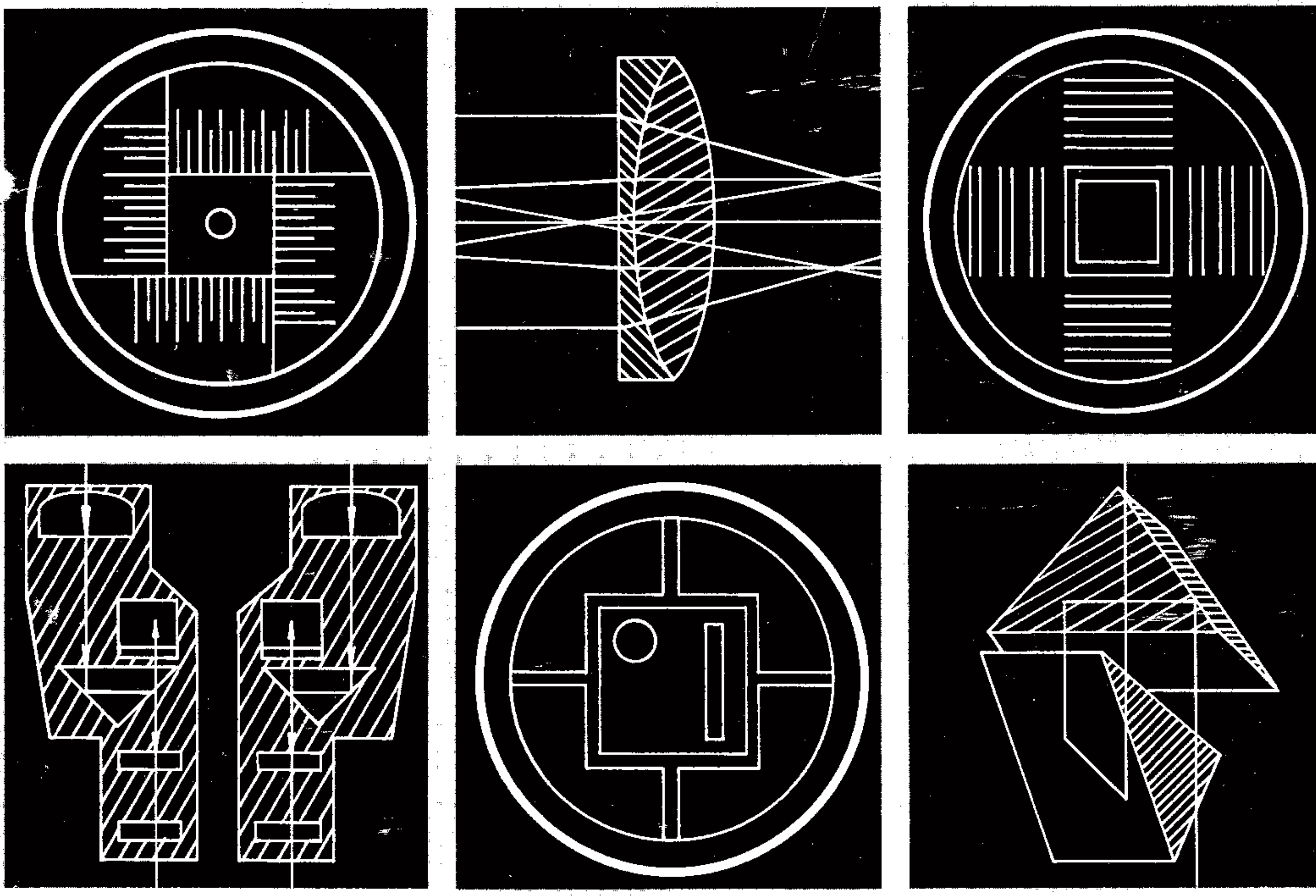

Collimators & Collimation

No. 9072

Please Note!
Many of the parts listed in this book may not be currently available because of stock changes over the years. Before you start your project, please check the current Edmund Scientific catalog for current pricing and availability of the various parts listed in the instructions.

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COLLIMATORS

COLLIMATION

A FIRST OF ITS KIND

"Collimators and Collimation" has been published to fill a long-standing gap in the literature on this important subject. It was produced on short notice and makes no claims on being a comprehensive technical manual; however, you will find it very helpful in solving many collimating problems. Specific how-to-do-it information is included in the appendices.

We welcome your constructive suggestions on how to make this book more valuable. if you will direct them to our Engineering Department, they will be carefully considered for inclusion in the next edition.

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INTRODUCTION

Prior to World War II precision optical instruments, including most military Fire Control Instruments, were usually tested on out-door targets that were at known distances. Such military instruments were used for measuring or computing ranges. It was extremely important that the distance, or range, be computed accurately. This was accomplished by using an engineer's transit to measure the correct distance and angles.

The old procedure was as follows: A base-line was laid out inside a building on a floor in front of windows looking out on the selected target area. Permanent inserts were then put in the floor. If the target area was not visible from the building, the base line was then constructed on a roof providing it was flat and the permanent locating points could be inserted.

An engineer's transit (assembled on a tripod) was set up at one end of the base-line. A plumb bob, with its cord attached to the center line of the instrument, was lowered and centered over one of the inserts. (See Figure 1.)

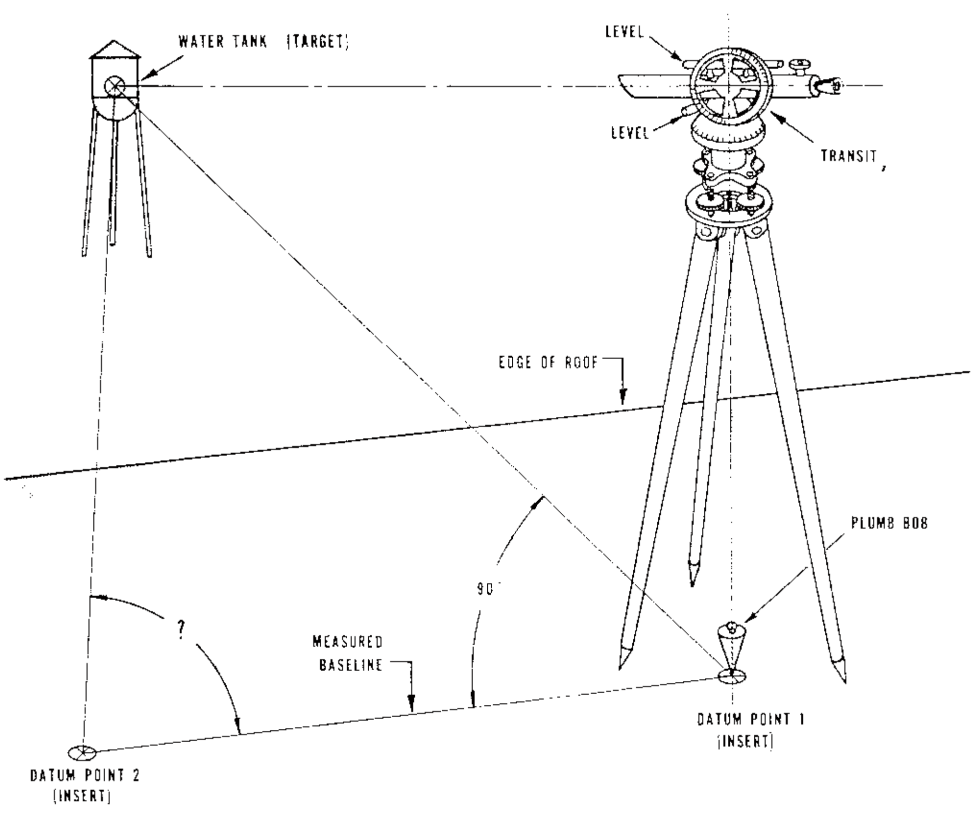


FIGURE 1 Accurate determination of range by use of engineer's transit

The line of sight through the telescope of the transit was directed at the selected target and the focus adjusted to clearly define a straight edge on the target. The adjusting screws on the base of the transit were adjusted to level the two perpendicular spirit levels in the horizontal plane.

With the magnetic needle of the compass indicating north, the deflection scale of the transit was set at zero, the spirit level on the top of the sighting telescope leveled, and the reticle in the telescope adjusted to the operator's eye. Then the focus was oriented to define the target sharply.

Fine vernier adjustments were made with the azimuth knob to place the vertical reticle line on target. A reading was taken and recorded. The transit was then set up in the same manner at the other end of the base line and, following the same procedure, the angle was determined. Having the two angles and the exact length of the base line, the distance to the target was accurately computed. A whole series of targets at various distances were constructed for the different types of observation. Wall targets were limited to short distances due to the construction of the buildings, heavy pillars, and beams and girders which obstructed lines of sight. Required checks and tests such as resolution (definition), parallax removal, etc. were performed outdoors.

Targets were selected for their size and stability; usually water tanks, smoke stacks, electric towers, bridge standards or the cross on church steeples. However, the use of these targets was limited due to foggy and rainy weather.

It is understandable because of the above condition and other factors, why the target collimator had to be developed. Instrument production would shut down and often several days would pass before production could resume. Conditions preventing use of collimators were not only confined to bad weather, but on good, clear days problems were also encountered. The bright, hot afternoon sun caused optical illusions; visible heat waves caused the target to appear as if it were moving. When this condition occurred it was impossible to adjust the telescope.

During the war years, manufacturers of precision optical instruments were confronted with the same problems; and in the case of military suppliers, these problems caused delay of urgently needed Fire Control sighting equipment.

The wall targets mentioned previously were not as accurate as the long distance range target. When utilizing an inside target, a peep sight adapter had to be used as a parallax shield at the eyepiece or the objective lens. (The magnification of the telescope plus the short distance to the wall target caused excessive parallax). This error could only be eliminated by the reduction of light to make the image appear sharp and distinct.

The wall target did a good job, but it was realized that a more accurate method was needed. Targets that could be reduced to relatively short distances and still be as accurate as the long range targets were necessary. With the conditions then existing, the supply was not meeting the demand. Thus, the target collimator was developed.

The potential of the first collimators was not realized until after World War II. New developments and applications were then found in the heavy machine and the aircraft industries.

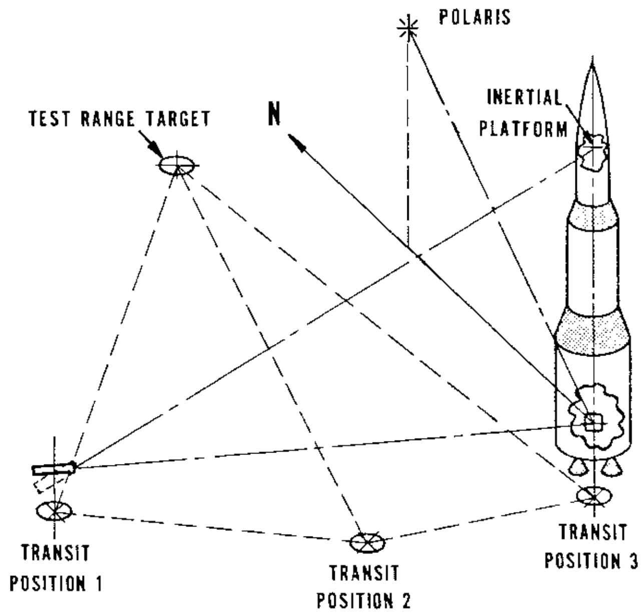


FIGURE 2 **Optically aligning a missile guidance system showing use of transit and fixed target**

Later the collimator, the aligning telescope, and other telescopes were used to fabricate, aim, and track our space rockets and other military missiles. (See Figure 2.)

BASIC COLLIMATORS

The basic collimator is an optical instrument similar to a telescope. Light from a distant object enters the telescope objective lens in parallel rays. The rays then converge at a focal point (See Fig. 3) usually where the reticle or field stop is placed. This is the principle focus of the objective lens. Another method (See Figure 4) shows an internal light source used to illuminate

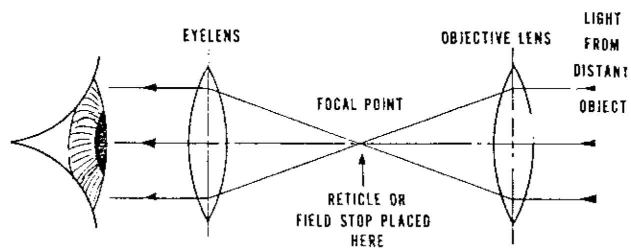


FIGURE 3 **Optics of the collimating telescope and optical light path**

the reticle placed at the principle focal point of the objective lens. The light rays pass through the reticle and are collimated (rendered parallel) by the objective lens. The image of the reticle appears at infinity. Different methods of

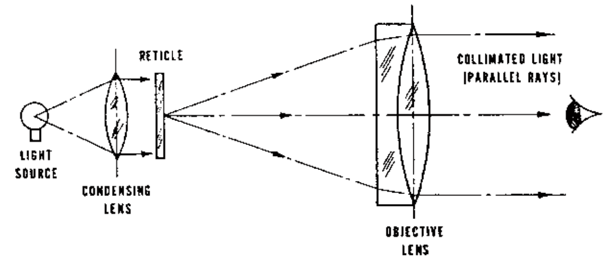


FIGURE 4 **Basic collimator system**

light diffusion have previously been used. One method was to put a frosted light bulb behind the reticle. This only proved fair; the element wire was visible and caused a bright spot which became hard on the eyes of the operator. A disc of fine ground glass was then used to replace the light bulb. This diffused the light evenly, but the light appeared silvery instead of white. A milk glass disc was finally used to get the proper reticle contrast.

With most of the previously described problems controlled, the target was moved inside and confined to the work bench.

The basic collimator was used to inspect and test optics and optical instruments. (See Figures 5 and 6.)

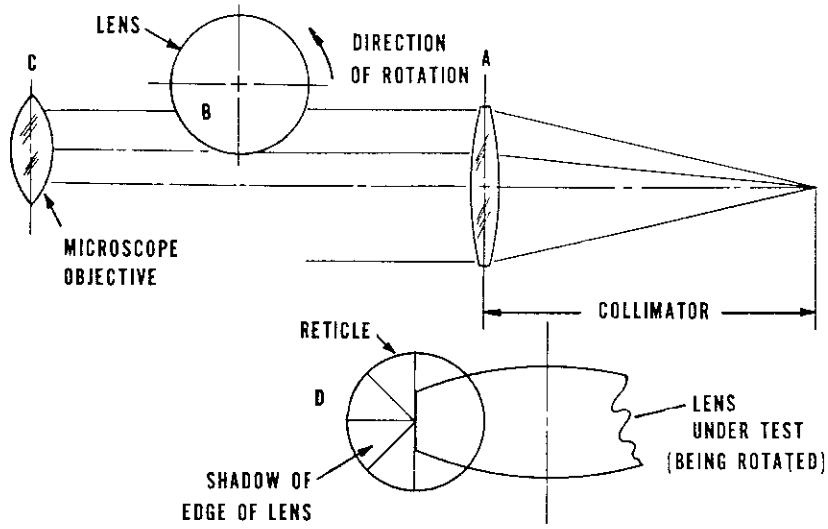


FIGURE 5 Typical lens set-up for measuring lens eccentricity

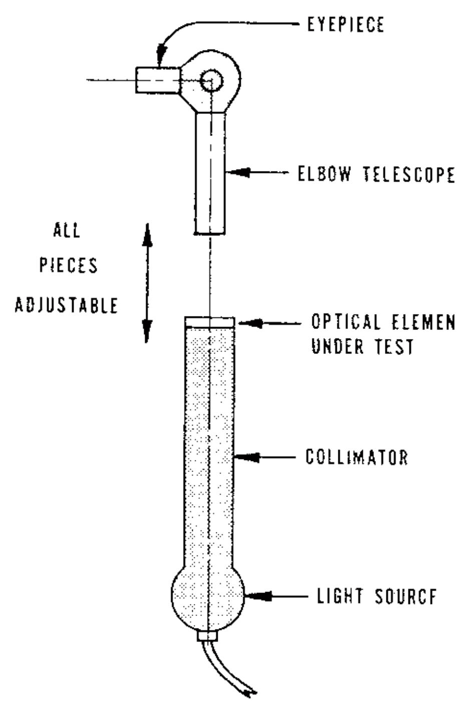


FIGURE 6 Collimator for checking parallelism of filters, reticles, and other flat pieces of glass

ALIGNMENT COLLIMATOR

The alignment collimator, similar to that used in optical tooling, is an instrument used to set up precise reference lines of sight. The collimator does not have an eyepiece. (See Fig. 7.)

This type of instrument is known as a laboratory collimator. It has a tube made from tool steel machined from solid stock. It is hardened and chromium-plated, then ground to a standard outside diameter of 2.2498 inches.

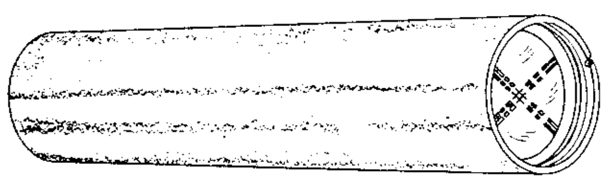


FIGURE 7 Laboratory alignment collimator

A displacement or an alignment reticle pattern is centered near the front surface of the objective lens with the etched pattern on the rear surface. An infinity or tilt reticle is then placed at the principle focus of the objective lens, approximately 10 inches from the objective lens. (See Figure 8.) The tilt reticle is usually graduated every 30 seconds, in four directions from zero, as shown in Figure 9. The centers of the tilt and displacement reticles are positioned on the optical axis of the collimator. The reticle is illuminated by a 110-volt, removable light source.

In operation, the tilt reticle is illuminated by rays which emerge through the objective lens as a parallel beam. If an alignment telescope is

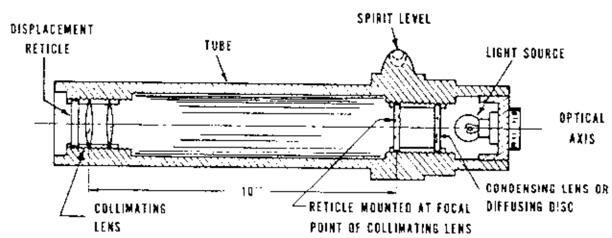


FIGURE 8 Sectional view of typical collimator

focused at infinity and placed in the light beam, the tilt reticle can be made to appear in the telescope. Graduations on the tilt reticle allow a direct reading of the angle which the optical axes of the collimator and the telescope make with each other. By superimposing the tilt reticle of the collimator

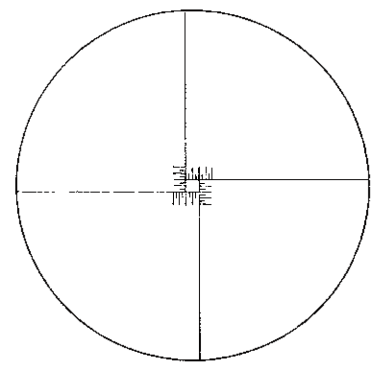


FIGURE 9 Reticle graduated 30"

onto the telescope reticle, collimation will be accomplished; that is, the optical axes of the two instruments will be parallel. However, they may be displaced an unknown amount. (See Figure 10.)

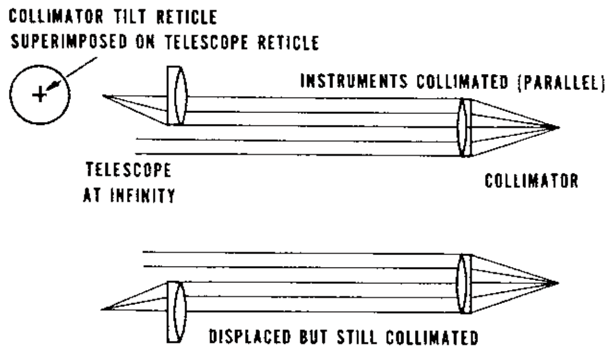


FIGURE 10 Collimation of the alignment telescope

Focus the telescope on the collimator displacement reticle. The amount of displacement between the two instruments can be read directly and collineated (both having common optical axes). This establishes a straight reference line of sight between the two instruments, from which other lines of sight or measurements may be taken. (See Figure 11.)

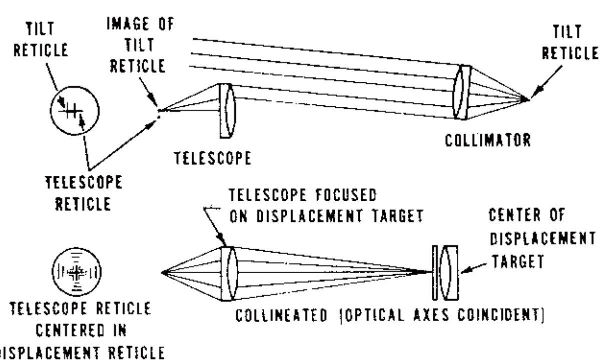


FIGURE 11 Collineation (optical axes collimated)

The alignment collimator with the operations and uses to which it can be put, is a very expensive, custom-made, laboratory optical tool. If a need arises for a collimator with these requirements, one can be machined from brass that will be inexpensive compared to a standard laboratory-type instrument. With it you can obtain the same accuracies as the more expensive instrument.

Both types of reticles can be used, if desired. The use of the displacement reticle is limited and therefore not recommended, unless it can be used for a specific purpose or project. It is more practical to use the tilt or target reticle at the principle focus of the objective lens since it is a great deal less expensive.

The accuracy of this type of reticle is achieved through its mount and the mount's relationship to the outside diameter of the tube (determined by the size of the objective lens) and to the optical axis. Additional expense is eliminated since the tube will not require hardening, drawing, tempering, and finish grinding. To reduce the cost still further, aluminum may be substituted for steel.

There is no restriction to the kind or type material that can be used except that it must be some kind of metal. Cardboard or plastic materials cannot be used because they are not stable. If equipment is available by which to machine and assemble parts, a collimator can be made as follows:

The outside tube can be designed to your specifications; however, the tube's outside diameter must be concentric with respect to the inside diameter. It need not be as large in diameter as the laboratory collimator previously described. Select round bar stock or the thickest walled tubing that might be available. Make sure you have enough material to make the outside tube, the lamp house, two (2) retaining rings, and one reticle cell.

If optical components to make a collimator are needed to meet specific requirements, such as one with a smaller or larger outside diameter than already described on page 3, consult the Edmund Catalog for an excellent selection of objective lenses and reticles. It is wise to make your selection of optics first and then build the collimator to their specifications (focal lengths, etc.).

CONSTRUCTING A COLLIMATOR

The first step of constructing a collimator is to sketch the inside diameters of the tube with respect to the diameters of the reticle and objective. The objective end of the tube should have a bore deep enough to accept the objective lens and a retaining ring. The front surface of the objective lens should be recessed in the end of the tube. (See Figure 12.)

