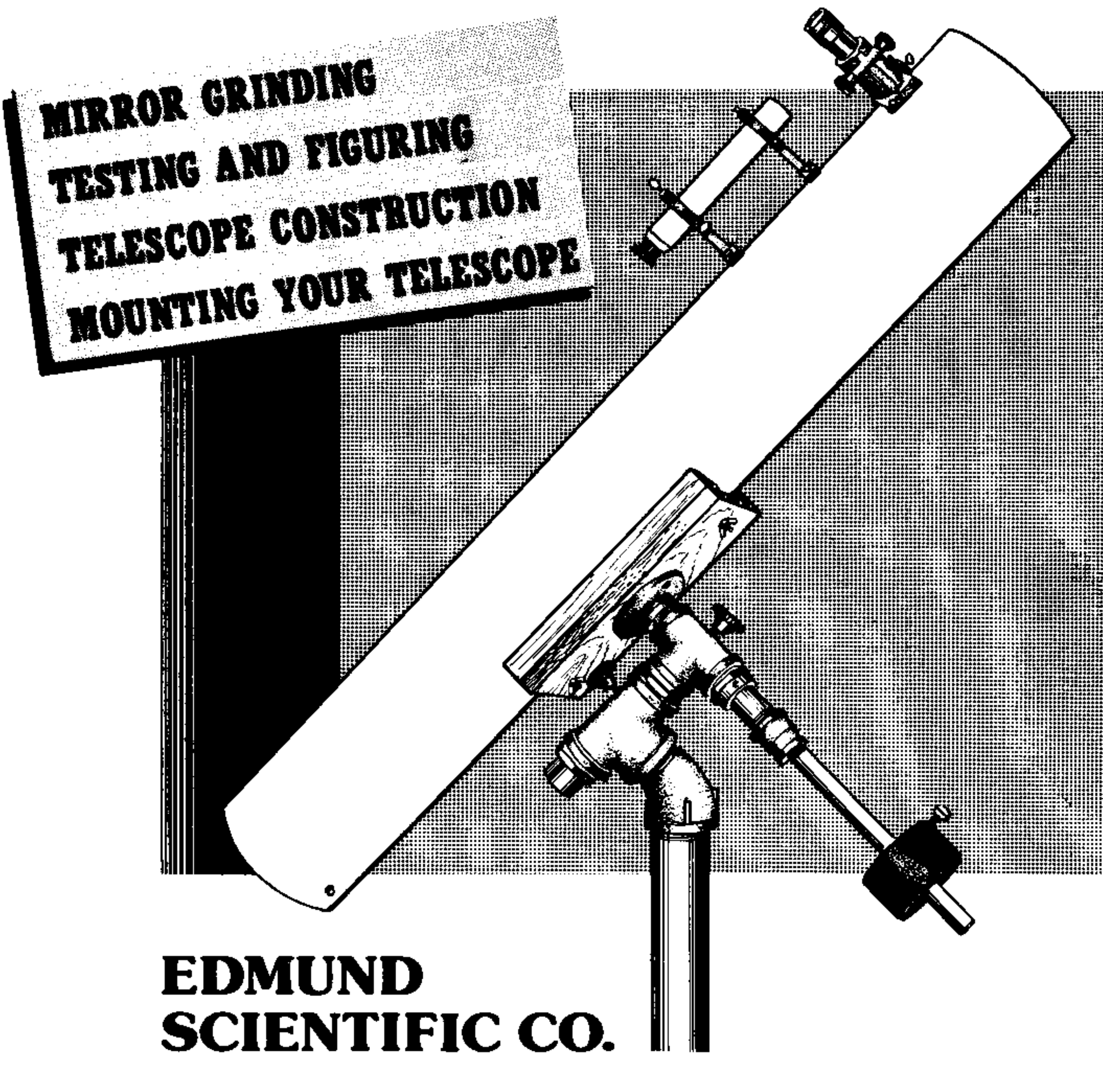
HOMEBUILT REFLECTOR TELESCOPES

No. 9066

By Sam Brown



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INTRODUCTION

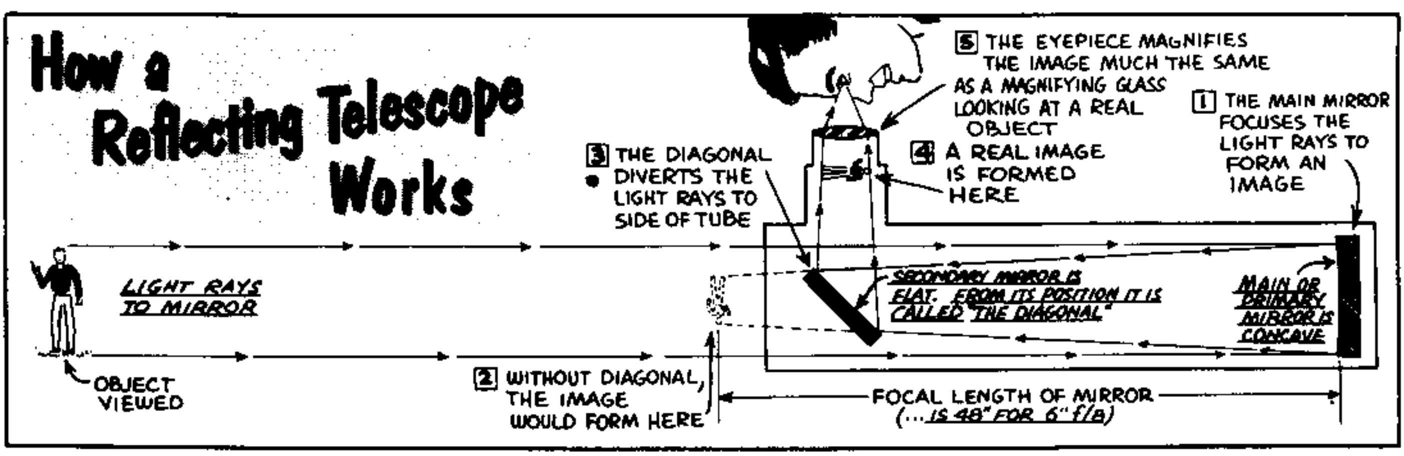
TELESCOPE BUILDING is a hobby any person can enjoy regardless of manual skill or workshop equipment. The easy way, of course, is to buy your optics and parts ready-made, thereby reducing the job to a simple matter of assembly. The most satisfaction is obtained when you make some or all of the parts yourself, and the biggest thrill of all is to grind and polish your own mirror. With your own hands you can fashion a glass surface accurate to a millionth of an inch.

In precision work mirror grinding is unique in that the high degree of accuracy required can be obtained with the crudest kind of makeshift equipment. All you need is some kind of solid support to hold the work at about waist level. Then if you rub two disks of glass together, one on top of the other with abrasive grains and water between, the top disk will automatically become hollow (concave) while the bottom disk will become convex. Since you want a concave mirror, the top disk becomes the mirror, while the lower convex disk is the "tool". If you walk around the work post while rubbing the two disks together, the glass will wear uniformly all around, producing a nearly-perfect segment of a sphere for the simple reason this is the one and only curve which can remain in contact when rubbed together.

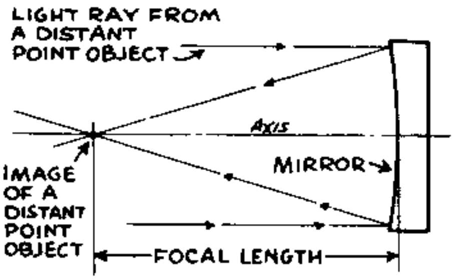
Most beginners know the rest of the story. By using finer and finer abrasive, you make the surface smoother and smoother until finally with red rouge it acquires a shining face of gemlike smoothness. In terms of ordinary accuracy, it will be a perfect spherical section, but for the super-precision required in optical work, the 25 millionths it may be in error becomes an item of considerable importance.

Up to this point, any 12-year old can do the work because the job is a routine procedure requiring only neatness and thoroughness. Youngsters being what they are, it is not strange that the most common defect is plain, ordinary lack of polish. Providing the mirror has a good polish, any shape near a sphere will form a good image.

Most of the actual work in making a first mirror of top quality comes in testing and correcting. This is more than just making a stab at parabolizing; it means that you stick with correcting technique until you acquire the know-how and skill to correct a glass surface with reasonably predictable results. This is a skill you don't acquire by mere reading. Like punching a typewriter, plastering a wall or hitting a golf ball, it takes practice. You can expect up to a hundred hours of study and practice before you become an expert glass pusher.

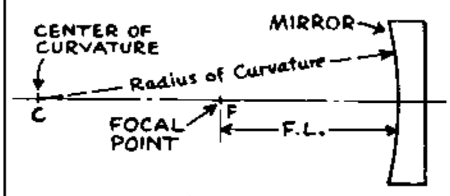


FIRST FACTS about Telescope Mirrors



FOCAL LENGTH

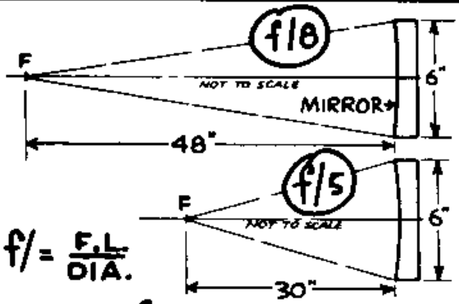
DISTANCE FROM SURFACE OF A MIRROR TO THE POINT WHERE IT FORMS AN IMAGE OF DISTANT OBJECT



ALL TELESCOPE MIRRORS: F.L. = 1/2 Radius; Radius = 2 × F.L.

RADIUS OF CURVATURE

THE RADIUS OF A SPHERICAL MIRROR, OR, RADIUS OF CENTER ZONE OF A PARABOLIC MIRROR



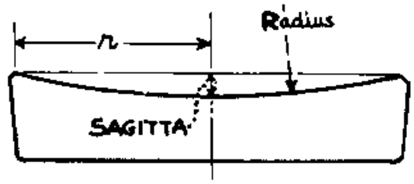
$f/ = \frac{F.L.}{DIA.}$

f/ VALUE

THE FOCAL LENGTH OF A LENS OR MIRROR DIVIDED BY ITS DIAMETER. f/8 IS MOST COMMON

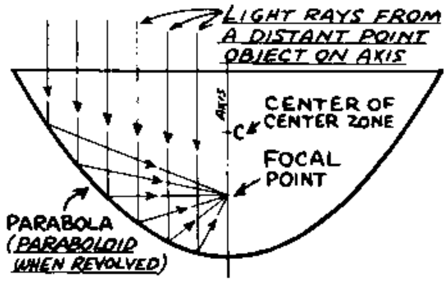
SAGITTA FORMULA:

$SAG = \frac{r^2}{2R}$ (*EXACT FOR PARABOLA AND NEARLY SO FOR SPHERICAL MIRROR*)



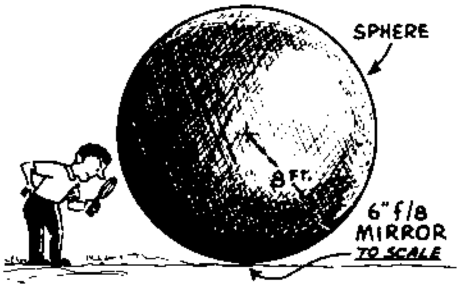
SAGITTA

THE DEPTH OF A CURVE. THE SAGITTA FORMULA IS USED TO CALCULATE ALL TELESCOPE MIRRORS



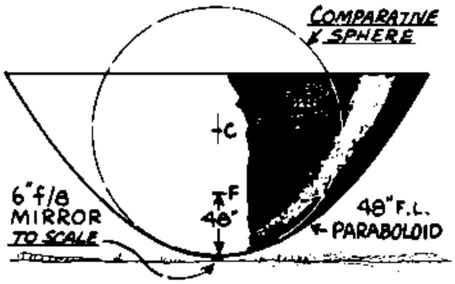
PARABOLA

A CURVE WHICH REFLECTS PARALLEL LIGHT TO A POINT. *THE PARABOLA REVOLVED FORMS A PARABOLOID*



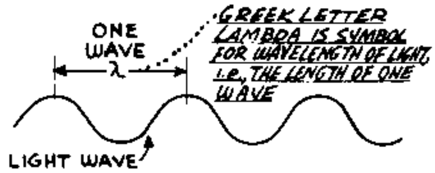
SPHERICAL MIRROR

A MIRROR WITH A SPHERICAL SURFACE. THIS SHAPE MAKES A GOOD TELESCOPE IF f/VALUE IS f/10 OR HIGHER



PARABOLIC MIRROR

A MIRROR WITH A SURFACE WHICH IS A REVOLUTION OF A PARABOLA. IT IS THE PERFECT SURFACE FOR TELESCOPES



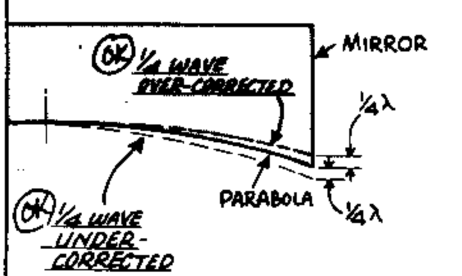
ONE WAVE (λ) = .000022" (*22 MILLIONTHS-OF-AN-INCH*)

1/4 WAVE ($\frac{1}{4}\lambda$) = .0000055" (*5 1/2 MILLIONTHS-OF-AN-INCH*)

1/8 WAVE ($\frac{1}{8}\lambda$) = .00000275" (*2 3/4 MILLIONTHS*)

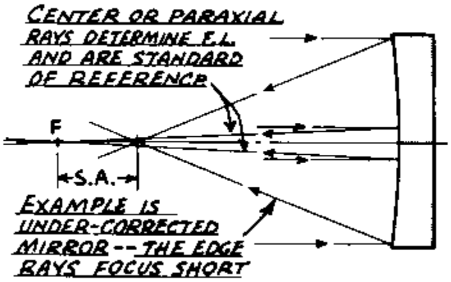
WAVELENGTH OF LIGHT

. . . IS USEFUL AS A UNIT OF MEASURE TO SPECIFY THE SURFACE ACCURACY OF A LENS OR MIRROR



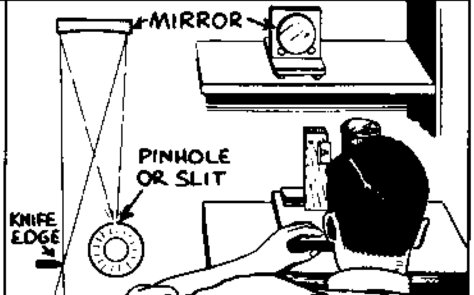
1/4-WAVE MIRROR

A MIRROR WILL PERFORM CLOSE TO PERFECTION IF ITS CURVE IS SMOOTH AND NOT OVER 1/4-WAVE FROM THE IDEAL PARABOLIC SHAPE



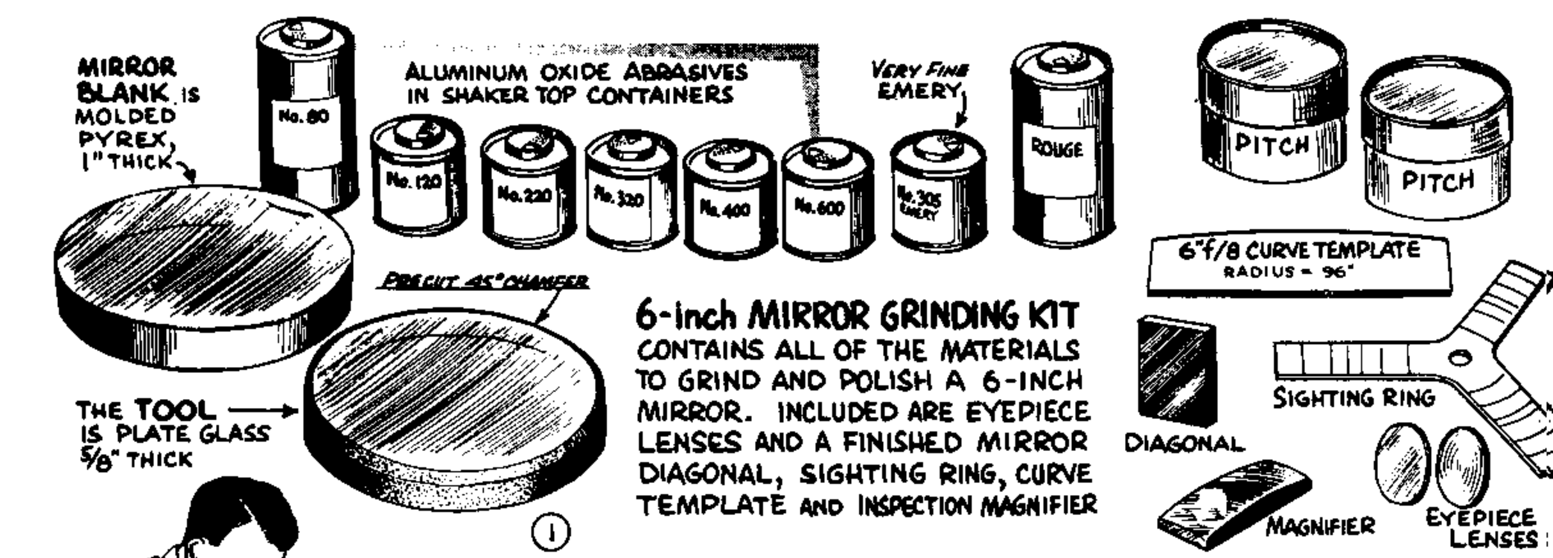
SPHERICAL ABERRATION

THE VARIATION IN FOCUS BETWEEN EDGE RAYS AND CENTER RAYS. IT IS THE ONLY ABERRATION YOU HAVE TO DEAL WITH IN GRINDING YOUR OWN MIRROR



THE SHADOW TEST

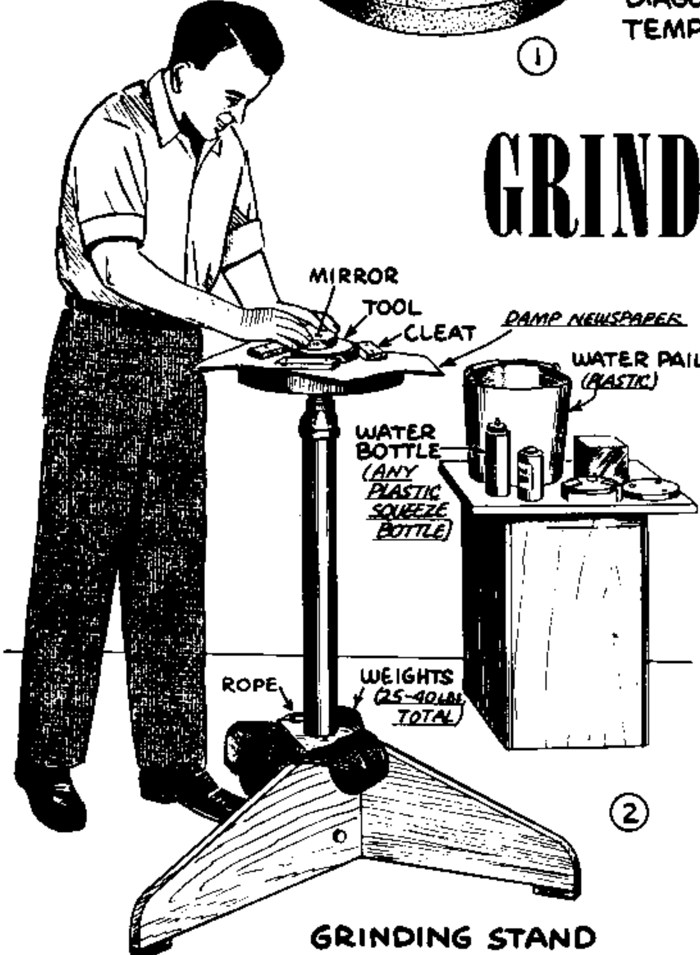
SHADOW OR KNIFE-EDGE TEST ORIGINATED BY FRENCH PHYSICIST, JEAN FOUCAULT, LETS YOU SEE AND MEASURE SHAPE OF MIRROR TO 1/12 WAVE



6-inch MIRROR GRINDING KIT CONTAINS ALL OF THE MATERIALS TO GRIND AND POLISH A 6-INCH MIRROR. INCLUDED ARE EYEPIECE LENSES AND A FINISHED MIRROR DIAGONAL, SIGHTING RING, CURVE TEMPLATE AND INSPECTION MAGNIFIER

①

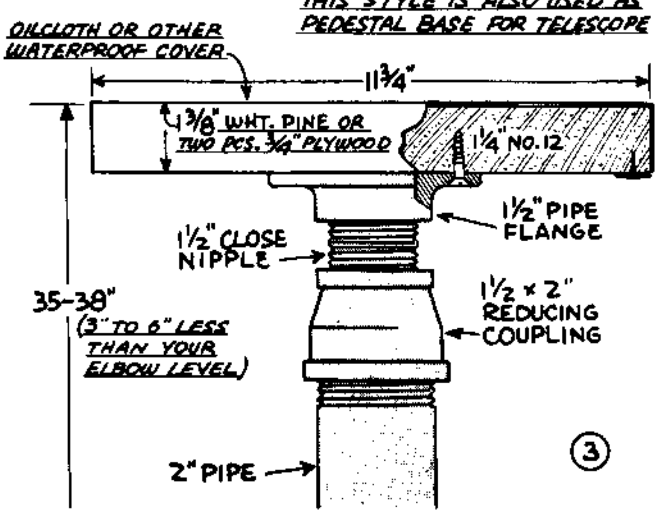
GRINDING your own MIRROR



②

GRINDING STAND

THIS STYLE IS ALSO USED AS PEDESTAL BASE FOR TELESCOPE



③

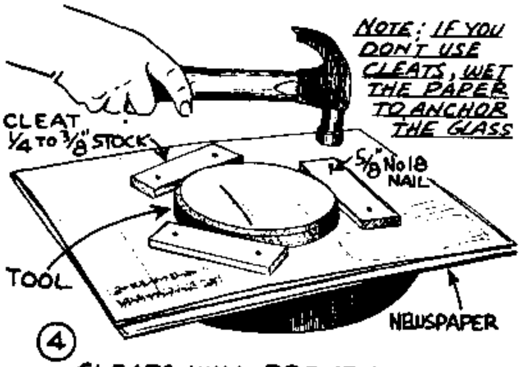
EVERYTHING needed to grind a mirror is commonly purchased in a mirror grinding kit, Fig. 1.
A few dollars spent for a rubber pitch lap mat (see page 10) is worthwhile.

The advantages of Pyrex® are that it is tougher, scratches less easily and has only 1/3 the expansion of plate glass (expansion per ° Centigrade plate glass .0000091, Pyrex® .0000031).

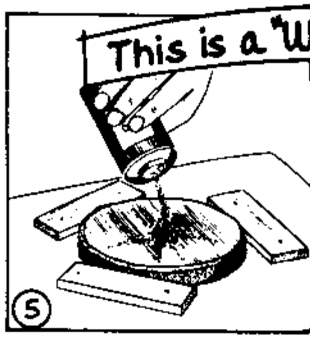
GRINDING STAND. For comfort, this should be fairly high, about waist level. An old oil drum with water ballast does nicely. A sturdy box or crate loaded with a sand bag, concrete block or other weight is satisfactory. If you must make something, a happy solution is the pedestal base, Fig. 2, which you will later use to mount the telescope. Of course, you have to keep hopping over the sprawling legs, but this is altogether a minor matter. In any case you should be able to walk completely around the stand since the walk-around is one of the secrets of successful mirror grinding.

GRINDING STROKE. The back and forth stroke used in mirror grinding has its amplitude measured in mirror diameter. A full stroke indicates a total travel equal to the mirror diameter; a one-third stroke means the glass travels 2 inches, Fig. 8. The one-third stroke is used for about 75% of all grinding and polishing operations. The full stroke is used right at the beginning when you form the curve and again at the end of the polishing job when you go from sphere to parabola. In all cases, one stroke indicates the combined forward and back movement. The speed should be about 60 strokes a minute.

