection.

RAYS, MARGINAL.—Rays of light passing through an optical system near the edge of the aperture.

REFLECTION.—When light rays strike a smooth, polished surface they are bent back into the medium whence they came. Specular or regular reflection from a polished surface, such as a mirror, will return a major portion of the light in a definite direction lying in the plane of the incident ray and the normal (see REFLECTION, ANGLE OF). After specular reflection, light can be made to form a sharp image of the original source. Diffuse reflection occurs when the surface is rough and the reflected light is scattered from each point in the surface. These diffuse rays cannot be made to form an image of the original source, but only of the diffusely reflecting surface itself.

REFLECTION, ANGLE OF.—The angle between the normal to a reflecting surface and the reflected ray.

REFLECTION, DIFFUSE.—See REFLECTION.

REFLECTION, INTERNAL, TOTAL.—The reflection that takes place within a substance because the angle of incidence of light striking the boundary surface is in excess of the critical angle.

REFLECTION, LAW OF.—The angle of reflection is equal to the angle of incidence; the incident ray, reflected ray, and normal all lie in the same plane.

REFLECTION, MIXED.—The simultaneous occurrence of specular and diffuse reflection.

REFLECTION, REGULAR.—See REFLECTION.

REFRACTION.—The bending of oblique incident rays as they pass from a medium of one index of refraction into a medium of a different index of refraction.

REFRACTION, ANGLE OF.—The acute angle between the normal to a refracting surface at the point of incidence and the refracted ray.

REFRACTION, DOUBLE.—The separation of unpolarized light into two plane polarized components by a doubly refracting crystal.

REFRACTION, INDEX OF.—A number applied the relation between the angle of incidence and the angle of refraction when light passes from one medium to another. The index between two media is called the relative index, while the index when the first medium is a vacuum is called the absolute index of the second Examples: vacuum 1.000; air, 1.000292; water, 1.333; ordinary crown glass, 1.516. Since the index of air is very close to that of vacuum, the two are often used interchangeably as being practically the same.

REFRACTION, LAW OF.—A synonym for Snells' law.

RELIEF, EYE.—A synonym for eye distance.

RETICLE.—A scale, indicator, or pattern placed in one of the focal planes of an optical instrument that appears to the observer to be superimposed upon the field of view. Reticles, in various patterns, are used to determine the center of the field or to assist in the gauging of distance, determining leads or measurement. A reticle may consist of fine wires, or fibers, mounted on a support at the ends, or may be etched on a clear, scrupulously polished and cleaned plane parallel plate of glass. In the latter case the entire piece of glass is referred to as the reticle.

RETICULE.—See RETICLE.

REVERSIBILITY, LAW OF.—If the direction of light is reversed, it will travel in the opposite direction over the same path despite the number of times it is refracted or reflected.

REVERTED.—Turned the opposite way so that right becomes left, and vice versa. It is the effect produced by a mirror in reflecting an image.

RINGS, NEWTON's.—When two polished surfaces are cleaned and placed in contact with a thin air film between them, reflected beams of light from the two adjacent surfaces interfere to form a series of rings or bands known as Newton's rings or fringes. By counting these bands from the point of actual contact, the departure of one surface from the other is determined. The regularity of the fringes maps out the regularity of the distance between the two surfaces.

SIGHT, LINE OF (Abbreviated L.O.S.).—The line of vision; the optical axis of a telescope or other observation instrument. The straight line connecting the observer with the aiming point; the line along which the sights are set.

SNELL, LAW OF.—When light is passing from a given medium to a denser medium, its path is deviated toward the normal; when passing into a less dense medium, its path is deviated away from the normal. Snells' law, often called the law of refraction, defines this phenomenon by describing the relation between the angle of incidence and the angle of refraction.

SPAR, ICELAND.—A transparent variety of the natural crystal calcite (also called calcspar) that displays very strong double refraction.