Also, the objective's focal length will position the locating shoulder for the reticle. (See Figure 13.) Allowances should be made in this bore for reticle adjustment. The aperture of the bore should be at least 1/4 in. in diameter smaller than the reticle diameter, not including the protective ring. The ring should be a snug fit on the reticle, but if it is a little loose it can be ce-

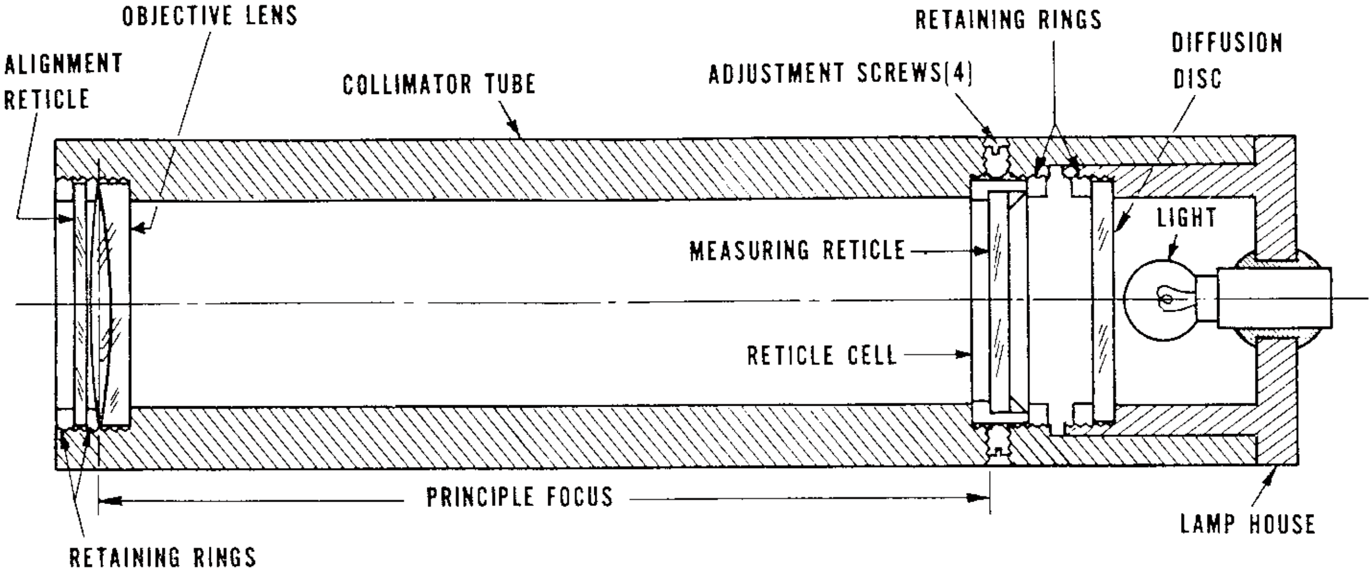


FIGURE 12 Cross section of alignment collimator

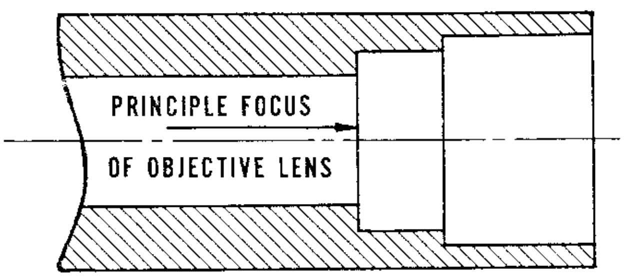


FIGURE 13 Focal length of objective positions locating shoulder for reticle

mented with an epoxy glue. The ring prevents chipping the reticle while adjusting it for collimation. The wall thickness of the ring should be 1/16 in. thick. The bore into which the reticle assembly fits, should be at least 1/4 in. in diameter larger than the diameter of the reticle (not including the ring).

Threading the retaining ring is not necessary; a push fit is all that is needed since a set screw will hold both the ring and reticle pieces in place when the assembly is complete. (See Figure 14.)

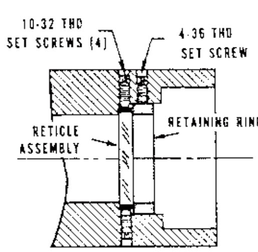


FIGURE 14 Securing the reticle retaining ring in position by use of set screws

Drill four, equally-spaced holes in the outside tube. These holes are often located toward center on the edge of the reticle and should be drilled for tapping a 10-32 thread. This screw size is used because it will move the reticle easily and slowly in the tube. Next, the set screws selected should have relatively short length and be rounded at the points to prevent gouging the metal. And finally, try using the easier-adjusting, socket-head set screws as opposed to the slotted type. The screws are used to orient the reticle assembly inside the larger diameter bore. The reticle should and must adjust freely in all directions and should need only a slight adjustment to properly align it. (See Figure 15.)

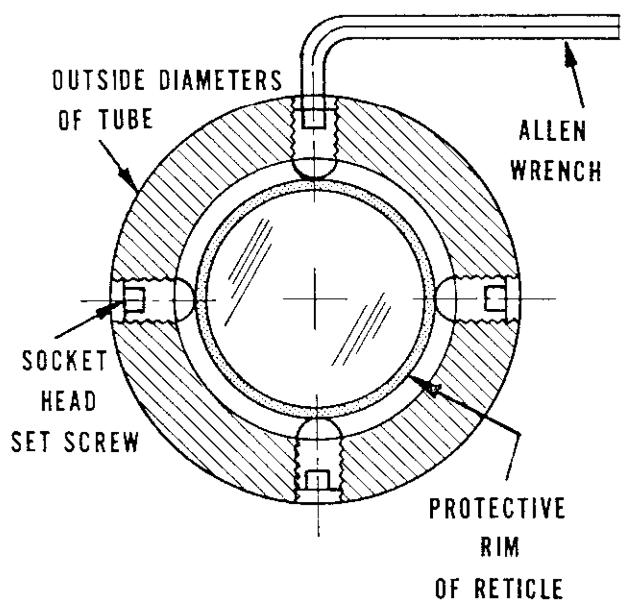


FIGURE 15 Mounting of reticle cell with set screws for elliptical adjustment

If you decide to make a lamp house for your collimator, you can make it fit either the inside bore or the outside diameter of the collimator tube. The lamp house must have a slip fit so that it can be removed easily even with the light on. Usually, after prolonged use, the heat of the lamp expands the metal, making the fit tighter if secured in the inside diameter or loose if fitted over the outside diameter.

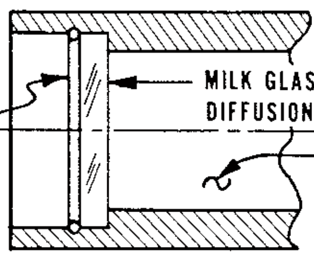


FIGURE 16 Method of mounting lamp house diffusing glass

The lamp house should be constructed with a shoulder for the ground glass to rest on and a piece of music wire to act as a retaining ring to hold the glass in. This wire can be set in a groove to hold it, or it can be pushed in the end of the tube. (See Figure 16.)

Paint the inside of the lamp house with white gloss enamel to improve light reflection. It might be well to put a variable auto transformer or potentiometer in the line to provide a means of reducing or increasing the intensity of the light.

Several types of lamps are available that can be used to illuminate the reticle. You can use a standard 7-watt, 110-volt lamp, either the clear or frosted type. However, if a clear lamp is preferred, it will require a piece of ground glass or milk glass to diffuse the light.

After the sketch is finished you are ready to begin machining. Face off the tube or bar stock to make the ends parallel. Rough out and finish boring the entire inside diameter of the tube. This diameter will control the accuracy of the finished instrument. Working from the inside diameter and keeping tolerances as close as possible will make the job of collimating your instrument easier.

After the machining operations are completed you are ready to assemble the collimator. Finish the inside and the outside of the tube and all of the parts made of brass with a mild bronzing solution. Avoid paint finishes as they tend to build up in uneven layers and will cause "out-of-round" conditions.

A word of caution when assembling. Optical elements will show strain (distortion) if their adjustment screws are tightened too much. The best way to avoid this is to tighten the screw only until it is snug and then back it off just enough to release the strain. If a strain has been set up in the collimator and distortion is present, its presence will be evident in any optical system you check with it.

Collimating the optical and mechanical axes of the collimator can be performed utilizing the following equipment: (1) A surface plate or a means of supporting the collimator; (2) A pair of identical vee blocks or two sets of parallel bars, 1/2 x 1 x 6 inches.

Position the vee blocks or the parallels on the surface plate as illustrated. (See Figure 17.) If parallel bars are used, two straight edges will be needed to keep the bars aligned until permanently clamped. To hold the vee block or the parallels from slipping, a small piece of putty will hold them until they can be clamped. The final important item, the one required to make the final adjustments for collimation, is an aligning telescope, Edmund Stock No. 70,674.

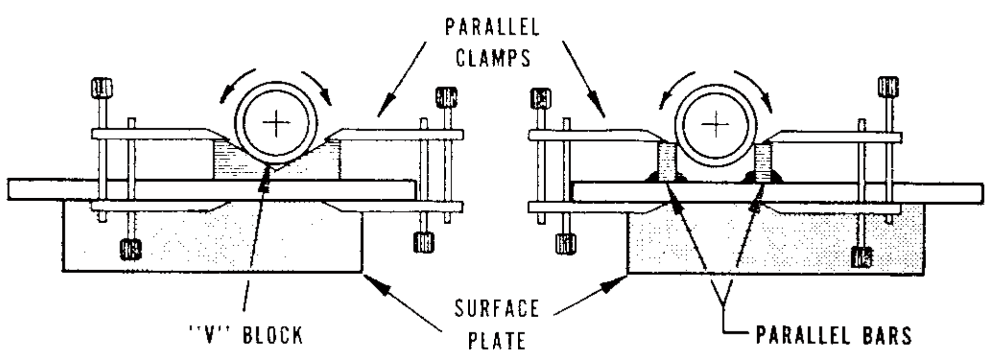


FIGURE 17 Collimating optical and mechanical axes of the collimator

Place the aligning telescope (adjusted to infinity) on one of the vee blocks, with the objective lens facing toward the center of the set up. Secure the putty. Now place the aligning collimator on the other vee block with its objective lens facing the objective lens of the telescope. (See Figure 18.)

To begin collimation, switch on the collimator lamp (if one has been provided) and adjust it for brightness. Allow the lamp to heat up for awhile. This part of the procedure should be practiced each time you use the collimator. Adjust the eyepiece of the telescope and focus it to obtain a sharp reticle image. If the reticle in the collimator is not visible, release the screw that holds the slip tube of the telescope. Adjust the slip tube (with objective lens) until the target reticle appears as sharp as the reticle in the telescope. Reset the holding screw. Observe both the collimator and the telescope reticle; they may not be in coincidence. If the telescope and collimator are too far apart; then, if necessary make manual adjustments by shimming up either instrument.

To see just how much misalignment is present, slowly rotate the collimator in the vee block and observe the rotation of the target reticle with respect to the stationary telescope reticle. Observe the intersecting point of the rotating reticle. It should move in a circular pattern. (See Figure 19.) It will return to the starting point when one full revolution is completed. Rotate the collimator 180 degrees and stop; read the amount of error and establish the direction of adjustment. Adjust either the four screws around the reticle to eliminate half of the error, or release the clamps holding the vee block and manually shim it. Either method is correct. Move the collimator vee block sideways if you desire to align the reticles, and re-clamp the block before rotating the collimator again. Reset the starting point; rotate 180 degrees and adjust for error. Continue to remove any errors in the same manner until all the visible error is eliminated.

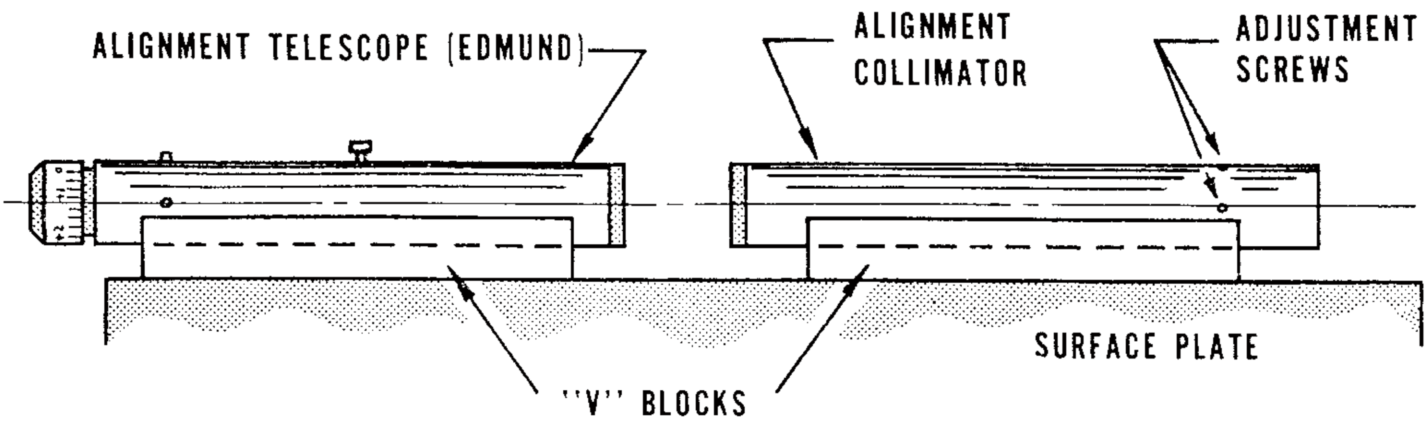


FIGURE 18 Collimating the collimator by use of the alignment telescope

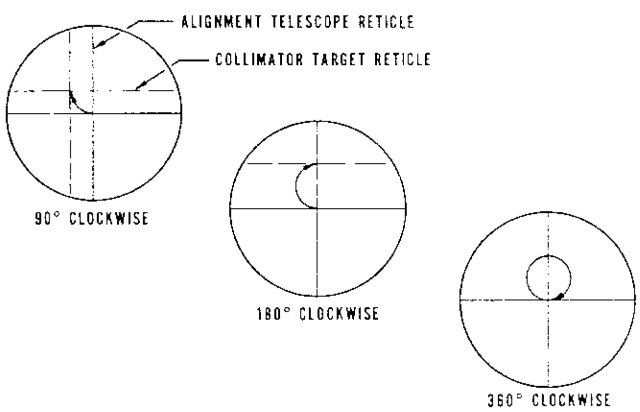


FIGURE 19 Relative motion of reticle patterns with rotation of the collimator

To improvise an aligning telescope, draw a crosshair target on a piece of bristol board and project the image of the collimator reticle onto the target. (See Figure 20.) Then proceed to adjust as previously described. When collimation is completed the light rays projected through the objective lens will be parallel to the outside tube within the tolerance of the thickness of the reticle line.

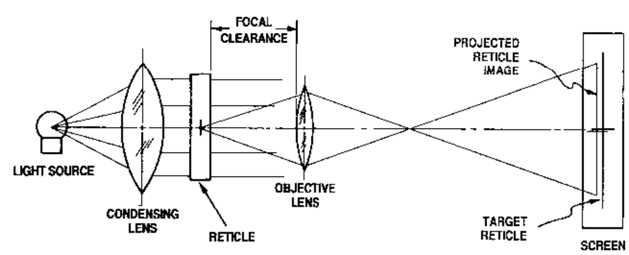


FIGURE 20 A method of projecting the reticle pattern for collimation

ZERO HAND COLLIMATOR

When using the zero collimator the optical and mechanical axes are collimated within the accuracy of the width of the intersecting cross-lines on a reticle. Originally this type collimator (See Figure 21) was used as an aid in the manufacturing and inspecting of optical and mechanical instruments. It is used for testing individual optics, eyepiece adjusting, limited-resolution testing, fixture set up, and many more alignment applications similar to those discussed previously.

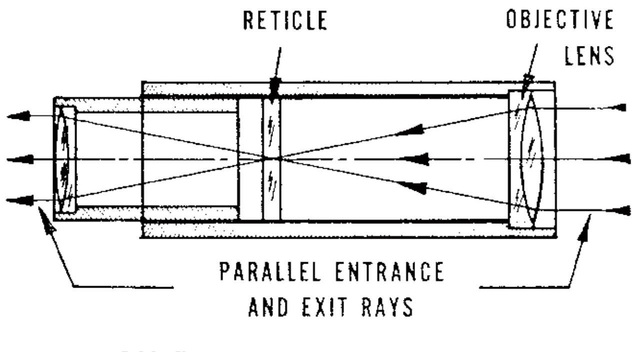


FIGURE 21 3X Zero (hand) collimator

It is believed the zero (hand) collimator was developed to assist the telescope maker. As more and more precision was demanded, it was found that definition and eyepiece settings could not be determined by the individual unaided eye. With this three power telescope held in their hand, observers could see whether or not the target was sharp and clear. It eliminated individual opinions and guess work; definitions could be considered either good or poor.

In the case of a fixed eyepiece with reticle, the reticle could be adjusted from minus one (-1) diopter to a minus 3/4 diopter. This focus setting is for the average human eye. Prior to the hand collimator, the only way possible to make this required reticle adjustment was to use diopter lenses; but orientation in this instance again needed guesswork. With the hand collimator, a preset reticle was always present. The reticle in the hand collimator was considered the standard and the reticle in the eyepiece was adjusted to it.

Adjustable eyepieces can be set using the collimator. Usually eyepieces that are adjustable have the diopter graduations on the eyepiece scale. Adjustment is just the reverse of the fixed eyepiece whose reticle is adjusted to the eyepiece and secured when it appears to be collimated with the collimator reticle. In the case of the adjustable eyepiece, hold the collimator against the eye lens while the eyepiece is rotated. Focus the reticle of the instrument to the approximate sharpness of the collimator reticle, check results on the index and diopter scale, and reset. It is always a good idea to recheck the setting to be sure of accuracy.

If the zero collimator is going to be used to check the definition of an individual optical element (for a production set-up) make a mock-up of the system. Use a lens bench or something similar to the wooden bench illustrated in the Edmund booklet, "Telescope Optics", No. 9074. Hold the collimator, and when the element under

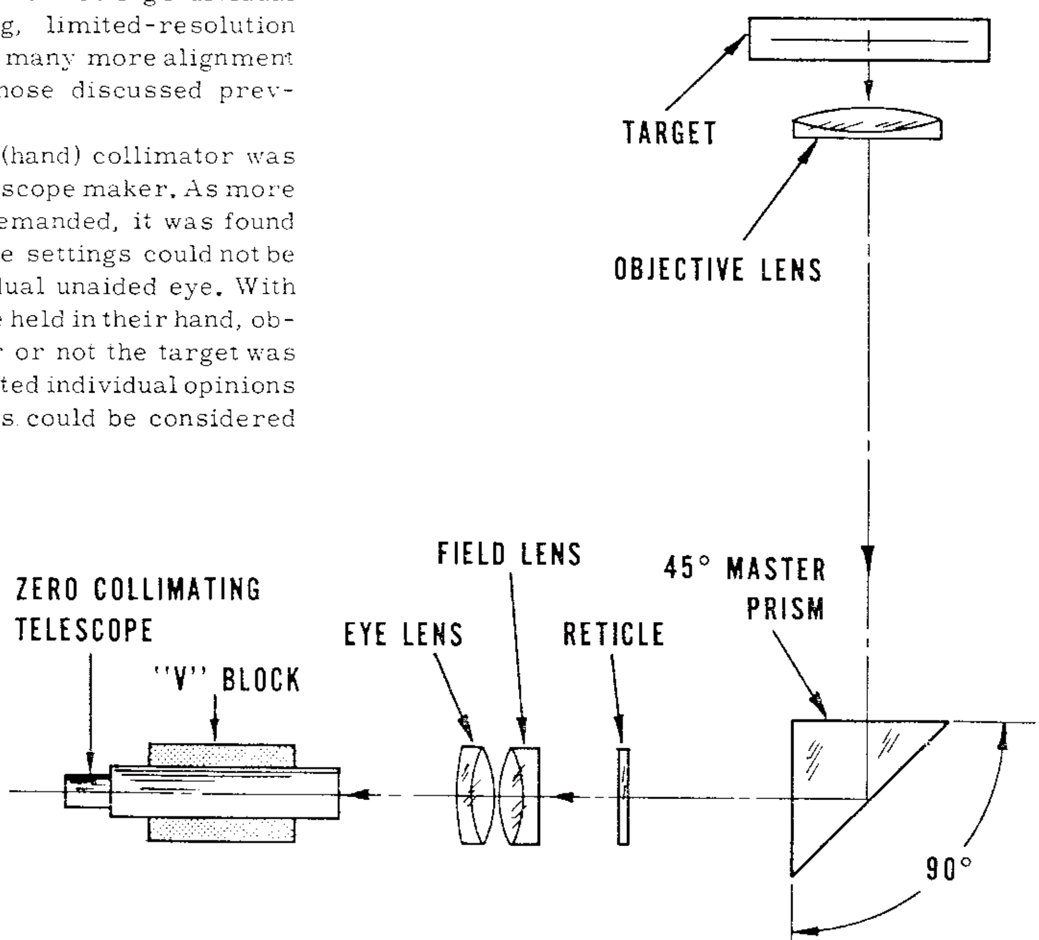


FIGURE 22 Initial setting of test fixture by use of master prism (top view)

test is inserted, view the target. With a little experience a good definition can be distinguished from a poor one. It can be used to tell if a prism is deviating light more than the drawing tolerance allows. A mock-up similar to the above can be laid out on a flat surface with a target at one end and zero collimator fixed at the eyepiece end. (Check target construction sheet in the appendix.) Position a master prism or one of known value in the system, and adjust the collimator and target (See Figure 22.) until target and reticle are in coincidence with each other. Then remove the master prism and insert the prism to be tested. If a target with graduated or known markings is used, read the error against the stationary reticle of the zero collimator. The target will be displaced by the error shown on the reflecting surface. (See Figure 23.)

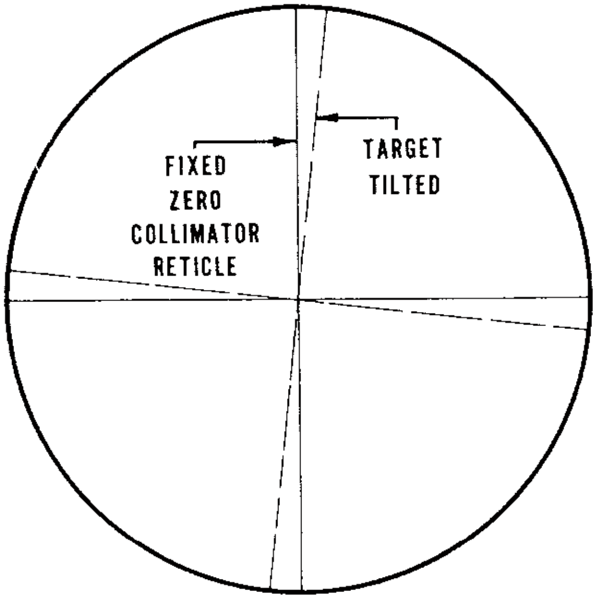


FIGURE 23 Target displacement shows error of prism surface

The zero collimator can also be used to set up a variety of test and checking fixtures. (See Figure 24.) Because it can be applied in single and multiple mountings its versatility is considerable.

The zero (hand) collimator is manufactured to the same drawing specifications as the laboratory alignment collimator. The inside and outside diameters are concentric and the reticle is adjustable on four adjusting screws (which are equally spaced around the outside tube for mechanical and optical collimation). The unit is completely made of brass (very easy to machine) and produces an excellent, inexpensive, universal hand tool.