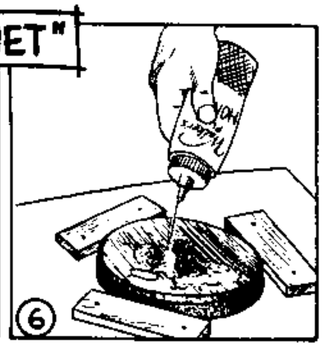
GREATEST WEAR. Fig. 9 diagram shows the basic



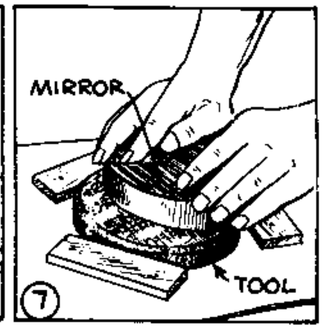
④ CLEATS WILL PREVENT SKIDDING WHEN DOING THE HEAVY, ROUGH GRINDING



⑤ ... A CHARGE OF DRY ABRASIVE



⑥ ... A SPRINKLE OF WATER

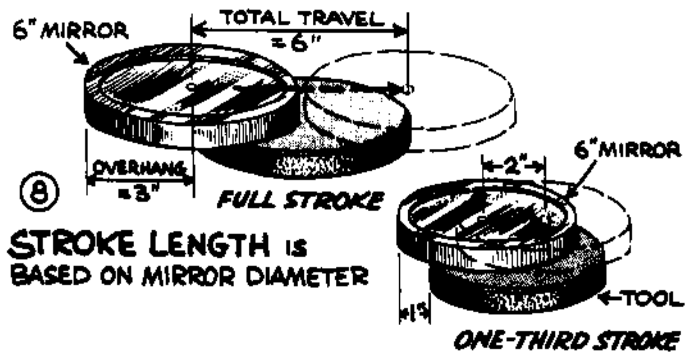


⑦ ... A FEW MINUTES OF BACK AND FORTH RUBBING

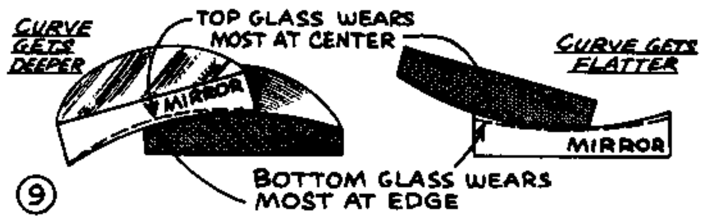
principle of mirror grinding and polishing. The top glass wears most at the center; the bottom glass wears most at the edge. The action will be rapid with a long stroke; slower but more uniform with a short stroke. Since the mirror is to have a concave surface, it becomes obvious it must be on top to form the curve. Less obvious is the case shown at right in Fig. 9 where with tool on top, the mirror curve will flatten. By using mirror or tool on top as needed, you can control the shape of the surface.

THREE MOVEMENT. The three movements used in mirror grinding are shown separately in Fig. 10, and the combined movements which form the grinding cycle are shown in Fig. 11. There are no strict rules regarding the magnitude of the rotation and walk-around, but if you want some average figures, it can be said you will make about 15 steps around the post and the mirror will turn around twice in your hands during this period. Once you start actual work your own personal style of grinding motions will develop naturally. The mirror's edge normally gets the least grinding action. You can speed up the operation by grinding half of the time with the mirror in top position then alternating it with the tool in the top position.

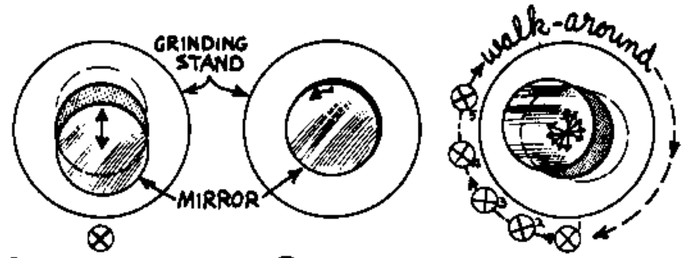
FORMING THE CURVE. The commonest way of doing this is to use a full stroke, that is, 3-inch



⑧ STROKE LENGTH IS BASED ON MIRROR DIAMETER

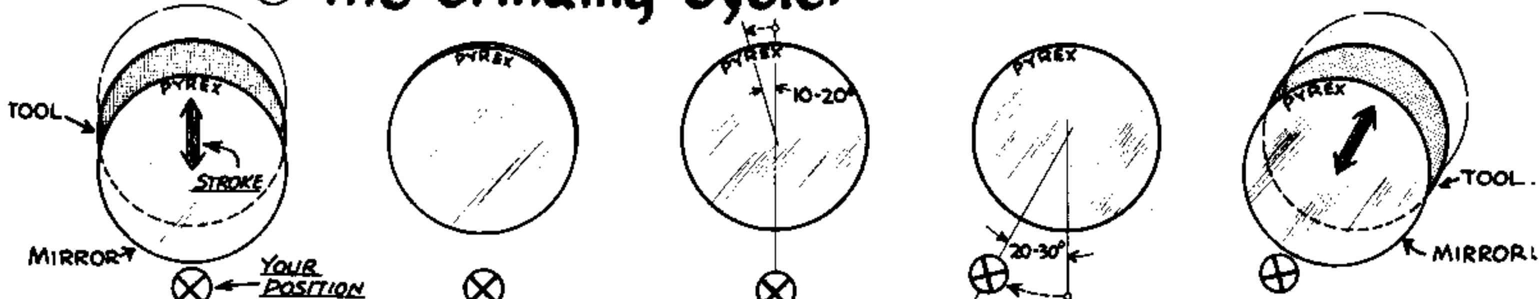


⑨ GREATEST WEAR



⑩ THREE MOVEMENTS OF GRINDING
THE BACK AND FORTH STROKE DOES THE ACTUAL GRINDING... *ROTATION AND WALK-AROUND DISTRIBUTE THE WEAR*

⑪ **The Grinding Cycle:**



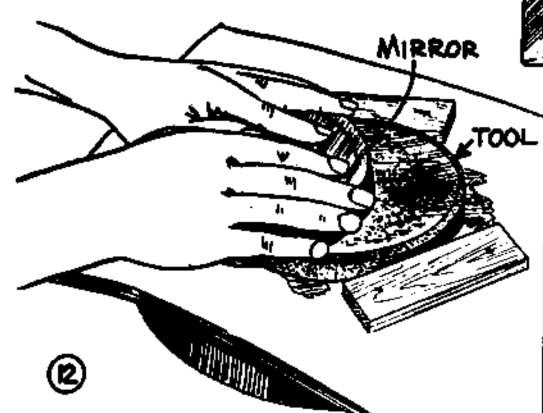
START WITH TWO DISKS CENTERED. MAKE SEVERAL STROKES IN SAME POSITION

END FIRST GROUP OF STROKES WITH DISKS APPROXIMATELY CENTERED

TURN TOP DISK A LITTLE. TAKE YOUR HANDS OFF THE GLASS...

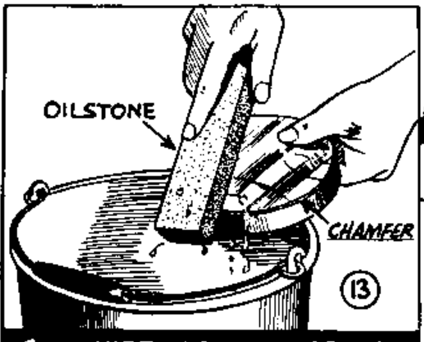
...AND SIDE STEP TO A NEW POSITION

MAKE SEVERAL STROKES IN NEW POSITION. *REPEAT THE CYCLE*

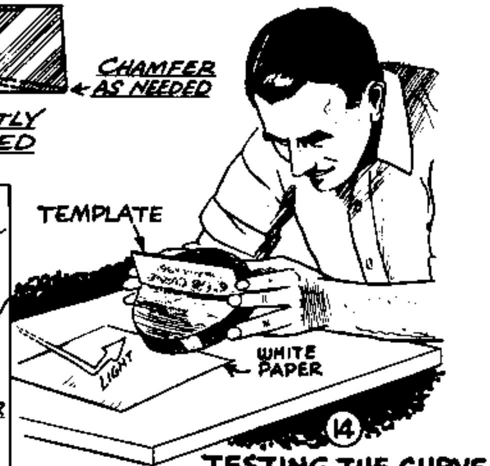


12

FORMING THE CURVE
IS A SIMPLE OPERATION WITH FULL STROKE, CENTER-OVER-CENTER



13 CHAMFERING THE EDGE



14 TESTING THE CURVE

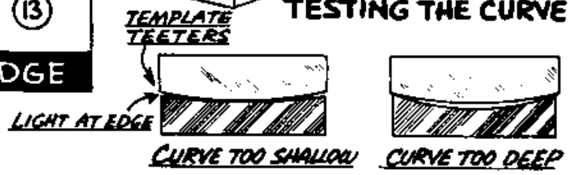
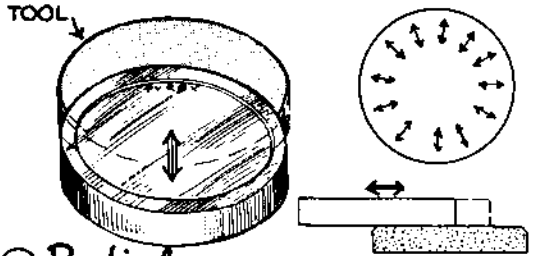


TABLE 1 GRINDING SCHEDULE*

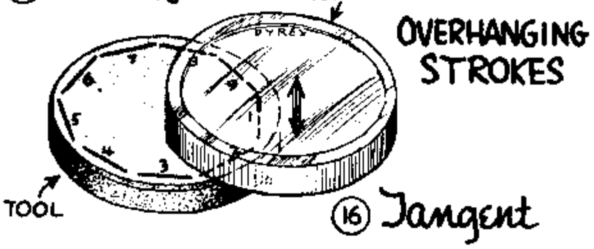
	ABRASIVE	NUMBER OF WETS	AMOUNT OF ABRASIVE PER WET	TIME PER WET	TOTAL TIME
ALUMINUM OXIDE	№ 80 FORMING	20-30	½ Teaspoon (FULL-SIZE)	1-4 Min.	2 Hrs.
	№ 80 SMOOTHING	15-20		2-4 Min.	2 Hrs.
	№ 120	12-15		5 Min.	1 Hr.
	№ 220	8-12	¼ Teaspoon	5 Min.	1 Hr.
	№ 320	6-10		5 Min.	1 Hr.
	№ 400	6-8	⅛ Teasp.	5-10 Min.	1 Hr.
	№ 600	6-8	1/16 Teasp.	5-10 Min.	1 Hr.
EMERY	№ 305 †	6-8	1/20 Teasp.	5-10 Min.	2 Hrs.
					11 Hrs.

*6" MIRROR

†MIX 305 EMERY WITH WATER AND APPLY WITH BRUSH. THIS ELIMATES SCRATCHING



15 Radial



16 Tangent

overhang at each end of the stroke, Fig. 12. You can tell the abrasive is working by the harsh, grating growl it makes when it bites into the glass. However, you lose this quickly as most of the abrasive is pushed off over the edge of the tool. It is not a total loss because it can be scooped up later and used again. The first few wets with No. 80 will last hardly a minute, but by the time you have gone twice around the post you will be getting more mileage out of each charge. Do a couple more turns and then dunk both mirror and tool in the water bucket to remove the sludge. Sure enough, a little hollow is beginning to appear at the center of the mirror!

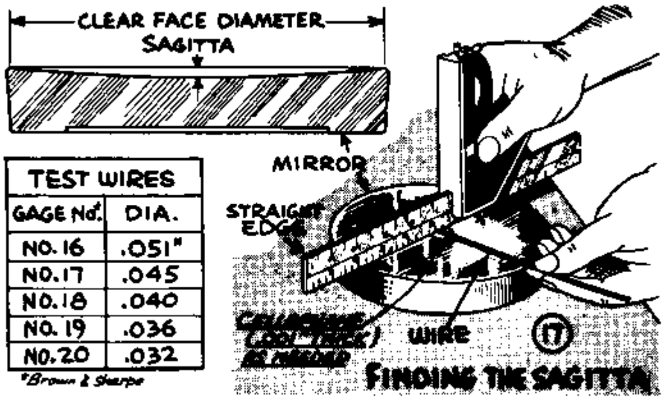
As soon as you can get about three minutes of grinding time per wet, the water bottle, Fig. 6 can be discarded. Instead, you wash both mirror and tool for each new charge of abrasive, using both disks wet from the water bucket. Grinding the curve takes about two hours. The work must be done with a fair amount of pressure of from 15 to 20 lbs. The rolling action of the abrasive grain builds up pressure on the sharp cutting edges of the abrasive. This chips out small pieces of the glass surface. Too much pressure crushes up the abrasive and you get no "chipping out". It is instructive to press your hands on the bathroom scales to register at least 20 lbs., and then maintain this in the actual grinding. Several work periods of 15 or 20 minutes at 20 lbs. will get the job done in the allotted 2 hours time. It will take an extra hour to smooth the roughly-formed curve to an accurate sphere.

CHAMFER. The edge of a Pyrex disk is gently rounded as purchased and needs no attention if you can obtain the desired surface curve without removing too much of the edge. However, if the edge starts to wear to a sharp edge liable to chip, it should be cut back with a 45-degree chamfer about 1/16 in. wide, using a fine oilstone, with water lubricant, Fig. 13. Lacking the oilstone you can use No. 220-grit abrasive made up with water to form a paste applied with a piece of metal or glass. The glass tool as purchased is already chamfered.

TESTING THE CURVE. All the time you are grinding the curve you have to watch its shape and depth. Start using a template early, Fig. 14. The cardboard template you get with the kit is satisfactory for rough testing but you may prefer to make something more accurate from sheet metal. Another useful mechanical check is to measure the sagitta, Fig. 17. If you are working a 6-inch, f/8 mirror, the ultimate goal is 48 in. focal length or 96 in. radius, but a focal length a couple inches more or less does no harm. A goodly amount of radius adjustment can be made during fine grinding. If the mirror is worked on top (the usual case), the radius will shorten; if the tool is on top, the radius will lengthen. Using a one-third stroke throughout, you can expect a maximum change of about 6 in. radius if you use one position exclusively during fine grinding.

ALTERNATE FORMING STROKES. Most mirror grinders like to see a hollow form in the center of the mirror without delay. This impatience to get on with the job has popularized various overhanging strokes, all of which are aimed at wearing the center of the mirror directly over the edge of the tool. You can use either a radial stroke, Fig. 15, or a tangent stroke, Fig. 16. The radial stroke is very much like one end of the long stroke already described. The tangent stroke is a one-third stroke with side overhang and is worked on 10 or 15 chords spaced around the edge of the mirror. Use the standard grinding cycle, Fig. 11. The first walk-around with either of these strokes is done with the center of the mirror almost directly over the edge of the tool. Following rounds are made with less and less overhang until the stroke assumes the normal center-over-center position.

SMOOTHING THE CURVE. As soon as you think the sag is about right, switch to a one-third or shorter stroke and continue with No. 80-grit until good contact is obtained. The commonest test for contact is merely a matter of watching the bubbles that form between the disks during grinding. By manipulating the top disk, you can move an air bubble from center to edge, and its changing size will show hollows and ridges if



TEST WIRES	
GAGE No.*	DIA.
NO. 16	.051"
NO. 17	.045
NO. 18	.040
NO. 19	.036
NO. 20	.032

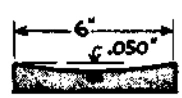
*Brown & Sharpe

FINDING THE SAGITTA

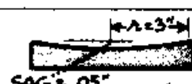
TABLE 2 FOCAL LENGTH OF 6" MIRROR WHEN SAGITTA IS KNOWN

SAGITTA	CLEAR FACE DIAMETER				
	5 3/4"	5 13/16"	5 7/8"	5 15/16"	6"
.038"	54.38"	55.57"	56.77"	57.98"	59.21"
.039	52.98	54.14	55.31	56.49	57.69
.040	51.66	52.79	53.93	55.08	56.25
.041	50.40	51.50	52.61	53.74	54.88
.042	49.20	50.27	51.36	52.46	53.57
.043	48.05	49.10	50.17	51.24	52.32
.044	46.96	47.99	49.03	50.08	51.13
.045	45.92	46.92	47.94	48.96	50.00
.046	44.92	45.90	46.89	47.90	48.91
.04687					48.00
.047	43.96	44.93	45.90	46.88	47.87
.048	43.05	43.99	44.94	45.90	46.87
.049	42.17	43.09	44.02	44.97	45.92
.050	41.33	42.23	43.14	44.07	45.00
.051	40.52	41.40	42.30	43.20	44.12
.052	39.74	40.61	41.48	42.37	43.27
.053	38.99	39.84	40.70	41.57	42.45
.054	38.27	39.10	39.95	40.80	41.66
.055	37.57	38.39	39.22	40.06	40.91
.056	36.90	37.71	38.52	39.34	40.18
.057	36.25	37.04	37.84	38.65	39.47
.058	35.63	36.41	37.19	37.98	38.79
.059	35.02	35.79	36.56	37.34	38.13
.060	34.44	35.19	35.95	36.72	37.50

Example SHOWING USE OF TABLE:
YOUR MIRROR IS 6" CLEAR FACE AND SAGITTA IS .050"
From Table: F.L. = 45"

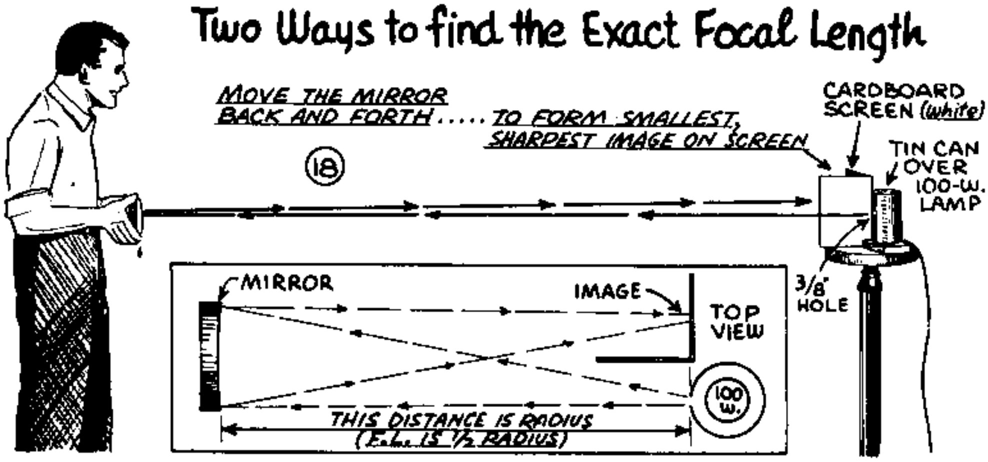


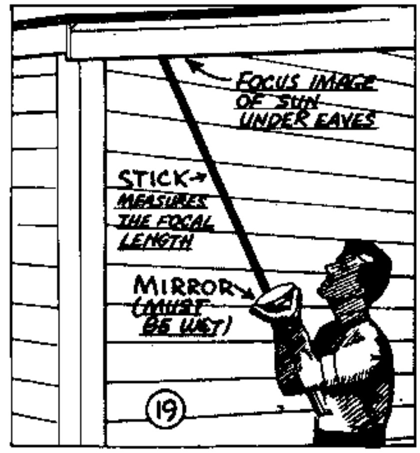
Formula FOR CASES NOT COVERED BY TABLE:



$$F.L. = \frac{r^2}{SAG} \times \frac{1}{4}$$

Example: $F.L. = \frac{3^2}{.05} \times \frac{1}{4} = \frac{9}{.20} = 45"$





present. Another simple test is done with a wrinkled and re-smoothed strip of cellophane pressed between the glass disks--it should press equally flat all over. Also popular is the trick of drawing a line across the face of the mirror with waterproof ink and then noting if this wears evenly when grinding is resumed. Perfect contact means you have a perfect spherical shape.

FINE GRINDING. Follow the schedule in Table 1. Naturally, you have to clean up thoroughly after each grade, changing paper and water, etc., to prevent stray coarse grains from getting into the act. The one-third stroke is used throughout. A charge of abrasive should last for about five minutes or two or three turns around the barrel. When the water starts to dry, the disks will start to stick together. At this point you are probably two times or more around the barrel and can call that wet finished. Alternately, it is practical to add more water from the squeeze bottle. This prolonged grinding is especially useful for the last wet in each grade. Your main water supply comes right from the water bucket where you dunk and clean both disks before charging with fresh abrasive. A certain amount of tool-on-top grinding is recommended to assure equal wear at the edge of the mirror--use this for at least two wets per grade. If you like a handle or push block, the snap-on type shown in Fig. 21 can be fitted or removed instantly. If you get tired, a 15 lb. weight on top of the glass will substitute for hand pressure.

IMPORTANT HINT. If mirror and tool "freeze together" during grinding use wooden block against edge of mirror and drive apart with mallet.

FINDING EXACT F.L. A simple reflection test can be used, Fig. 18. The mirror must be wet with water to make it reflective; a few drops of glycerin added will keep the surface wet much longer. The room must be dark. The screen should be ample size to simplify picking up the image, which is faint and elusive in the early stages of grinding.

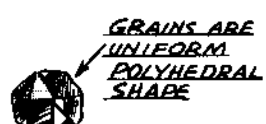
If sunlight is available, the test shown in Fig. 19 can be used. Stand alongside a garage or porch so that the mirror is in sunlight but your face is shaded. This test measures the focal length directly, which can be marked on a stick held in your hand as shown. The image of the sun will be a little under 1/2 in. diameter. More glycerin and less water will keep the mirror reflective for several minutes.

Abrasives

SILICON CARBIDE

IS VERY HARD, SHARP AND BRITTLE. EXCELLENT FOR FAST REMOVAL OF GLASS BUT TOO DRASTIC FOR FINE OPTICAL WORK

TRADENAMES: CARSILON, CARBORUNDUM, CRYSTOLON

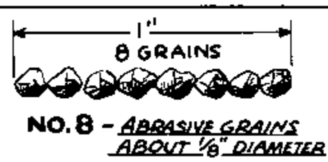


ALUMINUM OXIDE

VERY TOUGH, BUT NOT AS HARD AS SILICON CARBIDE. SMOOTH AND UNIFORM CUTTING ACTION MAKES IT IDEAL FOR MIRROR GRINDING

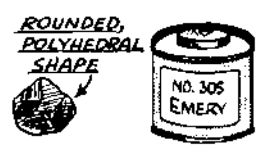
TRADENAMES: ALOXITE, ALUNDUM, LIONITE

BOTH ALUMINUM OXIDE AND SILICON CARBIDE ARE ARTIFICIAL ABRASIVES, PRODUCTS OF THE ELECTRIC FURNACE



GRIT SIZE

TO A ROUGH APPROXIMATION, THE GRAIN SIZE OR GRIT INDICATES THE NUMBER OF GRAINS PER INCH. GRITS TO NO. 220 ARE GRADED BY PASSING THROUGH WIRE SCREENS WHILE FINER (FLOUR) SIZES ARE GRADED BY WATER FLOTATION



EMERY

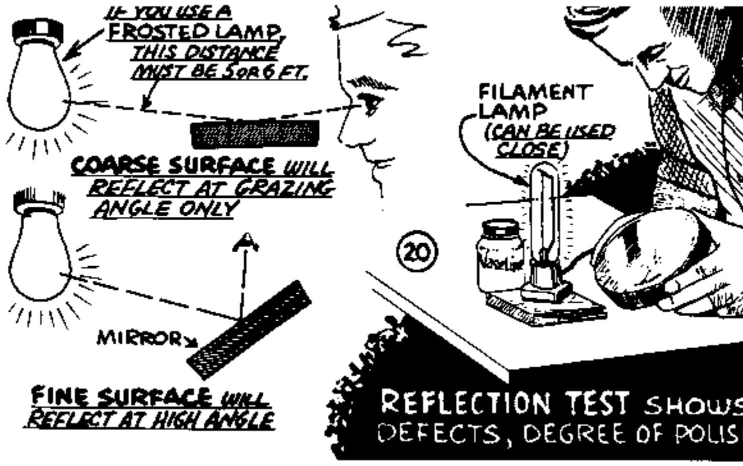
EMERY IS A NATURAL ABRASIVE MINED FROM THE GROUND. IT IS SIMILAR TO ALUM. OXIDE BUT SOFTER. NO. 305 FURNISHED WITH MIRROR KITS IS A CATALOG NUMBER--NOT A GRIT SIZE. COMPARATIVELY, NO. 305 EMERY IS ABOUT 1000 GRIT

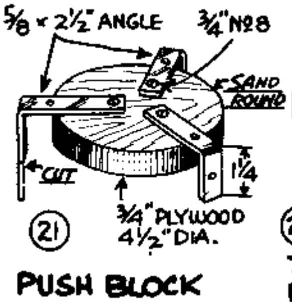
REFLECTION TEST. On grits No. 120 and finer, a reflection test is excellent for checking both the shape of the mirror and its surface smoothness. This is done with a dry mirror, Fig. 20. When the surface is coarse, you can see the lamp reflection only at a low angle, as shown. The shape of the curve is checked by turning the mirror slightly to cause the reflection to move across the mirror. Any sudden brightening indicates a ridge: any decrease in brightness means a low spot. If the reflection remains the same brightness from center to edge, the surface is spherical. The most common fault is a decrease in brightness at the edge. This is always the last to grind and polish out; hence you see the dimmer reflection from the coarser surface of the previous grade. Test after each grade and continue with each grade until the reflectivity appears uniform from center to edge of mirror.