SPECTRUM —The visual spectrum is the band of color produced by decomposing white light into its components by the process of dispersion The rainbow is an example of a spectrum produced by the dispersion of white light by water droplets (see SPECTRUM, ELECTROMAGNETIC)

SPECTRUM, ELECTROMAGNETIC.—The entire range of wavelengths, extending from the shortest to the longest or, conversely, that can be generated physically. This range of electromagnetic wavelengths extends almost from zero to infinity and includes the visible portion of the spectrum known as light.

SPECTRUM, VISIBLE.—The portion of the electromagnetic spectrum to which the retina is sensitive and by which we see. It extends from about 400 to about 750 millimicrons in wavelength of the radiation.

SPEED, LENS.—That property of a lens that affects the illuminance of the image. Lens speed is specified in terms of the following expressions: aperture ratio, numerical aperture, T-stop, or F-number.

STOP.—See STOP, APERTURE; STOP, FIELD.

STOP, APERTURE.—The diaphragm that limits the size of the aperture.

STOP, FIELD.—A diaphragm used to delimit the usable field. The field stop is used to produce a sharply defined edge to the field.

STRAIN.—Mechanical tension, compression, or shear in optical glass by internal stress and brought about by improper cooling or annealing during manufacture of the glass or the subsequent weakening of molded parts.

STRESS, INTERNAL.—The tension, compression, or shear stresses within an optical element usually caused by cooling or improper annealing.

STRIA.—A defect in optical glass consisting of a sharply defined streak of transparent material having a slightly different index of refraction than the body of the glass.

STRIAE.—Internal imperfections of glass appearing as wavy distortion.

STRINGS.—Wavy transparent lines appearing as though a thread of glass had been incorporated into the sheet

SURFACE.—A term used to denote one of the exterior faces of an optical element. It is also used to describe the process of grinding or generating the face of an optical element.

SYSTEM, ERECTING.—A system of lenses or prisms, the function of which is to produce an erect image which would otherwise be inverted. An erecting system may consist of a lens or system of lenses to reimage the object or of one or more prisms.

SYSTEM, ERECTING, PORRO PRISM.—A prism pair designed by M. Porro, in which there are four reflections to completely erect the image. Each prism has angles of 45° and 90°. The hypotenuse faces are parallel and may be either air-spaced or cemented. The edges at the 90° angle of the two prisms are at right angles to each other. The line of sight through this system is laterally displaced but not deviated. This system is generally used as an erecting system in binocular field glasses.

SYSTEM, ERECTING, PORRO PRISM.—A direct vision prism system containing two Porro prisms with their roof edges at right angles, and their hypotenuse faces parallel and opposed. This system will invert and revert the image (erects the image) and has the characteristic of displacing the line of sight laterally and vertically.

SYSTEM, LENS.—Two or more lenses arranged to work in conjunction with one another.

SYSTEM, OPTICAL.—A combination of optical components arranged to perform one or more optical functions.

TELESCOPE.—An afocal optical instrument containing a system of lenses or mirrors usually, but not always, having a magnification greater than unit, which renders distant objects more clearly visible by enlarging their images on the retina of the eye. Telescopes have two major uses: observing and pointing as in the measurement of angles and in aiming.

TELESCOPE, ASTRONOMICAL.—A telescope that produces an inverted image.

TELESCOPE, AUXILIARY.—A small telescope, placed between the eyepiece of an optical instrument and the observer's eye, to increase the overall magnification of the image. This type of telescope is usually of low magnifying power.

TELESCOPE, COLLIMATING.—A telescope, whose mechanical axis is coincident with its optical axis. In this telescope instead of an eyepiece, a reticle and generally an illuminating system replaces the eyepiece. This telescope provides bundles of parallel light rays; that is, it images the reticle at infinity. It is generally used for optical adjustments where parallel light is necessary.

TELESCOPE, TERRESTRIAL.—A telescope that produces an erect, or natural, image.

THICKNESS, CENTER.—The thickness of a lens measured at the optical field.

TRIPLET.—A three-lens component of an optical system, which may or may not be cemented.

ULTRAVIOLET.—Those rays of radiant energy immediately beyond the violet ends of the visible spectrum in the range of 390 to 100 millimicrons.

VERTEX.—The point of intersection of the optical axis with an optical surface.