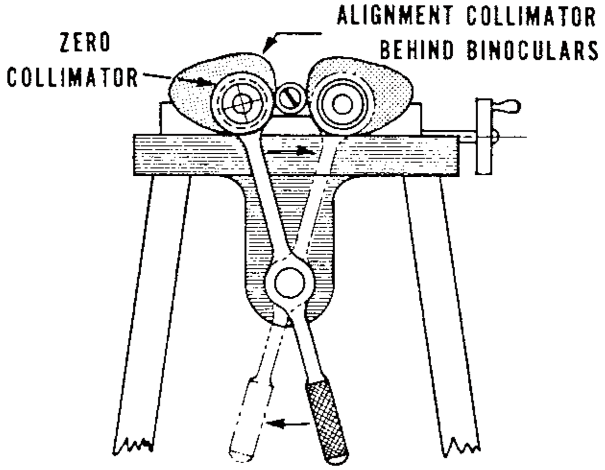


FIGURE 24A Zero collimator mounted on a single swivel rod

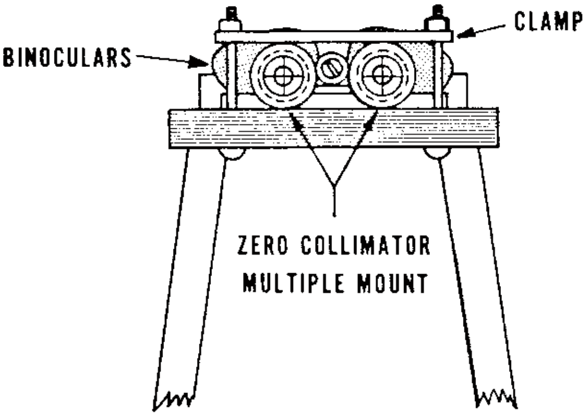
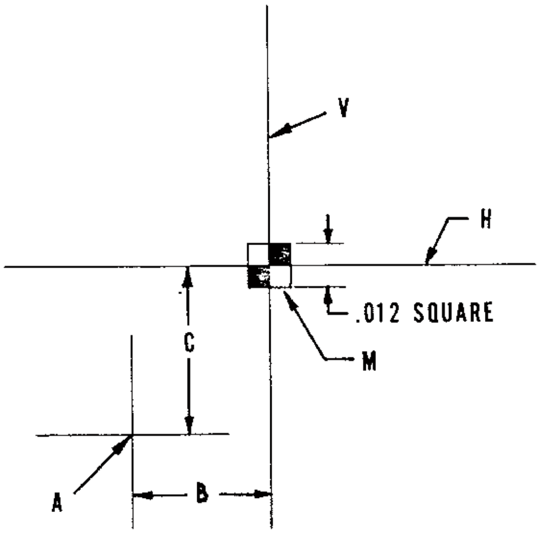


FIGURE 24B Zero collimator, multiple mount

All components made of brass should be treated in bronzing acid or black oxidized. Again, the collimator never should be painted because it produces an uneven surface--not a good reference from which to work. The zero collimator should never be given use that will destroy the accuracy built into it. Therefore, when not in use, store it in a box with a felt lining. This is also recommended for the alignment collimator, if manufactured, because the outside diameter of the collimator is the known diameter from which mechanical layout measurements are taken.

Let's assume a target collimator is not available and there is sufficient distance for a wall target to be constructed. Try laying one out as illustrated. (See Figure 25.) Suspend a plumb line in front of, and as near as possible to, the center of the target. Using the plumb line as the vertical center, all horizontal collimation points can then be constructed from the plumbed zero collimator to the plumb line. A horizontal line



A = Intersection for coincidence with the optical line of sight of the Zero collimator.
B = To suit the horizontal center distance, on the fixture, between the Zero Collimator and the telescope under test.
C = To suit the vertical center distance between the Zero Collimator and the telescope.
H = Horizontal line for checking the horizontal line of the telescope.
V = Vertical line for checking the vertical line of the telescope.
M = Mil blocks for gaging collimation error.

Note: - The mil block dimension given is for a target distance of one (1) ft. When constructing the actual target, multiply the given value by the number of feet the target is from the telescope objective.

FIGURE 25 Target layout

can be put on the wall to match the reticle in the collimator. By doing this a quick check point is obtainable without sighting through the collimator. The plumb line is a constant deflection collimation check and the zero collimator reticle should always be in coincidence with it when an accuracy collimation check is made. (See Figure 26.)

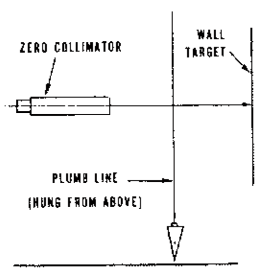


FIGURE 26 Alignment of zero collimator using plumb line and wall target

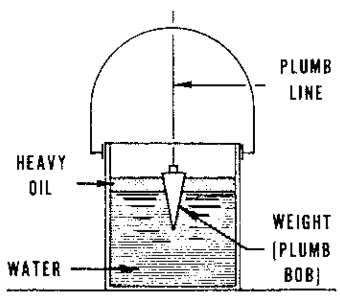


FIGURE 27 Eliminating plumb bob swing due to air currents

When you hang the plumb line, use a length of good heavy cord, such as butcher's twine or something equally as sturdy. Weight one end with about a half pound weight (plumb bob), and make an "s" shaped hook from a coat hanger for the other end. Suspend the line so the weight will be off the floor about 6 inches. Allow the weight to hang in a paint can or bucket and fill with water (until the weight is about half covered). Then, pour enough machine oil on top of the water to come to the top of the weight. (See Figure 27.) This eliminates swing because of building movement or disturbance by air currents.

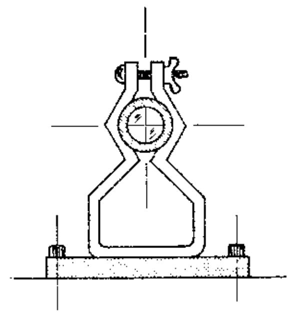


FIGURE 28 Zero (hand) collimator mounted on test fixture

When the zero (hand) collimator is mounted on a test fixture (See Figure 28.), the vertical reticle line should be plumb to a plumb line; and the horizontal line should be in coincidence with a predetermined elevation line. To accomplish this, mount a zero collimator in an adapter and attach it to a surface gage. (See Figure 29.) Adjust it to a plumbed line and a horizontal line. This gage can then be moved in front of the fixed collimators, and they can be adjusted to match the collimator on the movable

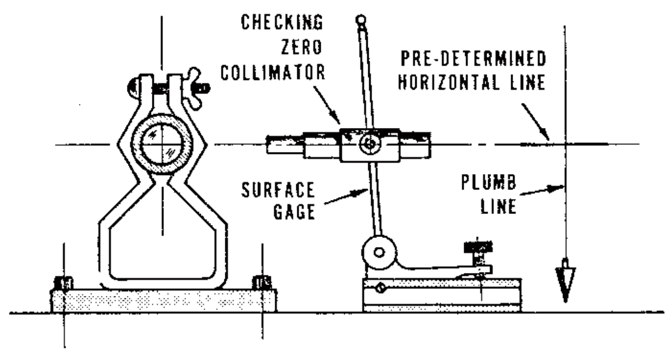


FIGURE 29 Portable zero collimator mounted on surface gage for accuracy and stability tests

zero collimators. If binoculars are being repaired it would be advantageous to know the resolving power of the binoculars; the target collimator can be used with external resolution chart(s) (set at a distance and well lighted) or equipped with resolution reticle(s). (See Figure 32.)

The width of each line on the chart is equal to the width of the space between the lines, and the centers of the adjacent black line subtend an angle of 7.5 seconds at 66 ft. and 5.0 seconds at 100 ft. These distances can be transferred to the target collimator in the same manner as described in a previous paragraph, utilizing an Edmund Scientific Co. Alignment Telescope. The zero collimator can be hand held when observing the resolution target and the outer field. In order to see the outer field, the collimator must be shifted around. (Remember, the image is in reverse; look to the right to see left, or down to see up.)

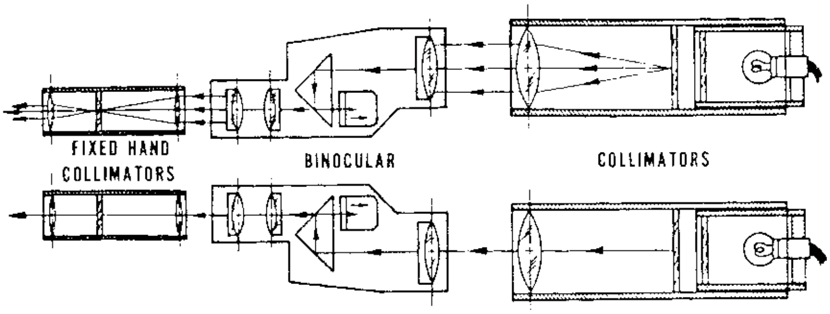


FIGURE 30 Collimation with a double target collimator

stand. The portable collimator makes it easy to make accuracy and stability tests.

Binoculars are usually adjusted on a double target collimator. (See Figure 30.) Two target collimators are mounted side-by-side in front of the binoculars. Behind the binocular and holding device, two zero collimators are also mounted side-by-side. Each set of collimators represents two parallel lines of sight. When the binocular is placed in its holding device, the zero collimator measures the deviation from parallel. (See Figure 23.)

In collimating binoculars that contain reticles for measuring distance, such as military binoculars, the collimator target reticle can be a rectangle or circles of various sizes representing 3, 6, and 12 minute tolerances. Military binoculars are adjusted for 6 minutes or less. (See Figure 31.) This setting will not cause eye strain.

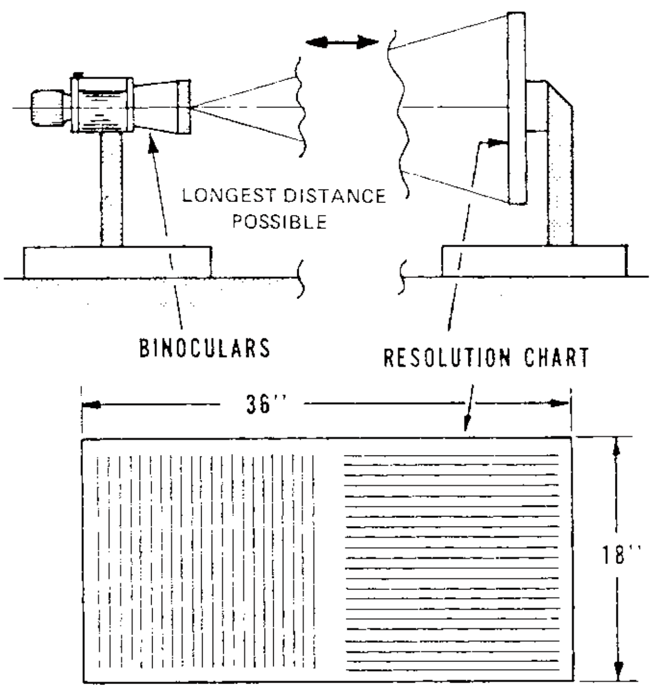


FIGURE 32 Using a resolution chart to test binoculars

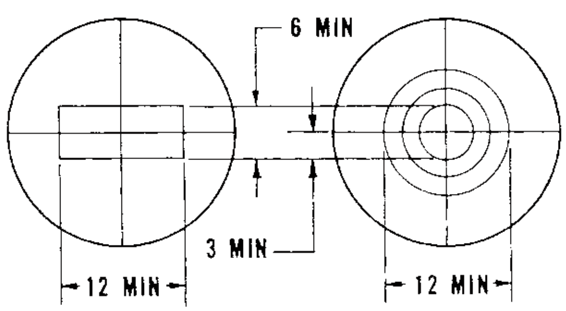


FIGURE 31 Target reticles used for collimating military binoculars

When the individual eyepieces of the binoculars are adjusted, they should each read between minus one (-1) and minus 3/4 diopter when the target reticle is observed in sharp focus through the

FOLDED COLLIMATORS

The word "folded" means that the light path of the collimator, seen from the side, would look like an accordion, or a large "Z." Because collimators are manufactured to various designs depending on the individual requirement, they may vary in size (from 3/4 of an inch in diameter to 12 inches in diameter, and from 4 inches in length to 4 or 5 feet). When they reach this length, space is important, especially if two or more such collimators are required. The folded collimator is designed on the principle of the optical level. (See Figure33.) It replaced the long straight tube type and proved to be an efficient instrument and a space saver. (See Figure 34.) This type of collimator is a little more difficult

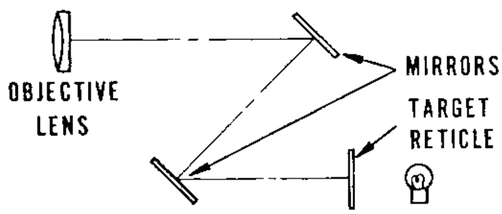


FIGURE 33 Optics of the folded collimator

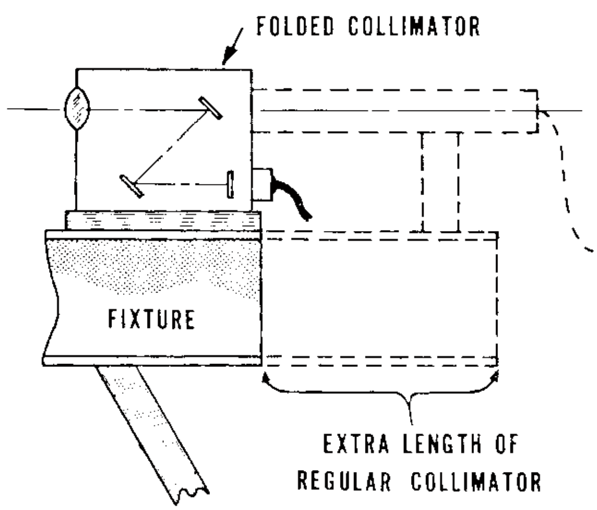


FIGURE 34 Space saved by using a folded collimator

to adjust because the reflecting surfaces (added to bend the light path) need to be positioned at specific points and angled to reflect the light in the proper direction. The mirrors in the system have no magnification power and do not add or take anything from the collimator. Again, the focal length of the objective lens determines the point at which the reticle will be in sharp focus.

This type of collimator can be constructed from plywood. (See Figure 35.) The body can be square-shaped or it can be in the shape of the "Z."

Either type is good for bench work where space is limited. It can be constructed with a groove to fit the base of a lens bench or the support with

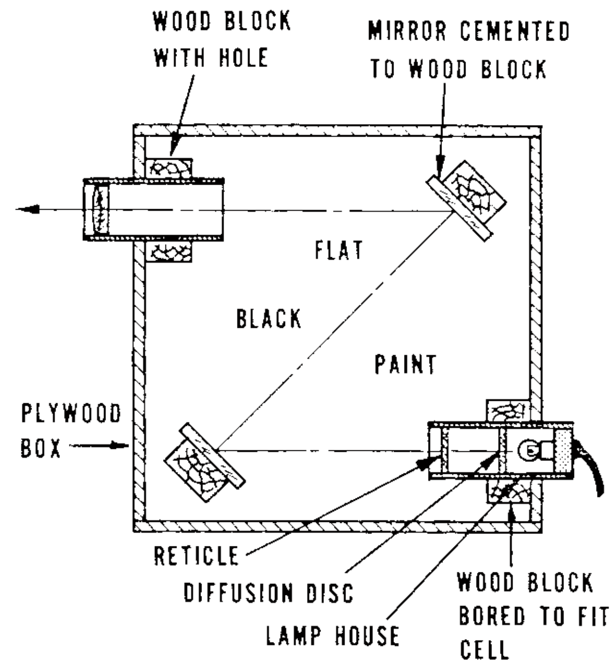


FIGURE 35 Folded collimator constructed from plywood

which you work. Finish by painting and sealing all wood before assembling. The line of sight from the objective will be much higher, but this helps because it reduces stooping during use. The objective lens can be designed to allow sufficient adjustment so it can be focused at finite points as well as infinity. (The optical components for a collimator similar to this type are available from Edmund Scientific Co.).

AUTO COLLIMATION

The combination of a telescope and a collimator into one instrument made auto-collimation possible. Auto-collimation is achieved by sighting the combination instrument at a plain mirror which reflects the parallel rays; projected through the objective lens. The light returns back through the same instrument and onto a reticle. The perpendicularity of the mirror, with respect to the axis of the auto-collimator can be verified by viewing the reticle of the auto-collimator together with the reflected reticle image.

In theory, a beam of light, striking a reflecting surface will be reflected back at the same angle (the angle of incidence equals the angle of reflection). The angle formed by the two beams will be twice as great as the tilt of the reflecting surface. This rule must always be remembered when you are working with plane reflect-

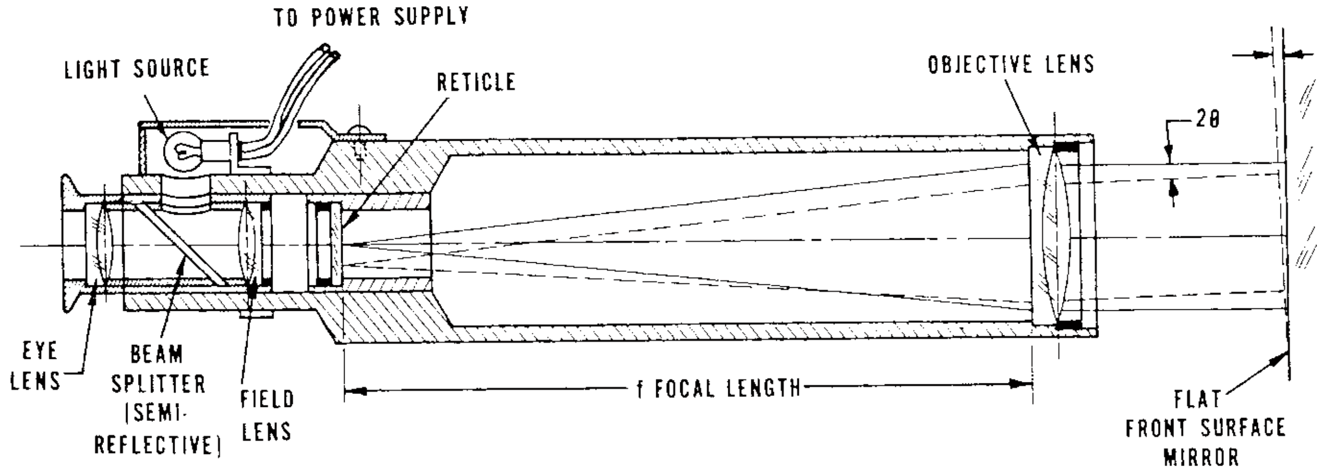


FIGURE 36 Sectional view of auto-collimator (telescope and collimator combined)

ing surfaces. (See Figure 36.) The auto-collimator, containing an eyepiece, permits a close examination of the projected reticle image and the reflected image simultaneously. It is possible to superimpose the two images just as if only one were present. Referring to the projector collimator, remember that the collimator was adjusted to meet the reflected image. Now, in this case, the surface on which the mirror rests can be made perpendicular to the axis of the auto-collimator by superimposing the two images. If other mirrors are placed against this surface, auto-collimated angular errors can be determined. Remember in reading by the auto-collimation method, twice the amount of the actual error is observed. (See Fig. 37.)

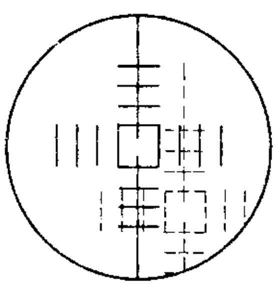


FIG 37 Target reticle of auto-collimator showing twice the amount of actual error

The error is determined by the position of the returned image on the reticle with respect to the graduations themselves. The error will be an amount very closely equal to the tangent of 2 θ times the focal length (f) of the objective lens when the angle θ is small. Therefore, by graduating the reticle, the angle θ (of the reflecting surface) can be determined.

To calculate the spacing of the auto-collimator's graduated reticle, as explained above, the distance X (a unit distance on the reticle pattern) is a function of the tangent of 2 θ (f) (tan 2θ). If the desired accuracy is one minute of arc, and assuming an objective focal length of 10 inches, the unit spacing of the graduations would be 10 times the tangent of 2 minutes, or .0058 inches. It must constantly be remembered that the auto-collimator is always adjusted to infinity.

Auto-reflection is similar to auto-collimation, but not as accurate. When the auto-reflection method is used, the collimator is focused at a finite distance (i.e. twice the distance from the target to the mirror). Therefore, any observed error in centering the target image on the collimator reticle is equivalent to the perpendicularity error of the mirror, a function of the distance from the collimator to the mirror. When you auto-collimate, sighting into the reflection of the collimator's reticle is the same as sighting into another collimator. The distance to the mirror is not a factor so the angle will remain constant. With auto-reflection, the angle will increase or decrease with distance. (See Figure 38.)

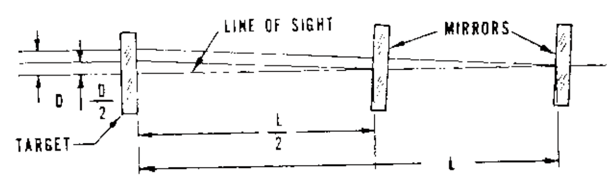


FIGURE 38 Auto-reflection method of collimation

If a longer focal length objective lens is used, the linear spacing of the graduation may be increased, thus permitting the measurement of angles smaller than 1 minute of arc. However, the tube length should be kept in proportion to the instrument.

When the power of the eyepiece is increased, the accuracy and sensitivity are also increased, but this reduces the field of view and limits the range of the graduated scale. Vibration and disturbances tend to limit the accuracy of observation with smaller angles. Under the best laboratory conditions, accuracies of 0.1 second of arc are possible; but under average conditions 30 seconds is practical.

PROJECTOR COLLIMATOR

To discuss this type of collimator may seem like repeating what has already been said. But like everything else that is produced in the optical field, it is usually "a little bit better and will do a little bit more."

Projector collimators are sometimes associated with projection comparators and movie projectors. This type of collimator can do neither of these jobs. It is a large, exact duplicate of the zero collimator, approximately 2-1/2 inches in diameter and 12 to 14 inches in length. Also, it is equipped with an adjustable objective lens that changes the parallax distance from 75 yds. to infinity. Like the zero collimator, it has an eyepiece. This collimator has a lamp house that can double as an auto-collimator unit (See Figure 39.) When the collimator is used as a target, tight tolerances are required.

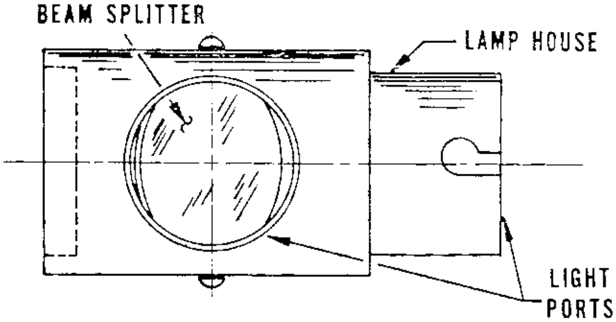


FIGURE 39 Lamp house doubles as an auto-collimator unit

The reticle is graduated for numerous diversified tests rather than for only one type of operation; it is used for collimation checks, resolution, plumb travel, elevation accuracy, image tilt, and backlash readings. These tests are largely associated with military instruments having extremely fine accuracies, but are slowly finding their way into the industrial world.

The collimator projector is more widely used as a target then most of the other collimator designs. It is often set up in multiple positions on fixtures requiring more than one accuracy test to be made. (See Figure 40.)

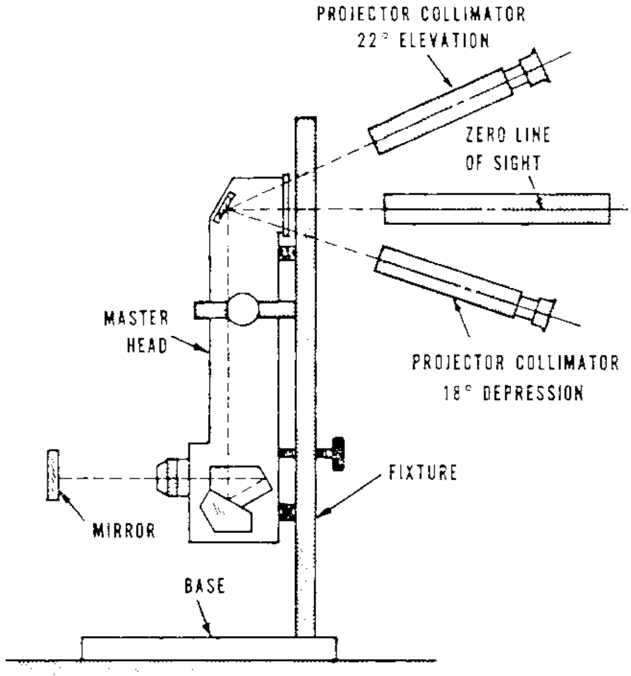


FIGURE 40 Collimator projector set-up with multiple fixtures

The illustration, showing different elevation angles, is designed to insure a stationary check point that can not move unless it is bumped. Each elevation point is positioned by the auto-collimation method. A master reflecting surface is positioned in the fixture, the same as in the production instrument. Then it is set at a predetermined angle, and an auto-collimating lamp house unit is installed. The reticle is projected to the reflecting surface, and the image is reflected back through the collimator where it is picked up on the reticle by the eyepiece. If the collimator is not in alignment, two reticle patterns will be seen. The amount of error between them is of no importance. The target or the collimator should be adjusted until the two images of the reticle are superimposed, thus making a straight line of sight. Repeat the operation at each angular position in elevation and/or depression. By setting up these lines of collimation, accuracy and precision can be applied to almost any project.