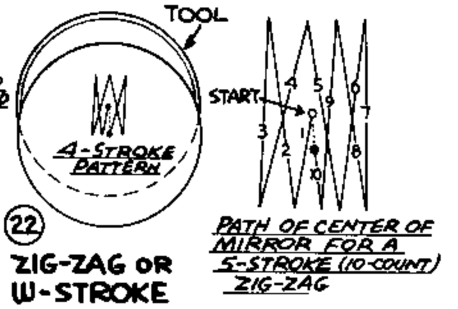
You will pick up a secondary reflection from the back of the mirror. If annoying, this can be eliminated by spreading a thin coat of vaseline on the back of the mirror. The test lamp can be any wattage, filament or frosted. A filament lamp can be used at close range, as shown, but a frosted lamp must be viewed from 5 or 6 ft. to kill diffuse reflections.

THE W-STROKE. Toward the end of fine grinding, start learning the zig-zag or W-stroke shown in Fig. 22. The pattern can be any number of strokes from about 4 to 10--a 5 or 6-stroke pattern is average. This is a blending stroke and produces a better surface than a straight center-over-center stroke. The side overhang should be about 1/2 in. each way.

FINAL GRINDING. The final grind with No. 305 emery can be prolonged to advantage, adding water only. Hand pressure tapers off gradually with the use of finer grits, and when you get to the finest grade it is hardly more than the







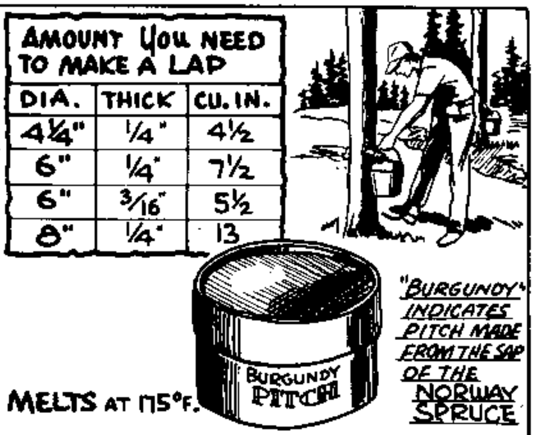
weight of your hands on the glass. It is a good idea to eliminate air bubbles on this and the previous grade, and this is easily done by sliding the mirror nearly off the tool and then slowly sliding it back to center; do this after you have made about a half-turn around the barrel.

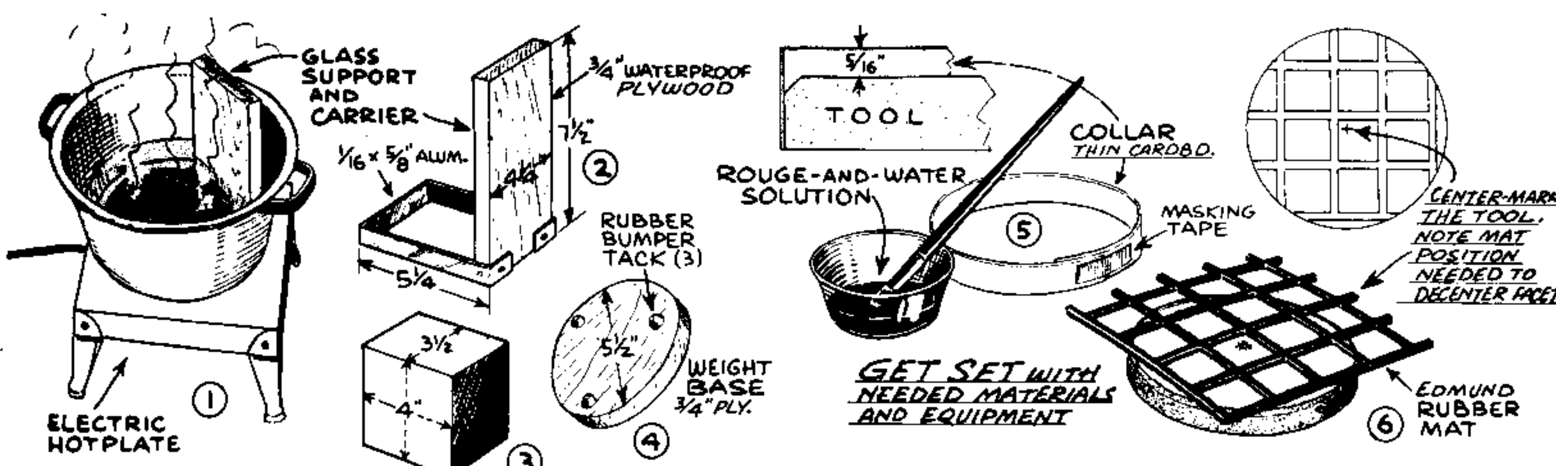
ARE YOU READY TO POLISH? Do not abandon grinding until you are sure you have a smooth surface and a good sphere. The surface is smooth if you can read a newspaper through it with the mirror several inches from the paper. The surface is both smooth and spherical if it passes the reflection test already described at a 45 degree angle. And, of course, the surface should look smooth and uniform--any kind of bloom or shading is a sure indication of insufficient grinding.

Pitch Most of the optical pitch is obtained from certain pine and spruce trees, that from the Norway spruce being rated especially good. The resinous sap is boiled and refined to produce a semi-solid product, which is further tempered by the addition of pine rosin, turpentine and beeswax. Pitch will burn but it is not explosive in the manner of gasoline and only ordinary precautions are needed in melting it. It can be melted in a tin can directly over an electric hot plate; if you use an open flame, put the tin can in a pan of water. Heat slowly, let cool a half-minute before pouring, and pour slowly on the warm tool. The difficulty of making a pitch lap increases with its thickness--beginners take notice!

AMOUNT YOU NEED TO MAKE A LAP

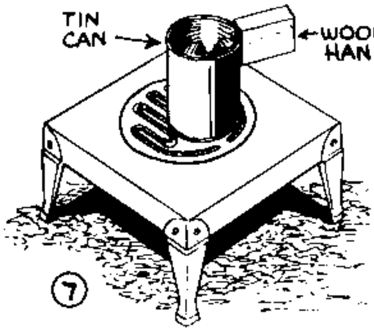
DIA.	THICK	CU. IN.
4 1/4"	1/4"	4 1/2
6"	1/4"	7 1/2
6"	3/16"	5 1/2
8"	1/4"	13



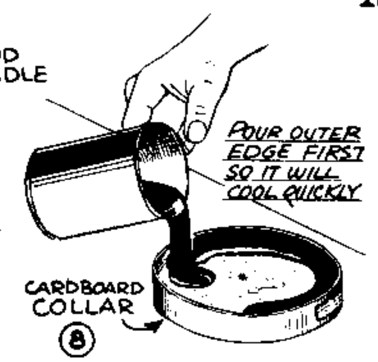


EDMUND RUBBER MAT METHOD

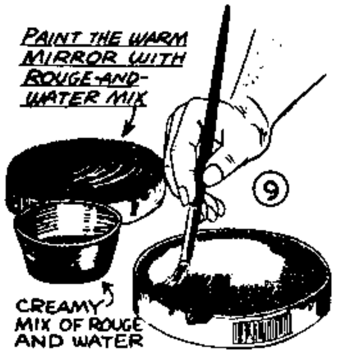
Making a PITCH LAP



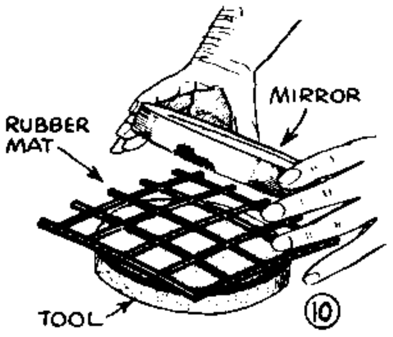
MELT THE PITCH IN A TIN CAN... IT WILL MELT IN LESS THAN 10 MINUTES



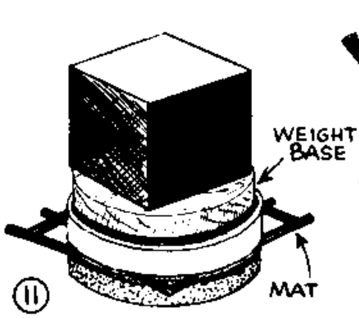
POUR THE PITCH OVER THE DRY, WARM TOOL. COLLAR IS ROUGED TO AVOID STICKING



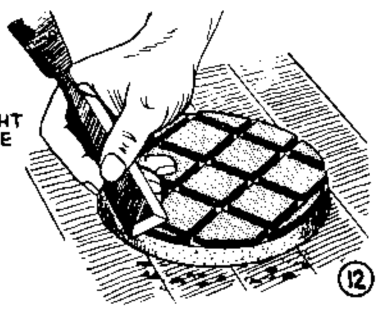
PAINT THE PITCH WITH ROUGE AND WATER. STRIP THE COLLAR AFTER PAINTING



PRESS THE MAT INTO THE WARM PITCH BY PLACING THE PAINTED MIRROR OVER IT



PRESS WITH **WEIGHT** IF PITCH GETS TOO HARD FOR EASY FORMING. *REHEAT THE WHOLE LAP IF NEEDED AS SHOWN AT TOP OF PAGE*



TRIM THE LAP WITH A WOOD CHISEL OR RAZOR BLADE. *INCLINE THE EDGE A LITTLE TO MAKE LAP ABOUT 1/16" LESS THAN MIRROR DIAMETER*

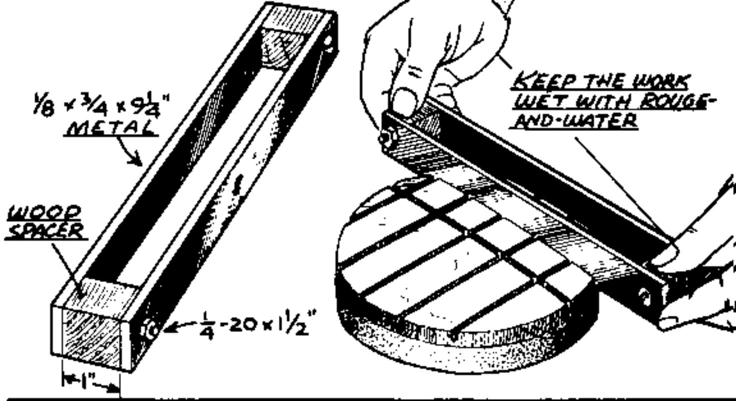
THE FASTEST and easiest way to make a pitch lap is by pressing the channels with a rubber grid while the pitch is warm. The work equipment--Figs. 1 to 4--will be used throughout the polishing operation. The rouge-and-water mixture used to prevent the hot pitch from sticking to the mat and mirror is made from one level tablespoon of rouge to four water. If you want to conserve rouge, you can substitute some or all soap flakes for the rouge. In either case, the addition of about 10% glycerin helps by retarding the drying speed. Previous to making the lap you should centermark the tool and then note how the mat must be placed to offset the facets, Fig. 6. A centered system of facets should be avoided since it tends to polish rings on the surface of the mirror. A 1/2 lb. carton of pitch will be enough for a 6-inch lap. Hit the carton several times with a hammer and then peel off the wax paper cover, working over a sheet of clean newspaper. Funnel the broken lumps into the melting pot or can.

Hot pitch adheres poorly to cold glass, so you start the job by warming the glass tool. This is done by heating a pan of water with the tool in it. The mirror can be warmed at the same time, the idea of this heating being that a cold mirror might chill the pitch too quickly in the pressing operation, Fig. 10. After heating the water a little hotter than your hand can stand, remove the water pan and start melting the pitch. When the pitch is nearly melted, remove the tool and mirror from the hot water and dry both. Paint the surface of the mirror with the rouge solution. It is also a good idea to paint the rubber mat. Put the tool on a level surface. Paint the inside of the cardboard collar and slip it over the tool. You are all set to pour the lap.

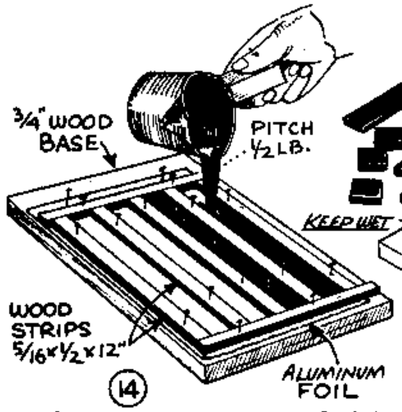
After the pitch is fully melted, remove it from the hotplate, wait about 15 seconds and then pour onto the tool to the level of the cardboard collar, Fig. 8. Wait another 15 seconds and then paint the surface of the pitch, Fig. 9. Strip off the cardboard collar. Put the rubber mat in place and press it down with the mirror, Fig. 10. The mat should sink into the pitch easily with light hand pressure. Take a peek to see how it is doing. If a full impression has not been made, you can use a weight, Fig. 11, for a few minutes or longer. After the channels are formed, remove the mat. Press down lightly with the mirror alone. This may cause the channels to close slightly and if so, put the mat back in place and repress. Repeat pressing with mat-and-mirror and mirror alone until you get a perfect impression and good contact.

If you see the pitch is too cold, put the tool with its pitch coating into the pan of hot water and put the pan on the hotplate. Heat for 3 to 8 minutes as may be needed. You can test the pitch with a screwdriver or stick and so determine the degree of softness which you think is needed to complete the pressing. If you heat the lap too much, the channels already more or less formed will start to run together. This heating needs water hotter than your hand can stand, and that's where the glass support and carrier comes in handy in removing the lap and transporting it to the bench. Then you go through the various operations again. Use plenty of rouge-and-water to prevent sticking. Trim the lap with a sharp wood chisel or razor blade.

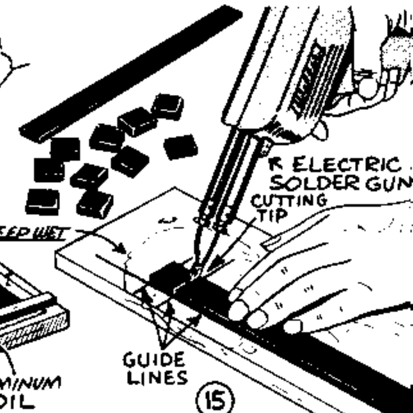
The big 1-5/16 inch facets of the rubber mat are satisfactory for a 6-inch or larger mirror. If desired you can double-press the mat to form a second set of channels with facets about 1/2 inch square. This can be done at any time and is best delayed to the final stages of polishing where the slightly smoother action of the small facets can be used to best advantage.



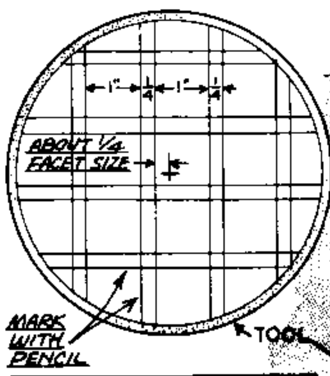
(13) USING A CHANNELING TOOL



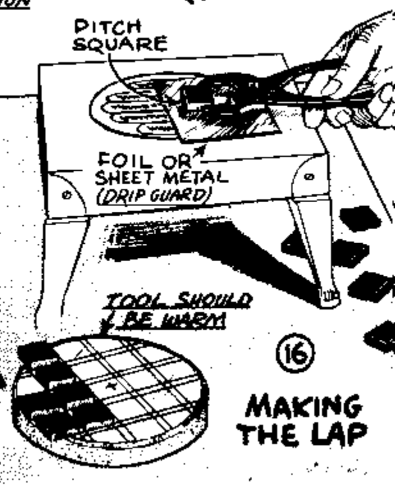
(14) CASTING PITCH STRIPS
PAINT THE FORM WITH ROUGE-AND-WATER SOLUTION



(15) CUTTING SQUARES



INDIVIDUAL PITCH SQUARES

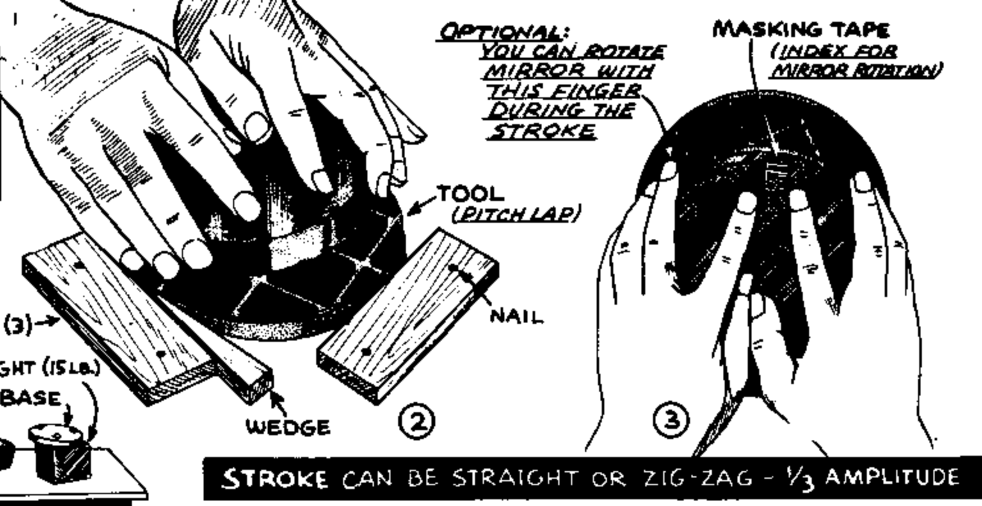


(16) MAKING THE LAP

USING A CHANNELING TOOL. This is identical with the rubber mat method except you use a rigid channeling tool, Fig. 13. Press all of the channels one way and then the other. Alternate with mirror alone until good contact is made.

INDIVIDUAL PITCH SQUARES. This is a long-time favorite, especially useful for steeply-curved mirrors difficult to flow-coat to uniform thickness. The wood mold is a simple job of sawing and nailing; it should be painted with rouge-and-water to prevent sticking. The pitch strips are cut into squares, Fig. 15, with a hot knife or the cutting tip of an electric soldering iron. Each facet square is heated, Fig. 16, and then pressed onto the glass tool. After all facets are in place, perfect adhesion and contact is obtained by heating the lap in water, Fig. 1 and then, pressing with the mirror.

CUTTING METHOD. The direct way to make a lap is to cut the channels with a knife or saw after the pitch is cold. Soapy water is used as a lubricant. This is a messy job because the pitch tends to chip and crack in all the wrong places. If your lap is not perfect don't despair. With care and patience bubble holes and incorrectly cut facets can be repaired with hot pitch. However, with much patience and patching, you can make a fair lap with this method.



it takes 8 to 12 hours POLISHING

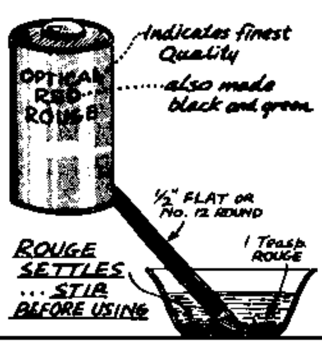
POLISHING is very much like grinding except the abrasive is red rouge and the tool is now a pitch lap. The mirror is on top throughout. The job is simply to get the mirror polished "as clear as glass". This takes some 4 to 6 hours--and kid yourself not that the superficial polish which shows after the first hour is the real thing. The edge will polish out last, so don't be alarmed if a narrow halo persists after 2 or 3 hours.

THE POLISHING STROKE. This can be straight or zig-zag, with an amplitude no more than one-third, or 1 inch overhang at either end of the stroke for a 6 inch mirror. Long strokes should be avoided since the increased overhang tends to turn or flatten the edge of the mirror. Fig. 2 shows the usual hand position, with the thumbs applying modest down pressure at the center. The mirror rotation can be the stop-and-go method described for grinding, or, you can impart the turning movement with your fingers during the stroke, Fig. 3. Both the walk-around and the rotation should be as uniform as possible; stick a piece of masking tape on the mirror and note how smoothly you can make it go around.

The first two hours of polishing can be done with a normal arm action, 60 strokes per minute. For the last hour or two, you can get a smoother surface if you use a body-action stroke, Fig. 1. On a small-top grinding stand such as the one shown, the body stroke can also be done by tucking your elbows into your sides. The rouge-and-water abrasive mix should be thick at the start when contact may be poor or the lap sur-

Polishing Materials

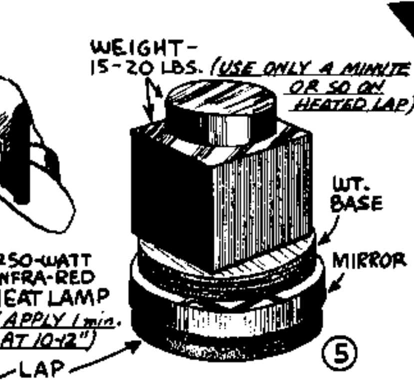
ROUGE IS A FORM OF IRON OXIDE. IT IS A FINE, RED POWDER, MIXING FREELY WITH WATER. IT IS CHEAP AND PRODUCES A GOOD POLISH ... SLOW ACTION HELPS TO KEEP THE BEGINNER OUT OF TROUBLE. MAIN FAULT IS THAT IT STAINS TO SOME EXTENT ... IT IS NOT "MESSY" UNLESS YOU ARE MESSY



[illegible]	
THICK	1 PART ROUGE 4 PARTS WATER *USE AS ANTI-STICK*
MEDIUM	1:6 *FOR INITIAL POLISHING - HOT PRESS - PARABOLIZING*
THIN	1:8 *GENERAL POLISHING*
VERY THIN	1:10 *FINAL POLISHING TO SPHERE*

CERIUM OXIDE IS A PINK METALLIC OXIDE. NON-STAINING. POLISHES ABOUT TWICE AS FAST AS ROUGE. MIXES FAIRLY WELL WITH WATER AND CAN BE COMBINED WITH RED ROUGE

BARNESITE. A TRADENAME MATERIAL MADE OF SEVERAL RARE EARTHS. BROWN COLOR, NON-STAINING, EXTREMELY FINE. DOES NOT MIX READILY WITH WATER. IT CUTS TWICE AS FAST AS ROUGE



HOT PRESSING ASSURES GOOD CONTACT AND SHOULD PRECEDE ALL MAJOR WORK PERIODS. LAP CAN BE HEATED IN HOT WATER OR WITH HEAT LAMP

TRIMMING THE LAP

THE CHANNELS MUST BE KEPT OPEN - THE LAP MUST BE LESS DIAMETER THAN MIRROR

INSPECTION WILL REVEAL PITS ... SUPERFICIAL POLIS IS EASY TO OBTAIN BUT A LOT OF WORK IS NEEDED TO REMOVE FINAL PITS

face sparsely charged. Each wet of rouge should be worked nearly dry since it is in this state that the rouge begins to wipe the glass with a vigorous polishing action. The drying mirror will become harder to push, and when it starts to stick and skip, it is time for a new charge of rouge. Polishing periods should be no less than 30 minutes and better an hour in order to obtain the frictional heat needed to allow the mirror to bed down snugly on its pitch pad.

HOT PRESSING. Do this with hot water heat in the manner described for lap making. Start with cold water. Heat until you see the first wisps of steam and then give it about 20 seconds more. Then proceed with the actual pressing, Fig. 5. An alternate heat treatment employs a heat lamp, Fig. 4, and this is useful for a fast press when the contact is already fairly good. An overnight cold press without weight is a perfect substitute for hot pressing; cover the work with a damp towel to retard evaporation. Various mesh materials such as onion sacking or nylon net can be hot pressed into the lap, producing numerous subfacets which facilitate making contact while giving the lap a good "bite".

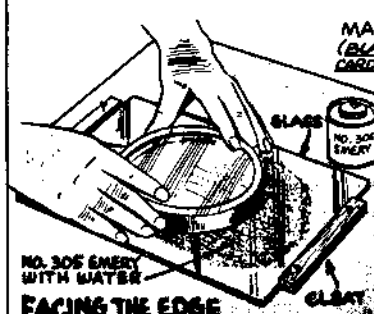
TRIMMING THE LAP. After you have been polishing some 90 minutes, you will note the channels in the lap are beginning to close. Open them up with a sharp knife or chisel, Fig. 6, using a firm, bold stroke. Best results are obtained if the lap is mildly warm, as it will be immediately after polishing. An alternate here is to heat the lap and repress the rubber grid. This takes more time but in the long run it is probably the fastest method. Certainly, it is the neatest. Don't forget to trim around the edge of the lap, always keeping the lap about 1/16 inch less diameter than the mirror. It can be seen that the mirror must cover the lap completely all around to avoid forming a ridge at the edge of the lap during hot pressing. It is also easy to see that a turned edge results when the mirror plows into this ridge when polishing is resumed. Use a thinner rouge solution as polishing nears completion, and slow down the stroke for maximum smoothness. The job is done when the polish extends right out to the edge.

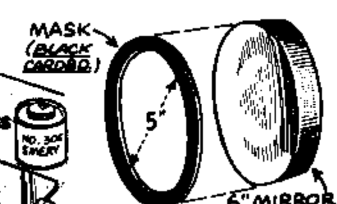
You can stop here!

IF YOU like, you can call your polished mirror finished--9 times out of 10 the surface will be accurate enough to produce a good image. If you want proof before getting the mirror aluminized, you can assemble and test a bare glass telescope. A bare 6-inch f/8 will pick up as much light as a small, 1-1/4-inch refractor --plenty of light to look at the moon or any daytime object.

