A TEN-DOLLAR TELESCOPE

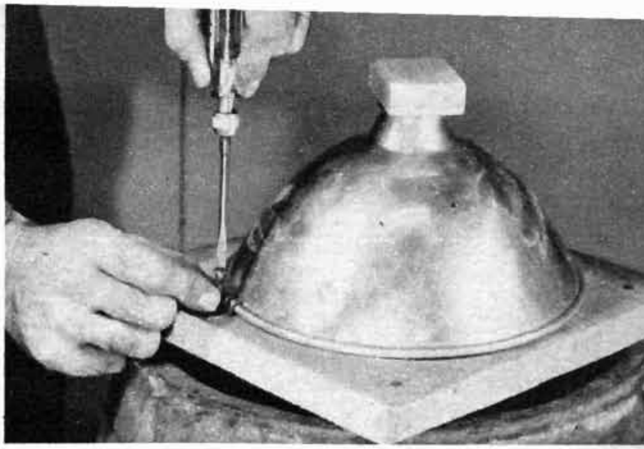
By Robert Brightman

LAST month we left you in the middle of the polishing operation. By this time your work clothes and hands have been probably stained a gory red by the rouge. You are doing fine!

The polishing stroke, as we have indicated before, is similar to the grinding stroke. In other words, two inches forward and two inches back. Keep up the good work for at least a half-hour. Now stop for a look-see.

Remove the mirror from the pitch lap, wash off the rouge, stand it on end to dry, then sit down, and cool off. When you have finished your cigarette, take a look at the mirror. Your heart will regain its lost beat when you see a gleaming polish starting to cover the surface of your speculum—a ten-dollar word for an optical mirror. You will notice, however, that polishing is more apparent in the center than along the edges. The edge of the mirror is the last surface to be polished. This is so because polishing is a kind of grinding operation with more wear taking place in the middle of the mirror.

A polishing spell should consist of at least 30 minutes. It usually takes three or four minutes for the surface of the

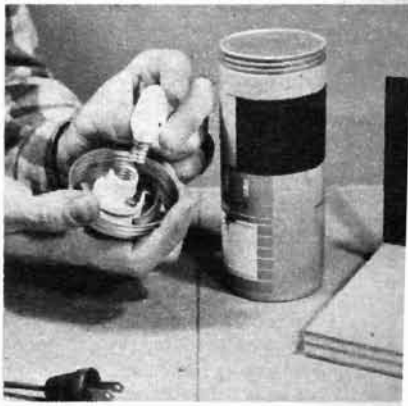


POLISHING STROKE is the same used in grinding. To parabolize, lengthen stroke.

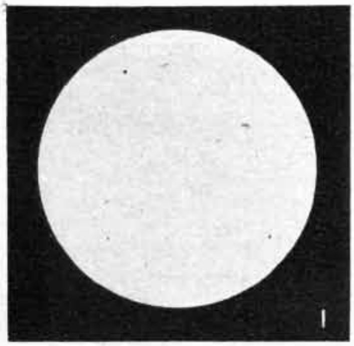
A PHOTOFLOOD REFLECTOR clamped over mirror will frustrate housekeeping enthusiasts.

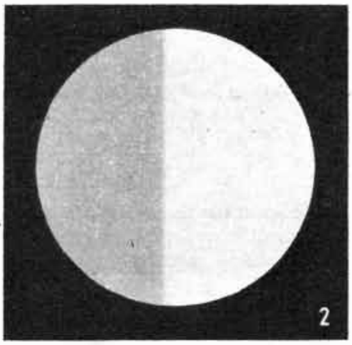
mirror and the top of the pitch lap to make good contact. For this reason there is no point in stopping after, say, ten minutes' work.