After the fixture is set, the lamp house is removed and a diffusion disk is placed over the eye lens. If desired, the lamp house can be replaced and the lamp located in the rear port to illuminate the reticle. Now the tests can be conducted from the objective end of the collimator. These tests are not auto-collimated; the idea is to adjust the instrument to the auto-collimated line of sight.

BASIC COLLIMATOR

In this instrument, the reticle is usually made of optical glass containing finely etched lines. Additional graduations may be added to indicate the amount of deviation. Illustration (See Figure 41.) shows these graduations.

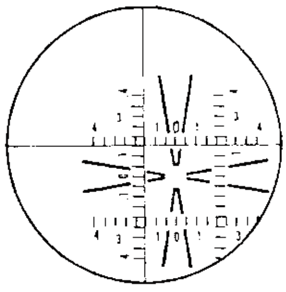


FIG 41 Optical glass reticles showing displacement

The objective lens renders light into parallel rays. When a plane reflecting surface is placed at any position perpendicular to these rays, they will be reflected back through the objective and re-focused on the reticle.

The semi-reflector (beam splitter) is a partially-coated, plate glass plane that reflects some of the light into the lens system and also allows some light transmission. Thus, the reticle and the reflected image can be observed at the same time. The illuminating source may vary from a 6-volt light source built into the collimator, to a high-powered, separate, external light source concentrated on the reflector.

When using the auto-collimator there is a decided advantage to parallel light rays. The parallelism of the projected rays of light enables the collimator to be rotated about its optical axis and to be any distance from a reflected light source without having to re-focus the instrument. (In some cases the distance might be as long as 25 ft.). Two diverse effects of distance would be: (1) loss of clarity due to stray light getting into the parallel light path and (2) the falling off of light intensity. These conditions would tend to dim the reflected image. Nevertheless, the basic auto-collimator as discussed is the most versatile and the most easily adapted version of the collimator. Other designs provide greater accuracy, but at a sacrifice of mobility.

MICROMETER EYEPIECE

The micrometer eyepiece auto-collimator is similar to the basic collimator instruments, except a micrometer has been added to the eyepiece, and it is used to view two images. Instead of reading the angle error directly on the graduations of the reticle, it is measured by the eyepiece. The eyepiece has fixed and movable cross lines, the movable one actuated by a micrometer screw. When setting up the collimator, the eyepiece's fixed horizontal cross hair is set to the horizontal line of the reticle; the micrometer dial is preset at zero (matching the verticle reticle line). When the reflected image is observed, the micrometer dial is rotated and the movable cross line is brought into coincidence with the reflected image. Instead of reading the angular error on the reticle, the amount is read directly on a drum which can be graduated to read in small increments. Another characteristic, the range of displacement, will be quite less than the standard eyepieces. (See Figure 42.) This is limited by the travel of the micrometer mechanism.

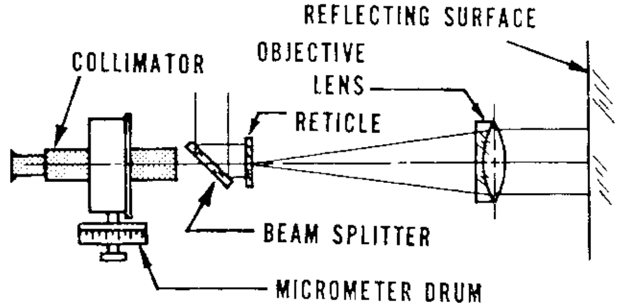


FIG 42 Reading angles from graduated micrometer drum

MICROSCOPE EYEPIECE

To gain still greater accuracies a microscope may be used as an eyepiece. The field of view is now so limited that nearly all displacement is outside of it. This makes it impossible to view or read beyond the restricted field, so the microscope is mounted on a micrometer-threaded cross slide. The reticle cross lines in the microscope are then lined up with the collimator reticle cross lines. The micrometer drum as previously explained is preset to zero, then rotated until the microscope cross lines are in coincidence with their reflected image. The difference in readings is equal to the angle of deviation. The micrometer drum may be graduated in any increments of angle, depending on the requirements or specifications with which the collimator is to be

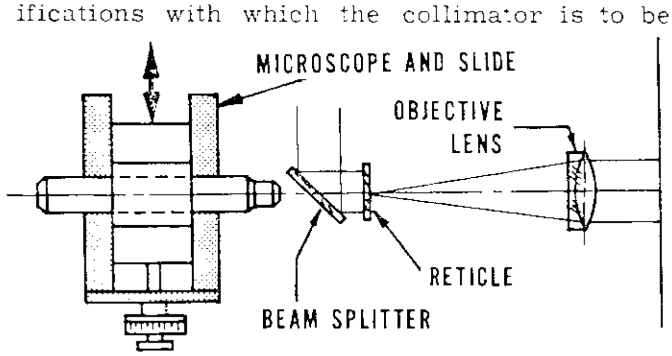


FIGURE 43 Gain in accuracy achieved by use of microscope as an eyepiece

used. This type of auto-collimator (equipped with a microscope eyepiece) will allow more precise alignment of the cross lines due to the greater magnification and the reduced field. (See Figure 43.)

OFF-AXIS PINHOLE TYPE

This type of auto-collimator projects a beam of light into the system through a beam splitter which orients the beam so that it is off the axis of the telescope. The light is concentrated on an extremely small hole (about .015 inch diameter) or a fine slit located (from the objective lens) a distance equal to the focal length of that lens. The reticle can still be graduated as in Figure 39 or to any specific pattern. Several reticle designs are available from the Edmund Scientific Co. . For best optical performance, the displacement (D) of the pinhole (A) and reticle (B) should be as small as practical. (See Figure 44.) Due to the displacement (D) the light rays must travel through angle (X).

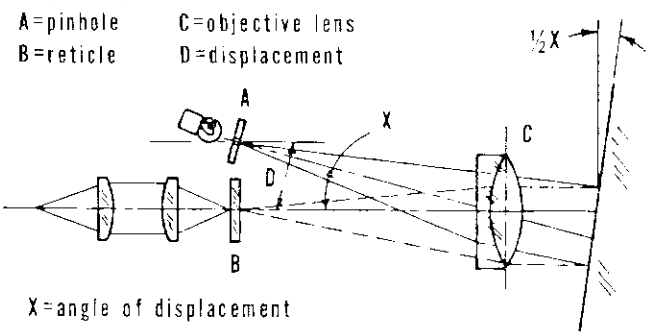
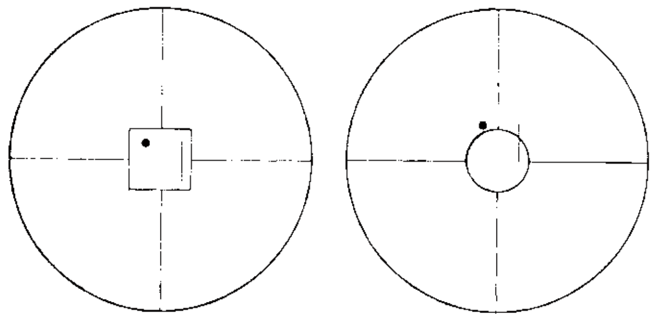


FIGURE 44 Off-axis pinhole type auto-collimator

When the reflecting surface is perpendicular to the bisector of angle (X), the returning light rays from the hole or slit will form an image in the center of the graduated reticle (B). This system has the distinct advantage of giving a simple, sharply defined, spot or line of light as the image. This eliminates reading the displacement of two complex patterns, since the spot can easily be viewed against the basic reticle pattern. (See Figures 45A & B.)

The design of the reticle pattern can be either a square or a circle; however, most contractors prefer the square-type pattern (whose dimensions represent a specified angular measurement) because it allows a little more room for acceptance.

The spot, dot, or line type of projection has been successfully used to position certain types of roof angle prisms, before and after their bonding operations, by placing the prism and its fixture in a pinhole auto-collimator. The prism is



IN COLLIMATION — OUT OF COLLIMATION

FIGURE 45A — FIGURE 45B

Reticle patterns for off-axis pinhole auto-collimator

then adjusted until the reflected dot or spot appears in the center of the reticle pattern. After the prism is adjusted and the bonding process completed, the fixture is again placed in an auto-collimator and re-checked for collimation. The advantage here is that the element can be adjusted as it is being viewed through the auto-collimator. This type of auto-collimator removes guesswork. Either the spot, dot, or line is in the square or circle, or it is not. There is no measuring, calculating, or double error to consider.

FIXTURE TYPE

By employing the previous principle together with a greatly increased focal length objective lens, the fixture-type auto-collimator was developed. Here again, to keep the auto-collimator compact, the same principle of the folded collimator has been applied (additional mirrors have been added to fold the long light path). An adjustable table or stage can be provided to increase the versatility of the fixture.

This particular collimator is very useful when checking parallelism of the glass surface of optical flats. Since the light is reflected from the top and bottom surfaces simultaneously, a displacement of the reflected image will indicate the magnitude of the error. (See Figure 46.)

Depending on the design provisions of the holding device or stage for the table, various flatness and angularity checks can be made. If a front surface mirror is to be tested, a stage designed to slide from side to side and move to and fro can be used. The stage is adjusted to zero in both directions, a master element is inserted, and the position of the reflected image is checked for position on the reticle. The micrometer screw has a slip drum. If adjustment for the master setup is necessary, the drum is slipped to zero. Subsequent to the master layout any number of pieces can be tested.

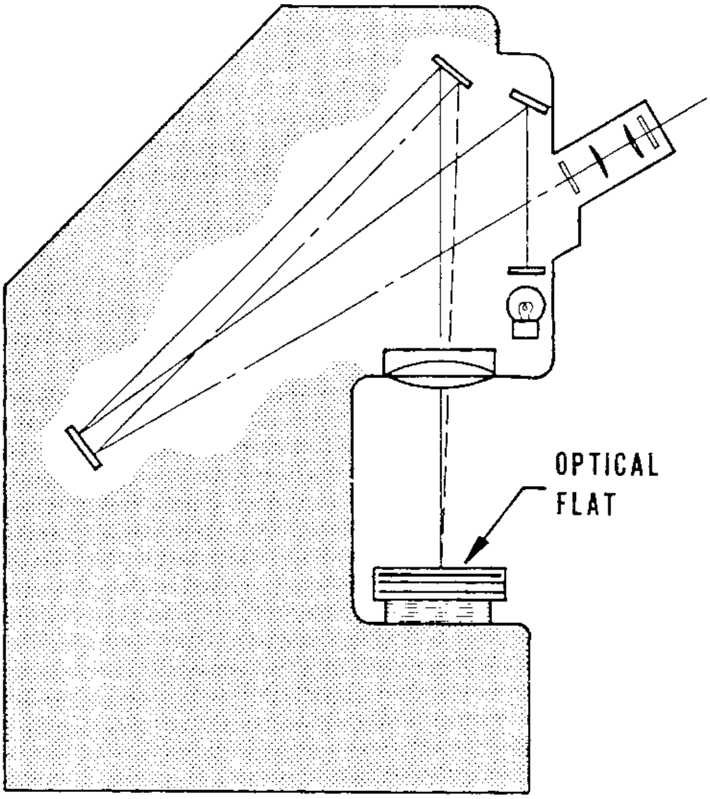


FIGURE 46 Fixture type auto-collimator

The various types of collimators and auto-collimators discussed here are only samples of the instruments and methods of collimation constantly in use today. There have been great strides made since the very early days when the British designed and put to work what is believed to be the first aligning telescope and target collimator. The application was aligning and locating the centers of widely separated shaft bearings in ships. (See Figure 47.) How accurately

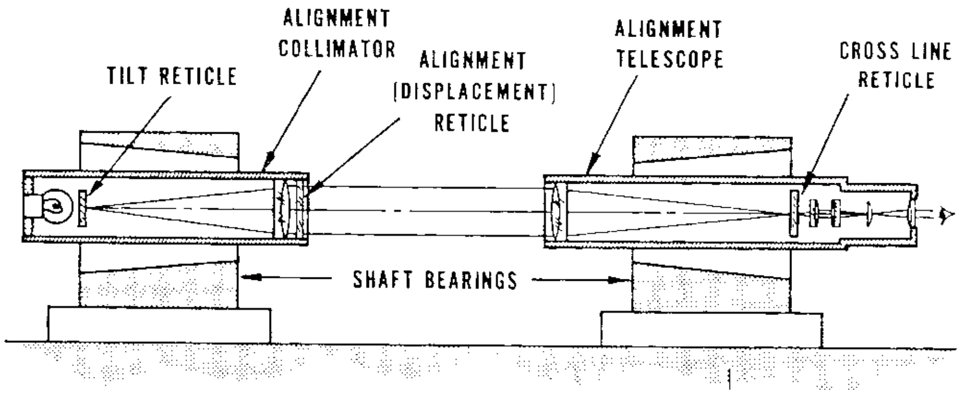


FIGURE 47 Aligning ship's shaft bearings with telescope and target collimator

the instruments were manufactured in that day is unknown, but today it is possible to maintain a tolerance of 0.0002 inches (about 0.0008 in. at 100 feet) between the optical and mechanical axes. As illustrated in Figure 47, you can see how ships' drive shaft bearings are adjusted to such close alignment. Without this precision a ship would shake apart. This then illustrates the present-day use of optical tooling in the ship building industry. Certain operations that in the past constituted major problems have been simplified by the adaption of the alignment telescope, collimators, and auto-collimators.

The aircraft industry uses such optical tooling in the assembly of a wing for a jet liner. (See Figure 48.) This process was a giant-sized headache until the jig-and-fixture makers learned that easier visual methods could be applied instead of using layouts and long, inaccurate straight edges. Optical instruments insured positive positioning no matter what the line of sight. (See Figures 49 A and B.)

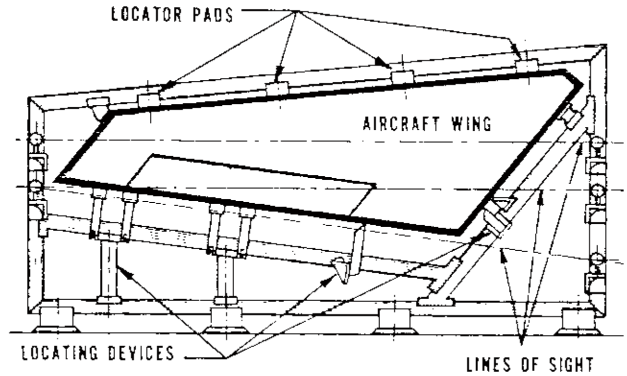


FIGURE 48 Optically aligning a jet liner wing during its assembly

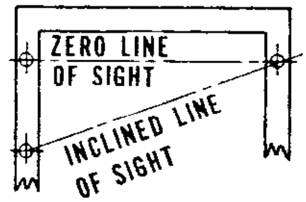


FIGURE 49A

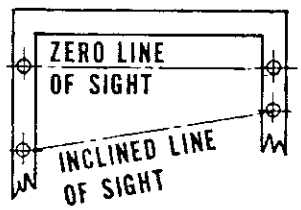


FIGURE 49B

(A) Inclined Line of Sight Intersects Horizontal Line of Sight, Only Three Reference Points Required.

(B) Inclined Line of Sight Intersects Horizontal Line of Sight Beyond The Jig Frame. Four Reference Points Required.

The following paragraphs will further illustrate some typical and basic applications of the collimator and auto-collimator, for general measurement.

ANGLE COMPARISON

Any angle can be checked using an auto-collimator of the type in Figure 38, by comparing one angle to the corresponding angle of a master. The 90 degree angle is illustrated, but as has been previously stated any angle can be tested or checked. (See Figure 50.) In practice the axis

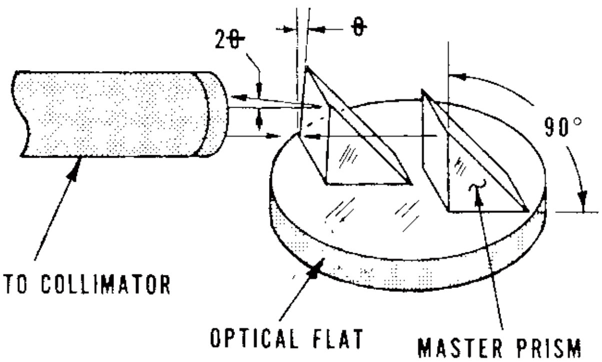


FIGURE 50 Angle comparison checked with auto-collimator

of the auto-collimator is adjusted to be perpendicular to the surface of the master angle by superimposing the reflected image of the reticle on the reticle itself (as viewed through the eyepiece). The master angle is then replaced by the angle being tested. Any error in the angle of the test piece will displace the reflected image. If the stage is large enough both the master and the piece being tested are placed in the field of view of the auto-collimator. The master can then be used as a constant check. In Figure 50 an optical flat is shown with both the master and the test piece positioned. This test is used when extreme accuracy is required. But for average work a good surface plate will serve as a working surface. All contacting surfaces must be kept as clean as possible.

DIRECT ANGLE

An angle may be tested by viewing its reflection from one of the faces of an optical flat with which the angle's face is in contact. Figure 51 shows the arrangement of right angles in which two images are formed in the auto-collimator. One is formed by the light rays that first strike the optical flat (dotted) and the other by the rays that first strike the face of the test piece (solid). If the angle is precisely 90 degrees the two sets of rays are parallel, and the images coincident.

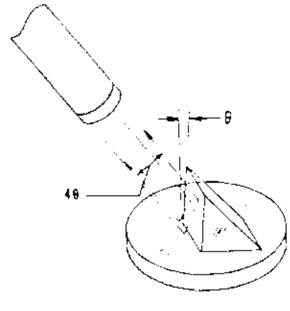


FIGURE 51 Direct angle testing using reflected image

If an error is present the two sets of angles form an angle equal to 4 times the angle displacement (4θ, where θ is small), the images showing separation. This is a very convenient method, since the auto-collimator may be adjusted to any desired angle and the working surface adjusted until both images are in the field of view. This technique can be used to measure any simple angle ∝ which is a sub-multiple of 180 degrees. For an even number of uniform divisions of 90 degrees (45 degrees and 22.5 degrees) the same freedom of elevation of the auto-collimator is present. However, for other angles such as 30, 60, and 75 degrees, the axis of the auto-collimator must be parallel to the bisector of the test angle or the light beams will not return to the collimator.

INDIRECT ANGLE

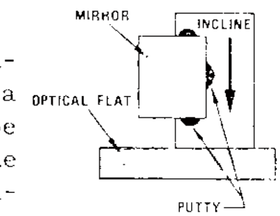


FIGURE 52A Indirect angle testing of unpolished prism surface

The checking of an unpolished surface of a wedge or prism can be accomplished with the comparison test, although it might seem quite impossible at first glance. Since the surface will not reflect light (auto-collimation depends on a reflecting surface) one is added. A plane mirror is laid on a side adjacent to the undetermined angle and placed so that it overhangs the edge of the unknown's surface. (See Figure 52A) (A front surface mirror of desirable size is available from Edmund Scientific Co.) Then the object's base is set on a polished flat. Enough mirror is allowed to protrude over the edge so that a full reflection in the collimator is obtained. Then the mirror is secured with putty and placed on the optical flat.

Two images will be produced exactly as in the direct angle test; but the ray which first strikes the flat (solid line) is reflected from the mirror and back to the auto-collimator such that it is deflected two times by the undetermined surface. The same condition holds true for the ray which first strikes the mirror surface (dotted line).

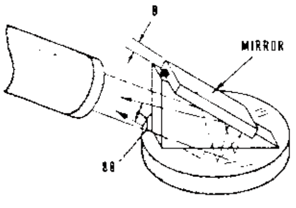


Figure 52B Rear view, mirror on incline

The two images in the auto-collimator will show a separation of 8 times the θ error. Remember though that if θ is large two collimators may be needed to view the angular spread.

SINE-BAR

A sine-bar and metal surface plate can be used to extend the application of the auto-collimator. First the collimator is adjusted to be perpendicular to the plate. Then the upper surface of the sine-bar is set to the compliment of the angle to be checked. (See Figure 53.) Deviations from this

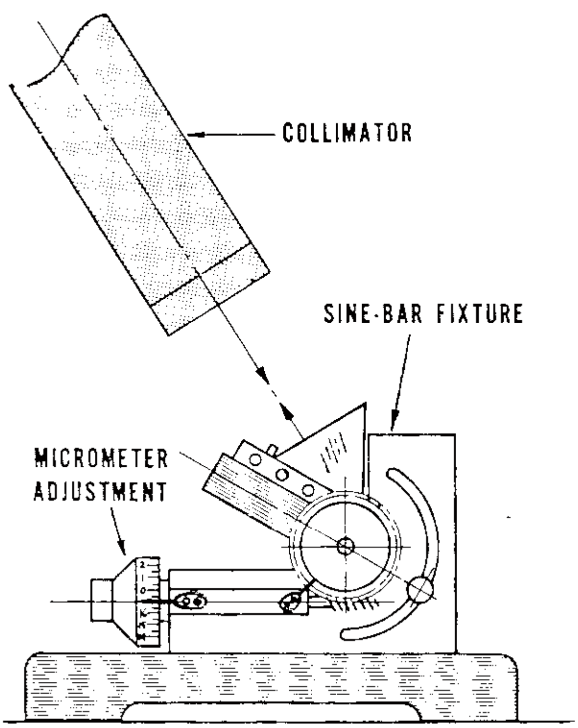


FIGURE 53 Use of auto-collimator with sine-bar fixture for checking a production run

basic angle are reflected onto the auto-collimator reticle and can be read either on the reticle or on the micrometer drum scale. Once the set up is made any number of duplicate pieces can be checked rapidly.

Another method employing the sine-bar is to set the angle in question directly on the sine-bar. The prism is placed on the surface plate and the auto-collimator is adjusted normal to the inclined surface of the sine-bar. The sine-bar and the pieces to be checked are then placed on the surface plate for angle comparison. It should be noted that all the pieces shown in the illustrations are blocks of metal, either with or without polished surfaces. All exterior and interior surfaces of optical prisms, wedges, windows, and mirrors can be conveniently checked by all the methods indicated here for metal pieces.

The great advantage of using the auto-collimator is the fact that internal optical reflecting surfaces can be checked. To illustrate this Figure 53 shows the 90 degree angle of a right angle prism being examined. The auto-collimator is directed at the hypotenuse face (which need not be placed on an optical flat as is the case for metal parts) and the returning reticle image scrutinized. An error of θ in a 90 degree angle will return an angle of 4nθ to the auto-collimator, where n=index of refraction of the glass.

Care must be exercised relative to the type reticles used. Some are compensated to allow for the double error while others must be compensated for this by the operator.

COLLIMATING A RIFLE BORE

The gunsmith, hunter, and target shooter are always looking for means of sighting and checking the accuracy of their guns. Guns are sometimes knocked to the ground accidentally or banged against trees hard enough to knock them out of "collimation" (i.e. the gun bore and the line of sight are not in alignment). The gunsmith or the sportsman who likes to do his own work can, with a little ingenuity and minimum of expense, fashion something on which to zero his sights.