As a final touch before getting the glass aluminized, it is worthwhile to grind the face, as shown below. 20 or 30 seconds work will put a neat flat rim around your glass.

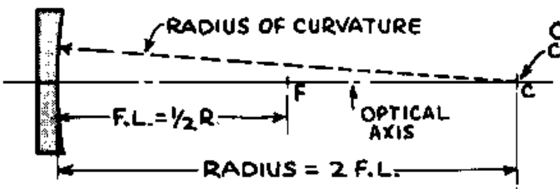
In case you are not satisfied with the imagery of the bare glass telescope, try masking to 5 in. diameter. If the only fault of the mirror is a turned edge, masking will cure it completely.



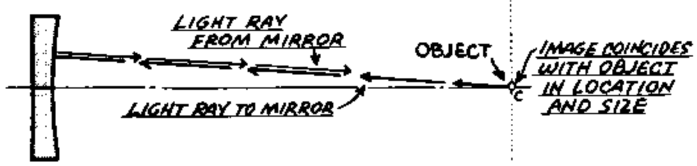


SUB SIX... f/9.6
CORRECTS A BAD TURNED EDGE AND RATES ¼ WAVE WITH SPHERICAL SURFACE

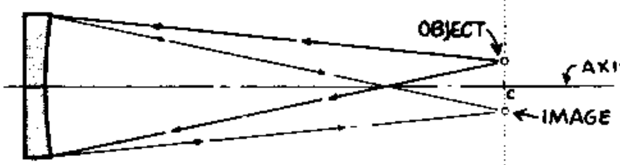
Pre-Testing OPTICS



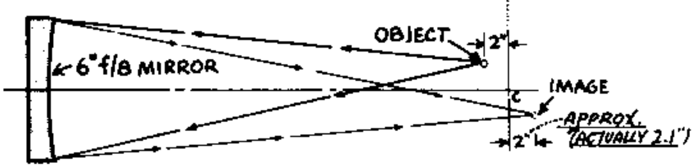
[1] **GENERAL CASE - ALL MIRRORS:** THE FOCAL LENGTH OF A MIRROR = ½ THE RADIUS OF CURVATURE



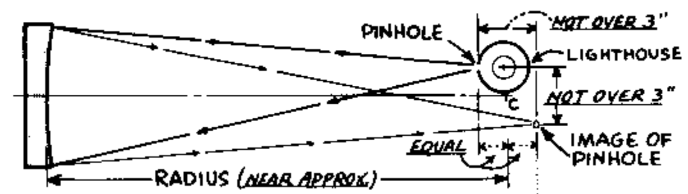
[2] LIGHT RAYS FROM A SMALL OBJECT AT THE CENTER OF CURVATURE WILL BE REFLECTED OVER THE SAME PATHS TO FORM AN IMAGE COINCIDING WITH THE OBJECT



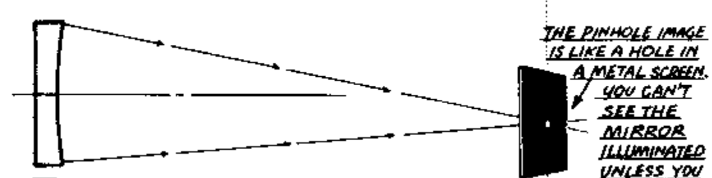
[3] IF THE OBJECT IS DISPLACED TO ONE SIDE OF THE AXIS, THE IMAGE WILL FORM AT SAME DISTANCE ON OPPOSITE SIDE



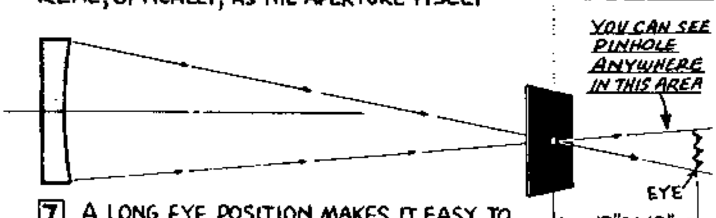
[4] IF THE OBJECT IS MOVED A SHORT DISTANCE TOWARD MIRROR, THE IMAGE WILL MOVE A SHORT DISTANCE AWAY FROM MIRROR



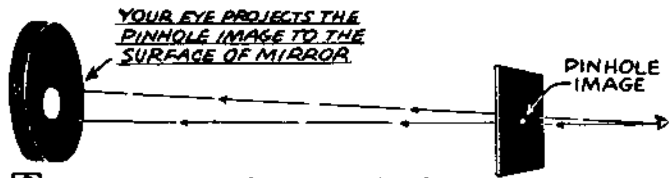
[5] **USUAL SETUP FOR TESTING.** PINHOLE IMAGE AT REAR OF LIGHT IS CONVENIENTLY PLACED FOR OBSERVATION. *THE SMALL DISPLACEMENTS WILL NOT AFFECT IMAGE QUALITY OR MEASUREMENTS*



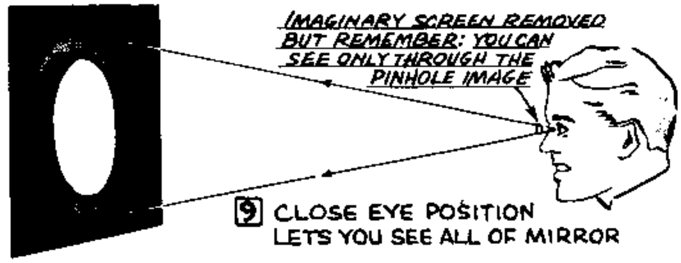
[6] THE IMAGE OF ANY APERTURE IS AS REAL, OPTICALLY, AS THE APERTURE ITSELF



[7] A LONG EYE POSITION MAKES IT EASY TO SEE THE PINHOLE IMAGE ... *BUT*... (*SEE NEXT COL.*)

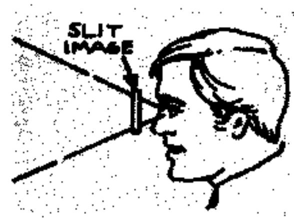


[8] WITH LONG EYE POSITION, YOU SEE ONLY A SMALL PART OF THE MIRROR ILLUMINATED



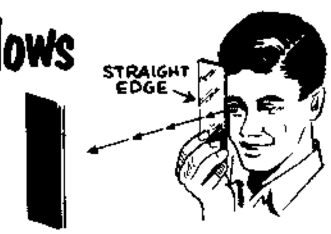
[9] CLOSE EYE POSITION LETS YOU SEE ALL OF MIRROR

[10] A SLIT IS EASIER TO FIND, OFFERS A BIGGER TARGET AND PROVIDES THE MOST EVEN ILLUMINATION



ALL TESTING SHOULD BE DONE IN SEMI-DARKNESS TO OBTAIN BEST CONTRAST. DO NOT BLACK OUT... SOME ROOM LIGHT IS DESIRABLE

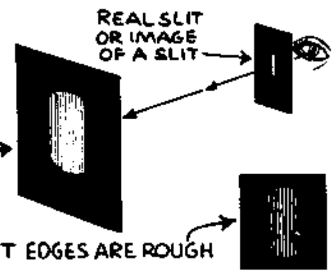
Diffraction Shadows



[1] **A STRAIGHT EDGE CLOSE TO YOUR EYE**

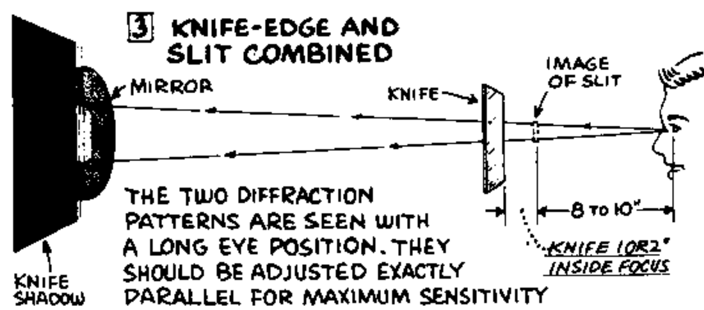
YOUR EYE CAN'T FOCUS AT SUCH SHORT RANGE. YOU SEE THE EDGE AS A DARK SHADOW BORDERED WITH A GRAY FRINGE

[2] **TWO STRAIGHT EDGES CLOSE TOGETHER - A SLIT**



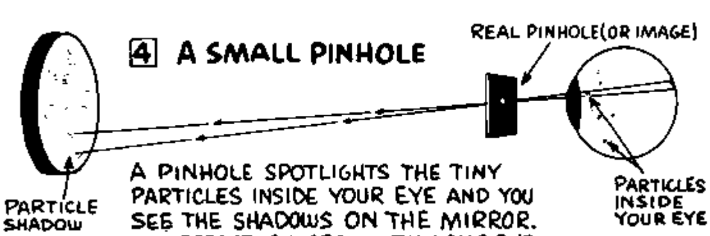
YOU SEE AN EXPANDED SLIT OPENING FILLED WITH FINE VERTICAL LINES. THE SHADING IS COARSER WITH A LONG EYE POSITION, AND IS VERY COARSE AND IRREGULAR IF THE STRAIGHT EDGES ARE ROUGH

[3] **KNIFE-EDGE AND SLIT COMBINED**

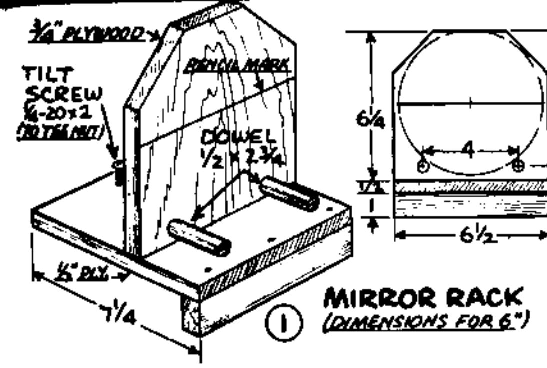


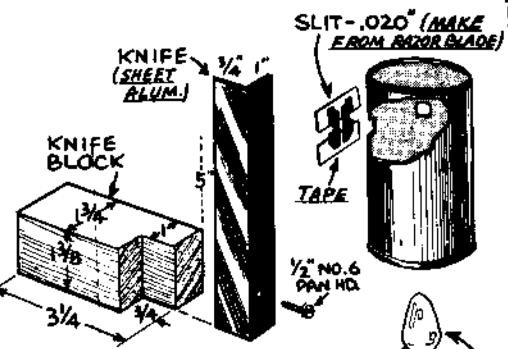
THE TWO DIFFRACTION PATTERNS ARE SEEN WITH A LONG EYE POSITION. THEY SHOULD BE ADJUSTED EXACTLY PARALLEL FOR MAXIMUM SENSITIVITY

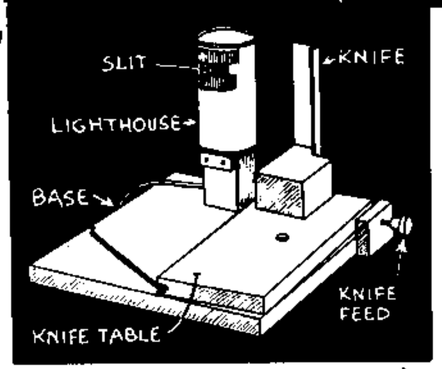
[4] **A SMALL PINHOLE**

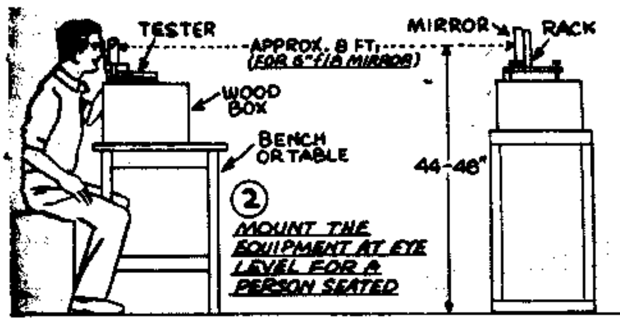


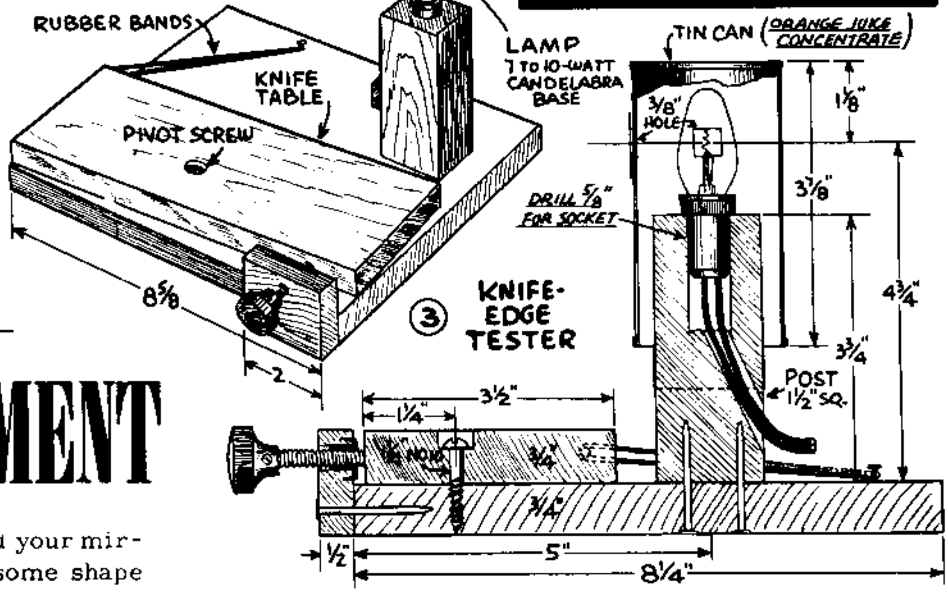
A PINHOLE SPOTLIGHTS THE TINY PARTICLES INSIDE YOUR EYE AND YOU SEE THE SHADOWS ON THE MIRROR. THE EFFECT IS WORST WITH LONG EYE POSITION∴VERY FAINT WHEN EYE IS CLOSE









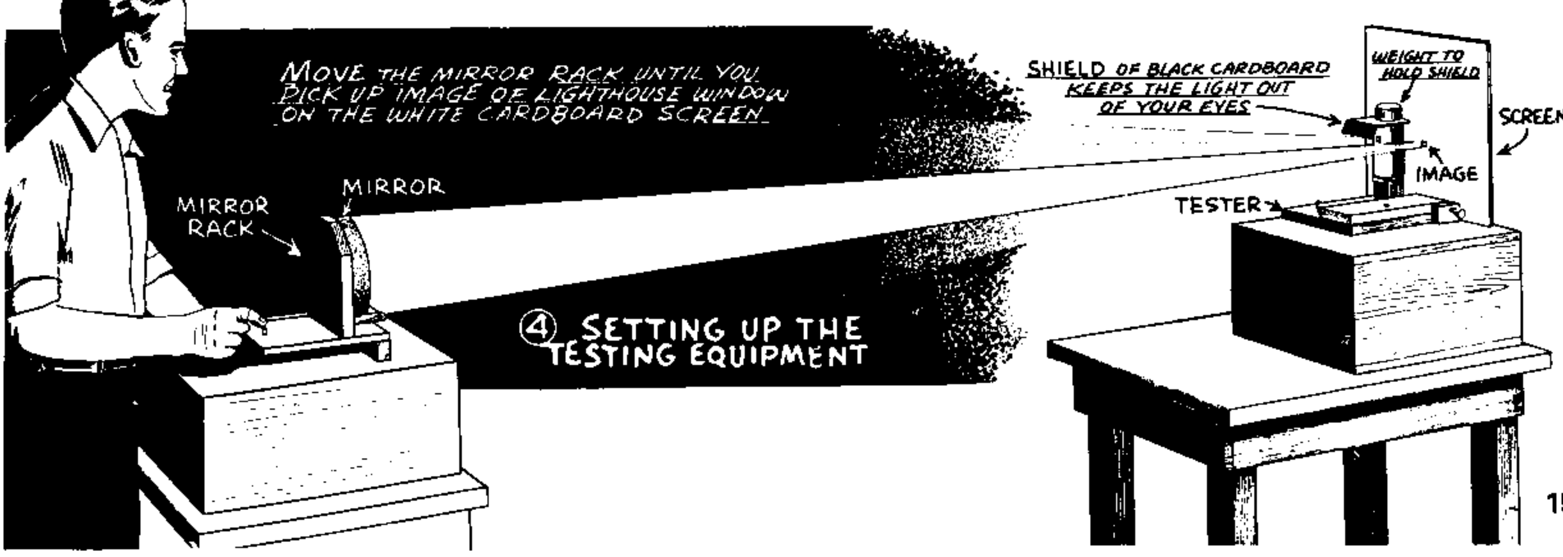


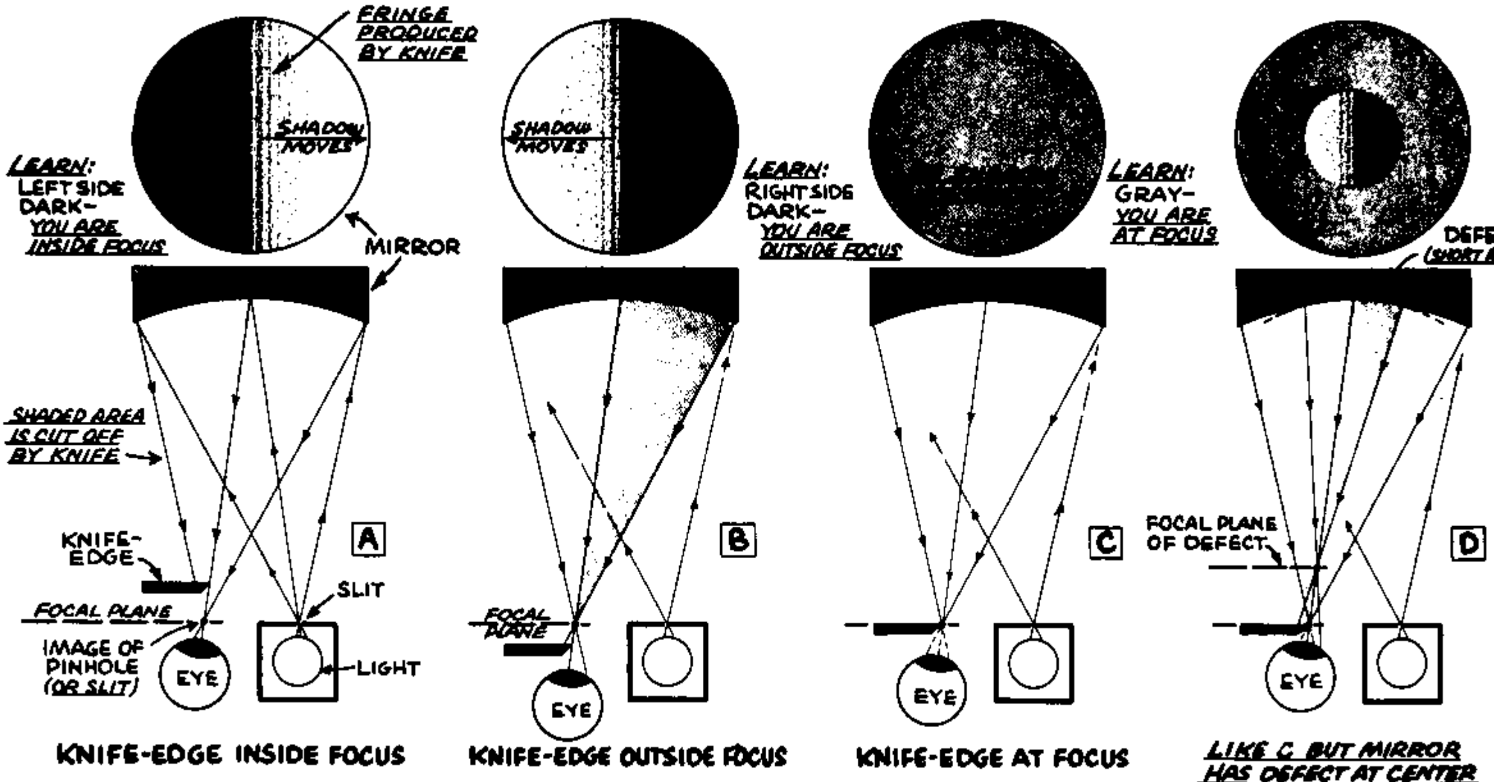
TESTING EQUIPMENT

AFTER you have ground and polished your mirror, its surface will be a sphere or some shape very close to a sphere. The rest of the job consists of testing and correcting to an exact spherical surface, and then changing the sphere to a paraboloid. In testing the paraboloid, it is necessary to measure the exact radius of various zones, and for this delicate work a micrometer test rig is a convenience. Testing the sphere does not require zonal measurements and can be done with very simple equipment.

TESTING EQUIPMENT. Only two items are needed. One is the mirror rack, Fig. 1, and the other is the knife-edge tester itself, Fig. 3. The knife block is not fastened and can be manipulated either by hand or with the screw feed shown. The knife itself is fastened to the knife block with a single screw to permit a slight tilt adjustment when needed. The light is 10-watt, candelabra base, white or clear. If clear, tracing paper should be taped inside the can behind the slit window. The other window is used for setting up the equipment and is left open for maximum light output. A slit is recommended, and is easily made from razor blade pieces, spaced about .020" apart (five sheets of this paper). The tin can lighthouse rotates on the lighthouse post to put either window in position.

You will spend a good bit of time testing, and the idea is to be comfortable. This means the equipment should be set up at eye level for a person seated, Fig. 2. The setup should be in a





(5) SHADOW APPEARANCE OF A SPHERICAL MIRROR

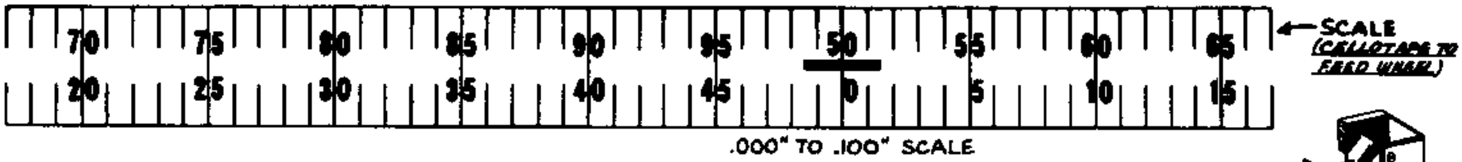
location where it can remain undisturbed until the mirror is finished. A setup near the grinding stand is preferable in order to avoid temperature changes. Vibrations and cold air drafts must be avoided.

SETTING-UP. Fig. 4 shows the equipment being adjusted for use. The room must be completely dark. Even so, it may take you a few minutes to pick up the faint reflection of the lighthouse window on the cardboard screen. Once you get the image on the screen, it is brought to a sharp focus by moving the mirror rack back and forth; final adjustments locate the image level with the window and about 3/4" from the lighthouse. Now, seat yourself behind the tester. Remove the cardboard screen. You will see the lighthouse window reflected in the mirror. Then, rotate the lighthouse until the slit image comes into view. You are ready to test.

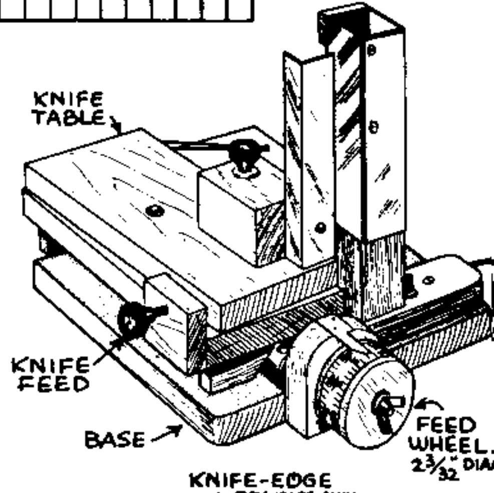
TESTING A SPHERE. Although it is not likely your mirror is a good sphere at this stage, you can probably make it perform somewhat like a spherical mirror, Fig. 5. You will not be able to make the mirror an even gray all over, as at C, since this occurs only when the surface is a perfect sphere. The general idea in testing is that your mirror is an unlimited number of concentric mirrors or zones. You can gray any zone, and when you gray any specific zone the knife is cutting-in at the exact radius of that zone. Zones of longer radius will show dark on left side; zones of shorter radius will darken on right side. Fig. D is an example. By moving the knife forward, you could gray the center of this mirror, and the outer zone of longer radius would then show dark on the left-hand side.

Practice a little on your own mirror. Cut the knife-edge into the light beam well inside focus (toward the mirror), to form a shadow on left side of mirror. Insert the knife-edge outside focus (away from the mirror) to darken the right side. Somewhere between these two extreme knife settings, you will find an "average" knife setting where the shadows on the mirror are about evenly divided right and left. If you measure the distance from this knife position to the mirror, you will get the radius of the mirror--and, of course, half of this is the focal length. It will shrink another quarter-inch or so during correcting and parabolizing.