VISION, BINOCULAR.—The simultaneous use of both eyes in the process of vision.

VISION, DISTINCT, DISTANCE OF.—The near-point distance of the normal eye conventionally given the value of 10 inches or 25 centimeters. This value is used in calculating the designated magnification of a simple magnifier or eyepiece.

VISION, STEREOSCOPIC.—Vision in depth of three dimensions due to the spacing of the eyes. This spacing permits the eyes to see objects from slightly different points of view.

WAVEFRONT.—A surface normal to rays as they proceed from a source. The wavefront passes through those parts of the waves that are in the same phase.

WAVELENGTH.—The length of a wave measured from any point on one wave to the corresponding point on the next wave; usually measured from crest to crest. Wavelength determines the nature of the various forms of radiant energy that comprise the electromagnetic spectrum; it determines the color of light.

WEDGE.—A prism with a very small angle between the refracting surfaces. Wedges may be circular, oblong, or square in outline.

WEDGE, CORRECTION.—In rangefinders and heightfinders, a rotatable or sliding wedge-shaped element used to divert the line of sight in a precise manner in order to correct errors in the optical system caused by temperature variation or any other errors of collimation.

WEDGE, MEASURING.—A wedge in a rangefinder or heightfinder used to displace the image formed by one telescope so that it coincides with that formed by the other telescope, thus affording a measurement of the parallactic angle between the line of sight of the two telescopes. There are two principal types of measuring wedges. The sliding wedge is mounted on slides parallel to the optical axis, between the objective lens of one telescope and its focal plane. It produces an image displacement equal to the product of the deviation of the wedge multiplied by its distance from the focal plane. Compensating wedges rotate simultaneously through equal angles in opposite directions. The pair of equal compensating wedges, which is mounted in front of one telescope, is equal to a wedge having a variable angle of deviation in the plane of triangulation, but none at right angles to it.

WEDGE, ROTATING.—A circular optical wedge (prism of small refracting angle) mounted to be rotated in the path of light rays to divert the line of sight to a limited degree (see WEDGE, CORRECTION; WEDGE, MEASURING).

WINDOW.—A piece of glass with plane parallel surfaces used to admit light into an optical instrument and to exclude dirt and moisture.

APPENDIX II

COMMON FORMULAE USED IN OPTICAL REPAIR AND MACHINE OPERATIONS

$$DP(\emptyset) = 40 \div FL \text{ in inches}$$

$$DP(\emptyset) = 100 - FL \text{ in cm}$$

$$DP(\emptyset) = 1000 \div FL \text{ in mm}$$

$$FC = CP - D^2$$

$$\frac{1}{F} = \frac{1}{DO} + \frac{1}{DI}$$

$$MAG = \frac{\text{Apparent field}}{\text{True field}}$$

$$MAG = \frac{\text{FL objective lens}}{\text{FL eyepiece}}$$

$$MAG = \frac{\text{Free aperture}}{\text{Exit pupil}}$$

$$MAG = \frac{Si}{So} \text{ or } \frac{Di}{Do}$$

$$MP = \emptyset - 4 \text{ (Diopters)}$$

$$MP = 10 - FL \text{ in inches}$$

$$MP = 25.4 - FL \text{ in cm}$$

$$MP = 2\ 54 - FL \text{ in mm}$$

$$MP = 10 \text{ EEL in inches}$$

$$N \times \sin\theta = N' \times \sin\theta' \text{(Theta)}$$

$$\frac{Si}{So} = \frac{Di}{Do}$$

$$IR = \frac{186{,}000 \text{ mps}}{\text{Speed of light in the media under consideration}}$$