All rifle bores vary in size, from .22 cal. rifles to the high powered, large-bore rifles. If you have several guns then you will need to make a "collimator" rod (See Figure 54) for each bore. Obviously, the rod's length (A) will depend on

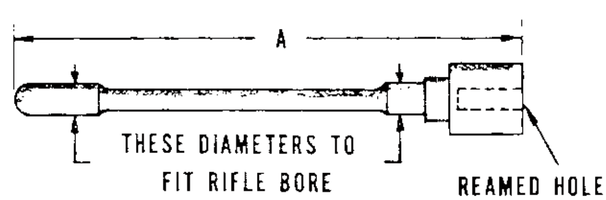


FIGURE 54 Rifle bore collimation "Rod"

your rifle bore length. Also, the diameter of the rod should be made for a push fit into the rifle bore. The rod can be made of any material but a good grade of steel is recommended to insure best results. The hole in the end can be threaded or made to a standard reamer size. (The illustration shows a reamed hole.) Next, a button with a stud should be made to fit the reamed hole. (See Figure 55.) When the parts have been finished, push the button into the hole in the rod end and check the squareness of the button face to the shaft diameter. It should run perpendicular to the shaft within a few ten-thousandths of an inch. The outside diameter of the button can vary in size from 1/2 in. to 1 in.; anything larger is not necessary. (Mirrors are available in a variety of sizes from Edmund Scientific Co.) Apply a small dab of good epoxy molecular cement and press the mirror and the button together to thin out the cement. Place assembly with cemented mirror face down on paper covered surface. Put weight on top and allow it to set.

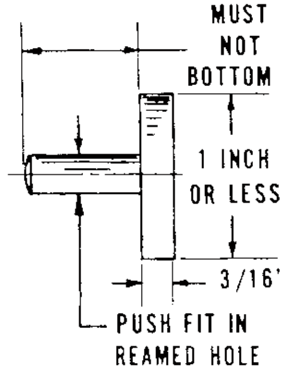


FIGURE 55 Mirror button for auto-collimating rifle bore

Next a target collimator is needed with which the riflescope is aligned. A mount with up and down adjustment is used to level and position the riflescope. (See Fig. 56.) The target collimator can

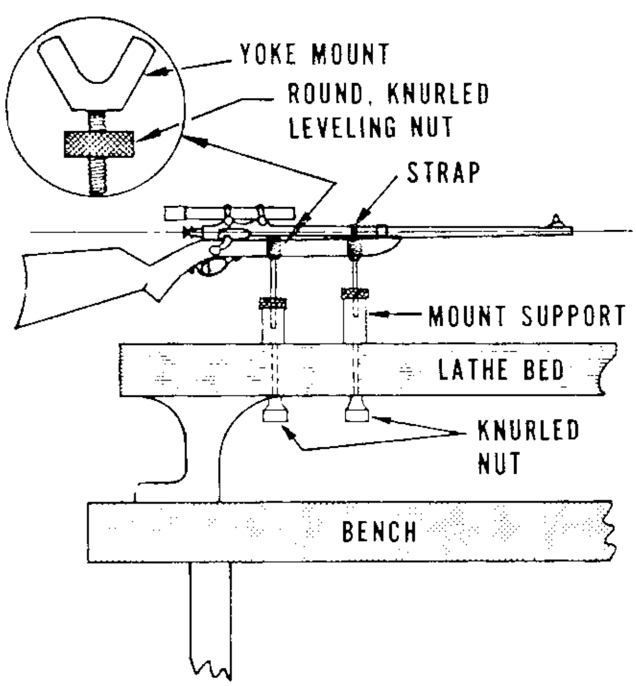


FIGURE 56 Method of mounting rifle for collimating sight with bore

be designed and made similar to the alignment collimator, or it can be constructed of wood as illustrated on page 22; this will do as good a job as any. The only thing needed now is an auto-collimating unit which also can be made out of wood or metal. (See Figure 57.) All of these components can be mounted on an old bench lathe bed or a piece of "I" beam 4 or 5 in. wide, about 5 ft. long. A suggested setup procedure is as follows: level the rifle in the mounts, select the bore rod that fits the rifle, push the mirror button into the rod, and insert the rod into the rifle bore. Next hold the auto-collimating unit behind the target collimator, project the reticle onto the surface of the mirror, and pick up the reflection on the target reticle. Make your adjustments to align the two images. With this operation complete, the bore axis and the target are auto-collimated.

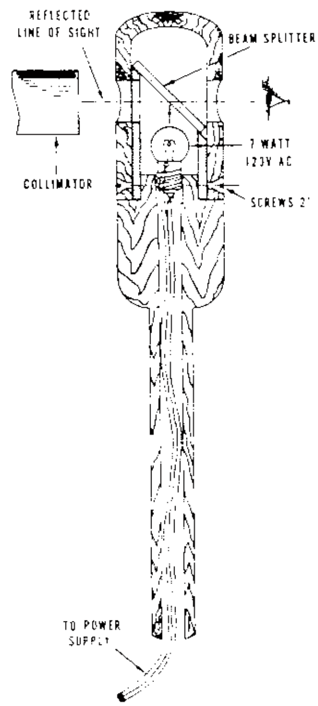


FIG 57 Auto-collimation hand unit (wood construction)

Now any adjustment of your riflescope can be made. If it has wind and elevation adjustments, set everything to zero and adjust for the range desired. To obtain the desired range of the rifle and scope the scope's angle of depression can be adjusted to alter both the range and apex angle between the scope's line of sight and that of the rifle bore. (See Fig. 56). The same will hold true for azimuth or windage angles. The knobs are usually graduated, and the thread accuracy can be checked against the target.

Aligning the sights can also be accomplished by designing a stage to hold a small elbow telescope. (See Figure 58.) The telescope is mounted on and collimated with the stage as shown in the diagram. The stage is mounted the same as the mirror button, on the end of the bore rod, and is collimated to the target collimator while it is in the end of the gun barrel. By rotating the elbow telescope and adjusting it in at least 3 positions, the cross line of the elbow telescope should coincide with the center of the target reticle in all positions. Having established the line of sight, the

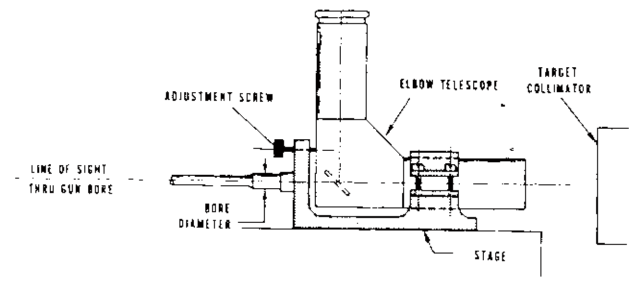


FIGURE 58 Elbow telescope for aligning sights (alternate method)

riflescope can be adjusted as previously explained. The axis of the rifle bore should be true to the line of sight; after each adjustment of the riflescope a check for stability on the line of sight should be made. There are several good trajectory reference tables available to help you adjust your scope for the best "recommended zero distance" position for riflescopes. This distance is set by the rifle manufacturer. If detailed instructions are not available, 100 yds. is a good range to parallax and set your scope.

Helpful Hints for Collimation Tests

To determine the magnification (power) of a telescope that will be used to test another telescope or instrument, the following formula can be used to compute the minimum power:

$X = \frac{120 \div R}{X_1}$ where: X = power of telescope; X_1 = power of telescope to be tested. R = resolution (in sec arc) specified for instrument to be tested. 120 sec. = constant for eye accomodation.

STAR TEST

The stars were once used to test the image quality (resolution) of optical elements--thus the name "Star Test." The results of these tests formed much of the background for the design of types of equipment now in use. Because so much time was lost waiting for good clear nights to view the stars, the artificial star was developed. For practical use, a star test system (which will take multiple and single elements) can be set up quickly and economically. (See Figure 59.) For interpretations of star test images see Figure 60.) Only a few star images are illustrated to give the reader some idea of what to look for when star testing.

In retrospect the material contained in this booklet is considered sufficient to enable the reader to identify the instruments described, and in most cases to judge the suitability of a particular device for a specific application. As an aid in making such a determination, the accuracy of each type of instrument was discussed wherever possible. It must be remembered, however, that the precision of any instrument depends not only upon theory, but also upon the design, care, and workmanship that enter into its construction.

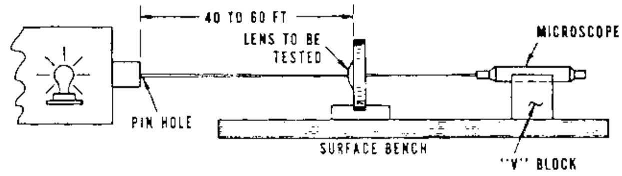
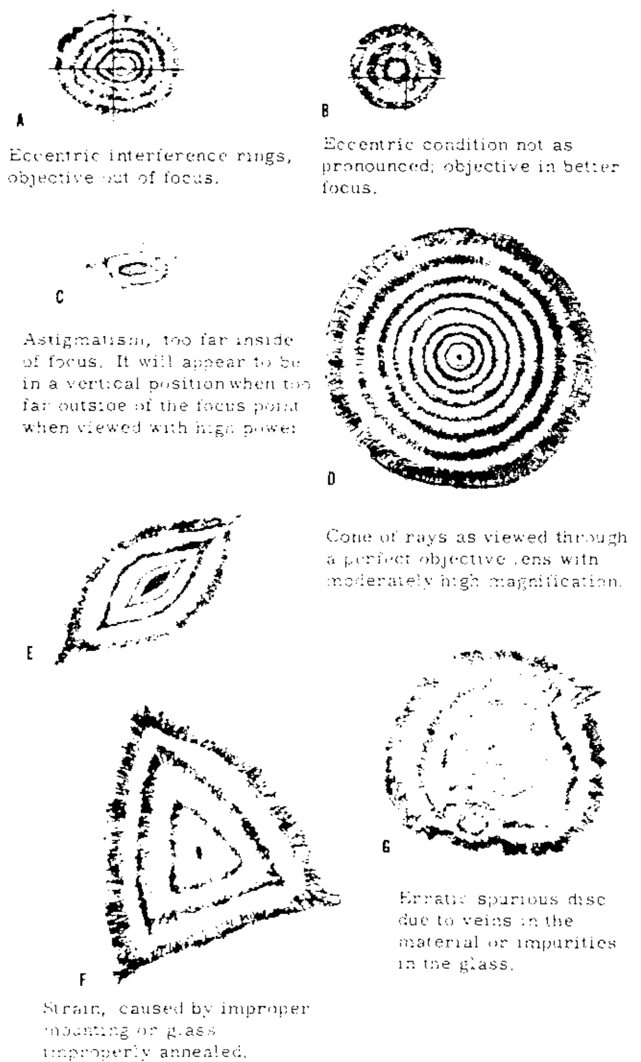


FIGURE 59 Set up for making a star test



A — Eccentric interference rings, objective out of focus.

B — Eccentric condition not as pronounced; objective in better focus.

C — Astigmatism, too far inside of focus. It will appear to be in a vertical position when too far outside of the focus point when viewed with high power.

D — Cone of rays as viewed through a perfect objective lens with moderately high magnification.

E

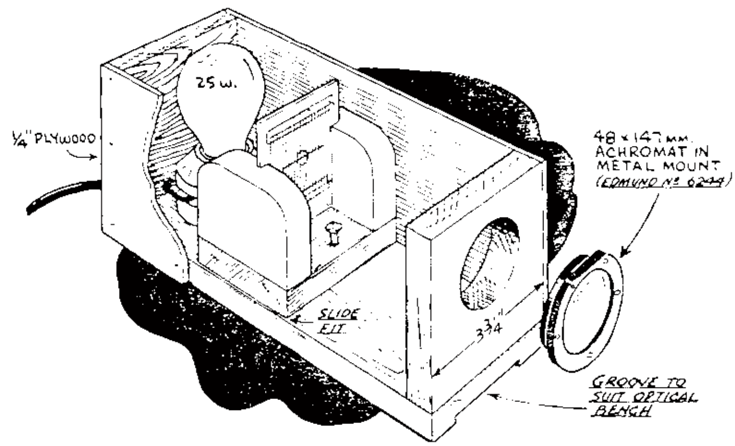
F — Strain, caused by improper mounting or glass improperly annealed.

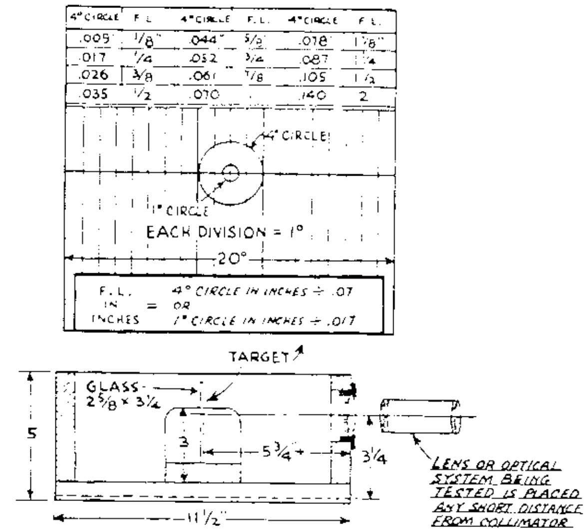
G — Erratic spurious disc due to veins in the material or impurities in the glass.

FIGURE 60 Star test images as viewed through an astronomical telescope. A through G are the ones most commonly seen

The following appended pages you may find helpful for your collimation work.

APPENDIX I





4° CIRCLE	F.L.	4° CIRCLE	F.L.	4° CIRCLE	F.L.
.009"	1/8"	.044"	5/8	.078"	1 1/8"
.017	1/4	.052	3/4	.087	1 1/4
.026	3/8	.061	7/8	.105	1 1/2
.035	1/2	.070		.140	2

FIGURE 61 Direct-reading angular scale collimator target

THE COLLIMATOR TARGET is a handy gadget for the telescope builder, providing as it does the equivalent of a distant target right at the work bench. This one is also scaled so that you can read the angular field of any telescope by simply counting the degree marks.

The target reticle can be made as above and pasted to a piece of plate glass. It should be located at the principle focus of the objective lens; this point can be determined by using a Zero Collimator or Alignment Collimator. Either one is set at infinity and transferred to the target collimator.

INFINITY TARGET. Set up your telescope, camera or other optical system facing collimator lens, as shown in diagrams. Focus on collimator target - it serves the same purpose as a distant target.

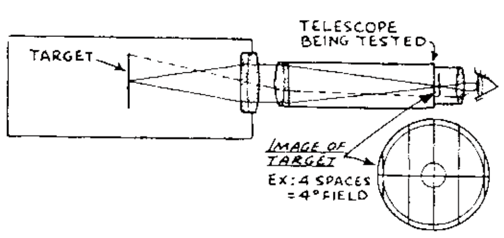


FIGURE 62 Angular field of a telescope

ANGULAR FIELD (Figure 62.)

Read the true angular field directly by counting number of lines which are visible. Each degree of field is equal to about 17 yds. of linear field at 1,000 yds.

The apparent field (angle covered by telescope eyepiece) is the true field times the magnification of the telescope.

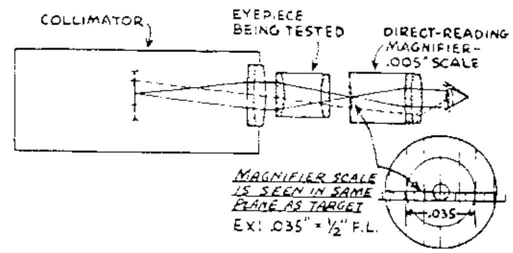


FIGURE 63 F.L. of an eyepiece

F.L. OF LENS SYSTEMS (Figure 63.)

In this setup the image of the target produced by the lens system being tested may be very small. If so, image must be viewed and measured with a direct-reading scale magnifier. Measure diameter of 4° circle. Refer to table on target to obtain corresponding F.L. of the lens system.

For focal lengths not given in table, calculate by using factors at bottom of target. EX: Testing a 6" F.L. System: 4° Circle measures .42".

FOCAL LENGTH OF A LENS

Set up lens as shown in Figure 64. Move tracing paper screen along optical bench to pick up a sharp image of collimator target. Distance from screen to center of lens is the focal length of lens.

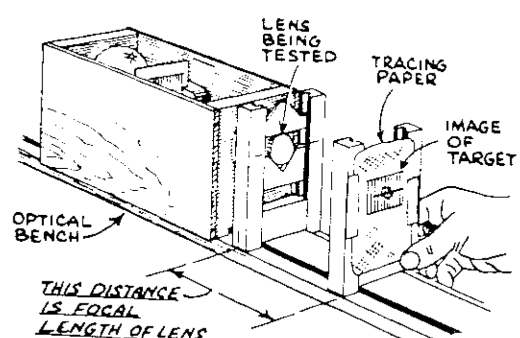


FIGURE 64 Focal length of a lens

APPENDIX II

For testing and measuring lenses and telescopic instruments it is highly desirable to make use of a test target upon which the instrument or lens in question may be focused at infinity. The appearance of such a target is not difficult to imagine. It might consist of a large vertical wooden structure similar to a billboard with a test pattern painted on its surface. While a large outdoor target might be very useful, there are many serious objections to it which are fairly obvious. In view of the great size and expense of an outdoor target a suitable substitute must be used.

A Collimator Target is just such a substitute upon which a telescope may be focused at infinity and yet not be more than a few inches away.

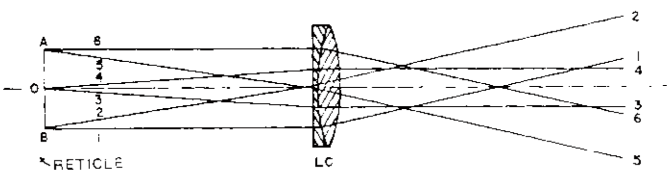


FIGURE 65 Placing a small illuminated reticle in focal plane of collimator lens has same effect as viewing a large target from an extreme distance

In Figure 65, line AB represents a small illuminated target, or reticle, placed in the left-hand focal plane of a lens LC, designated the Collimator Lens. All rays originating from any point on the target will emerge from the Collimator Lens parallel to each other. To an observer at the right of lens LC, the emergent rays 5 and 6 from point A appear to have their origin in a point that is at an infinite distance to the left of the lens, and above the principal axis O. Similarly, emergent rays 3 and 4 appear to have their origin in a point that is on the principal axis at an infinite distance to the left of the Collimator Lens. Emergent rays 1 and 2 appear to have their origin at an infinite point beyond the lens LC. Therefore, the visual effect of placing a small illuminated reticle in the focal plane of the Collimator Lens is exactly the same as that produced by viewing a large target from an extreme distance.

Needless to say, the Collimator Lens must be a good achromat with excellent correction over a small field. Thus one can contribute defects observed in the final image to the test lens and not to the collimator. An excellent telescope objective is usually suitable.

If one chooses an achromat for a collimator, the problem of color correction is not completely solved because of secondary spectrum; it cannot be considered negligible unless one chooses an achromat having a focal length in inches at least 5 times the square of the diameter of the lens in inches. The table below should be helpful.

Desired Diam. of Collimating Lens	Minimum required focal length of Col. Lens
1 inch	5 inches
2 inches	20 inches
3 inches	45 inches
4 inches	80 inches
5 inches	125 inches
6 inches	180 inches

Figure 66 below illustrates a home-made collimator system which may be made in an evening's time. It consists of an appropriate reticle, an achromatic lens with a focal length chosen as above, and a light source located behind a piece of ground glass (which acts as a diffusing screen). A mounting tube is cut approximately to the focal length of the lens being used and is painted black on the inside. The collimator lens is then mounted squarely into one end of the tube. The desired reticle and light source are mounted as illustrated within a smaller tube which slide-fits into the larger tube.

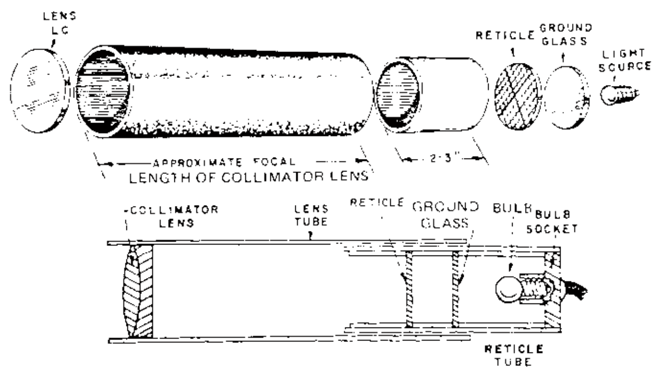


FIGURE 66 Typical collimator system

By the use of a small telescope the reticle may be adjusted to the correct distance from the collimator lens and then secured permanently in place. The adjustment procedure is outlined below.

1. Focus the telescope at an infinite object such as a star and secure the draw tube with a piece of scotch tape.
2. Mount the collimator system and the prefocused telescope on an optical bench with principal axis of each coinciding.
3. While looking through the telescope, adjust the collimator reticle by means of the small sliding tube until it comes into accurate focus.

4. Gradually move the telescope away from the collimator target. The image of the reticle should remain the same size and be in focus at all times.
5. If step 4 is accomplished, fasten the small reticle tube permanently to the collimator lens tube.

An alternate method is available to those who have not the use of an auxiliary telescope. The method is auto-collimation. When the reticle is in the proper position with respect to the collimating lens, all rays leaving the collimating lens are essentially parallel. Thus a flat mirror placed in front of the collimating lens and perpendicular to the beam will cause the rays to reflect upon themselves and form an image of the reticle superimposed on the reticle itself. When this occurs the reticle is in the proper position with respect to the collimating lens. The mirror is then removed.

The collimator lens should be as large or larger in diameter than the largest objective likely to be tested with it; and a provision to change reticles may also be useful. Once the reticle position is established it need not be adjusted again for the same collimator lens.

RETICLES: For testing Telescope Objectives, pinholes are recommended about as follows:

Dia. of Telescope Obj. to be tested.	Maximum diameter of pinhole. / Focal Length of Collimator.					
	5"	20"	45"	80"	125"	180"
1 inch	.0004	.002	.004	.006	.010	.020
2 inches		.001	.002	.003	.005	.007
3 inches			.001	.002	.003	.005
4 inches				.001	.002	.004
5 inches					.001	.003
6 inches						.002

Pinholes may be made in tin foil or other thin metal. To puncture holes in tin foil, draw a fine fibre of a chemical stirring rod over a gas flame and use it to puncture the hole. Another method is to sharpen a needle on a fine stone, twirling and drawing it out at the same time under the finger tip until it appears perfectly sharp under a magnifier.

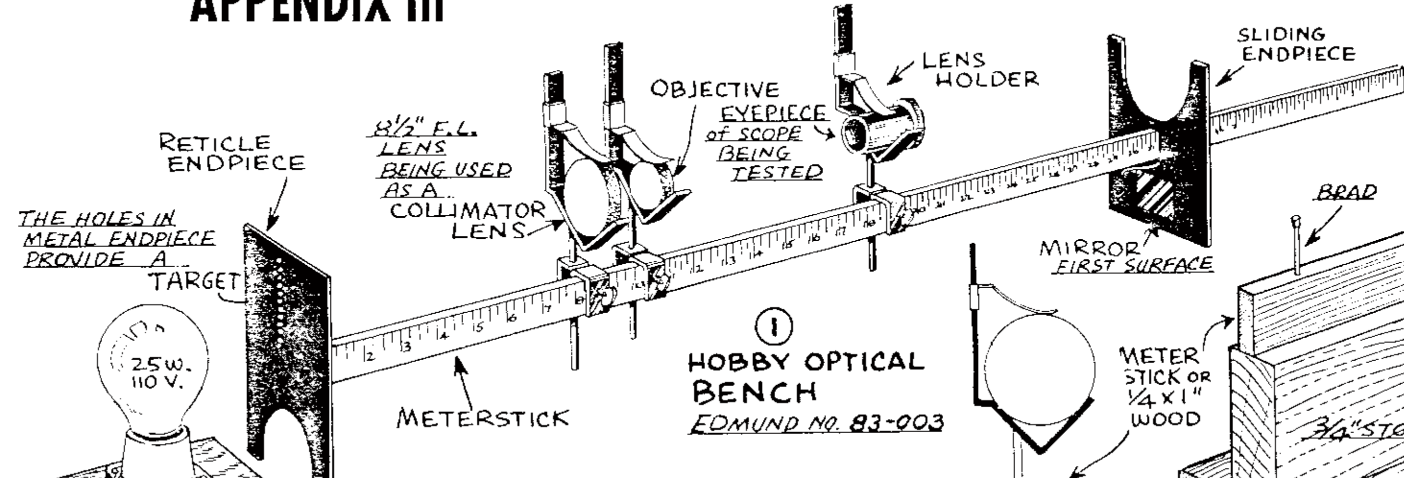
For Photographic Lenses: When one is testing photographic lenses one is interested in resolution. Therefore, a reticle for the collimator should contain a known number of lines in each unit distance. These lines should be both horizontal and vertical. The Edscorp E-17 Reticle (Stock No. 30,075) is an example (10mms. divided into 100 parts).