If your mirror shows moving clouds, you will know that the test rig is located in a current of cold air. It is possible to see through these clouds, but you will have trouble enough trying to interpret shadows without this extra complication. The trouble usually comes from a basement window and can often be cured by sealing the window with cardboard and tape.

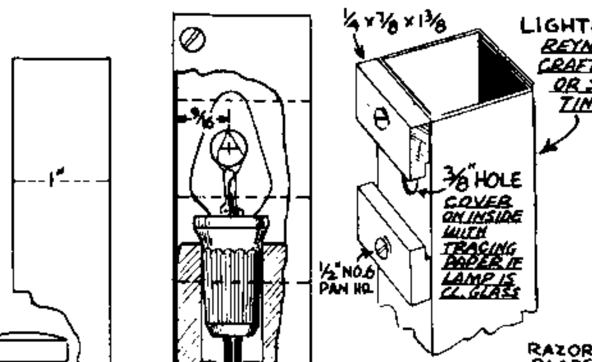


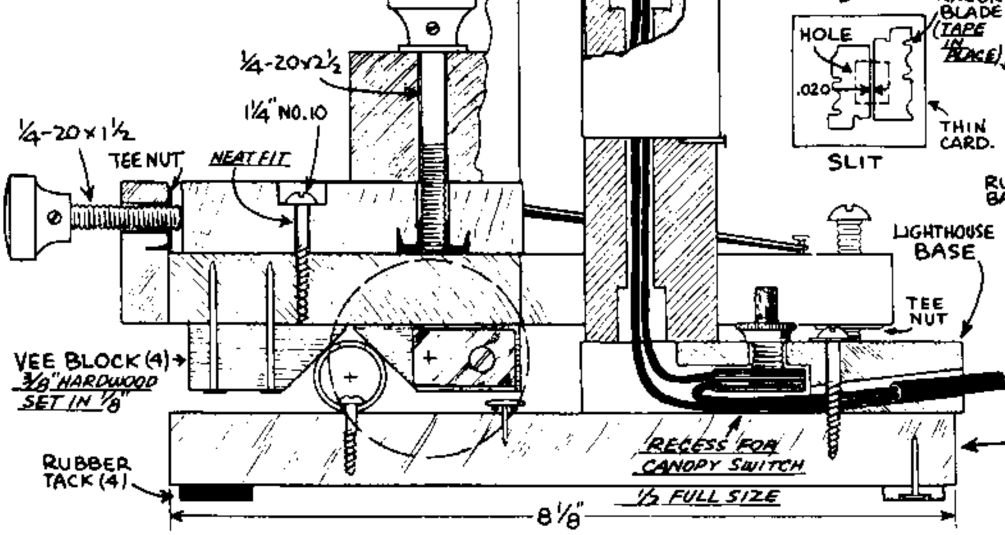
Micrometer Knife-edge Tester

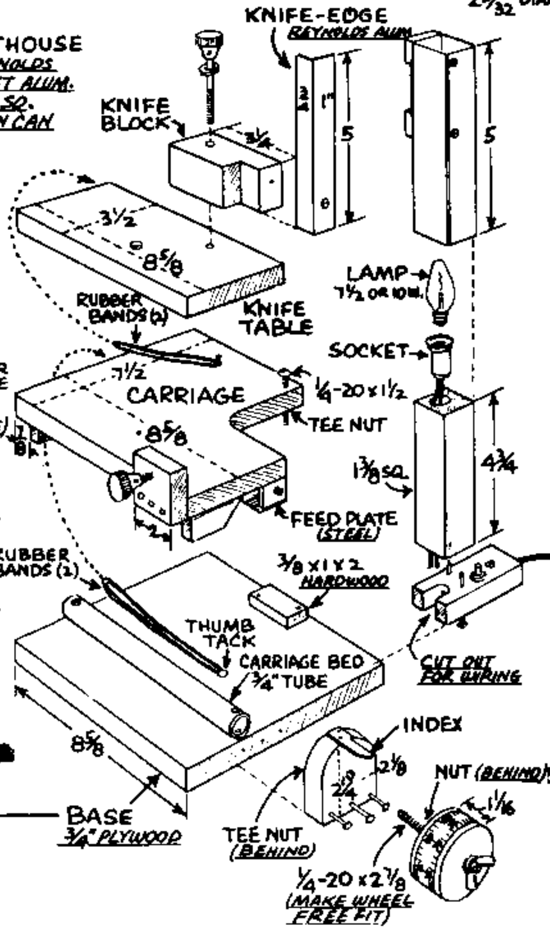


If you plan to parabolize your mirror, a tester with micrometer scale is a convenience, worth making for even a single mirror. This one is all-wood construction except the monorail bed on which the carriage slides, this part being a length of polished aluminum or steel tubing. The carriage is moved by a 1/4-20 screw, giving a feed of fifty thousandths per rev. The scale reads two revs, allowing you to read the whole correction for the average mirror. Lathe-turn the feed wheel to an exact diameter to accept the paper scale. Make the wheel a free fit on the feed screw to permit setting to a zero position.

A pivoting action is used to cut in the knife edge, controlled by the knife feed screw. A single screw holds the knife and permits tilting to a position parallel with the slit image. A fine adjustment for knife parallelism is obtained by means of the screw at right side of the carriage. The slit can be .015 to .030-inch; it is mounted on a track and can be removed when you need the big window for setting-up.







SLIT or Pinhole?

The fluid in a normal eye is fairly clear in much the same manner as the average room contains clear air. Yet a beam of sunlight will show the clear air contains dust particles...and a cone of light from a small pinhole will show the normal eye contains many tiny particles, ranging in density from transparent to opaque.

Eyes vary greatly in this respect, but few persons can use a pinhole without seeing some traces of "eye bumps" on the mirror. Eye bumps move when you move your head, and in this way are distinguished from a similar "dog biscuit" surface which results from faulty polishing. The dog biscuit stands still.

Eye bumps can be practically eliminated with a close eye position, 1/2 inch or less from the pinhole image. However, this position is difficult to obtain if you wear glasses. There is a simple solution to the whole problem: Use a slit! Then the diffraction effect from eye particles is converted to a faint vertical streaking which causes no confusion at all in interpreting the normal mirror shadows.

FIRMS TO CONTACT FOR PRICES ON ALUMINIZING YOUR MIRROR

East—DENTON VACUUM INC., 1259 N. Church St., Moorestown, NJ 08057, Phone: (609) 439-9100
Mid West—P.A. CLAUSING, INC., 8038 Monticello Ave., Skokie, IL 60076, Phone: (312) 267-3399
West—KEIM PRECISION MIRRORS, 2117 Empire Ave., Burbank, CA 91504, Phone: (818) 842-4543

TESTING and CORRECTING

SHADOWS seen in knife-edge testing are easy to interpret by imagining the mirror to be side-lighted from the right, Fig. 1. Under this circumstance, a dark area on the right side means a down-slope or hole, **Fig. 3**; a light area on right side means a rising slope or hill, Fig. **4**. Putting this bit of know-how to work, it is easy to make a rough sketch of the apparent section shape. The apparent shape is then corrected by suitable polishing strokes and technics. This method of working with entirely imaginary shapes works out very well. However, you may gain a better concept of the work if you keep in mind the actual glass shape; a hill, Fig. 4, is actually a flat zone of long radius; a turned edge, Fig. 5, is not an actual turning-over of the glass except possibly at the extreme edge; the parabola, Fig. 7, is not a fancy reverse curve, but simply a single smooth curve, less and less curved toward the edge.

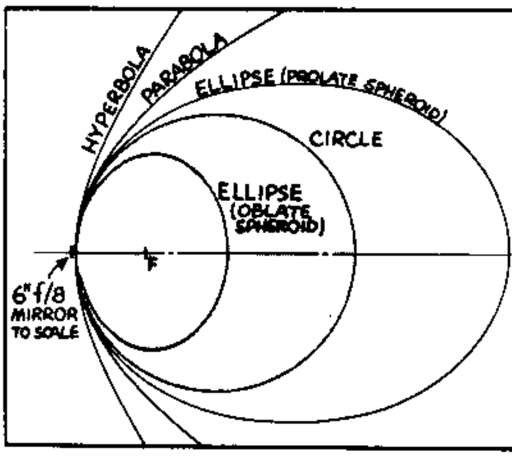
THE BEST SHAPE. At any stage of testing, the mirror will show a variety of shadow faces, changing as the knife is moved back and forth. The general behavior of the mirror shape is that it mimics the knife, as can be seen in Fig. 8--if you move the knife toward the mirror, the mirror will bulge out toward the knife. Any of the shapes you see can be used as a basis for polishing work. Since the shape variation is caused by moving the knife, each change in shape also means a slight change in radius.

The best shape for correction is the one requiring the least work. Consider the oblate spheroid in Fig. 8. Inside average focus, you see a big hill--lots of work. Outside focus it looks like less glass, but it is very tricky working right out at the edge. The middle diagram at average focus shows a moderate hill, which you can plane down with long strokes, and there is enough glass at the rim to permit long strokes without any danger of turning the edge.

In most cases, the best apparent shape for correction is seen when the knife is at the "average" focal plane. This position is located by balancing the shadows, looking mainly at the outer 1/3 of the mirror. If the left side seems to be darker than the right, you know you are inside focus, so you pull the knife back a little. If the right side is the darker, you push the knife forward until the two sides look about the same shadow depth.

There is rarely any need to interpret a complicated shadow for the simple reason you never try to doctor a complicated shape--it's back to the rouge pot for at least 30 minutes of ordinary polishing. With anything approaching smooth, systematic stroking, you should get a fairly smooth, concentric figure. Maybe it will be an oblate spheroid or show a hill, hole or turned edge, but it will be an easily recognizable face and one you can work on.

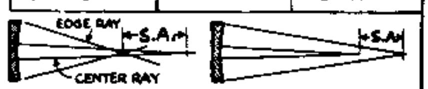
TURNED EDGE TESTS. While you can see a hill or hole easily enough, the turned edge is not always so obvious. The one best test is the appearance of the diffraction ring at the edge of the mirror, Fig. 9A. There is always a bright ring on the right side. If this is a narrow hairline of light on right side and nearly as bright on the left side, the edge is good, although it may be turned slightly. When the diffraction ring is broad and flaring on the right side and the left side is dark



A Family of Curves

You may meet the whole family of regular curves while working a single mirror. There are many variations of the ellipse and hyperbola, but only one shape for the circle and parabola. All of the curves have about the same shape over the span of a 6-inch mirror ...differences are measured in millionths of an inch.

SPHERICAL ABERRATION (S.A.)		
FIGURE	AT INFINITY FOCUS	AT CENTER OF CURVATURE
OBLATE SPHEROID	UNDER	UNDER
SPHERE	UNDER	NONE
ELLIPSOID (PROLATE SPHEROID)	UNDER	OVER
PARABOLOID	NONE	OVER
HYPERBOLOID	OVER	OVER



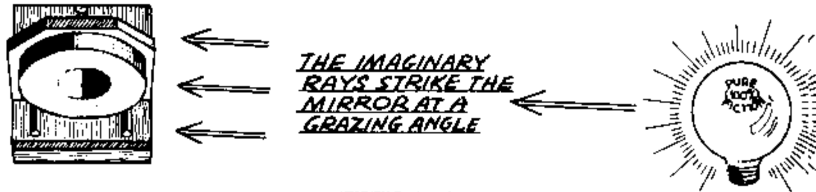
UNDER-CORRECTION *EDGE RAYS FOCUS CLOSER THAN CENTER RAYS*

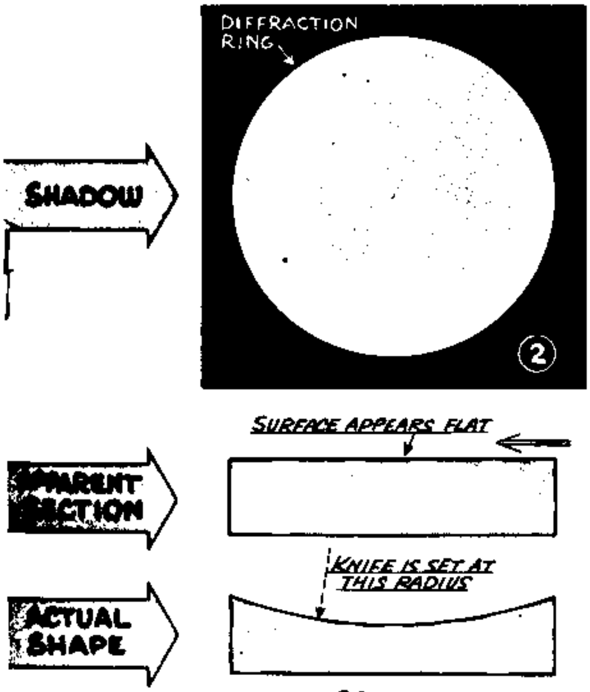
OVER-CORRECTION *EDGE RAYS FOCUS LONGER THAN CENTER RAYS*

AN IMAGINARY SIDE LIGHT REVEALS THE APPARENT SHAPE OF THE MIRROR

THE LIGHT DOES NOT CAST A SHADOW. IT IS NOT STOPPED BY AN APPARENT OBSTRUCTION

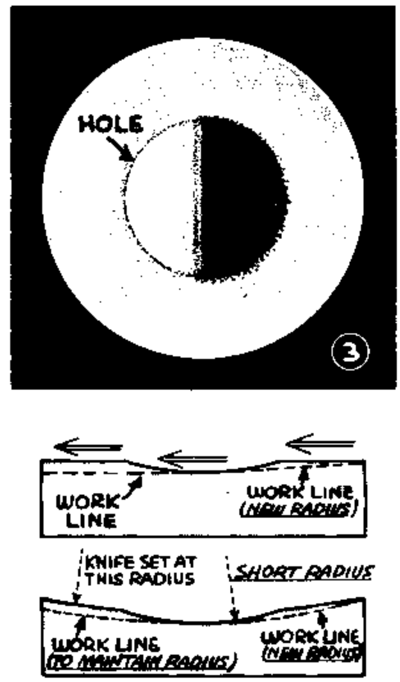
①





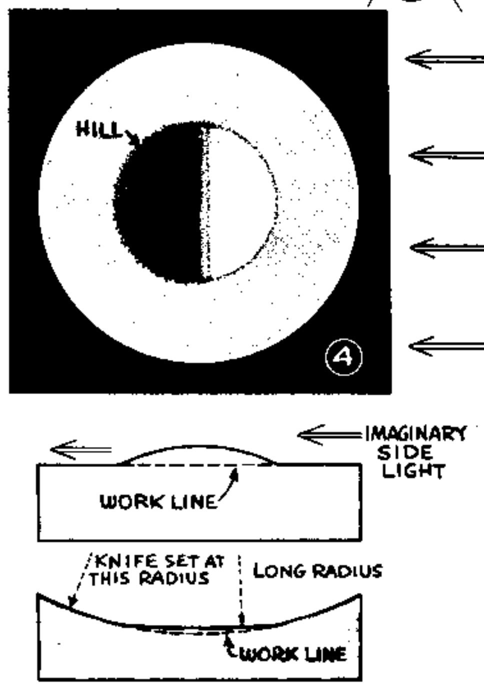
SPHERE

THE KNIFE-EDGE TEST AT CENTER OF CURVATURE IS A NULL TEST FOR THE SPHERE – THERE ARE NO SHADOWS. THE MIRROR LOOKS FLAT, GRAYS GRADUALLY TO BLACK WITH NO MOVING SHADOWS



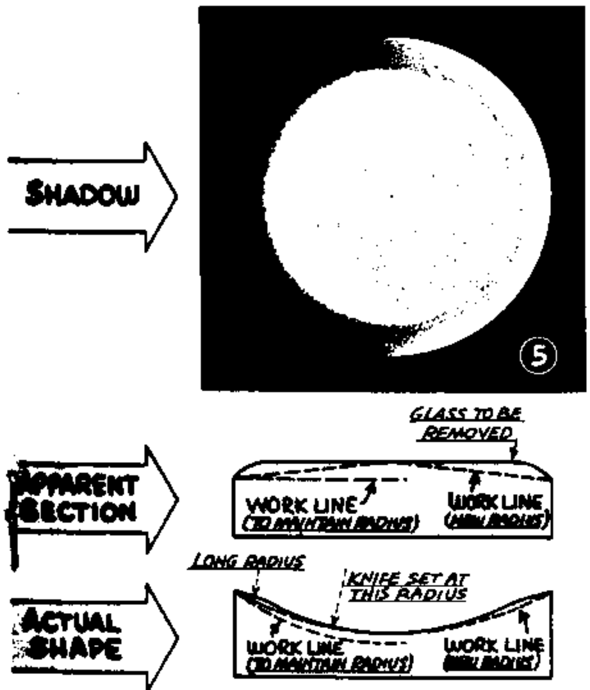
HOLE AT CENTER

WORK LINE SHOWS GLASS TO BE REMOVED IF ORIGINAL RADIUS IS TO BE MAINTAINED. NORMALLY A SLIGHT CHANGE IN RADIUS IS PERMISSIBLE... WORK LINE IS THEN AS SHOWN IN RIGHT HALF OF DIAGRAM



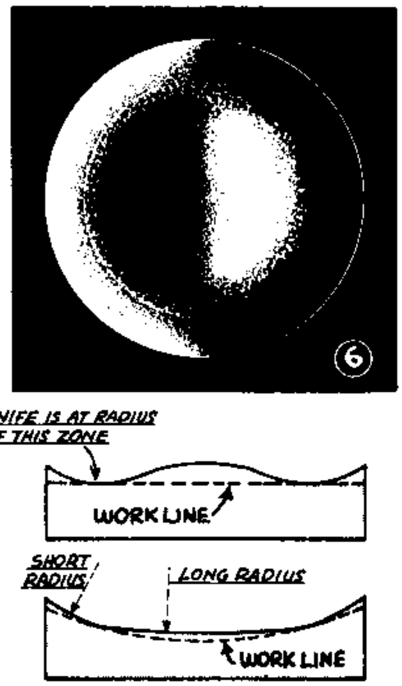
HILL AT CENTER

GOING BY THE APPARENT SECTION, YOU PLANE DOWN A HILL TO A FLAT SURFACE. *BUT*... KEEP THE ACTUAL SITUATION IN MIND: A HILL IS A ZONE OF LONG RADIUS... YOU CORRECT BY DEEPENING THE CENTER



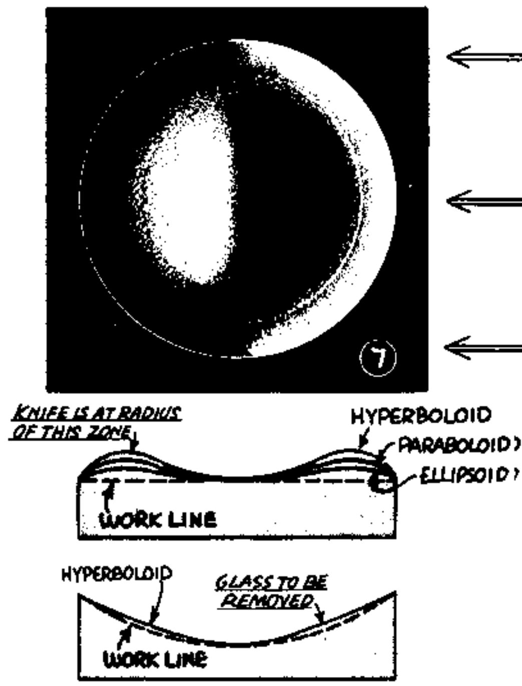
TURNED EDGE

THIS COMMON DEFECT GETS ITS NAME FROM THE TURNED-OVER APPEARANCE OF THE EDGE IN KNIFE TEST. THE ACTUAL GLASS SHAPE IS SIMPLY A FLATTENING OF THE CURVE



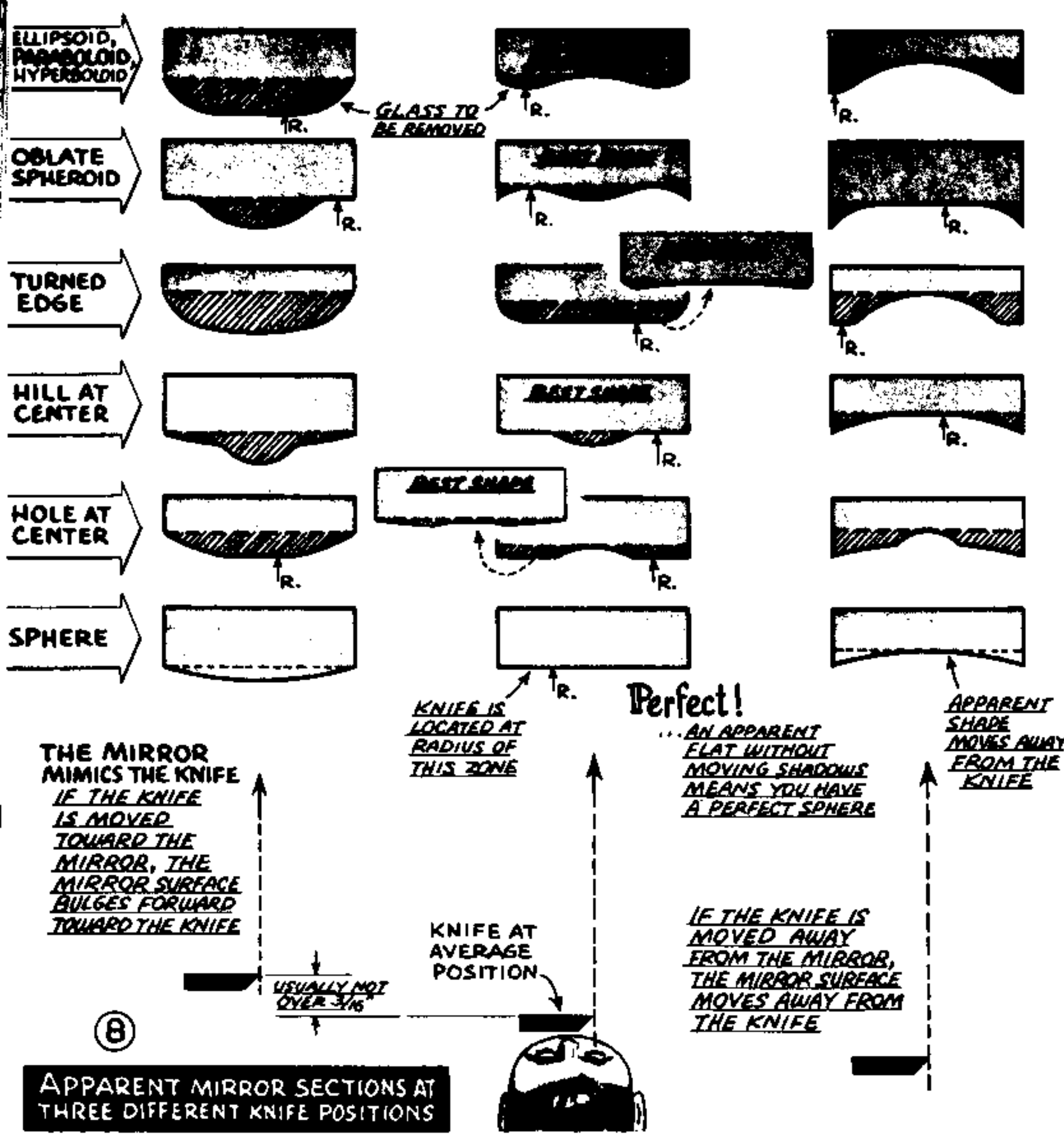
OBLATE SPHEROID

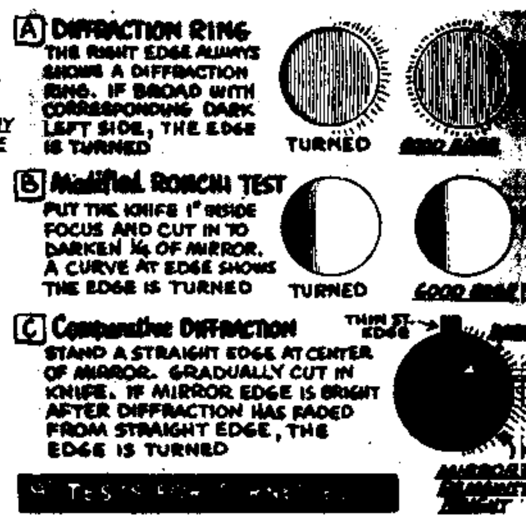
FAST, SHORT, STRAIGHT STROKE POLISHING ON A HARD LAP WILL USUALLY PRODUCE THIS KIND OF FIGURE. IT IS CORRECTED WITH A LONGER STROKE IN A WIDE ZIG-ZAG



ELLIPSOID, PARABOLOID, HYPERBOLOID

...ALL HAVE SAME APPARENT SHAPE AND DIFFER ONLY IN APPARENT DEPTH, THE HYPERBOLOID SHOWING THE DARKEST SHADOW. DIAGRAMS SHOW CORRECTION TO RETURN TO A SPHERE





WARNING. Mirror must be at room temperature for polishing and testing, otherwise errors will be introduced. Every time it heats up allow it to drop to room temperature before further work.

with no light at all, you have a real-for-sure turned edge. Fig. 9B shows one of the more popular tests; it works only when the light source is a slit. In applying Fig. 9C test, you must hold your head steady, eyes straight ahead, avoiding any tendency to sneak your gaze around the edge of the knife.