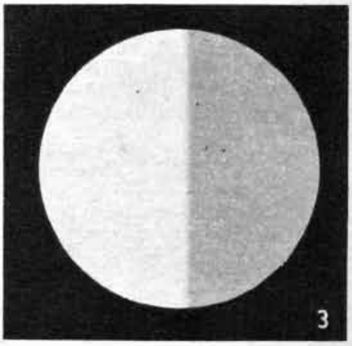
If you like you can continue at this pace for about eight hours. At the end of this time the mirror should be completely polished. But, as we humans are a curious lot, we like to see and know exactly what polishing is doing to the "figure" of our mirror. You see, what you are trying to do is grind and polish a parabola—or, as the highbrows call it, a paraboloid of revolution—for a parabola is the only

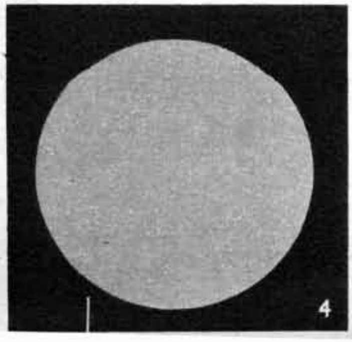


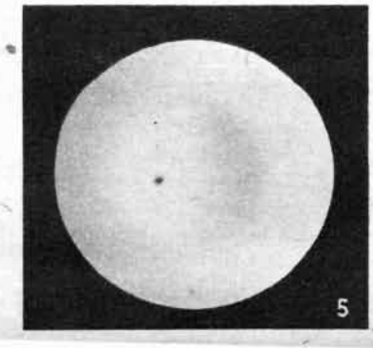
THE PINHOLE LAMP for making the knife-edge test consists of a white candelabra lamp mounted in container.



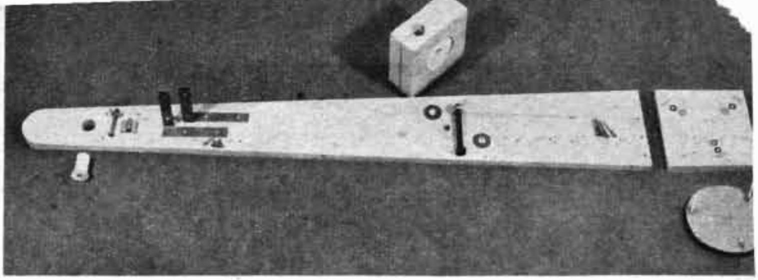








1. How mirror looks to the eye before knife-edge is moved in; it will be dazzling with light. 2. The knife shadow coming in at a point before focus. 3. The shadow will come in from the right when knife-edge is beyond the focal point. 4. Mirror darkens evenly all over with the knife-edge at the radius of curvature. 5. Shadow of a short-focus paraboloid, a doughnut shape.



HOW THE PIN-HOLE LAMP and knife edge are used to check the curve of the mirror as it approaches a parabola. Constant testing is most important to avoid getting too deep a curve. Photograph above shows the parts of the mounting.

kind of surface which will reflect light from infinity to a single point. All other curves—the ellipse, the sphere, the hyperboloid—bring rays to a focus at more than one point and so yield a fuzzy and degraded image.

Testing For A Paraboloid

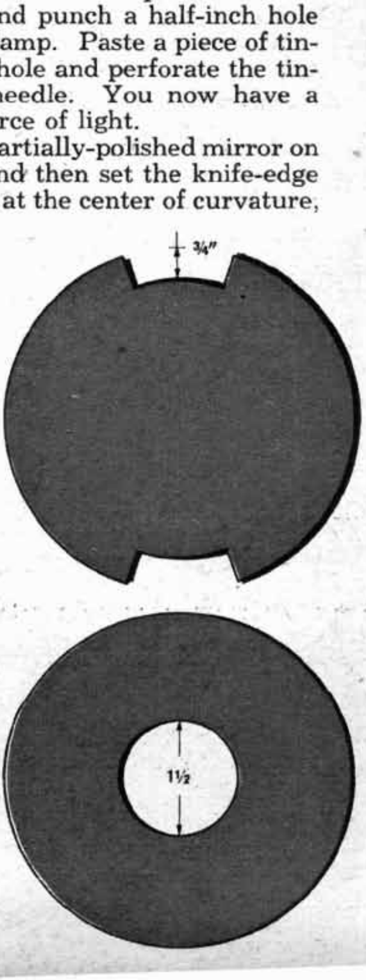
So, how can you be sure that you are polishing a paraboloid? Easy enough. You can test your mirror by means of a very simple rig invented by a French physicist called Leon Foucalt. (Foucalt was a man who also demonstrated visually to Parisians the turning of the earth on its axis.)