It must be remembered that a magnification or demagnification will result in the image obtained from the photographic lens. This magnification is equal to the focal length of the photographic lens divided by the focal length of the collimator lens.

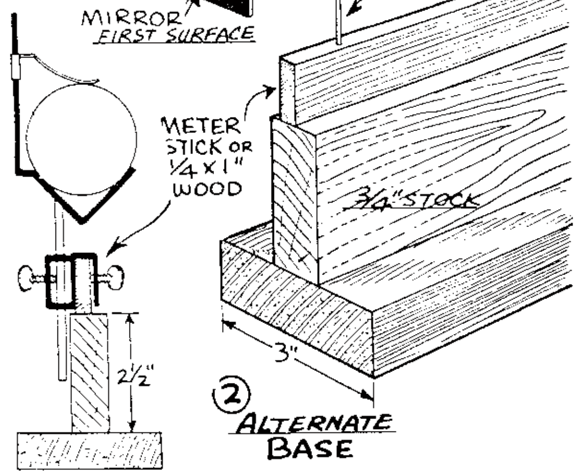
As an example let us test a photographic lens having a 2-inch focal length with an E-17 reticle and a collimating lens having a 20-inch focal length. The size of the final image will be 1/10 the size of the original reticle. If each line of the reticle is resolved in the final image the resolution of the photographic lens is 100 lines/mm, as the reticle has 10 lines/mm.

Illumination of the reticle is a matter that must be determined experimentally, as the proper illumination will depend upon the use to which the collimator is subjected. When using some of the smaller pinhole reticles, it may be necessary to replace the ground glass with a condensing lens. In general, a high illumination should be provided. If a test requires a lower illumination this can then be easily obtained by using a neutral filter.

Provisions should be made for mounting the collimator system securely to an optical bench. By so doing a source of infinite focus will always be available and will be a great aid towards designing, testing, and measuring optical equipment. For maximum results when using a collimator system, the principal axis of the system and the lens or instrument being tested must be in alignment.



Optical Bench and Collimator

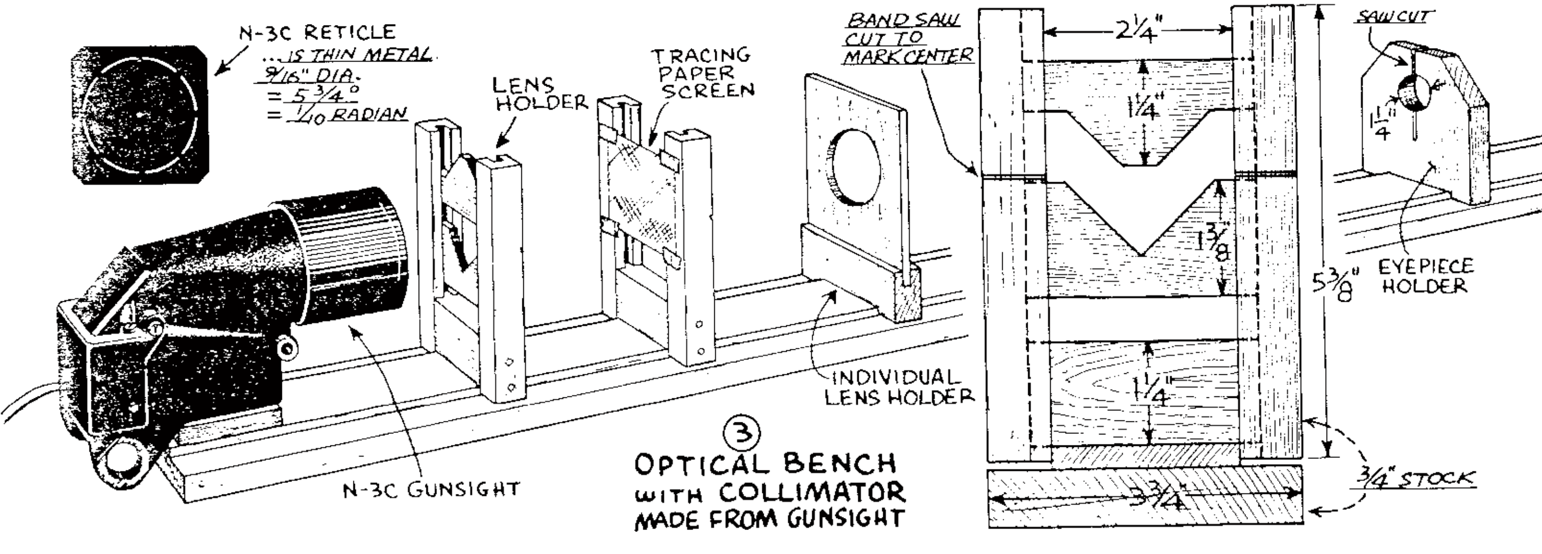


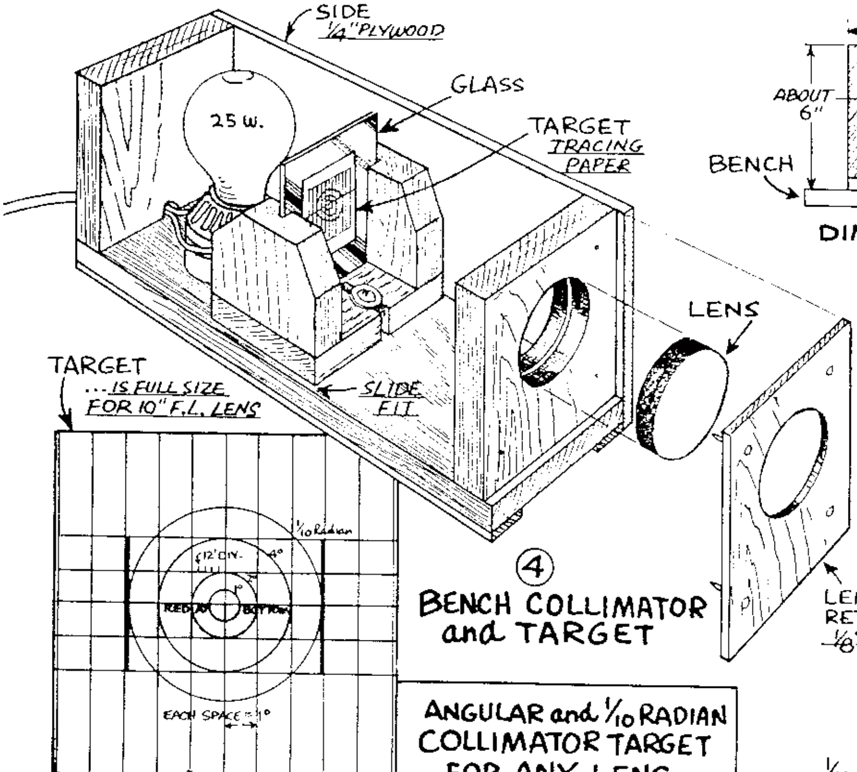
AN OPTICAL bench is the kind of equipment which may cost $5 or $5000. You can buy or build. Fig. 1 shows an inexpensive hobby optical bench you can buy. It is mounted on a wood meterstick. If you need a stronger or longer base, the construction shown in Fig. 2 can be used.

A collimator consists of some kind of illuminated reticle or target in the focal plane of an achromatic lens. Such an arrangement provides the equivalent of a distant target. A collimator can be built right on the optical bench as needed. In the equipment shown, the end plate is perforated with a vertical line of small holes. This is your "target." The collimator lens can be any good-quality achromat of 5 in. or more focal length. It is mounted at exactly one focal length from the reticle plate, a setting which is easily checked by auto-collimation as described on a following page. Fig. 1 setup shows a small finderscope being tested, the bench providing a means of holding the lenses while the collimator supplies the equivalent of a distant target

Fig. 3 shows a simple homemade optical bench. The adjustable lens holders can handle lenses to 2-1/8 inch diameter, and sizes over this can be mounted in individual holders. The sliding vee blocks which clamp the lens in the grooved frame should be made of hardwood plywood. The collimator is a military gunsight which requires only a simple conversion to 110-volt lighting.

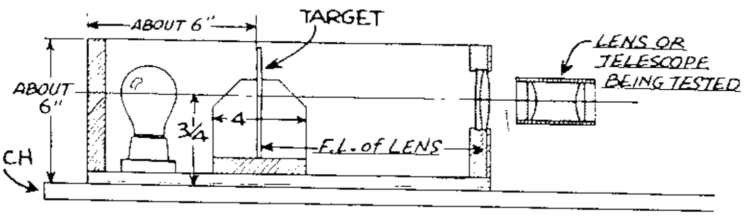
The obvious weakness of the optical bench and collimator is that the equipment should be somewhere near the physical size of the largest telescope you plan to test. Small equipment works



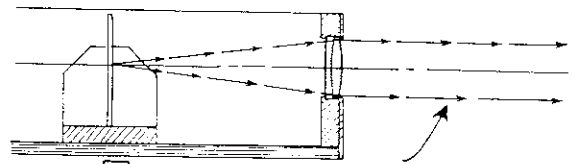


ANGULAR and 1/10 RADIAN COLLIMATOR TARGET FOR ANY LENS

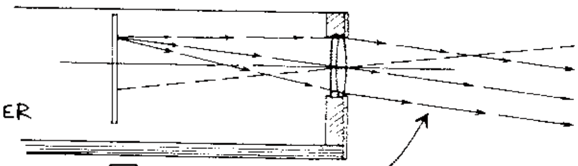
	You want to find	FORMULA	Ex: 20" F.L. COLLI. LENS
MAKING THE TARGET	DIA. of 1/10 RADIAN CIRCLE	.1 Radian CIRCLE (DIA.) = F x .1	20 x .1 = 2.0"
	DISTANCE EQUAL TO 1°	1° SPACE = F x .0175	20 x .0175 = .35"
READING THE TARGET	TRUE FIELD of a TELESCOPE	COUNT THE DEGREE SPACES. Ex: is about 4½°	Example: 2" F.L. YOU DO NOT KNOW F.L. IMAGE WILL READ .200"
	F.L. of a LENS BEING TESTED	$F = \frac{\text{IMAGE DIA. of .1 Radian CIRCLE}}{.1}$	$F = \frac{.200}{.1} = 2.0"$
	ALTERNATE: FOR LENSES OVER 5" F.L.	$F = \frac{\text{IMAGE OF 1° SPACE}}{.017}$	Ex: 20" F.L. LENS (IT WILL READ .350") $F = \frac{.350}{.017} = 20"$



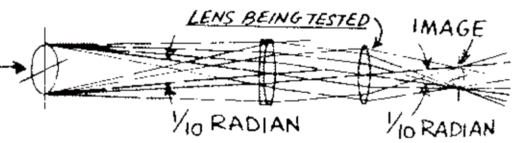
DIMENSIONS DEPEND ON F.L. OF LENS



A ALL LIGHT RAYS FROM CENTER OF TARGET EMERGE PARALLEL



B ALL LIGHT RAYS FROM A POINT AT EDGE OF TARGET EMERGE PARALLEL



C ANY ANGLE OF THE TARGET WILL BE MAINTAINED THRU ANY LENS BEING TESTED

fine for riflescopes, finderscopes and small terrestrial and astro telescopes. Suitable equipment to test a 6-inch reflector is somewhat of an oversize luxury. However, you can do many tests and operations with a small collimator.

HOMEMADE COLLIMATOR. You can house a collimator in either a box or a tube. Fig. 4 shows a typical box job. The collimator lens should be a good quality achromat of fair size and focal length--3 inches diameter and 24 inches f.l. is a good size, suitable for some tests with telescopes as large as 6-inch aperture. Much smaller equipment is perfectly satisfactory for some operations. The collimator target is drawn with ink on tracing paper. The target is taped or cemented to a piece of glass, as shown. Simple rules for scaling the target to suit any focal length collimator lens are given in the drawing, Fig. 4.

Light from any distant object reaches your eye in parallel bundles. In the same manner, light emerges from the collimator in parallel bundles. That is, a point at the center of the target will send out a beam like A in Fig. 4; a point at the edge of target will send out a beam at some specific angle, as at B. All of the light is in parallel bundles, but the whole light cone is spreading, diverging. In other words, parallel light does not mean quite the same thing as a parallel "beam" of light.

Any angle that the target makes with the collimator lens will be reproduced exactly by any lens or telescope placed in front of the collimator. Fig. 4C shows the situation as it applies to the 1/10 radian circle. This particular unit is used for the determination of focal length. The image of the 1/10 radian circle produced by any lens, eyepiece or telescope will be 1/10 the focal length of said lens, eyepiece or telescope. In other words, if you measure the image diameter formed by any lens, you will know immediately its focal length, which is simply 10 times the image diameter. For short focal lengths under 5 in., a pocket comparator (measuring magnifier) is ideal for measuring the image diameter.

APPENDIX IV
POSITIONING EQUIPMENT

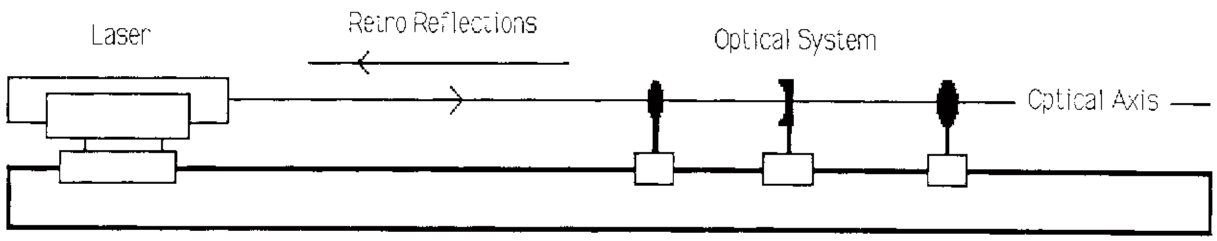
As technology progresses, the need for reliable testing equipment increases. In the field of optics the scientists need for accurate data require optical manufacturers to provide a wide range of positioning equipment.

The first step in many optical setups is to establish an optical axis. This can be done using an optical bench and positioning equipment.

In cases such as holography and interferometry, vibration has to be held to less than millionths of an inch. Then, the use of an isolation table becomes necessary.

OBTAINING AN OPTICAL AXIS BY USING A LASER

Mount a LASER to the optical bench and adjust the beam so that it is parallel to the bench as shown below. This is known as the reference optical axis.



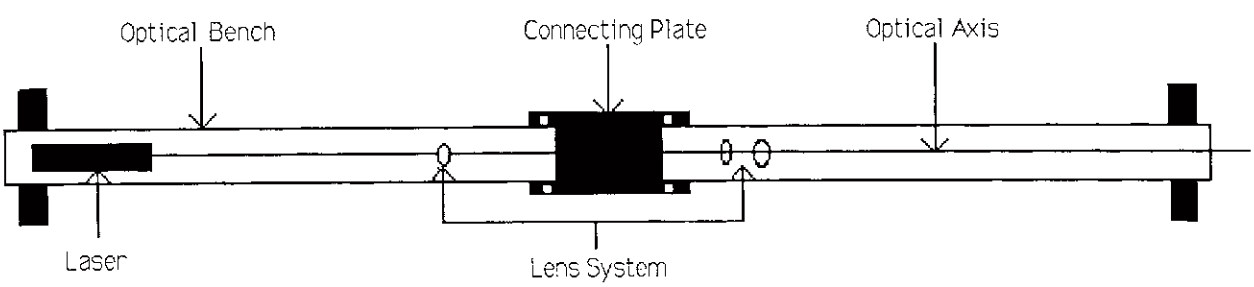
The best way to collimate an optical system is to introduce one element at a time and center it along the reference optical axis. To insure that the elements are not tilted , be sure to align all retroreflections along the axis. The precision to which the elements need be aligned largely depends upon the application. Two element configurations such as demonstrations of simple telescope and microscope systems are easily aligned. As more elements are added to the system the need for precision positioning equipment increases, for example, demonstrating the telescope with an image erector and a zoom lens.

Positioning equipment ranges from that which simply holds the optic to that which comes with x-y-z/tilt/rotation and fine adjustments for more precise alignments. By selecting the best positioning equipment for your optical needs, desired results with minimal error contributions are obtained.

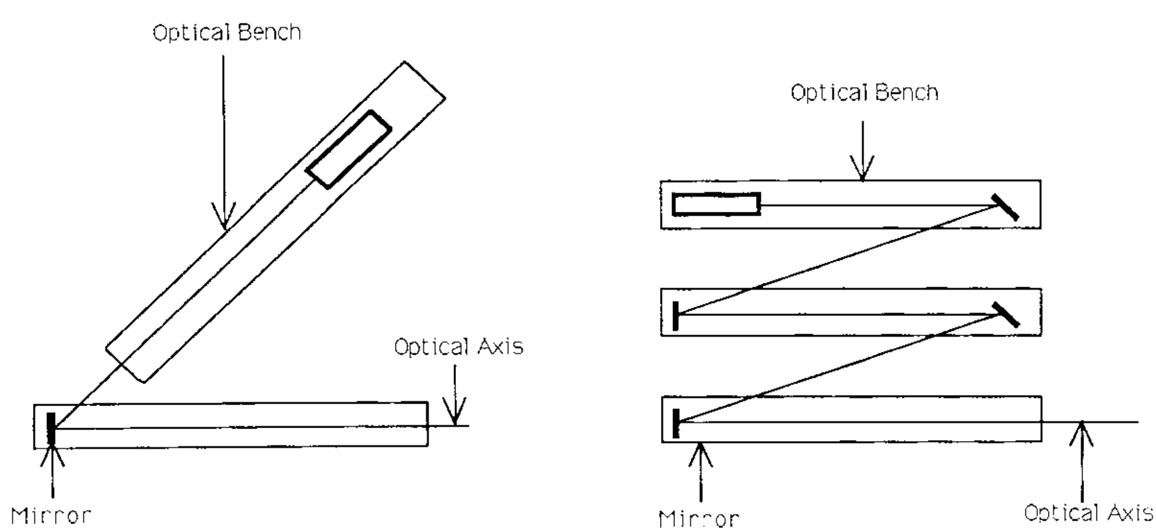
OPTICAL CONFIGURATIONS

When an optical path length is longer than a single optical bench, several benches are usually lined in series. This can be done by straight or folded alignment using mirrors as shown:

(a) straight alignment



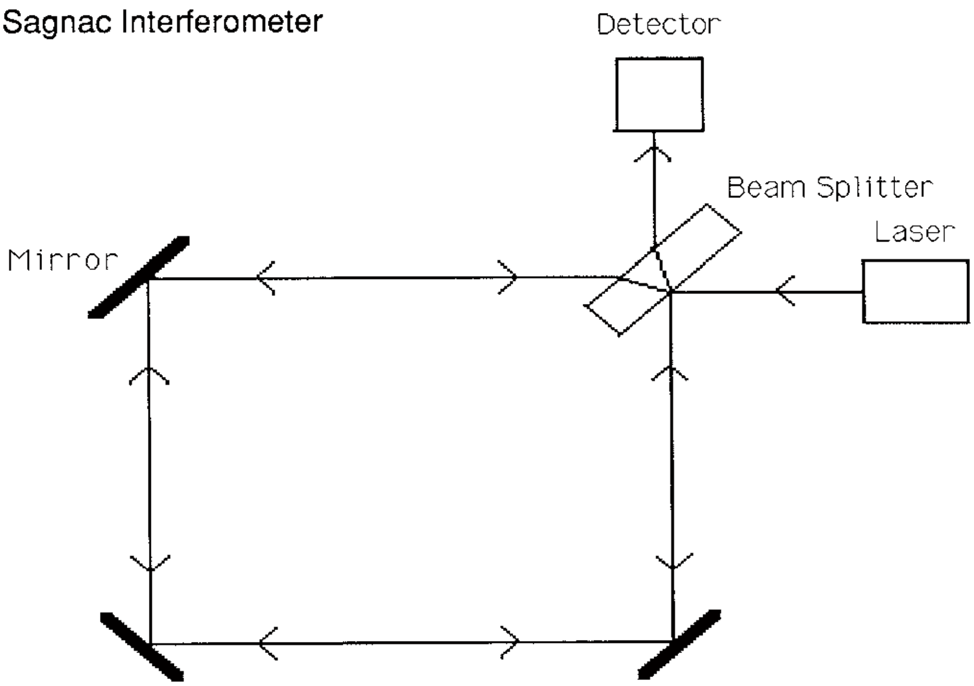
(b) folded alignment



It is generally preferred to keep a straight alignment, but often you are limited by the room available.

Another configuration which is commonly used is the perpendicular alignment of optical benches. In this case the optical axis must be bent 90 degrees, which is often accomplished using beam splitters. In this configuration the split optical axis can be recombined to form a Sagnac Interferometer.

Sagnac Interferometer



OPTICAL EQUIPMENT

There is a wide range of optical equipment available for use in research, education, and industry. The equipment selected depends on the goals of the user. Here is a list of the equipment and their uses.

POSITIONERS/HOLDERS. Used to maintain positions of optical components. This includes equipment such as an optical bench, mounting pins, pin carriers, laser holders, component holders, leveling bases, micrometer adjustments, stage positioners, and optic mounts.

COLLIMATORS. (see section on collimators)

LASERS. Used for alignment, interferometry, and holography.

LENSES. Used for magnifying, dispersing, condensing, and imaging. The common lenses are double-convex, double concave, plano-convex, plano-concave, meniscus, and achromatic.

MIRRORS. Used mostly for folding the optical axis at desired angles. Common mirrors include protected aluminum and enhanced aluminum for the visible range, protected gold for the infrared region.

PRISMS. Used for folding optical axes and as image erectors.

FILTERS. Used for taking away unwanted wavelengths. Different types of filters include neutral density, interference or bandpass, long bandpass, short bandpass, infrared, and polarizers.

BEAM SPLITTERS. Used to separate an optical beam into two axes. They can also be used to combine two beams.

EYEPIECES. Used to see real images with the eye. Also called oculars.

OPTICAL SCREENS. Used for projected real images. Paper, ground glass, and opal glass are common optical screens.

BEAM EXPANDERS. An afocal lens system used to increase beam diameter.

IRIS DIAPHRAGMS. Used to vary the f ratio of lens systems. Can be used to decrease the beam diameter without changing the energy per unit area.

RONCHI RULINGS. Used to diffract laser beams and test measurements.

OPTICAL APERTURES. The two common apertures are slits and pinholes. Used for spectroscopy, Fourier transforms, and diffraction patterns.

DIFFRACTION GRATINGS. Used to break up light into its component wavelengths for analysis. Standard diffraction gratings include mirror diffraction gratings, holographic gratings and transmission gratings.

EMITTERS. Used as light sources.