A turned edge is not all bad. A perfect parabola has a turned edge. A spherical mirror with a turned edge not exceeding the turned edge of a parabola is a better telescope mirror than a perfect sphere. The bad kind of turned edge is a gross fault inherited from fine grinding. If you are critical about the edge during grinding, you will not have this trouble.

CORRECTING TECHNIQUES. The first thing to try for most defects is simply more polishing, varying only the stroke length. For more positive action, all of the methods on opposite page are useful. They can also get you into a lot of trouble; first attempts at local retouching invariably make your mirror worse instead of better. For a hole at center, the deformed lap, No. 1 on opposite page, is usually effective. The overhanging stroke, No. 4, will reduce a central hill, while accented pressure, No. 5, is a good way to correct a turned edge. Work periods are short, ranging from 3 to 15 minutes. All work should be done with a whole number of walks or rotations, counting the mirror rotations if the mirror is on top, and the walks-around-the-post if the lap is on top. You can keep track of rotations by sticking a piece of masking tape on back of mirror; start with this between your index fingers and stop when the tape is under right index finger.

Keep a log book of your efforts. You can expect several hours of holes and hills before getting the flat, velvety moon indicating a perfect sphere. Some "dog biscuit" is permissible since you can see defects to nearly 1/100 wave, far finer than the 1/4-wave accuracy required.

Correcting Techniques

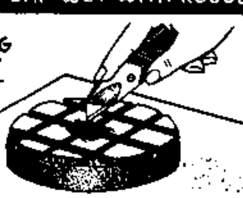
[1] DEPRESSING CENTER OF LAP

APPLICATION: **HOLE AT CENTER**

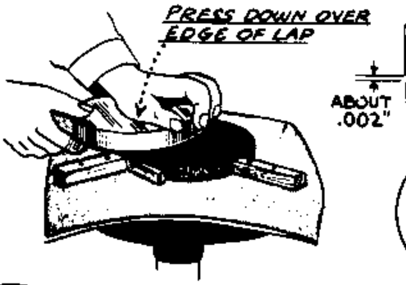
SINK WAX PAPER STAR INTO HEATED LAP. REMOVE WHEN COOL. RESUME POLISHING WITH 1/3 STROKE.

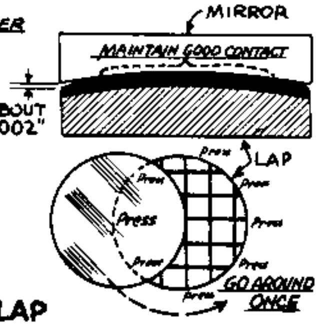
WARM LAP WITH 250-W. HEAT LAMP 1 1/2 MIN. KEEP LAP WET WITH ROUGE

ALTERNATE: SCRATCHING, SANDING SHAVING OR FILING AT CENTER OF LAP. *NO HEAT*



THE IDEA IS TO DECREASE AREA OF CONTACT -- 15 OR 20 SCRATCHES WITH A RAZOR BLADE WILL FIX A SMALL SHALLOW HOLE





[2] DEPRESSING EDGE OF LAP

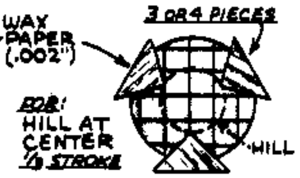
APPLICATION: **TURNED EDGE or HILL AT CENTER**

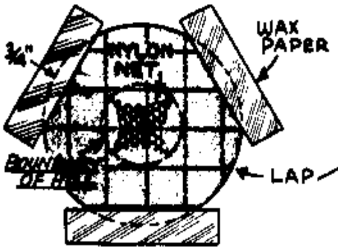
YOU CAN DO THIS WITH EITHER HOT OR COLD PRESS, DEPENDING ON ACTION DESIRED. *GOOD INSURANCE AGAINST TURNED EDGE WHEN YOU ARE REDUCING A CENTRAL HILL*

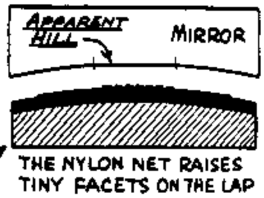
ALTERNATES:

FOR: TURNED EDGE USE 1/4 STROKE

FOR: HILL AT CENTER *1/3 STROKE*







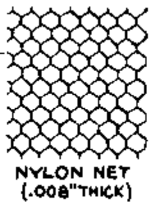
THE NYLON NET RAISES TINY FACETS ON THE LAP

[3] RAISING CENTER OF LAP

APPLICATION: **HILL AT CENTER**

HOT-PRESS NET AND WAX PAPER...REMOVE WHEN COOL. COLD-PRESS 2 MIN... RESUME POLISHING. *CAUTION: THIS CUTS FAST*

FULL SIZE



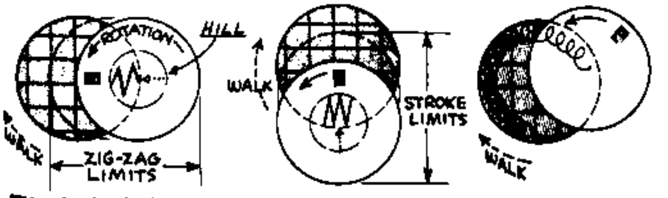
NYLON NET (.008" THICK)

Be Firm! DON'T WORK WITH A WARM LAP. WHENEVER YOU HOT PRESS, ALLOW 20 min. OR MORE "COOL-OFF" TIME

[4] OVERHANGING MIRROR

APPLICATION: **HILL AT CENTER**

THE GENERAL IDEA IS TO WEAR THE HILL OVER THE EDGE OF THE LAP ...... *THE WEIGHT OF THE OVERHANGING GLASS DOES THE WORK*



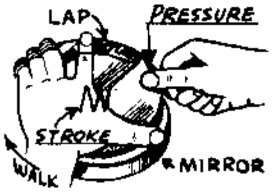
TANGENT STROKE	RADIAL STROKE	CIRCULAR STROKE
ZIG-ZAG 1/4 HILL DIA.	*STROKE 1/4 HILL DIA.*	

YOU CAN USE ANY OF THE THREE STROKES SHOWN

WATCH THE TAPE! ANY OVERHANGING STROKE WITH MIRROR ON TOP MUST BE PACED BY THE MIRROR ROTATION -NOT THE WALK-AROUND. *ALWAYS DO A WHOLE NUMBER OF ROTATIONS... TWO ROTATIONS WILL LEVEL A SMALL HILL*

[5] ACCENTED PRESSURE

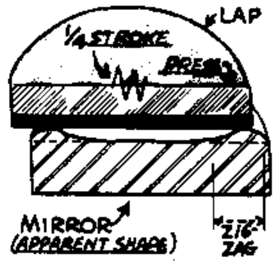
APPLICATION: **TURNED EDGE**



THIS TECHNIC USES THE LAP ON TOP. THE IDEA IS TO USE THE EDGE OF THE LAP AS A TOOL. THE RIGHT HAND IS THE PRESSURE HAND - THE LEFT HAND GUIDES AND ROTATES THE LAP, NO PRESSURE

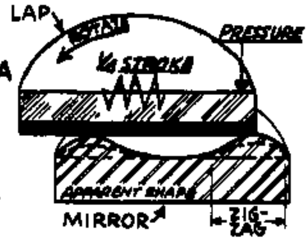
NOTE: *THIS IS AN OVERHANGING STROKE, BUT WITH LAP ON TOP, THE ACTION IS PACED BY THE WALK-AROUND*

ROTATE THE MIRROR. *DO TWO WALKS AROUND THE POST AND THEN ROTATE MIRROR A QUARTER TURN. REPEAT TWO WALKS*



[6] ACCENTED PRESSURE

APPLICATION: **REDUCING HYPERBOLA**

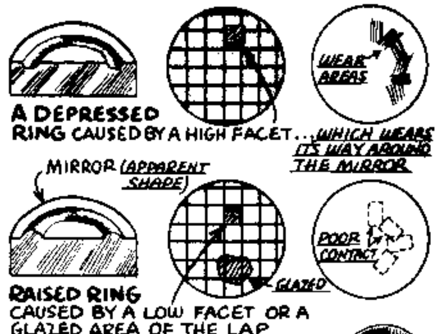


AS ABOVE EXCEPT ZIG-ZAG IS CENTERED ON APPARENT CREST. *IF THE CURVE IS SMOOTH, THE HYPERBOLA CAN BE REDUCED DIRECTLY TO PARABOLA - OTHERWISE REDUCE TO A SPHERE*

RING Defects...

ARE SOMETIMES CAUSED BY LAP FAULTS. DIRT OR ABRASIVE ON A FACET WILL WEAR A DEPRESSED RING ON THE MIRROR SURFACE

REMEDY: *HOT PRESS OFTEN, USING NYLON NET OVER WHOLE LAP WHEN NEEDED TO ASSURE GOOD CONTACT AND ELIMINATE GLAZING. PATCH MISSING CORNERS OF FACETS EXCEPT AT EDGE WHERE THEY DO NO HARM. USE A ZIG-ZAG STROKE TO BLEND OUT ANY MINOR DEFECTS IN THE LAP*

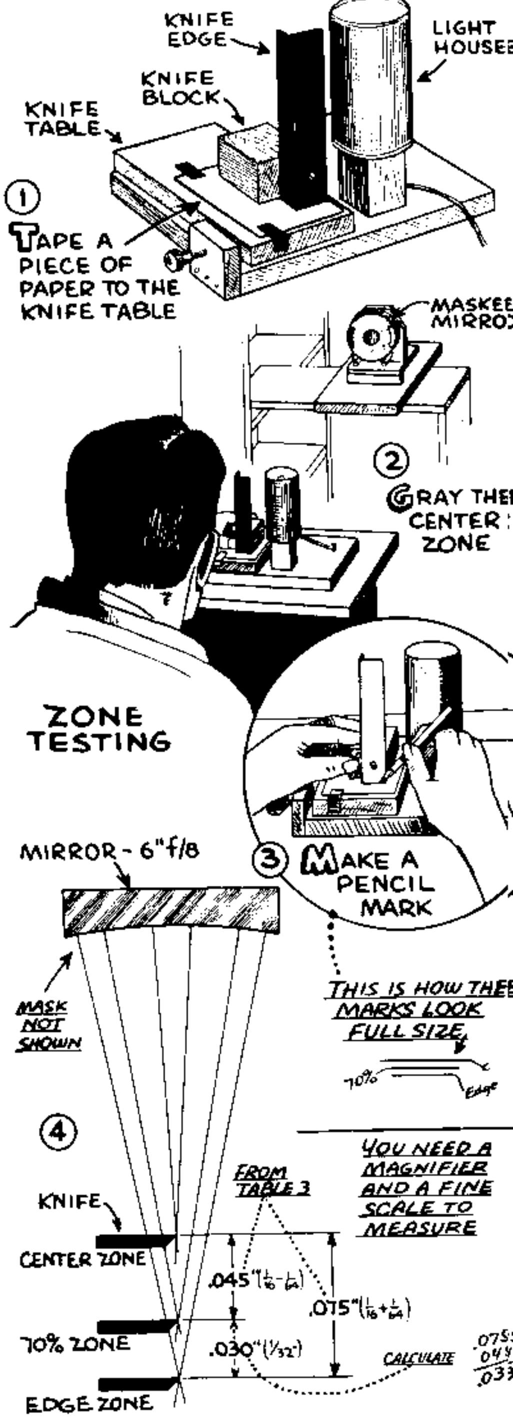


A DEPRESSED RING CAUSED BY A HIGH FACET... *WHICH WEARS ITS WAY AROUND THE MIRROR*

RAISED RING CAUSED BY A LOW FACET OR A GLAZED AREA OF THE LAP

DOG BISCUIT LAP FAULTS PERSISTING FOR 10 OR 15 Seconds CONTRIBUTE TO A "DOG BISCUIT" MIRROR

Figuring the PARABOLOID



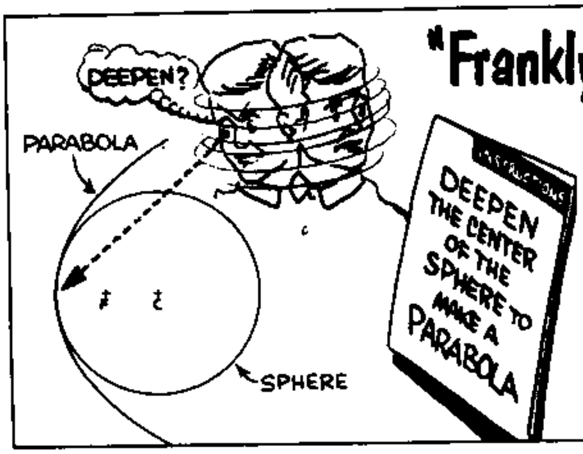
AS YOU may already know, the paraboloid is a defective surface when looking at a near object, suffering from a considerable amount of spherical aberration. If the near object is located at two focal lengths, as it is in the knife-edge test, the spherical aberration is easily calculated or can be obtained directly from Table 3. This particular amount of spherical aberration is known as the Mirror Correction. When your mirror shows the exact amount of "correction" specified in the table, the surface is a paraboloid, and it will have no S.A. at all when used for its intended purpose of looking at distant objects. Any departure from the mirror correction given is, of course, real spherical aberration and will affect the performance of your telescope.

ZONE TESTING. Testing involves measuring the difference in radii of three different zones of the mirror, or, as already explained, you measure the amount of spherical aberration. The zone to be tested is isolated with a thin cardboard mask. If you are using a simple tester, the procedure is as shown in Figs. 1, 2 and 3. After marking the position of the center zone, you move the knife back until a position is found where both edge zone openings in the mask show equally gray as the knife is cut into the light beam. Another mark is made on the paper. The operation is repeated for the 70% zone, and the result is a set of three marks, Fig. 4. They are close together and you will need a magnifier and fine scale or a direct-reading scale magnifier to measure exactly. If the marks measure within the values given in Table 3, you have a parabola or a near-parabola.

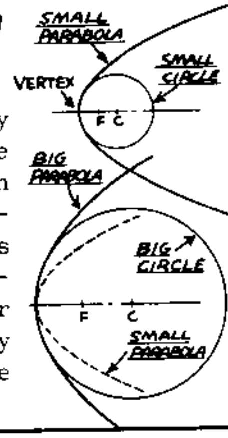
If you are using a micrometer tester, the center zone is tested first, after which the micrometer scale is set at zero, Fig. 6. The edge and 70% zones are then direct readings from the scale.

After each zonal measurement, you should remove the mask and get acquainted with the full-mirror shadow at that particular knife setting, Fig. 7. Of greatest interest is the shadow with

"Frankly, I Don't Get It!"

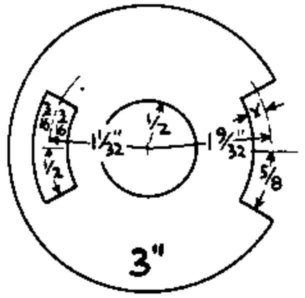


The parabola is commonly shown in relation to a circle of the same radius, as shown at left. What actually happens in making a mirror is that you form a smaller parabola--it is about 1/16" shorter radius and is more sharply curved at the vertex than the original sphere.



LIKE THE CIRCLE, THE PARABOLA HAS ONLY ONE SHAPE AND VARIES ONLY IN SIZE (*RADIUS*)
THE RADIUS OF A PARABOLA IS MEASURED AT THE VERTEX

WHEN CIRCLE AND PARABOLA HAVE THE SAME RADIUS, THE PARABOLA IS LESS CURVED -- IT IS OUTSIDE THE SPHERE. *HOWEVER*, A SMALL PARABOLA FITS INSIDE A BIGGER CIRCLE

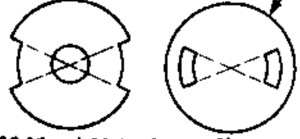


CLEAR FACE	X
3"	7/32"
2 15/16	3/16
2 7/8	5/32

<AVERAGE

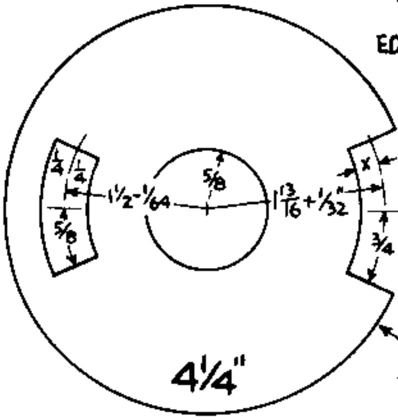
MASKS

DIA. SAME AS MAX. GLASS DIA.



EDGE and CENTER 70% ZONE

MAKE SET OF TWO FROM THIN WHITE CARDBOARD

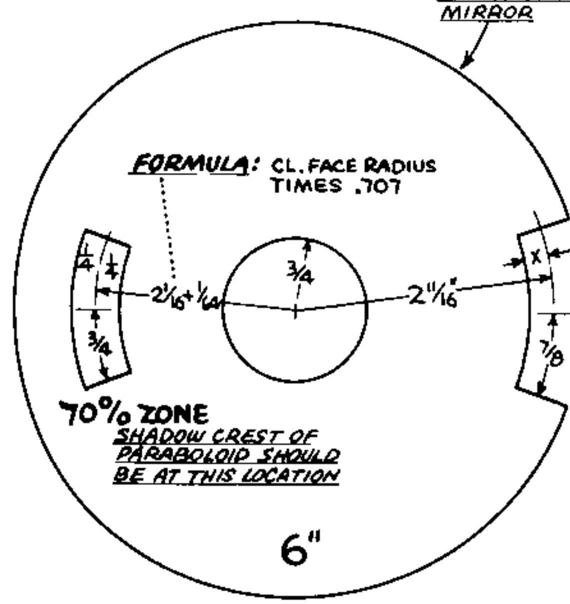


DIMENSION X *ACCORDING TO CLEAR FACE OF MIRROR*

CLEAR FACE	X
4¼"	9/32"
4 3/16	1/4
4 1/8	7/32
4 1/16	3/16

DIAMETER *SAME AS MAX. PHYSICAL DIA. OF YOUR MIRROR*

CLEAR FACE	X
6"	5/16"
5 15/16	9/32
5 7/8	1/4
5 13/16	7/32



CLEAR FACE	X
8"	3/8"
7 15/16	11/32
7 7/8	5/16
7 13/16	9/32

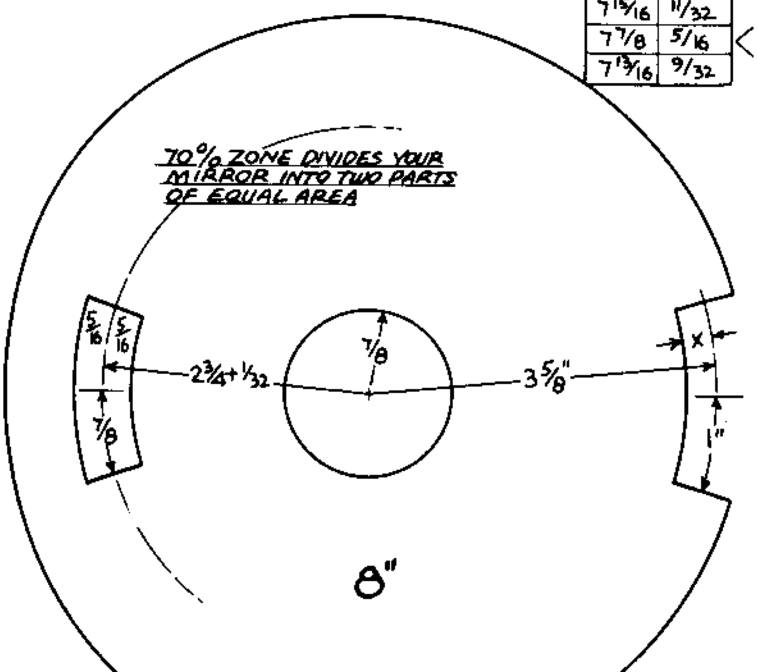


TABLE 3 — MIRROR CORRECTION [1]

NAME-SIZE DIA. [2]	NAME-SIZE f/	F.L.	R.	EDGE ZONE MIN.	EDGE ZONE IDEAL	EDGE ZONE MAX.	70% ZONE [3] MIN.	70% ZONE IDEAL	70% ZONE MAX.	WAVE RATING OF SPHERE [4]
3"	f/6	18"	36"	.028"	**.046"**	.064"	.018"	**.030"**	.042"	2/3 wave
	f/7	21	42	.014	**.039**	.064	.010	**.026**	.042	2/5
	f/8	24	48	.002	**.034**	.066	.001	**.023**	.045	1/4
	f/9	27	54	-.011	**.030**	.071	-.007	**.020**	.047	1/5
	f/10	30	60	-.024	**.027**	.078	-.016	**.018**	.052	1/8
AV. CL. FACE:	f/11	33	66	-.037	**.025**	.087	-.024	**.016**	.056	1/10
2 15/16"	f/12	36	72	-.052	**.023**	.098	-.034	**.015**	.064	1/12
4¼"	f/7	29¾	59½	.032	**.057**	.082	.020	**.037**	.054	1/2
	f/8	34	68	.016	**.050**	.084	.010	**.032**	.054	1/3
	f/9	38¼	76½	.002	**.044**	.086	.001	**.029**	.057	1/4
	f/10	42½	85	-.013	**.040**	.093	-.008	**.025**	.058	1/5
	f/10.6	45	90	-.022	**.038**	.098	-.014	**.024**	.062	1/6
AV. CL. FACE:	f/11	46¾	93½	-.028	**.037**	.102	-.018	**.023**	.064	1/7
4 3/16"	f/12	51	102	-.043	**.033**	.109	-.021	**.021**	.069	1/9
6"	f/5	30	60	.106	**.120**	.134	.063	**.072**	.081	2 1/8
	f/6	36	72	.080	**.100**	.120	.048	**.060**	.072	1¼
	f/7	42	84	.059	**.086**	.113	.035	**.051**	.067	4/5
	f/7.3	44	88	.051	**.082**	.113	.031	**.049**	.067	2/3
	f/7.7	46	92	.044	**.078**	.112	.027	**.047**	.067	9/16
	f/8	48	96	.039	**.075**	.111	.023	**.045**	.067	1/2
	f/8.3	50	100	.034	**.072**	.110	.020	**.043**	.066	1/2
	f/8.7	52	104	.027	**.069**	.111	.016	**.041**	.066	7/16
	f/9	54	108	.021	**.067**	.113	.012	**.040**	.068	1/3
	f/10	60	120	.004	**.060**	.116	.003	**.036**	.069	1/4
AV. CL. FACE:	f/11	66	132	-.014	**.055**	.124	-.008	**.033**	.074	1/5
5 7/8"	f/12	72	144	-.030	**.050**	.130	-.018	**.030**	.078	1/6
8"	f/4	32	64	.196	**.205**	.214	.116	**.121**	.126	5¾
	f/5	40	80	.149	**.164**	.179	.088	**.097**	.106	2 2/3
	f/6	48	96	.117	**.137**	.157	.069	**.081**	.093	1 2/3
	f/7	56	112	.089	**.117**	.145	.052	**.069**	.086	1
	f/8	64	128	.066	**.103**	.140	.038	**.060**	.082	2/3
	f/9	72	144	.044	**.091**	.138	.026	**.054**	.082	1/2
AV. CL. FACE:	f/10	80	160	.025	**.082**	.139	.014	**.048**	.082	1/3
7 7/8"	f/11	88	176	.005	**.075**	.145	.003	**.044**	.085	1/4

[1] THE MIRROR CORRECTION IS THE DIFFERENCE IN FOCUS BETWEEN CENTER ZONE AND EDGE ZONE (OR CENTER AND 70% ZONE) WHEN TESTED WITH A FIXED LIGHT SOURCE, USING THE MASKS SHOWN. THE TOLERANCE IS ¼ WAVE UNDER AND OVER-CORRECTED

[2] THE ACTUAL CLEAR FACE IS A LITTLE LESS THAN NAME-SIZE

[3] DOUBLE THE VALUES AT 70% ZONE WILL GIVE THE FULL CORRECTION AND TOLERANCE AT EXTREME EDGE OF AVERAGE-SIZE MIRROR

[4] THIS COLUMN GIVES WAVE-RATING OF MIRROR IF GROUND TO A SPHERICAL SHAPE. MIRRORS RATED ¼ WAVE OR LESS WILL BE SATISFACTORY, PROVIDING THE SURFACE IS A SMOOTH CURVE

Example:

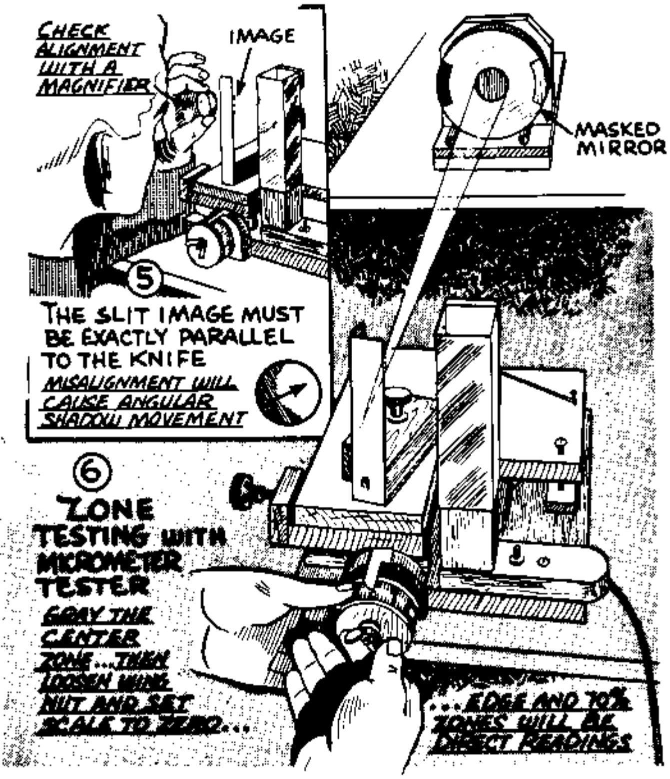
Your MIRROR IS 6" f/8

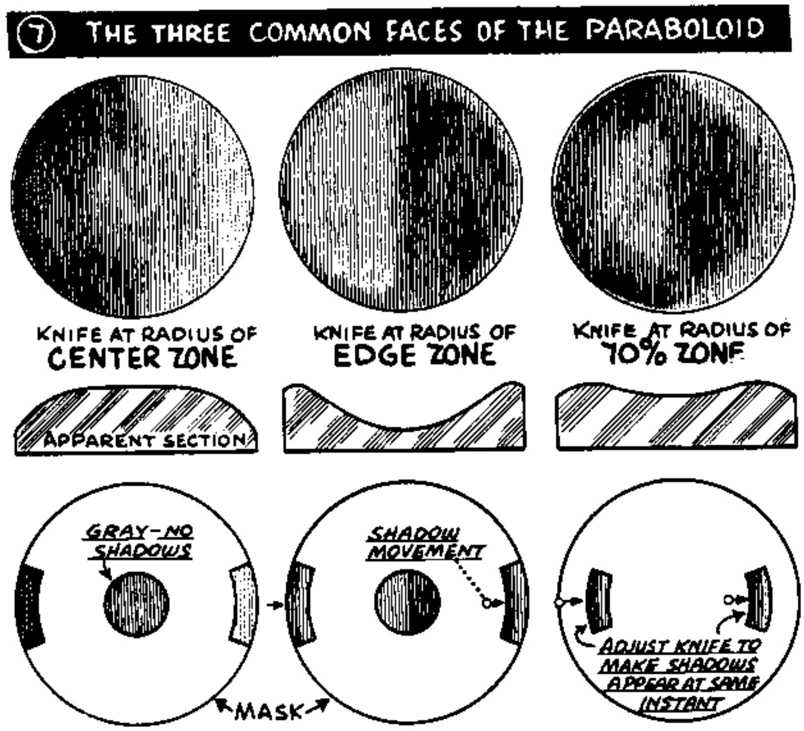
FROM TABLE, READ:

CORRECTION BETWEEN EDGE AND CENTER ZONES:
IDEAL *(PERF. PARABOLA)* = **.075"**
MIN. *(¼ WAVE UNDER)* = **.039**
MAX. *(¼ WAVE OVER)* = **.111**

CORRECTION BETWEEN 70% ZONE AND CENTER ZONE:
IDEAL *(PERF. PARABOLA)* = **.045"**
MIN. *(¼ WAVE UNDER)* = **.023**
MAX. *(¼ WAVE OVER)* = **.067**

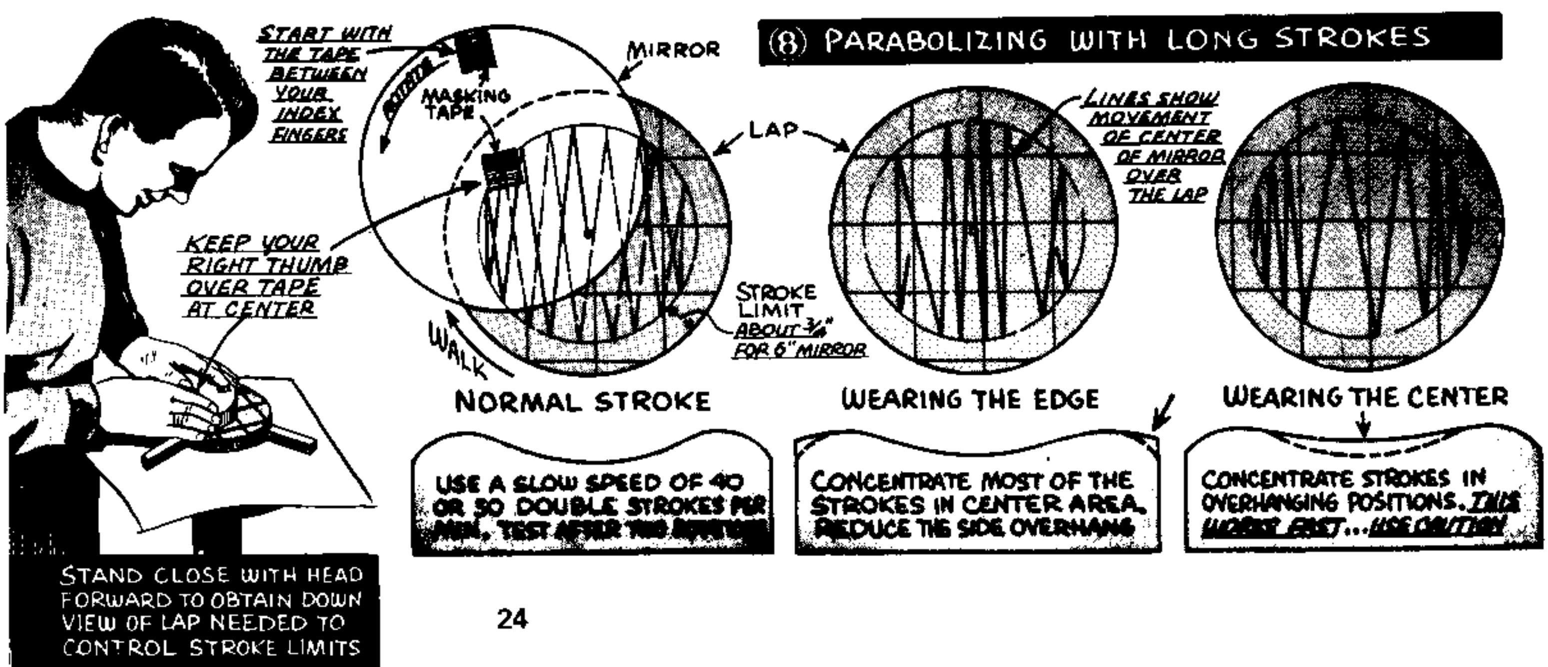
ANY CORRECTION BETWEEN MINIMUM-MAXIMUM VALUES IS A GOOD MIRROR, PROVIDING ALWAYS THE SURFACE IS A SMOOTH CURVE





knife graying the 70% zone; this is the face of the mirror you analyze and study for proof of the paraboloid. It is a lightly-shaded figure when first tested, barely visible, but becoming stronger and more contrasty as you approach full correction. The first shadow to appear is at the left edge, followed immediately by a second shadow which originates well inside the right edge. Both shadows advance to the right as the knife is pushed more into the light beam, and it is this advancing shadow which you try to equalize in zone testing. Instead of judging equal grayness when using the mask, you will find it easier to watch for the first wisp of shadows in the mask openings--when they appear at the same instant, you have the knife in the proper location.

Taking zone measurements is a delicate operation. Beginners are often mystified when successive measurements at the same zone vary as much as .030 inch. Did something slip? Not at all--it's just a case where you have to sharpen your eye and be super critical. With practice, you can reduce your observing error to about .015 inch, and if you take the average of three or four readings, you will be in error no more than about .010 inch. The center is especially difficult because the light beam is very narrow. This zone has no moving shadow at all--it simply goes gray gradually all over and if you can detect the least shadow movement from either side, you are not in the proper position.

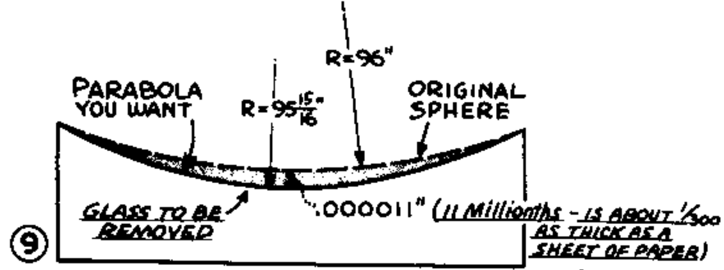


LONG STROKE PARABOLIZING. The actual work of parabolizing from a sphere or near-sphere is done with a stroke of maximum length and sidewise zig-zag, Fig. 8. Under good conditions you can parabolize a 6-inch f/8 in as little as five minutes. However, it is best to stretch the work over a longer period of about 20 minutes, using a slightly shorter stroke and less side overhang. Long stroke parabolizing works beautifully when the lap is of the proper temper, which is medium soft. The actual situation is that your much-used lap is now very thin and hard as a rock. Unless the lap deforms under the long stroke, the paraboloid will not develop--you will only make a hole at the center. The best way out is to make a new lap, adding about a half-teaspoonful of turpentine to the heated pitch and stirring gently for at least five minutes. Alternately, you can hot press and then start work while there is a trace of heat in the lap. This requires fine judgement but it is worth trying.

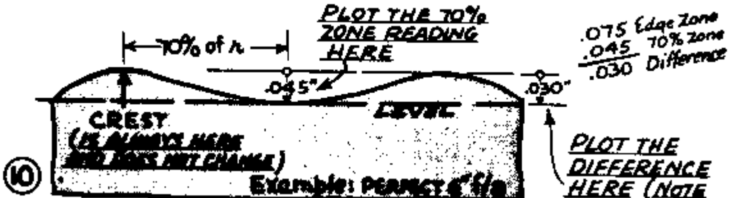
JOB PROCEDURE. Hot press for contact. A 5-min. dip in warm water (about 110 deg.) is satisfactory. Press with weight, about 10 lbs. for 5 min. and then let stand about 15 min. without weight. Use rouge about 1:5. Do two rotations (not walks), using a piece of masking tape on back of mirror as an index marker. Another piece of tape at center of mirror will be found useful; put your right thumb over this and then think in terms of pushing your thumb over the lap to the limits shown, Fig. 8.

Place mirror on test rack and let stand at least 10 min. before testing in order to normalize. Make zone measurements and analyze. The general idea is to deepen the sphere, Fig. 9, staying as close as possible to the paraboloidal shape according to Normal Wear values given alongside Fig. 11. Normal Wear is a function of the mask shown in Table 3, and the values given apply to any 6-inch mirror tested with the mask shown.

A sketch diagram should be made at each stage of the work based on the knife readings. The scale is the apparent section shape of the perfect parabola, Fig. 10, with 45 units for the center depth and 30 units for the edge depth, both measuring the same distance. Typical work examples covering most common situations are shown in Fig. 11. After the first cut, the schedule is hot press, one rotation, test. The action is fast, usually requiring no more than four single turns to shade the doughnut just right.



KEEP THE REAL GLASS SHAPE IN MIND!



You See... You Plot... You Correct THE APPARENT SHAPE

(11) SHAPE EXAMPLES - 6" f/8

READINGS (70% EDGE)	APPARENT SHAPE	REMARKS and CORRECTION
0 30 30 (DIFFERENCE 0)	30, 0	ALL HOLE. PUSH KNIFE FORWARD A LITTLE TO SEE BEST SHAPE TO RETURN TO SPHERE
0 0 75 (75)	0, 75	ALL TURNED EDGE. PULL KNIFE BACK TO SEE BEST SHAPE TO RETURN TO SPHERE
0 20 35 (15)	20, 15	NORMAL WEAR ... KEEP DOING JUST WHAT YOU ARE DOING
0 20 30 (10)	20, 10	OK BUT NEEDS A TRIFLE MORE WEAR AT EDGE. (SEE NORMAL WEAR AT RIGHT)
0 10 40 (30)	10, 30	SHALLOW CENTER. NEEDS WEAR AT CENTER (SEE OPPOSITE PAGE)
0 60 40 (-20)	60, -20	DEEP CENTER, RAISED EDGE. MOVE KNIFE FORWARD FOR BEST SHAPE BACK TO SPHERE
0 30 80 (50)	30, 50	TURNED EDGE. REDUCE AT 70% ZONE WITH LAP ON TOP (SEE PAGE 19)
0 90 120 (30)	90, 30	HOLE AT CENTER. REDUCE AT 70% ZONE WITH LAP ON TOP (SEE PAGE 19)
0 55 90 (35)	55, 35	GOOD SHAPE BUT OVER-CORRECTED. WEAR BACK TO PARABOLA (SEE p. 19)

...YOU ZERO AT CENTER. ALL READINGS IN THOUSANDTHS-OF-AN-INCH

NORMAL WEAR

0	0	0	SPHERE
0	3	5	
0	6	10	
0	9	15	
0	12	20	
0	15	25	
0	18	30	
0	21	35	
0	24	40	1/4 WAVE LIMIT*
0	27	45	
0	30	50	
0	33	55	
0	36	60	
0	39	65	
0	42	70	
0	45	75	PARABOLA*
0	48	80	
0	51	85	
0	54	90	
0	57	95	
0	60	100	
0	63	105	
0	66	110	1/4 WAVE LIMIT*

*for 6" f/8

(12) Wave-rating Your MIRROR

A LITTLE DETECTIVE WORK ON TABLE 3 WILL REVEAL THAT THE 1/4 WAVE TOLERANCE FOR A 6" f/8 MIRROR AT THE EDGE ZONE IS .036". HENCE, ONE WAVE = 4 × .036 = .144"

(.075 − .039 = .036)

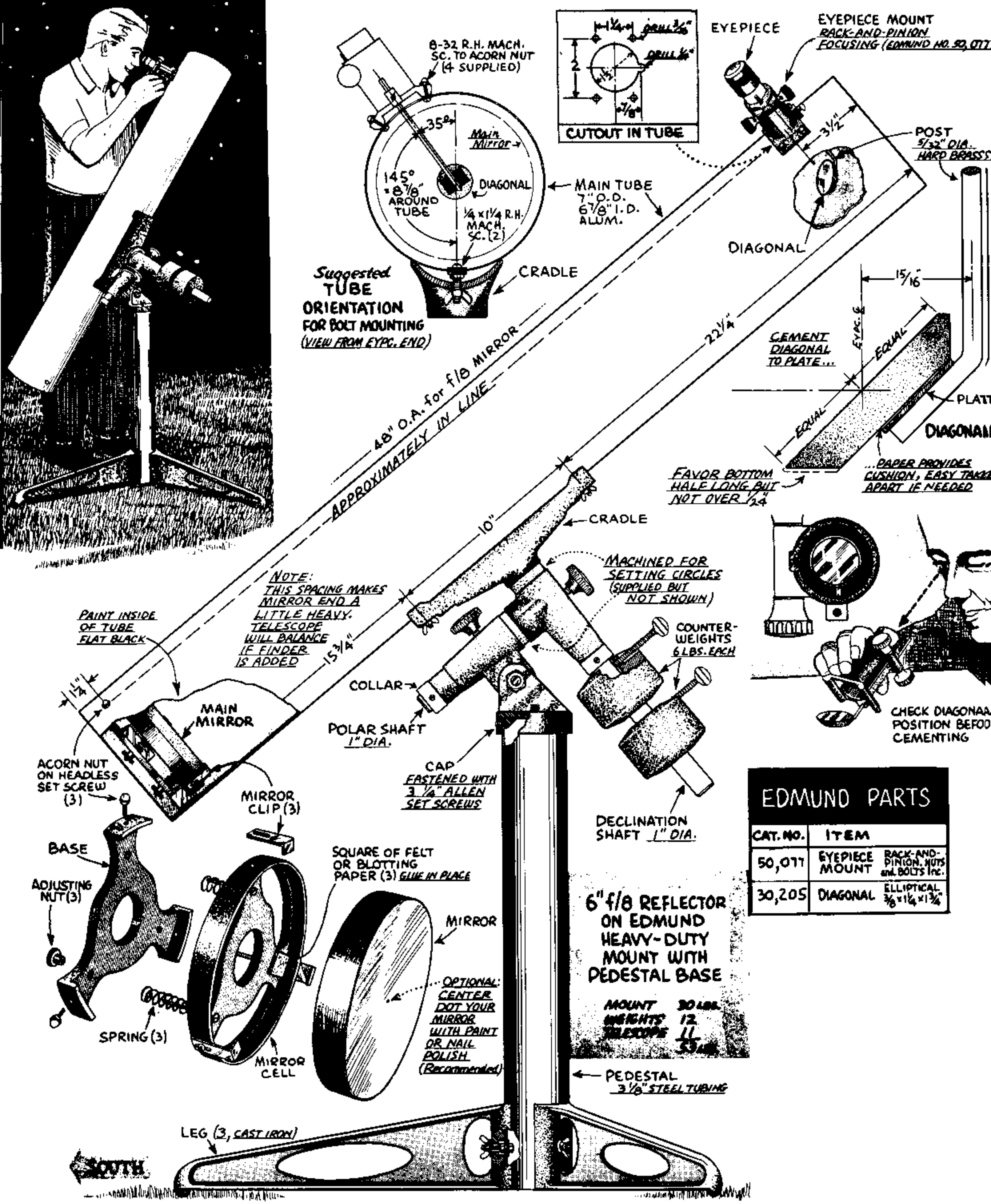
TO RATE YOUR MIRROR, DETERMINE HOW MUCH IT DEPARTS FROM THE IDEAL .075" CORRECTION. SAY YOUR READING IS .060"... YOU ARE .015" UNDER-CORRECTED. OMIT THE DECIMAL MARK AND WRITE THE FIGURE AS A FRACTION:

$$\frac{15}{144} = \frac{1}{10} \text{ WAVE}$$

AVERAGE: $\frac{1}{11}$ WAVE

DO THE SAME AT 70% ZONE WHERE 1-WAVE = .088". SAY YOU ARE .007" OFF EITHER OVER OR UNDER

$$\frac{7}{88} = \frac{1}{12} \text{ WAVE}$$



EDMUND PARTS

CAT. NO.	ITEM	
50,077	EYEPIECE MOUNT	RACK-AND-PINION, NUTS and BOLTS Inc.
30,205	DIAGONAL	ELLIPTICAL 3/8 x 1 1/4 x 1 3/4

Reflecting TELESCOPE CONSTRUCTION

COMPARED to mirror-making, the mechanical construction of a telescope is a simple project, especially if you are building a stock design from existing plans. Further simplification can be obtained by buying some or all ready-made parts. The one part which most builders purchase is the focusing rack-and-pinion eyepiece holder. Other parts including the mount can be homemade with ordinary home workshop equipment. Most expensive of the needed parts is the main tube and you may be able to purchase this cheaper locally.

Booklets and our catalog listed on outside back cover provide detailed information on collimation, finders, and various types of diagonal supports.

STANDARD SIX REFLECTOR. The popular 6-inch f/8 reflector with all purchased parts is shown on the opposite page. When you buy all the parts, the work reduces to a few minor jobs, the most difficult being the cutting of the hole at the eyepiece end of main tube. Actually this is not difficult at all if you have either a hole saw or a sabre saw, but it is more work if you have to do it by the makeshift method of drilling many small holes around the opening and then filing smooth.

The only other "hard" job is cementing the flat mirror diagonal to the metal base plate, this one being difficult because it must be exact. Before you cement, make a dry run, as shown, to locate exactly where the diagonal must be placed to center under the focusing tube. The cementing job should be done with a piece of glazed paper (magazine cover) at the joint. This provides a slight cushion and also makes it easy to remove the mirror from the plate should this become necessary. For a cement, you can use any kind of ordinary glue. A rubber band or two snapped around the assembly makes a convenient clamp. Needless to say, you handle the mirror only at the edges to avoid fingerprints on the aluminized surface. However, if the mirror gets dirty, it can be cleaned by any method used to clean eyeglasses.

The equatorial mount shown is a completely finished product and requires only minor assembly. The tilt of the polar axis should be the same as your latitude (the drawing is 40 degrees). Adjustment is made by loosening the single nut at cap lug, and then tightening securely after the proper setting has been made. Only approximate accuracy is needed unless you are making use of setting circles or doing star photography.

OPTICAL LAYOUT. Many builders want to know the technical side of telescope design. As a matter of fact, this is something you have to know if you plan to build something other than published plans. Making an optical layout is a simple process, shown in sequence by the num-

TABLE 4 LINEAR FIELD OF TELESCOPE IMAGE WITH VARIOUS EYEPIECES

APPARENT FIELD OF EYEPIECE		FOCAL LENGTH OF EYEPIECE															
		1/6"	1/5"	1/4"	3/8"	1/2"	5/8"	3/4"	7/8"	1"	1 1/16"	1 1/8"	1 1/4"	1 3/8"	1 1/2"	1 3/4"	2"
	65°	.19"	.23"	.28"	.42"	.57"	.71"	.85"	.99"	1.13"	1.20"	1.27"	1.42"	1.55"	1.70"	1.98"	2.27"
AVERAGE ERFLE	60°	.17	.21	.26	.39	.52	.66'	.79	.92	1.05	1.11	1.18	1.32	1.44	1.57	1.84	2.09
	55°	.16	.19	.24	.36	.48	.60	.72	.84	.96	1.02	1.08	1.20	1.32	1.44	1.68	1.92
AVERAGE KELLNER OR ORTHOSCOPIC	50°	.14	.17	.22	.32	.44	.54	.65	.76	.87	.92	.98	1.08	1.20	1.31	1.52	1.74
AV. SYMMETRICAL OR PLOSSL	45°	.13	.16	.20	.29	.39	.49	.59	.68	.78	.83	.88	.98	1.07	1.17	1.36	1.57
LIMIT for HUYGENS	40°	.12	.14	.17	.26	.35	.44	.52	.61	.70	.74	.79	.88	.96	1.05	1.22	1.40
LIMIT for RAMSDEN	35°	.10	.12	.15	.23	.31	.38	.46	.53	.61	.65	.69	.76	.84	.92	1.07	1.22
USUAL FIELD OF CHEAP TERRESTRIAL SCOPES	30°	.09	.10	.13	.20	.26	.33	.39	.46	.52	.55	.59	.65	.72	.78	.91	1.05
	25°	.07	.09	.11	.16	.22	.27	.33	.39	.44	.47	.49	.55	.60	.66	.77	.87
SINGLE ACHROMAT	20°	.06	.07	.09	.13	.17	.22	.26	.31	.35	.37	.39	.44	.48	.52	.61	.70
SINGLE SIMPLE LENS	10°	.03	.03	.04	.07	.09	.11	.13	.15	.17	.18	.19	.21	.23	.26	.30	.35

Example: YOU PLAN TO USE A 50° EYEPIECE OF 1" F.L. WHAT IS IMAGE DIA.?
SOLUTION: IN LEFT COL., LOCATE 50° A.F. ON SAME LINE UNDER 1" F.L., READ .87" (7/8") DIA. OF FIELD AT IMAGE PLANE

GRAY AREA — *STANDARD 1¼" EYEPIECE HOLDER WILL NOT COVER. YOU MUST MAKE OVERSIZE FOCUSING EYEPIECE HOLDER* bered operations in diagram on opposite page. You will need a 5-ft. length of 12-in. wide shelf paper tacked or taped to a smooth board of similar size. A 6-ft. length of extruded aluminum storm sash molding makes a fine straight edge, but you can use any straight length of wood or metal. Operations 1 to 5 are obvious, as shown. Operation 6 requires the selection of some desirable and practical image size. When you look at most optical diagrams, the impression is that the objective lens or mirror automatically forms an image of a certain linear size. This is not the case at all. By itself, the mirror will form an image over a large area of several feet. The image is sharp at the center, becoming less and less sharp at increasing distances from the center.

How much of this big picture you are actually going to see is solely dependent on the size of the eyepiece. Approximately, you will see a linear field about 10% less diameter than the clear diameter of the field lens of the eyepiece. In observing with any telescope, you will use one medium-power eyepiece about 80% of the time. The linear field of this eyepiece is, therefore, the logical choice as a suitable image diameter. For most portable telescopes, this medium-power eyepiece will be 1 inch or a little more in focal length. Assuming 1 inch F. L. and 55 degree field, the linear field will be .96 inch, as given in Table 4. Mark this image size at the image plane, Operation 6.