The method of testing a mirror to see whether or not it is a paraboloid is known as the Foucalt knife-edge or shadow test. You will need a pin-point source of light which can consist of a five- or ten-watt candelabra base lamp mounted on a block of wood and then inserted in a cardboard tube as shown in the photograph.

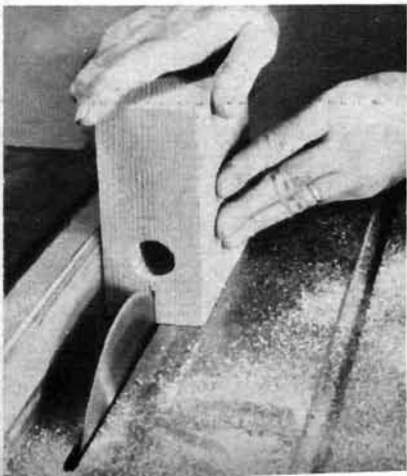
Insert the electric lamp in the cardboard tube and punch a half-inch hole opposite the lamp. Paste a piece of tinfoil over the hole and perforate the tinfoil with a needle. You now have a pin-point source of light.

Place the partially-polished mirror on a firm spot and then set the knife-edge and the lamp at the center of curvature,

TWO MASKS at right are used to check parabolization of the mirror. Top mask checks outer zone, lower mask measures curvature in center area. Masks are six inches wide.



TO MAKE the bearing block for mounting, cut it to the size shown in the drawing, bore a 1 3/32-in. hole two inches from edge. Then cut a slot about four in. deep as shown below.



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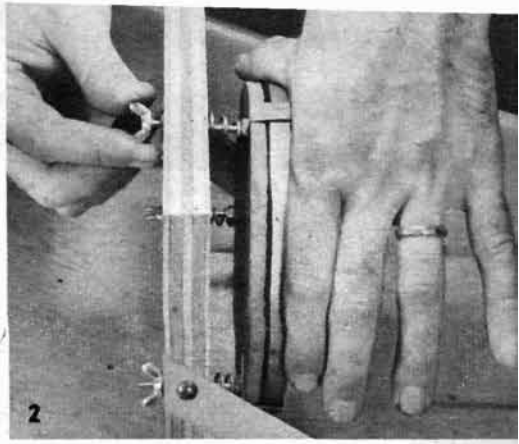

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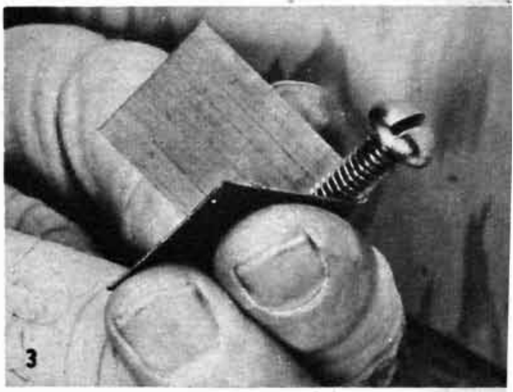