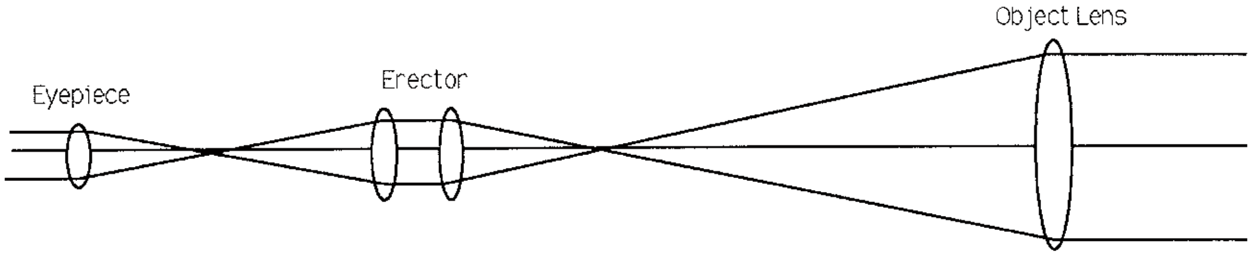
DETECTORS. Used to measure electromagnetic wave energy.

To insure accuracy and consistency of data acquisition of optical systems, Edmund Scientific offers these components in our Industrial Catalog.

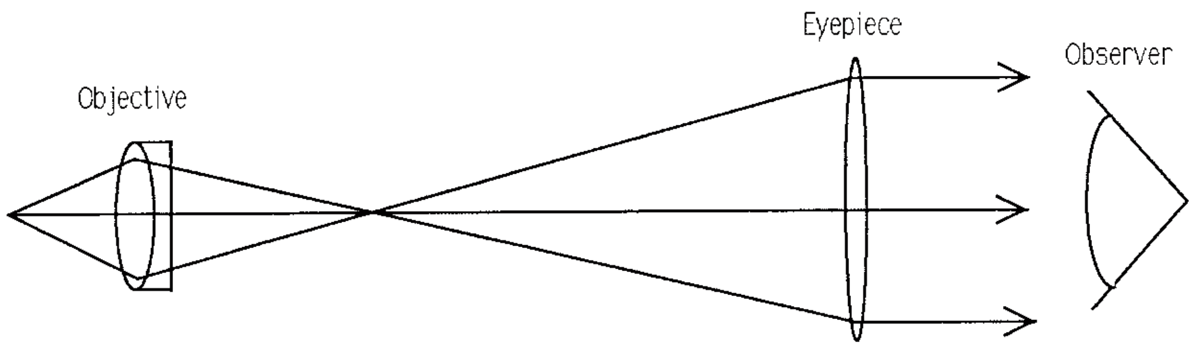
OPTICAL SYSTEM DESIGNS

In order to whet your appetite, here are some applications for the positioning equipment.

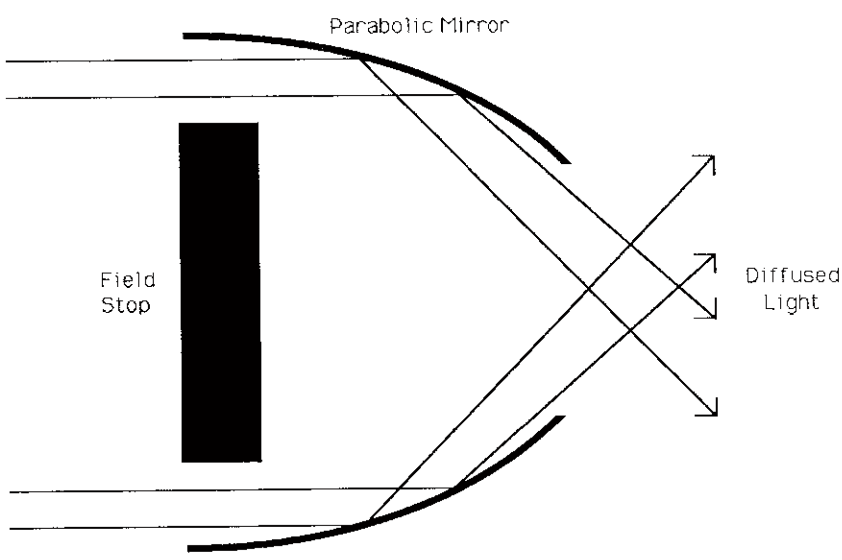
Telescope with optical image erector



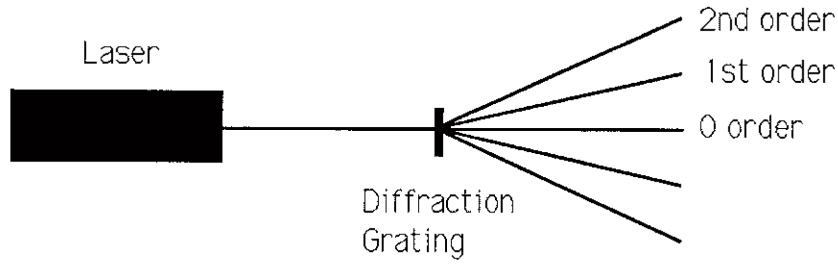
Microscope



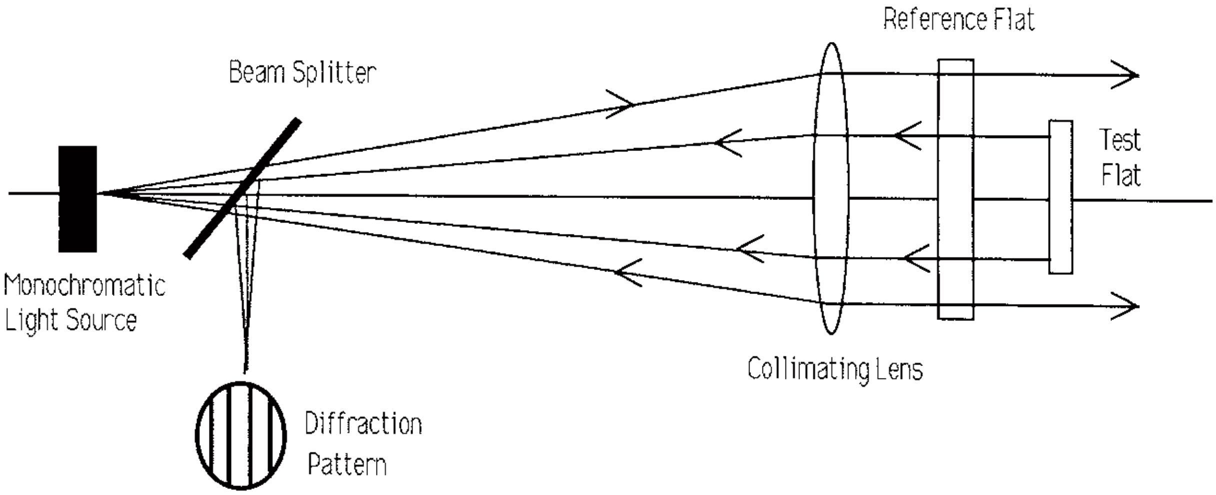
Dark field illuminator



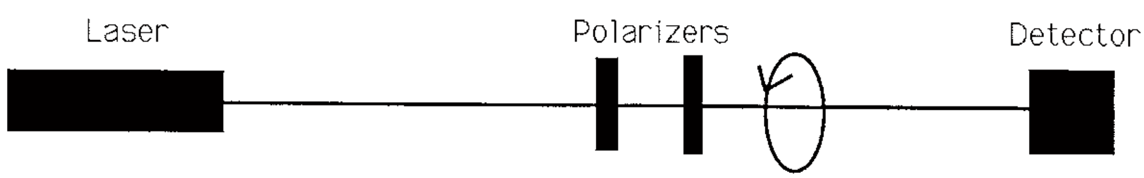
Laser diffraction

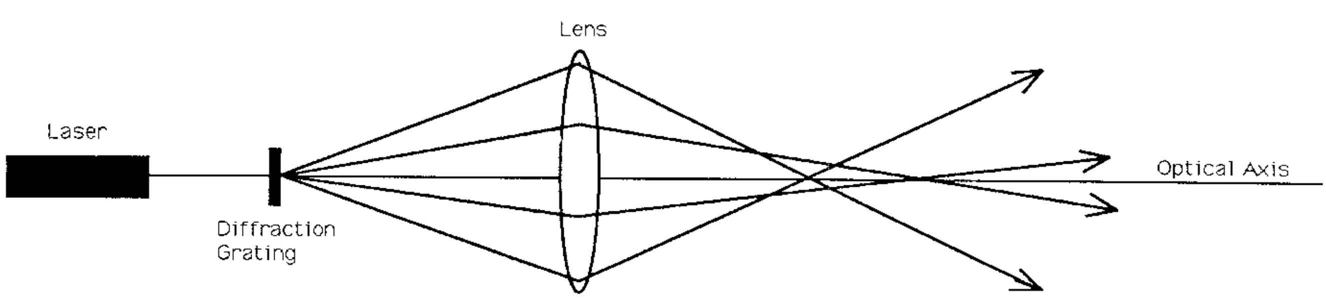


Fizeau interferometer



Measuring polarization



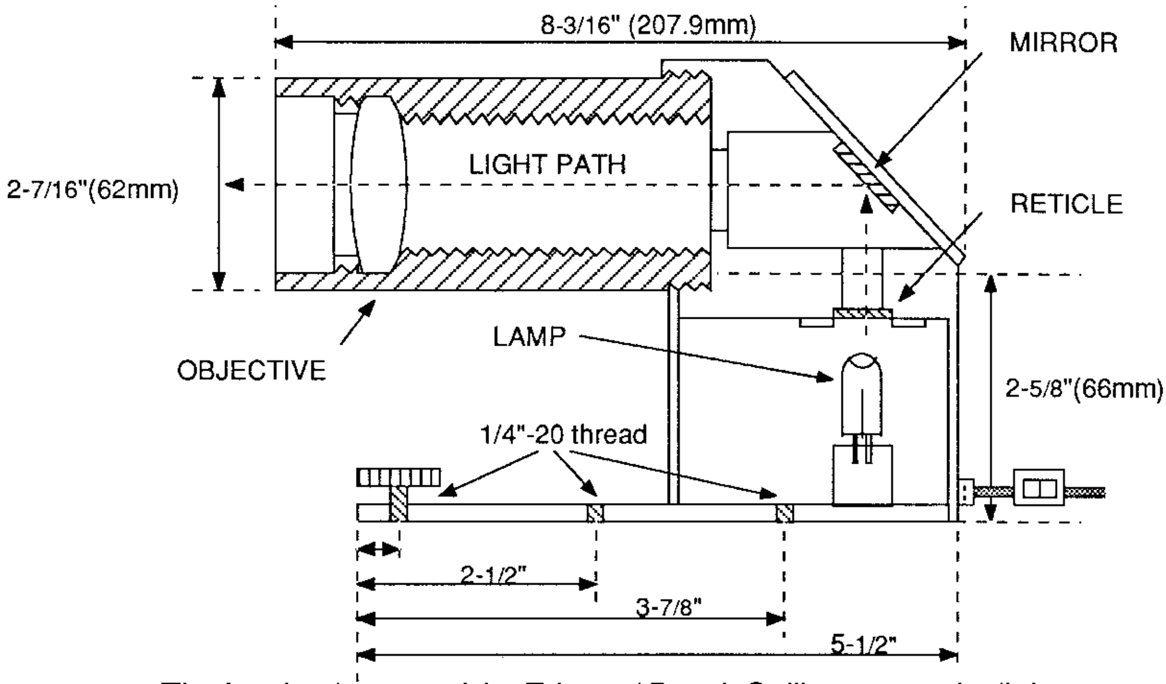


Studying optical aberrations using a laser and diffraction grating.

Edmund Bench Collimator

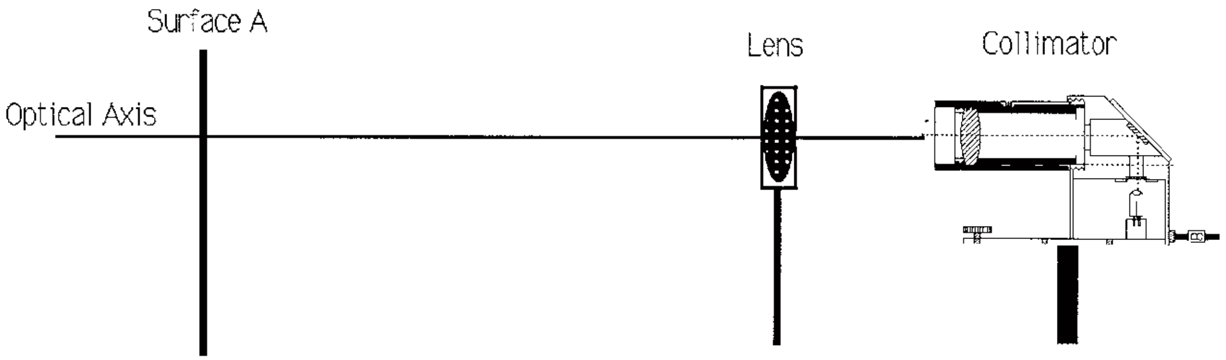
The Edmund Bench Collimator is a collimated projector used for the calibration and alignment of optical components and systems. Such components and systems include telescopes, eyepieces, rifle sights as well as individual optical flats, prisms, and lenses. The collimator can also be used in many mechanical operations, such as determining shape curvature, or angular relationships.

The basic design of the Edmund Bench Collimator is given in the diagram below.

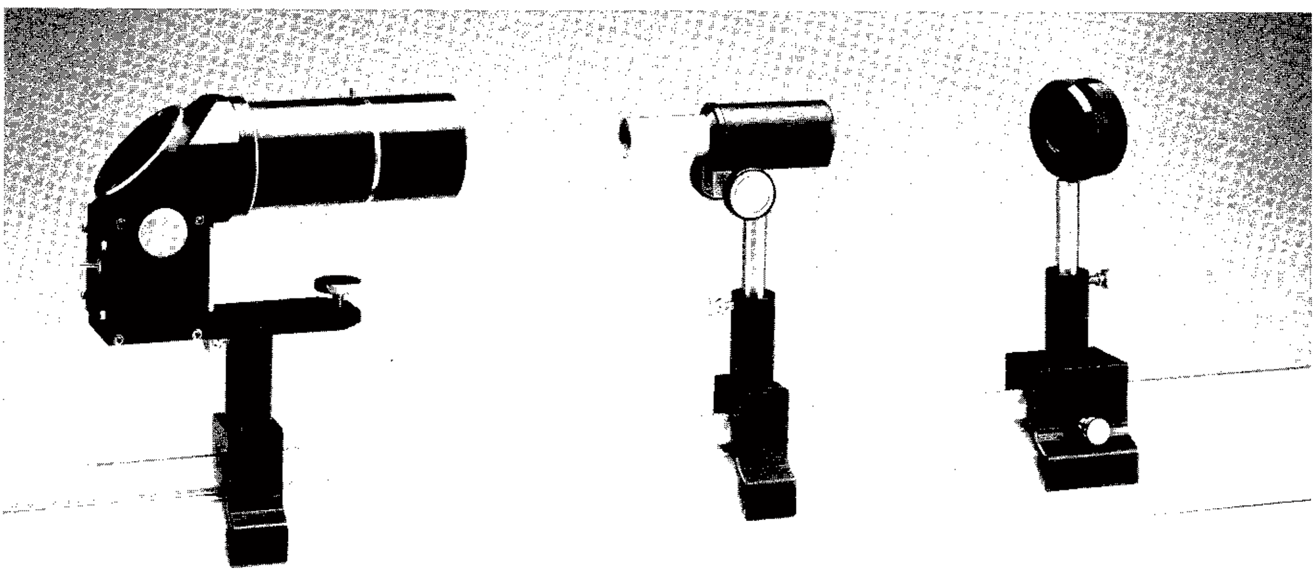


The four basic parts of the Edmund Bench Collimator are the light source (lamp), reticle (cross hairs), turning mirror, and objective lens. The collimator projects a parallel pattern of the reticle providing the user with a portable distant object. It should also be noted that the Edmund collimator is compatible with Edmund standard positioning equipment.

The most common use for a collimator is to determine the focal length of a lens. You may have done this before, using the Sun as an image source. Like the Sun, the collimator also provides a parallel image. However, instead of having your image at infinity, the collimator can be positioned at reasonable lengths. The following figure shows the basic design for measuring the focal length of a lens.



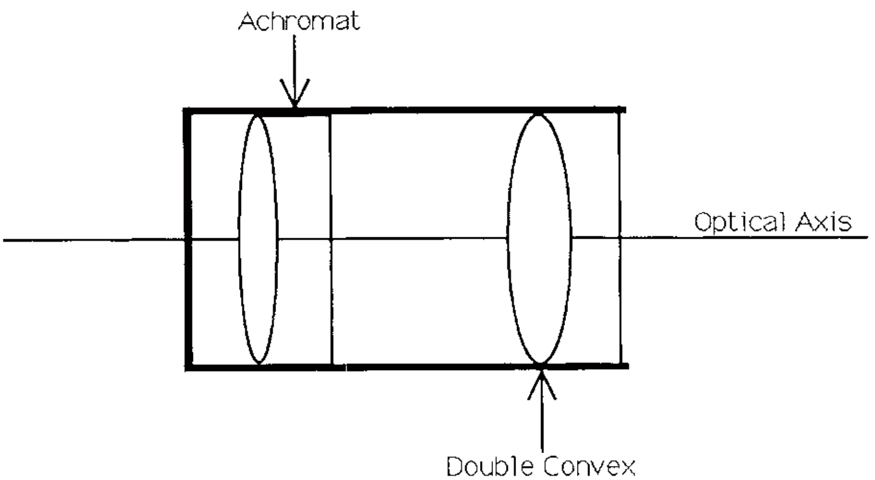
The first step in using the Edmund Bench collimator is to adjust the reticle (see reticle adjustment knob on drawing). This is done by first focusing the reticle image at ten or more feet away from the collimator. A distant wall will suffice. The collimator is then repositioned along the optical axis. By keeping the collimator and surface A a fixed distance apart,the lens can be adjusted until the sharpest image of the reticle is obtained. The distance between the lens and surface A is the focal length. To add convenience to this, especially when several measurements will be made, it is useful to use a calibrated linear bench like that shown below.



By using such a bench the need for external measuring devices is eliminated, thereby adding consistency and accuracy to the measurement.

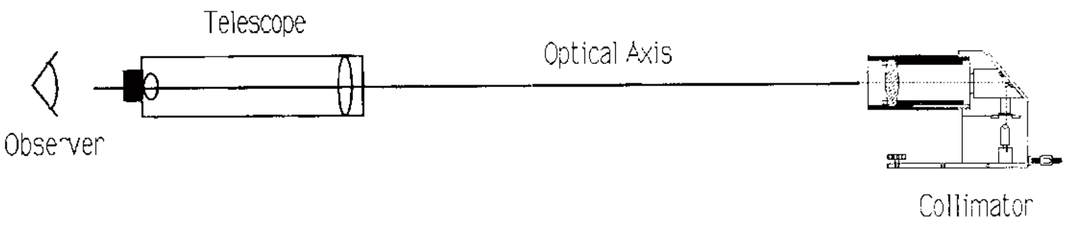
This next section describes a few examples for the collimator that can be extrapolated for other uses.

Consider the lens system below.

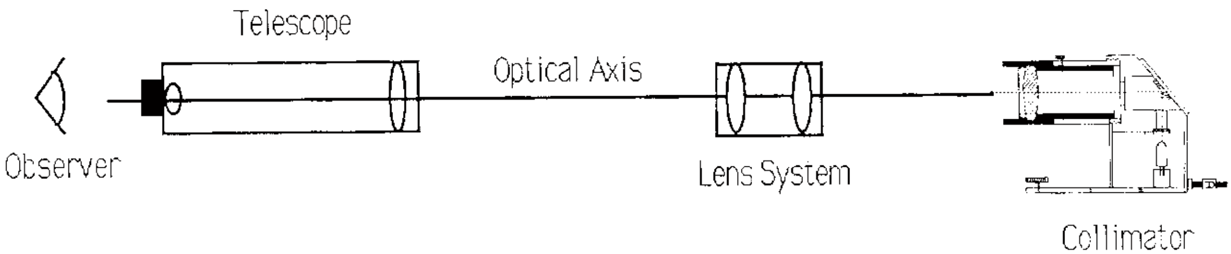


In this arrangement the engineer or student is confronted with the task of aligning the lens along the optical axis. This arrangement is needed for more exacting tolerances.

The general setup for testing a system is given in the following figure.



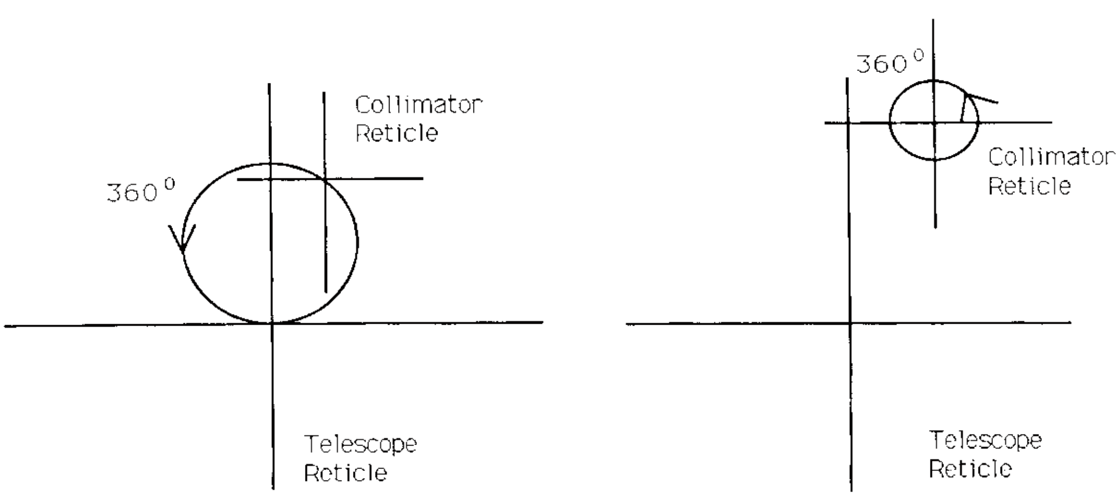
To start out, the lens system will be omitted in order to align the telescope reticle with the collimator reticle. This is done by adjusting the telescope until both reticles are in focus. Note, the collimator reticle should be focused roughly at infinity, as described in the previous example. By adjusting the telescope or collimator, the two cross hairs should be superimposed. Now the lens system can be positioned between the collimator and the telescope and visually aligned along the established optical axis.



It is now necessary to refocus the telescope so that the collimator reticle is once again sharp. At this point check the alignment. If both reticles are not visible the lens system should be readjusted. Do not adjust the collimator or eyepiece. An important point to remember is that the cross hairs need not be superimposed, only in the same field of view.

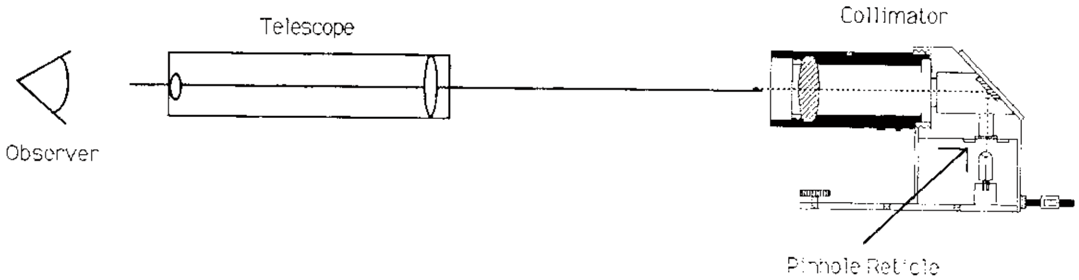
The next step is to rotate the lens system. This can be done by hand, or by a low RPM motor. If a motor is used it is crucial that the optical axis not be subjected to vibration.