$$RIB = \frac{(\text{Large F:})^2}{\text{Small f:}^2}$$

$$\text{Internal thread depth} = 0.541226 \times P$$

$$\text{External thread depth} = 0.61343 \times P$$

$$SD = 0.708 \times P$$

$$SD = 0.625 \times P$$

$$T = \frac{(LD - SD)}{L} \times 12$$

$$\text{Index} = 40 \div D$$

$$TDS = MD - 1 - N$$

$$TDS = MD - P$$

$$MD = (N \times 013) + 0.060$$

APPENDIX III

PREFIXES AND SYMBOLS USED IN METRIC SYSTEM

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr′ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ′ga)	G
1 000 000 = 10^{6}	mega (mĕg′a)	M*
1 000 = 10^{3}	kilo (kĭl′ō)	k*
100 = 10^{2}	hecto (hĕk′tō)	h
10 = 10	deka (dĕk′ȧ)	da
0.1 = 10^{-1}	deci (dĕs′ĭ)	d
0.01 = 10^{-2}	centi (sĕn′tĭ)	c*
0.001 = 10^{-3}	milli (mĭl′ĭ)	m*
0.000 001 = 10^{-6}	micro (mī′krō)	μ*
0.000 000 001 = 10^{-9}	nano (năn′ō)	n
0.000 000 000 001 = 10^{-12}	pico (pē′kō)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm′tō)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt′tō)	a

*Most commonly used

APPENDIX IV

ENGLISH AND METRIC SYSTEM UNITS OF MEASUREMENT
COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents		Conversions Accurate to Parts Per Million (units stated in abbreviated form) Number X Factor	
1 inch	= 25 millimeters	in X 25 4*	= mm
1 foot	= 0 3 meter	ft X 0 3048*	= m
1 yard	= 0 9 meter	yd X 0 9144*	= m
1 mile†	= 1 6 kilometers	mi X 1 60934	= km
1 square inch	= 6 5 square centimeters	in^2 X 6 4516*	= cm^2
1 square foot	= 0 09 square meter	ft^2 X 0 0929030	= m^2
1 square yard	= 0 8 square meter	yd^2 X 0 836127	= m^2
1 acre	= 0 4 hectare	acres X 0 404686	= ha
1 cubic inch	= 16 cubic centimeters	in^3 X 16 3871	= cm^3
1 cubic foot	= 0 03 cubic meter	ft^3 X 0 0283168	= m^3
1 cubic yard	= 0 8 cubic meter	yd^3 X 0 764555	= m^3
1 quart (lq)	= 1 liter	qt (lq) X 0 946353	= *l*
1 gallon	= 0 004 cubic meter	gal X 0 00378541	= m^3
1 ounce (avdp)	= 28 grams	oz (avdp) X 28 3495	= g
1 pound (avdp)	= 0 45 kilogram	lb (avdp) X 0 453592	= kg
1 horsepower	= 0 75 kilowatt	hp X 0 745700	= kW
1 pound per square inch	= 0 07 kilogram per square centimeter	psi X 0 0703224	= kg/cm^2

1 millimeter	= 0 04 inch	mm X 0 0393701	= in
1 meter	= 3 3 feet	m X 3 28084	= ft
1 meter	= 1 1 yards	m X 1 09361	= yd
1 kilometer	= 0 6 mile	km X 0 621371	= mi
1 square centimeter	= 0 16 square inch	cm^2 X 0 155000	= in^2
1 square meter	= 11 square feet	m^2 X 10 7639	= ft^2
1 square meter	= 1 2 square yards	m^2 X 1 19599	= yd^2
1 hectare	= 2 5 acres	ha X 2 47105	= acres
1 cubic centimeter	= 0 06 cubic inch	cm^3 X 0 0610237	= in^3
1 cubic meter	= 35 cubic feet	m^3 X 35 3147	= ft^3
1 cubic meter	= 1 3 cubic yards	m^3 X 1 30795	= yd^3
1 liter	= 1 quart (lq)	*l* X 1 05669	= qt (lq)
1 cubic meter	= 250 gallons	m^3 X 264 172	= gal
1 gram	= 0 035 ounces (avdp)	g X 0 0352740	= oz (avdp)
1 kilogram	= 2 2 pounds (avdp)	kg X 2 20462	= lb (avdp)
1 kilowatt	= 1 3 horsepower	kW X 1 34102	= hp
1 kilogram per square centimeter	= 14 2 pounds per square inch	kg/cm^2 X 14 223226	= psi

†nautical mile = 1 852 kilometers

* exact

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