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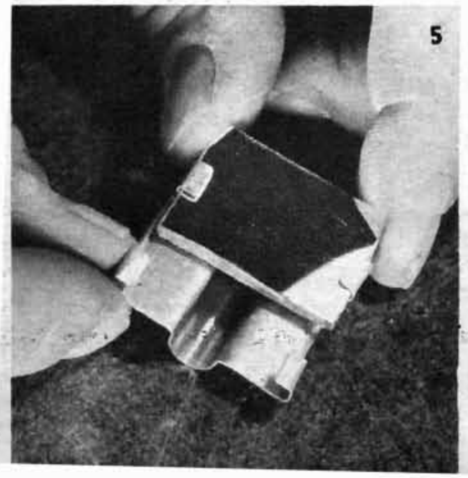
1. To determine the focal length of your mirror, point it at the sun. The point at which you get the sharpest possible image of the reflected sun on a business card, is the exact focal length. 2. Cell for mirror has three spring-loaded wing nuts which align mirror to the diagonal. 3. Holder for diagonal is formed by first bending strip of sheet brass around a bolt as shown. 4. Then hammer it flat in a vise. 5. Four clips hold the small mirror in place. 6. How the diagonal holder is fastened to the main mounting. 7. Bearing block fastened to mounting. Wing nut adjusts tension.

PLANS AVAILABLE

A complete set of plans describing the construction of this telescope, including silvering, will be available to our readers. To reserve your copy, send $2 to Mechanix Illustrated Plans Service, Greenwich, Conn. Ask for Plan No. 8, Ten-Dollar Telescope.



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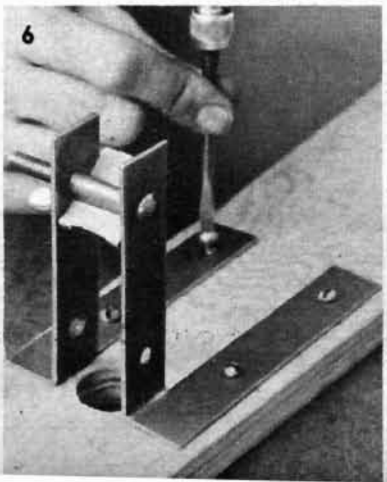

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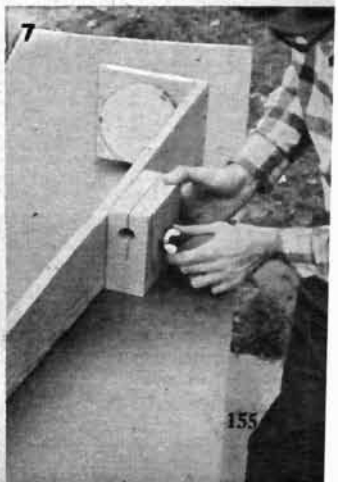