If the image of the collimator reticle moves in a circle, the system is out of alignment. In an aligned system the reticle image will remain stationary.



By adjusting the lenses in the system it is now possible to align them along a common optical axis. It is also possible to calculate the error in a system by measuring the revolution of the reticle image.

In the next example we wish to determine the aberration of a telescope. This is conveniently done by what is called a diffraction ring test (star test). The setup for doing this is shown in the following figure.



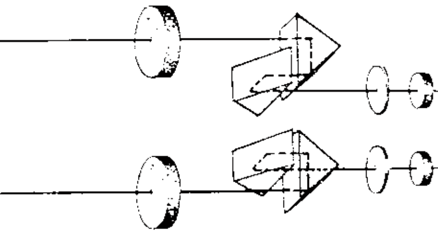
The cross hair reticle has been replaced with a pinhole reticle. It should also be noted that the Edmund collimator was designed with this in mind, and other reticles are available for other uses.

The pinhole provides a near point source of light. If we now view the point source through the telescope the following aberrations may be seen.

OVER CORRECTION UNDER CORRECTION ASTIGMATISM COMA

The above aberrations represent deviations from an ideal telescope. By comparing the diffraction rings of a test telescope to those of an acceptable telescope it is possible to make quick and easy quality tests. This makes the collimator particularly advantageous when used in production.

By providing quality, versatility, and an affordable price, the Edmund Bench Collimator is a practical choice for many optical applications.



BINOCULAR COLLIMATION

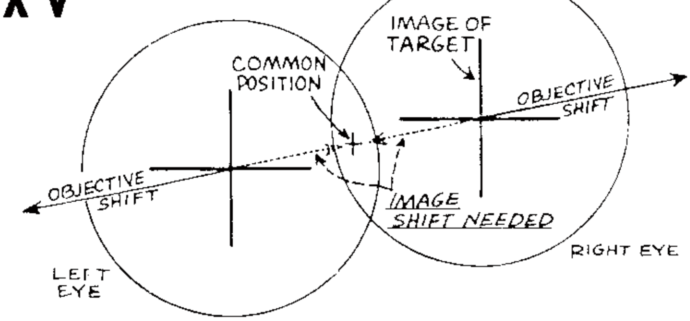
APPENDIX V

COLLIMATION of a binocular means simply that the two telescopes are to be made parallel. This applies to the optical axes. If this adjustment is considerably at fault, you will see a double image through your binocular. A smaller error in collimation will permit you to see a single image but only at the expense of more or less eye-strain.

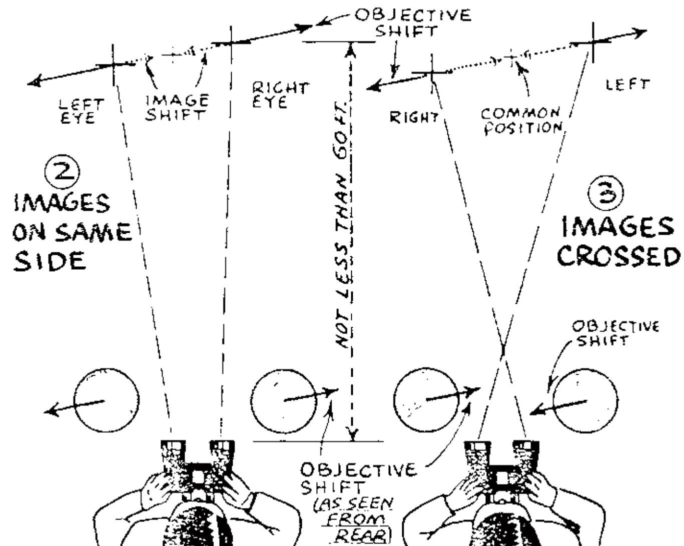
The double imagery of a poorly-collimated binocular can be seen by closing one eye while looking at a distant object through the binocular, and then opening the eye quickly. For an instant or two you will see the double image, but your eyes will work automatically and quickly fuse even widely-separated images. In the diagrams, a simple cross is shown as the target, but you can look at a chimney, telephone pole or other distant, well-defined object. The image separation may be normal right-left, matching your eyes, Fig. 2, or the images may be crossed, Fig. 3. The correction is made by moving one or both objectives laterally. This movement is always opposite to the direction you want image to shift; if you want the image to move up, you move the objective down, etc. The mechanical method of moving the objectives laterally is usually an eccentric mount and eccentric ring, as shown in Fig. 4. The movement is not large, rarely more than 1/32 inch from center, equal to about 1/2 degree in angular measure. Some imported glasses still feature the older style of screw adjustment, Fig. 5. Many inexpensive binoculars have no collimation adjustment at all.

Figs. 6 and 7 show how the light path direction is changed by shifting one or both binocular objectives laterally. Fig. 6 shows the light path for a center-of-field object. The mechanical axis coincides with the optical axis. The light enters parallel with the optical axis and emerges the same way. What happens when the objective is moved laterally is shown in Fig. 7. The former center-of-field object point is no longer the actual center of field--it has become an off-axis object. Since the target is now off-axis, the light bundle emerges at an angle. These diagrams show a simple astro telescope; with any erecting telescope, the emergent beam gets an additional flip and skews off in a direction opposite to the example shown.

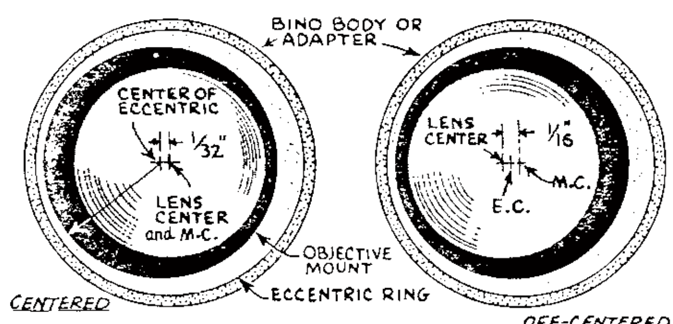
The lateral movement of objective in an eccentric mount can be made in any of the three



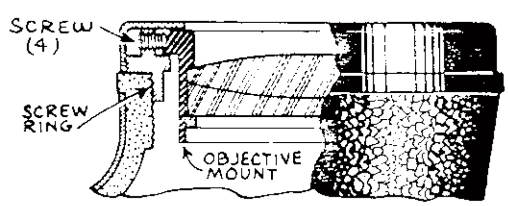
① DOUBLE IMAGE RESULTS IF BINOCULAR IS NOT COLLIMATED. CORRECTION IS MADE BY SHIFTING OBJECTIVES



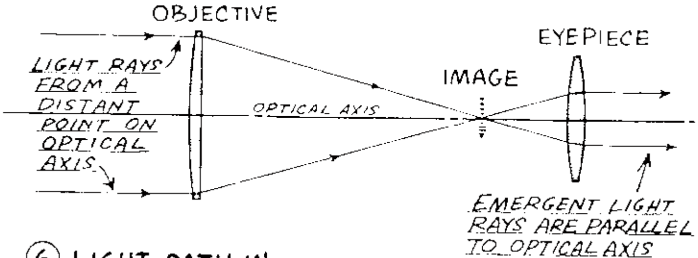
WHEN COLLIMATING BY EYE, THE OBJECTIVE SHIFT IS OPPOSITE TO THE DIRECTION YOU WANT IMAGE TO MOVE



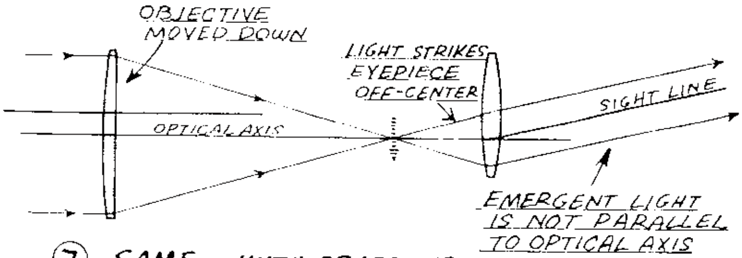
④ ECCENTRIC RING MOUNT



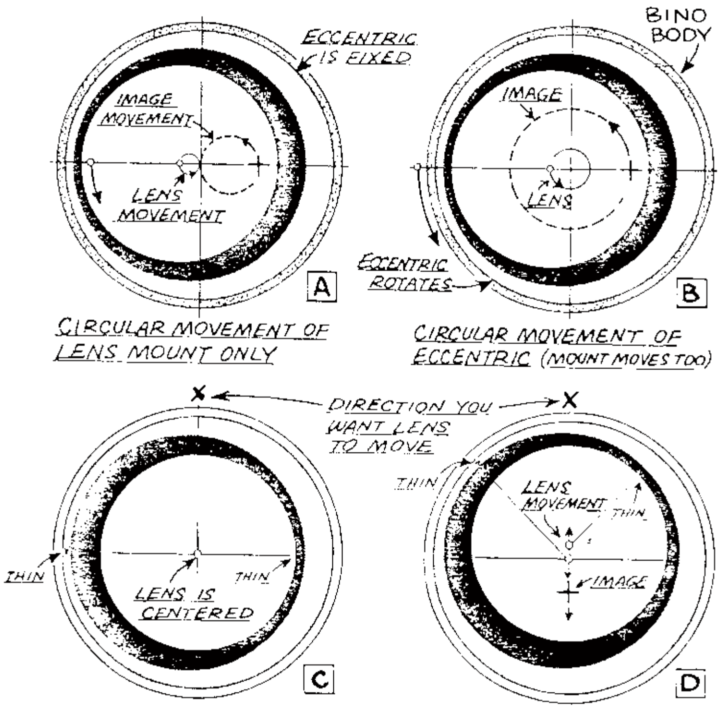
⑤ SIDE SCREW ADJUSTMENT



⑥ LIGHT PATH IN ASTRO TELESCOPE

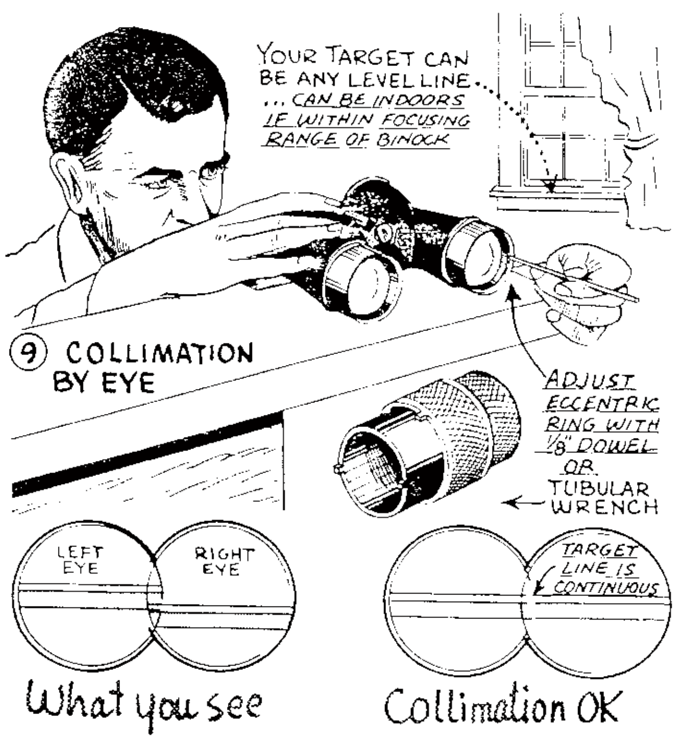


⑦ SAME...WITH OBJECTIVE SHIFTED LATERALLY



STRAIGHTLINE MOVEMENT IS OBTAINED WHEN THIN SECTIONS OF MOUNT AND RING ARE MOVED IN DESIRED DIRECTION

⑧ LENS MOVEMENT WITH ECCENTRIC RING

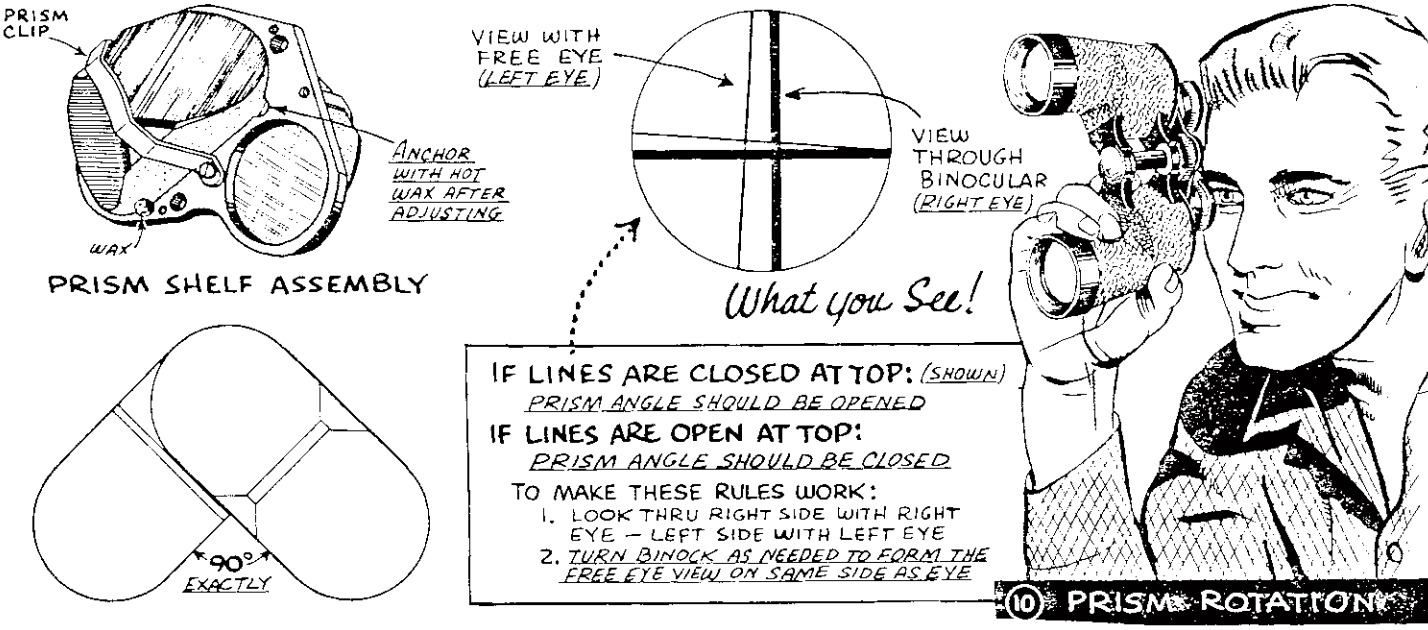


⑨ COLLIMATION BY EYE

ways shown in Fig. 8. Best control is obtained with the straightline movement, C and D, Fig. 8. The simple circular movement can be used for collimating by eye.

COLLIMATING BY EYE. One popular method of collimating a binocular is based on the fact you can look slightly cross-eyed in perfect comfort. On the other hand, it is difficult to look up with one eye and down with the other. So, knowing your eyes can readily accommodate for convergence, you set both objectives for maximum convergence and then confine actual collimation to the up-down movement. The target is any level line object, such as a window sill. It is best viewed at short range. Put the binocular on a support. Be sure both eccentric rings work freely. Have both thin sections together, like A in Fig. 8, and to the outside in each barrel. In such position, the initial rotation of the eccentric ring is almost pure up-down movement. Keep your eyes 6 or 7 inches behind the binocular, Fig. 9, to make image movement more apparent. The long eye position will produce the characteristic double-O view, as shown at bottom of Fig. 9, but this does not affect the accuracy of the collimation. The whole idea, of course, is to make the horizontal target line continuous. With close target and long eye position, this can be done with surprising accuracy--even 1/32 inch movement of the eccentric can be seen to produce a definite change in the position of the target.

PRISM ROTATION. Prism rotation or tilt is easily detected by looking through one barrel of the binocular at a time, allowing the free eye to see the target at the same time, Fig. 10. The two views are seen superimposed. If the prisms are properly adjusted, vertical lines will be perfectly parallel. The proper adjustment of each pair of binocular prisms is that they must be exactly at right angles to each other, as shown at left in Fig. 10. Any departure from 90 degrees will introduce twice the amount of tilt in vertical lines. This would be an easy fault to correct if it were not for the fact you usually have to disassemble



(10) PRISM ROTATION

the whole optical system to do it. Sometimes you can make a correction with one prism only, and this can sometimes be done without removing the prism shelf from the binocular. Usually you will end up by removing the whole prism shelf. The test is made just as readily with prisms alone, and the rules for adjustment as given in Fig. 10 are the same.

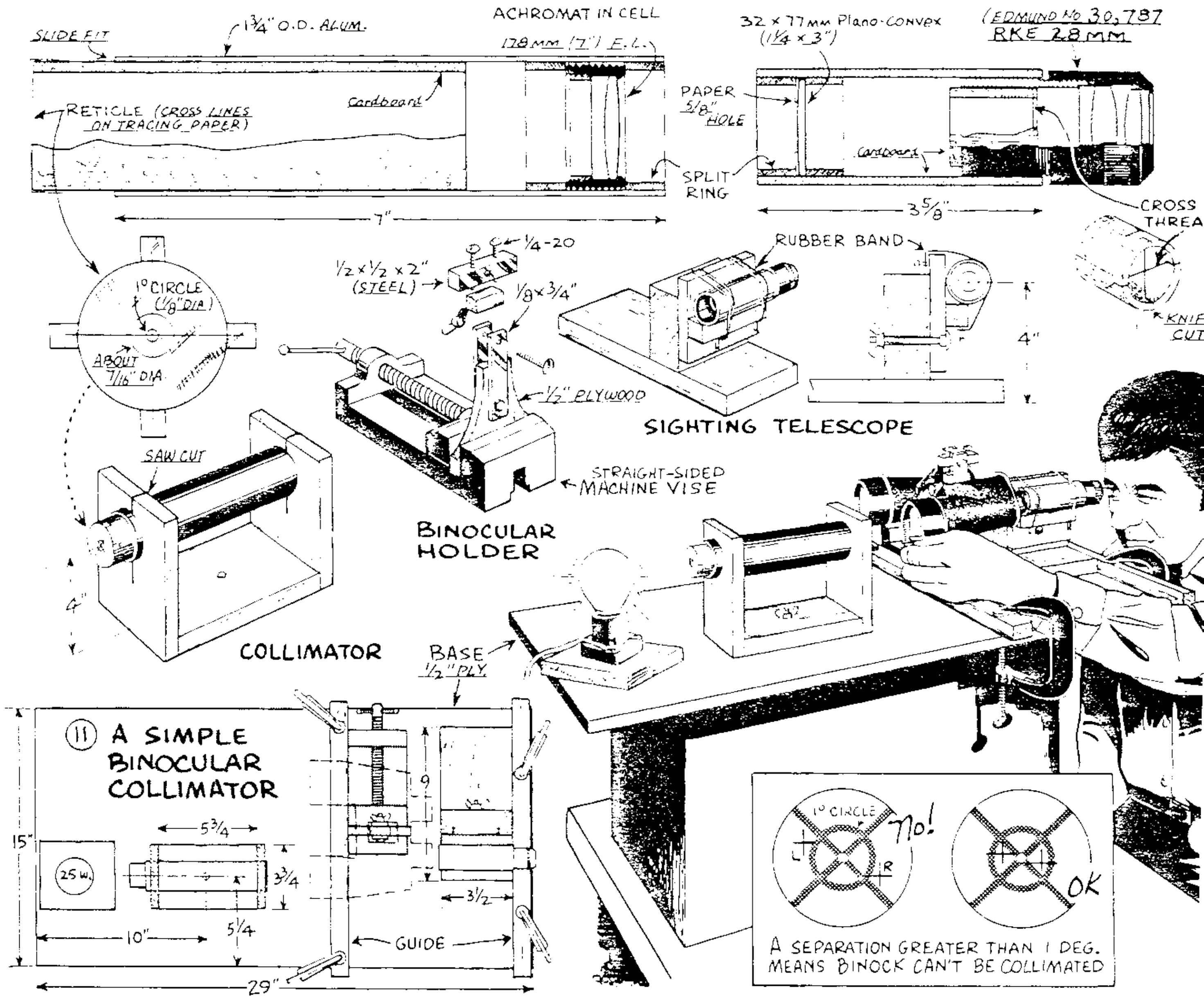
A SIMPLE BINOCULAR COLLIMATOR. Of several methods used in professional binocular collimation, the simple collimator and sighting telescope setup is the most common and also the easiest to make and use. The pros prefer twin collimators and twin sighting telescopes to reduce the actual work of collimation, but you can get along nicely with single collimator and single sighting telescope. A typical rig is shown in Fig. 11. You can build it in one evening for less than $5, assuming you already have a few of the parts (eyepiece and machine vise). The sighting telescope should be low power, not over 3x. The holder for the telescope should have a tilt adjustment, as shown.

The collimator lens is an inexpensive achromat, 7 inches f.l. The reticle target is drawn with a fine pen on tracing paper. A circle 1/8 inch diameter indicates maximum range of adjustment; the larger circle shown is simply a general guide and can be any diameter. The illumination can be obtained from a window (in daytime) or from any kind of table lamp or light bulb.

The eccentric rings and objective cells of the binocular must rotate freely. Quite often the main job of work in collimating a binocular is simply the business of getting the parts loose enough to turn. A tubular wrench as shown on a previous page is a great convenience in turning the eccentrics. Lacking this, it is permissible to drill small holes not over .031 inch (No. 68 drill) in which wires can be inserted.

The equipment is made ready by centering the sighting telescope on the collimator target, that is, the crossthreads of the sighting telescope are centered exactly on the crossline of the collimator target. To do this you can shift or tilt the sighting telescope as desired. There should be no visible parallax in the sighting telescope, which means the crossthreads should stay put on target as you move your head from side to side. After the proper centering is obtained, the wood guide strip is clamped in place alongside the sighting telescope holder. Recheck to see that the sighting telescope is still on target. Also, push the sighting telescope along the guide and you will note that the sighting telescope remains centered on the target. In other words, the sighting telescope does not have to be directly behind the collimator--it can be at any position so long as it picks up a good portion of the light. The same is true when the binocular is faced into the collimator--all you have to do is get it somewhere in the beam.

You start collimating with both binocular objectives centered in their eccentric mounts. Place the binocular in the holding fixture and clamp it securely. Face one objective toward the collimator. Focus the binocular eyepiece on the collimator target. Slide the sighting telescope behind the binocular eyepiece. Now, your line of sight is through the sighting telescope, through the binocular to the collimator target.



(11) A SIMPLE BINOCULAR COLLIMATOR

Shift the binocular as needed to put the sighting telescope reticle anywhere within the 1 degree circle on the collimator target; if a tilt adjustment is needed, it is obtained by loosening the vise and then reclamping the holding fixture. After a satisfactory line of sight is obtained, the guide strip of wood is clamped to the baseboard alongside the machine vise. Everything about the setup is now fixed and the only adjustment you can make is at the eccentric rings. You must be especially careful not to disturb the position of the binocular while manipulating the eccentric rings.

If the initial sighting shows both barrels of the binocular well within the 1 degree target circle, you are assured that the binocular can be collimated. This is what you proceed to do, adjusting each objective until the crossthreads of the sighting telescope intersect exactly the crossline of the collimator target. Check frequently to see if the sighting telescope itself is still centered exactly on the target. Be sure to maintain contact when you slide either the machine vise or the sighting telescope along its wood guide strip.

If a prism rotation adjustment is needed, this must be done first before you can collimate. The rotation is easily checked on the binocular collimator by rotating the collimator until one of the target lines is approximately vertical. The sighting telescope reticle is then made parallel with the collimator target. Then, putting the binocular in place, any non-parallelism of the target lines indicates the prism angle is in error.

Do not be in too much of a hurry to make a prism adjustment; if both barrels are tilted but in the same direction, the binocular will work satisfactorily and you will not notice the slight tilt in the view.