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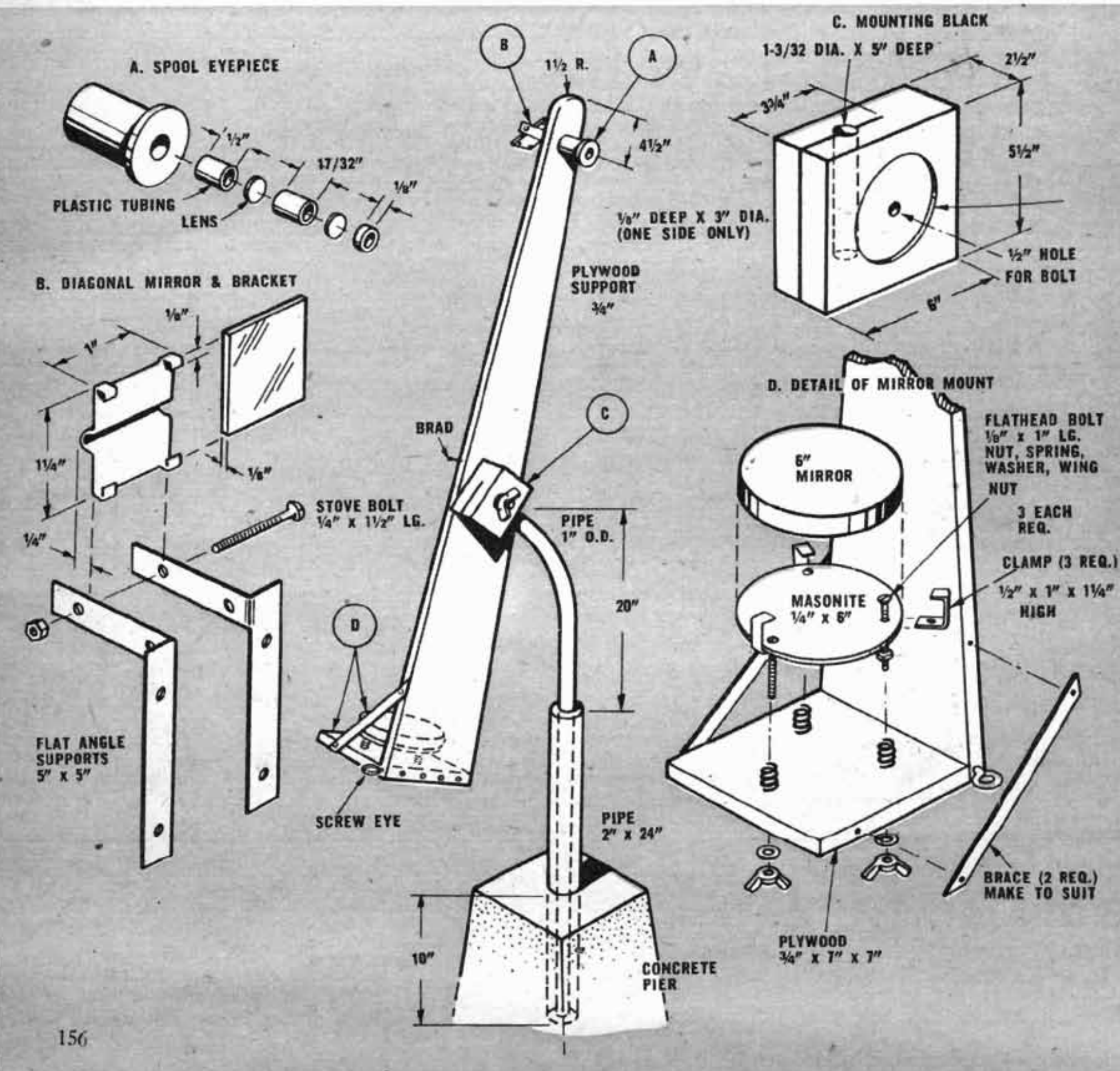
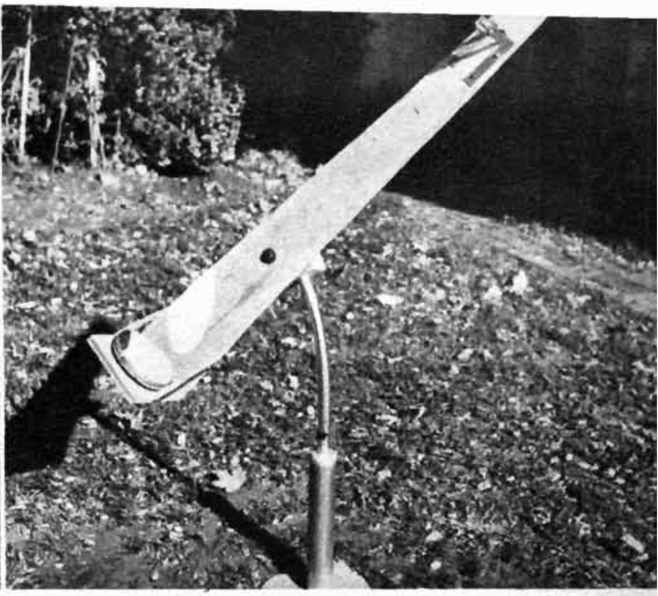
BENDING THE PIPE for mounting. The angle should be equal to the latitude of your home. The concrete pier holding the large pipe should extend below frost line to prevent heaving.



CEMENT the smaller pipe as shown so that it faces true North, not magnetic.



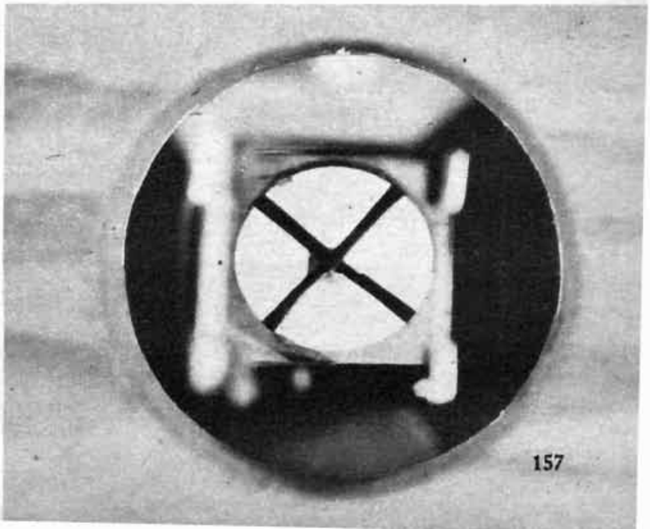
COMPLETED TELESCOPE on mounting with mirror in place. Moon can be observed without silvering.

which should be about eight feet or so from the mirror. The center or radius of curvature is always equal to *twice* the focal length. What you are trying to do is reflect the pin-point of light from the mirror to the knife-edge.

Inasmuch as it will be quite hard to pick up the pin-point of light, it is best to take the sleeve off the lamp and explore the area with a piece of ground glass. Put your eye close to the lamp and move back and forth and up and down until you suddenly see the reflected image of the lamp. This is a real image which appears to be suspended in the air. If you take the piece of ground glass and place it near your eye, you will see the image of the lamp thrown on the ground glass just as though you were using a camera.

Shim up the mirror or twist it slightly from side to side in order to bring the reflected light to a convenient point of viewing. A convenient point is at eye level when your chin is at the edge of the test bench. After the image of the lamp has been picked up, cover the lamp with the sleeve so that the pin-hole faces the mirror. This may disturb the setting somewhat and you may have to explore the area again until the pin-point of light is again picked up.

Since you will have to repeat this step many times during the stages of polishing, it is best to make some sort of reference mark on the table where the mirror is standing so that you can always place the mirror in the same position for each suc- [*Continued on page* 162]



WHAT YOU SHOULD SEE when aligning mirror, diagonal and eyepiece holder. Stretch black strings over the mirror. Adjust the mirror by means of the wing nuts so that strings cross the center of diagonal. This is the view you will see through the eyepiece adapter with the spool eyepiece removed.

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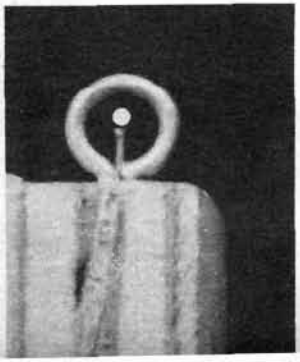
AIMING THE TELESCOPE. It is very difficult to pick up a particular star without sights.

ceeding test. It is also a good idea to note where the image of the lamp is reflected to the opposite corner of the room or wall with the cover off the lamp stand. This way you can always replace the mirror so that the reflected image always hits the same spot. Then when you replace the sleeve you will be reasonably certain that the pin-point of light is where you expect it to be.

Now for the actual tést. As the pin-point of light leaves the lamp, hits the mirror and comes back to enter the eye, the mirror will appear as though it were luminous, glowing with light. Now then, carefully slide the knife-edge in toward the right (toward the lamp). Do this very slowly and carefully. As you do so a vertical shadow will appear to cross the face of the mirror. This shadow will move from left to right (the same way that you are moving the knife-edge) *if the knife-edge is before the radius of curvature.* If you move the knife-edge back an inch or two so that you are beyond the radius of curvature, the shadow will appear to move in the opposite direction. In other words, from right to left. At this point we are beyond the radius of curvature. As the artillerists put it, "We have bracketed the target."

WHAT you will see when you line up the sights on the moon. Then look through the eyepiece.



Move the knife-edge to and fro until at a certain point you will notice the mirror darkens evenly all over as shown in the lower left drawing on page 153. At this point if you have a perfect sphere there should be no apparent movement of the shadow. You are looking at the shadow-graph of a true spherical concave surface.

You can consider the rays of light going from the pin-hole and coming back from the mirror as giant fingers or radii. From plane geometry you know that all parts of a sphere are equally distant from the center. Therefore, if you cut off half the light from the center, you are losing half the illumination. If you have a sphere then, it will seem to darken evenly all over. At this point, you could probably go ahead and use the mirror. But if you want perfection you must polish the mirror so that it is a paraboloid—for a paraboloid, as we said before, reflects all light from infinity to a single point.

Parabolizing

To parabolize the sphere you will have to deepen the center a few millionths of an inch. This sounds quite terrifying but actually it is quite easy.

Cut out two cardboard masks as shown, each six inches in diameter. One mask should have a hole in the center 1½ inches in diameter. The other mask should have two pieces, cut as shown, ¾ inches wide. With one mask you will determine the exact radius of curvature of the center zone; with the other mask, the radius of the outer area of the mirror. There should be a dif-

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ference of about 1/10 inch between the two zones.

How do we get this 1/10 inch? It's procured by means of a simple optical formula:

$$\frac{r^2}{R} \text{ or } \frac{3^2}{96} = \frac{9}{96} = .093 \text{ inch}$$

Small r is the radius of the mirror and large R, the radius of curvature.

In other words, if you get the inner zone of the mirror longer in radius than the outer zone by roughly 1/10 of an inch, you have achieved parabolization. This difference is a minute one because we are dealing with two optical surfaces, a sphere and a paraboloid, whose curves lie so close to each other that they actually touch at certain points.

Place mask No. 1 (the one with the outer cut-outs) over the mirror and carefully determine where the outer portion of the mirror seems to darken evenly all over. Move the knife-edge in very carefully as you conduct this test. At the point where even darkening seems to occur, draw a pencil line at the bottom of the knife-edge or the base to which it is attached. Then, with mask No. 2, make the same test on the central area of the mirror. You will find that you will have to push the knife-edge closer to the mirror in order to get the central area to darken uniformly. This is so because the central area has a shorter radius of curvature.

If you remove the masks and test the mirror as is, at the mid-point, you should get a shadowgraph of a paraboloid. It looks somewhat like a doughnut. We have tried our best to reproduce it at the bottom of page 153. We have deliberately exaggerated the light and dark area. Actually the shadows are much more delicate. The important thing to remember is that one shadow will be coming in from the right toward the left (central zone) and another shadow will be coming in from the left toward the right (outer zone).

Parabolization should only be attempted after the mirror has been completely polished and shows a true spherical curve. If you are satisfied that your mirror is free of all pits, probably after at least eight hours of polishing, and that your mirror turn is a true sphere, you are then ready to parabolize.

There are several methods of parabolizing a spherical mirror. The easiest one for the amateur is by means of a long stroke. To parabolize, lengthen your stroke from two to three inches. This has the effect of deepening the central area of the mirror.

How long should you "parabolize"? Use a long stroke for five minutes and then test. Parabolization can occur quite rapidly and if you use too long a stroke for too long a time you will probably find that you have overshot the mark. If you do, use the same technique that you did to correct over-grinding. In other words, place the mirror on the barrel head and polish with the tool on top.

Parabolization is the most arduous and exacting task in mirror making. *Go slowly, test frequently and keep a record of what the shadows look like.*

Now then, let us assume that you have completely polished and parabolized your mirror. At this point you are probably very anxious to try it out. To do this we have designed a rather simple mounting which will enable you to observe the moon and stars. The mirror can be used for observation of the moon without silvering or aluminizing.

The Mounting

The mounting consists of a ¾-inch plywood board, cut as shown, secured to a steel pipe which in turn is buried in a concrete pier. Before starting work on the mounting, determine the *exact* focal length of the mirror. (Do this by mounting the mirror temporarily on the mounting.) Point the mirror at the sun and place a business card in front of the mirror so that the shadow falls on the mirror. Move the card back and forth until at a certain point you get a bright, hot image of the sun. Get it as sharp as possible. Mark the spot. The distance from this mark to the center of the mirror is the exact *focal length* of your mirror.

The next step is to make the cell. Follow the details in the drawing on page 156. The three spring-loaded wing nuts are used

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to aim the mirror so that the reflected light strikes the diagonal, B, in the drawing. Your mounting really consists of a simple rig which will hold in correct optical alignment, the mirror, the diagonal and the eyepiece. Make the cell as indicated in the drawing on page 158. Mount the cell at the end of the long board. Make certain that the two braces connecting the cell support to the board are stiff enough so that there is no play.

Next make the eyepiece out of a spool as shown in detail A. The hole for the eyepiece should be drilled at a distance from the face of the mirror which is equal to the focal length of the mirror less four inches. This four inches is taken up by the distance between the diagonal and the eyepiece. If you don't hit the exact spot, don't let it bother you too much. You can always make adjustments by moving the mirror cell support up and down a half-inch at a time. For this reason it is a good idea to allow plenty of room behind the cell support instead of mounting it at the extreme edge of the mounting.

By designing the mounting along the lines of an "equatorial" you can follow any star or the moon by means of a single motion instead of two zig-zag motions. Build a concrete pier in the ground, deep enough to extend beyond the frost line. In it, before the concrete has set, place a 2x24-inch pipe.

Next, get a length of one-inch OD pipe and bend it as shown in the photograph. The bend should be equal to the latitude of your home. For example, in the New York area it is approximately 42°. Insert the bent pipe into the larger pipe. Do this at night. Insert the bent pipe so that it points due north, not magnetic north. The best way to determine due north is to aim the pipe at Polaris, the pole star. Then fill the opening up with concrete and go to bed. Give it a chance to set before installing the mounting.

Eyepiece And Diagonal

While you are anxiously waiting for the concrete to set you can proceed with the construction of the eyepiece and the diagonal mirror bracket. Their construction is fairly simple and obvious. Make them as shown in the drawing and the photographs. At about this point you will probably be very anxious to literally see what all this business is about. So, install the unsilvered mirror in its cell, stretch two black strings at right angles to each other across the mirror, insert the diagonal mirror in its brackets and then the eyepiece.

You probably won't see anything at all and it is at this stage where you will probably need some bit of assistance. Label each of the three wing nuts at the bottom of the mirror cell, 1, 2, 3. Seat an assistant at the rear end of the telescope and tell him to tighten or loosen wing nuts No. 1, 2 or 3 as you direct. Remove the eyepiece and look through the eyepiece hole. Have your assistant tighten and loosen the wing nuts until you see the large mirror in the small mirror. Keep adjusting the wing nuts until the reflected image is in the exact center of the diagonal mirror. The diagonal in turn should be in the exact center of the eyepiece hole.

At this stage it is a good idea to relax and wait for the moon. The unsilvered mirror will give you a beautiful view of the moon, our nearest celestial neighbor, which has an abundance of light and does not require a silvered or aluminized speculum. In order to help aim your telescope, insert a screw eye near the mirror and a brad at the eyepiece end. Aim the telescope as you would a gun.

Insert the completed spool eyepiece into the eyepiece hole and get the moon, by means of the sights, into the approximate field of view. At first you will be a little disappointed for all you will see is a giant glob of light and you are probably thinking —heck this doesn't work at all. But be patient!

Move the eyepiece in and out by means of a screwing movement until at a certain point you will find the glob of light getting into focus. With bated breath you will find yourself adjusting the eyepiece until this glob of light finally resolves itself under your trembling fingers into the rill and valleys, mountains and craters of our nearest heavenly neighbor. A never-to-be-forgotten thrill!