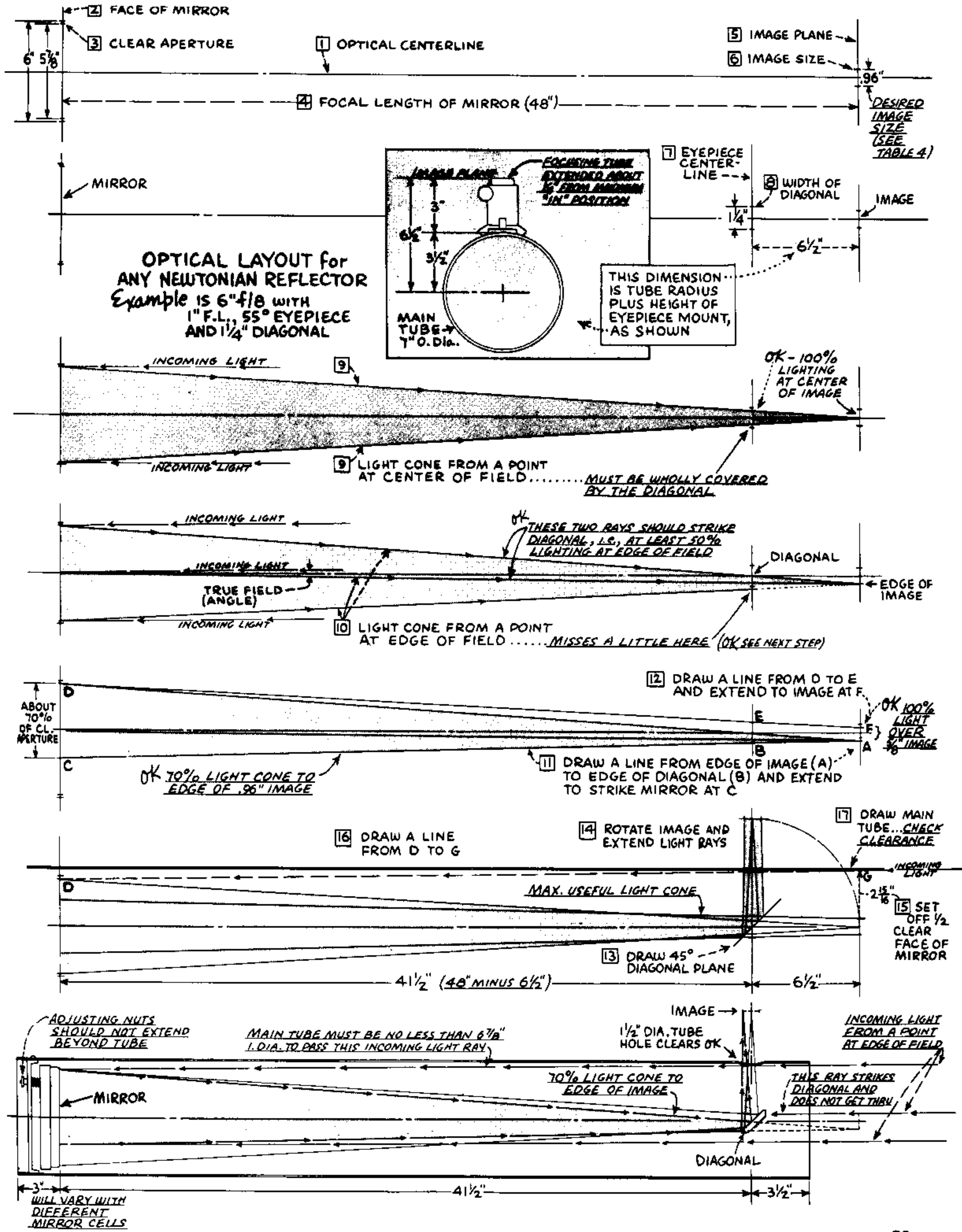
Assuming a 7-inch outside diameter aluminum tube, the eyepiece centerline can be drawn, Operation 7. You decide that a 1-1/4 inch elliptical diagonal is about right, proceeding with Operation 8. Now, you must determine if the image diameter size, diagonal width and tube diameter are actually workable. Operation No. 9 is the drawing of the cone of light rays for a point at the center of the field. The bottleneck is the diagonal, but for our 6-inch 5/8 example, the 1-1/4 inch flat covers the light cone completely. The incoming bundle of light rays will be concentric with the centerline and will have a diameter equal to the clear face of the mirror. Since the tube is larger than the mirror, the incoming light clears with room to spare.

The light cone for a point object at edge of field is commonly shown for one side only to avoid a confusion of lines. The diagram is for a point object at the top of the field, producing a point image at the bottom. To draw this light cone, you merely draw straight lines from the mirror to the edge of image, Operation 10. Having done this, you see immediately that a portion of the light cone misses the diagonal. The question is: Can you tolerate this? Operation 11 reveals how much of the mirror face is working for the edge-of-field image point. In the case shown, about 70% of the light cone gets through. The permissible tolerance limit for edge-of-field lighting is 50% of the objective diameter. In the example, the edge-of-field lighting is 70%--hence satisfactory. The tolerance itself is based on the fact that the human eye is self-compensating for a light loss at edge of field, that is, your eye is more sensitive to light for an object at the edge of field. Hence, if you lose some light at the edge of field, the loss will not be noticed. With 70% edge-of-field illumination, the light loss is undetectable even under close scrutiny. However, you will want to know what size of image gets full 100% lighting, and this is revealed by Operation 12. The accepted tolerance here is that the fully illuminated field should be no less than the image diameter of the full moon. Applying the simple formula given, you find the moon image for a 6 inch f/8 reflector is 7/16 inch. Since you have full lighting over a 5/8 inch circle, the design more than satisfies this requirement.

Assured that your design is okay, you now rotate the image to its actual position, Operation

Telescope Arithmetic

You Want to Find	What it is	MATH Formula	Example
MAGNIFICATION	INCREASE IN SIZE OF AN OBJECT AS COMPARED WITH NAKED EYE VIEW	$M = \frac{FO}{FE}$ (FO = F.L. OBJECTIVE, FE = F.L. OF EYPC.)	$M = \frac{48}{1} = 48\times$
TRUE FIELD	THE REAL ANGULAR FIELD OF THE TELESCOPE... *ABOUT 1° OR LESS*	$TF = \frac{AF}{M}$	$TF = \frac{55}{48} = 1.15° = 1°9$ MIN. (.15 / 60)9.00)
APPARENT FIELD	APPARENT ANGLE OF VIEW... IS SAME AS ANGULAR FIELD OF EYEPIECE	$AF = TF \times M$	$AF = 1.15° \times 48 = 55°$
IMAGE DIAMETER	LINEAR DIA. OF FIELD AT IMAGE ... IS SAME AS LINEAR FIELD OF EYPC.	*SEE TABLE 4* / *(IF F.L. NOT LISTED, USE VALUE FOR 1" AND MULTIPLY*	I.D. = .96" *(FROM TABLE 4)* / Example 1.1" F.L. .96 × 1.1 = 1.06" I.D.
I.D. OF MOON	LINEAR DIAMETER OF FULL MOON AT THE IMAGE PLANE OF TELESCOPE	ID MOON = .009 × FL	ID MOON = .009 × 48 = .43" = 7/16"


OPTICAL LAYOUT for ANY NEWTONIAN REFLECTOR
Example is 6" f/8 with 1" F.L., 55° EYEPIECE AND 1¼" DIAGONAL
2 FACE OF MIRROR
3 CLEAR APERTURE
1 OPTICAL CENTERLINE
5 IMAGE PLANE
6 IMAGE SIZE
6"
5⅝"
.96"
4 FOCAL LENGTH OF MIRROR (48")
DESIRED IMAGE SIZE (SEE TABLE 4)
MIRROR
IMAGE PLANE
FOCUSING TUBE EXTENDED ABOUT ½" FROM MAXIMUM "IN" POSITION
3"
6½"
3½"
MAIN TUBE 7" O. Dia.
THIS DIMENSION IS TUBE RADIUS PLUS HEIGHT OF EYEPIECE MOUNT, AS SHOWN
7 EYEPIECE CENTER-LINE
8 WIDTH OF DIAGONAL
1¼"
6½"
IMAGE
INCOMING LIGHT
INCOMING LIGHT
9
9 LIGHT CONE FROM A POINT AT CENTER OF FIELD.........MUST BE WHOLLY COVERED BY THE DIAGONAL
OK - 100% LIGHTING AT CENTER OF IMAGE
INCOMING LIGHT
INCOMING LIGHT
INCOMING LIGHT
TRUE FIELD (ANGLE)
OK THESE TWO RAYS SHOULD STRIKE DIAGONAL, i.e., AT LEAST 50% LIGHTING AT EDGE OF FIELD
DIAGONAL
EDGE OF IMAGE
10 LIGHT CONE FROM A POINT AT EDGE OF FIELD.....MISSES A LITTLE HERE (OK SEE NEXT STEP)
ABOUT 70% OF CL. APERTURE
D
C
E
B
F
A
12 DRAW A LINE FROM D TO E AND EXTEND TO IMAGE AT F.
OK 100% LIGHT OVER ⅝" IMAGE
OK 70% LIGHT CONE TO EDGE OF .96" IMAGE
11 DRAW A LINE FROM EDGE OF IMAGE (A) TO EDGE OF DIAGONAL (B) AND EXTEND TO STRIKE MIRROR AT C
16 DRAW A LINE FROM D TO G
14 ROTATE IMAGE AND EXTEND LIGHT RAYS
17 DRAW MAIN TUBE...CHECK CLEARANCE
INCOMING LIGHT
G
D
MAX. USEFUL LIGHT CONE
2 15/16"
15 SET OFF ½ CLEAR FACE OF MIRROR
13 DRAW 45° DIAGONAL PLANE
41½" (48" MINUS 6½")
6½"
ADJUSTING NUTS SHOULD NOT EXTEND BEYOND TUBE
MAIN TUBE MUST BE NO LESS THAN 6⅞" I.DIA. TO PASS THIS INCOMING LIGHT RAY
IMAGE
1½" DIA. TUBE HOLE CLEARS OK
INCOMING LIGHT FROM A POINT AT EDGE OF FIELD
MIRROR
70% LIGHT CONE TO EDGE OF IMAGE
THIS RAY STRIKES DIAGONAL AND DOES NOT GET THRU
DIAGONAL
3"
41½"
3½"
WILL VARY WITH DIFFERENT MIRROR CELLS

14. From diagonal to image, the maximum useful light cone for the whole image is bounded by straight lines drawn from the edges of the diagonal to the edges of the image. The hole in main tube must pass this bundle as must also the focusing tube itself or other mechanical apertures.

One point remains to be checked: Does the incoming light from edge of field get through the main tube? Operations 15, 16 and 17 show that it does, just grazing the tube at the position of the original image plane. Failure to get this ray through can be serious because you are already working with a reduced cone on one side, and this ray is the other side--if both are reduced the edge-of-field lighting may fall below the minimum 50% of aperture. You decide to end the tube 3-1/2 in. ahead of eyepiece centerline to gain a little extra clearance for the incoming light from edge of field.

DIAGONAL OBSTRUCTION. Some light is lost by the diagonal obstruction. Reference to Table 5 shows that the 1-1/4-inch elliptical diagonal commonly used in a 6-inch f/8 reflector blocks off 4-1/2 percent of the main mirror area. This is permissible. The tolerance for diagonal obstruction is about 6% and may be as high as 10% for visual astro use. If you want to use your reflector for daytime viewing, it is best to restrict the diagonal obstruction to 6% or less. For photo use, an 8% or even larger diagonal is essential for full-film lighting, and in this usage the large flat is perfectly satisfactory. For visual use, it is not the mere loss of light that sets the tolerance, but the fact that the diagonal is a real obstruction, a blind spot in your vision. If the obstruction is 6% or less of the area of main mirror, you will not be aware that it exists at all. A larger blind spot becomes more noticeable, especially in daytime viewing when the pupil of your eye is strongly contracted.

In any case, a rectangular diagonal can be a little smaller than an elliptical one. A 1-1/8 or even a 1-inch rectangular diagonal can be used for a 6-inch f/8 reflector. While the 1-inch size is a little small by the "cover the moon" specification, it will provide 100% illumination over a 5/16 inch diameter image, with 70% lighting at the edge of a 3/4 inch image--all of which is to say the little 1-inch flat is not too little.

MAKING YOUR OWN PARTS. A homemade mirror mount, such as shown on opposite page, is an easy project, requiring only drilling a few holes and cutting to shape on the band saw. The two wood parts should be nailed together for drilling the holes in order to obtain perfect alignment. The assembly should support a weight of 12 to 16 lbs. without further compression when the springs are compressed to normal working position. Mirror clips are usually fashioned from small angle brackets of steel or brass; contact points can be wrapped with plastic tape or masking tape to avoid metal-to-glass contact. The clips should not press heavily on the mirror,

TABLE 5 Percentage Light Loss by Diagonal Obstruction

ELLIPTICAL DIAGONAL SIZE	USUAL THICK.	MAIN MIRROR [1] 3"	4¼"	6"	8"	Remarks
5/8" x .88"	1/4"	4.5%	2.3%	1.1%	0.6%	OKAY FOR 3" f/10
3/4" x 1.06"	1/4	6.5	3.3	1.6	0.9	MIN. 4¼" f/10 [3]
7/8" x 1.24"	1/4	8.8	4.5	2.2	1.2	BEST FOR 3" f/10
1" x 1.41"	1/4	11.6	5.9	2.9	1.6	
1 1/16" x 1.50"	1/4	13.1	6.6	3.3	1.8	BEST FOR 4¼" f/10
1 1/8" x 1.59"	1/4	14.7	7.4	3.7	2.0	MIN. 6" f/8 [3]
1 3/16" x 1.68"	3/8	16.3	8.3	4.1	2.3	
1 1/4" x 1.77"	3/8	18.1	9.2	4.5	2.5	BEST FOR 6" f/8
1 3/8" x 1.94"	3/8	21.9	11.1	5.5	3.0	MIN. 8" f/8 [3]
1 1/2" x 2.12"	3/8	26.1	13.2	6.5	3.6	BEST FOR 8" f/8
1 5/8" x 2.30"	3/8	30.6	15.5	7.6	4.1	
1 3/4" x 2.47"	3/8	35.5	18.0	8.9	4.9	
1 7/8" x 2.65"	3/8	40.7	20.7	10.2	5.7	

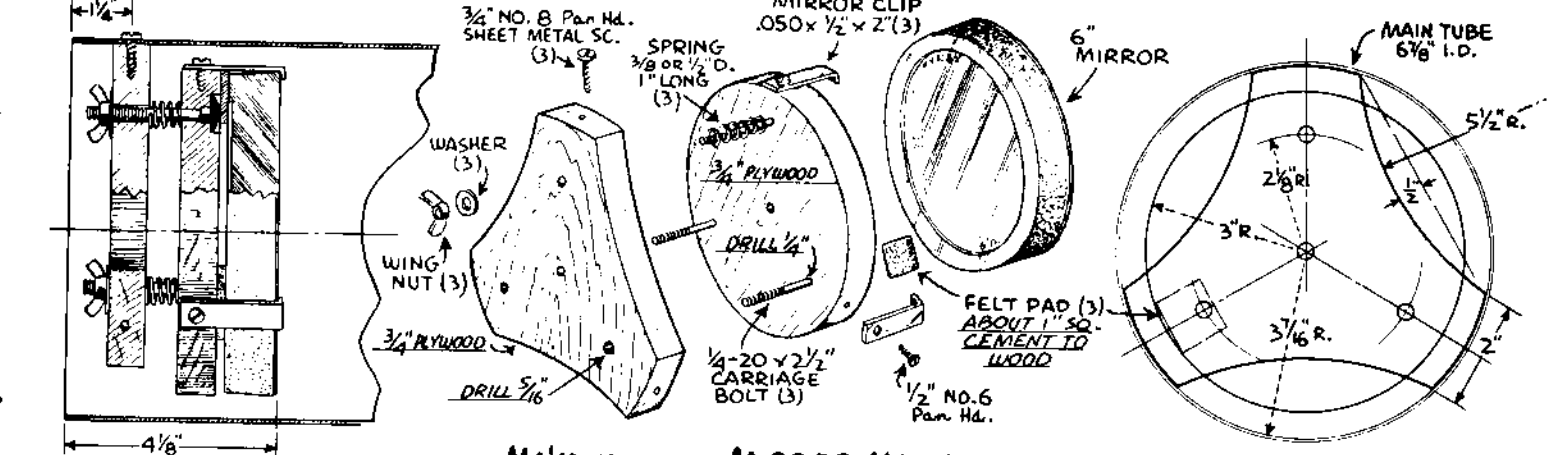
RECTANGULAR DIAGONAL SIZE	[2] THICK	MAIN MIRROR [1] 3"	4¼"	6"	8"	Remarks
5/8" x 7/8"	1/8"	6.6%	3.4%	1.7%	0.9%	BEST FOR 3" f/10
3/4" x 1 1/16"	1/8	9.5	4.8	2.4	1.3	MIN. 4¼" f/10 [3]
7/8" x 1 1/4"	3/16	13.0	6.6	3.3	1.8	
1" x 1 13/32"	3/16	16.8	8.5	4.2	2.3	BEST FOR 4¼" f/10
1 1/16" x 1 1/2"	1/4	19.6	9.9	4.9	2.7	CAN BE USED FOR 6"
1 1/8" x 1 19/32"	1/4	—	11.0	5.4	3.0	MIN. 6" f/8 [3]
1 3/16" x 1 11/16"	3/8	—	13.0	6.4	3.6	BEST FOR 6" f/8
1 1/4" x 1 3/4"	3/8	—	14.3	7.1	3.9	
1 3/8" x 1 15/16"	3/8	—	17.0	8.4	4.7	BEST FOR 8" f/8
1 1/2" x 2 1/8"	3/8	—	20.0	9.8	5.5	
1 5/8" x 2 9/32"	3/8	—	—	11.4	6.3	
1 3/4" x 2 15/32"	3/8	—	—	13.1	7.3	
1 7/8" x 2 5/8"	3/8	—	—	14.9	8.2	

GRAY AREA: DIAGONALS TOO BIG FOR SATISFACTORY VISUAL USE BUT ARE OKAY FOR PHOTOGRAPHY

[1] MIRRORS ARE LISTED BY "NAME-SIZE", BUT LIGHT LOSS IS BASED ON AVERAGE CLEAR FACE OF SLIGHTLY LESS DIA.

[2] PER CENT LIGHT LOSS INCLUDES EDGE OF DIAGONAL →

[3] MINIMUM DIAGONAL TO OBTAIN 100% LIGHTING OVER A FIELD AS LARGE AS THE ANGULAR SIZE OF MOON (1/2°)



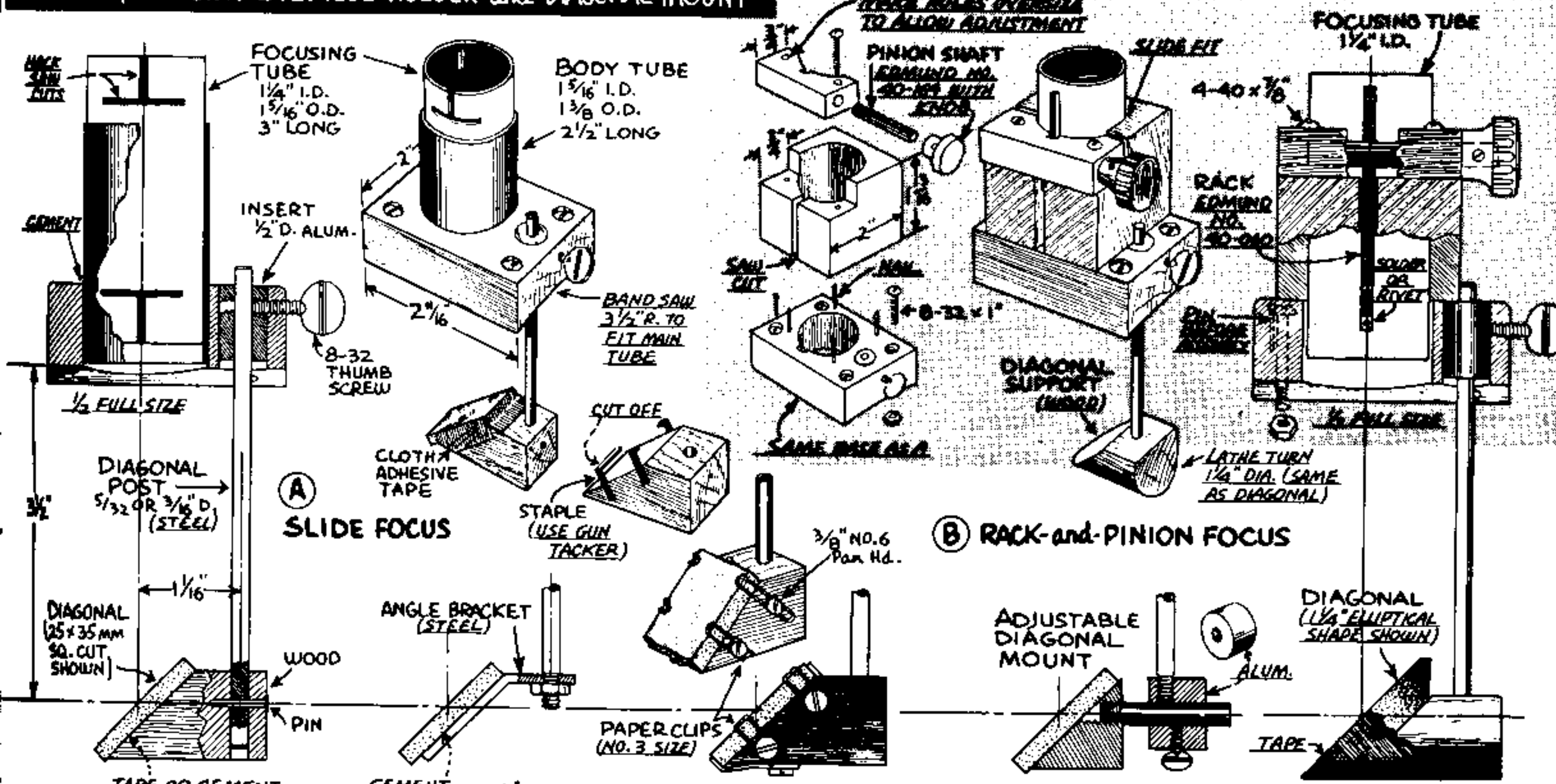
Make-your-own MIRROR MOUNT

which might cause distortion.

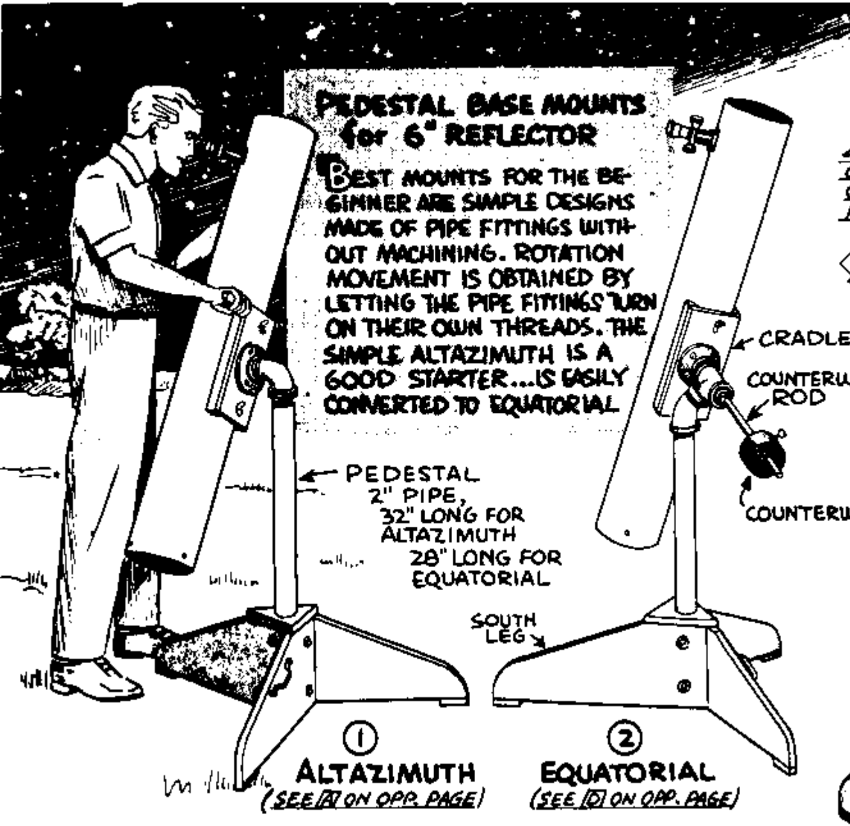
The eyepiece holder is the most difficult part to make. Even a simple slide focus device as shown at A below requires the use of a lathe, drill press, circular saw and band saw. Using the same base block, it is only a little more work to make a real rack-and-pinion eyepiece mount, as shown at B.

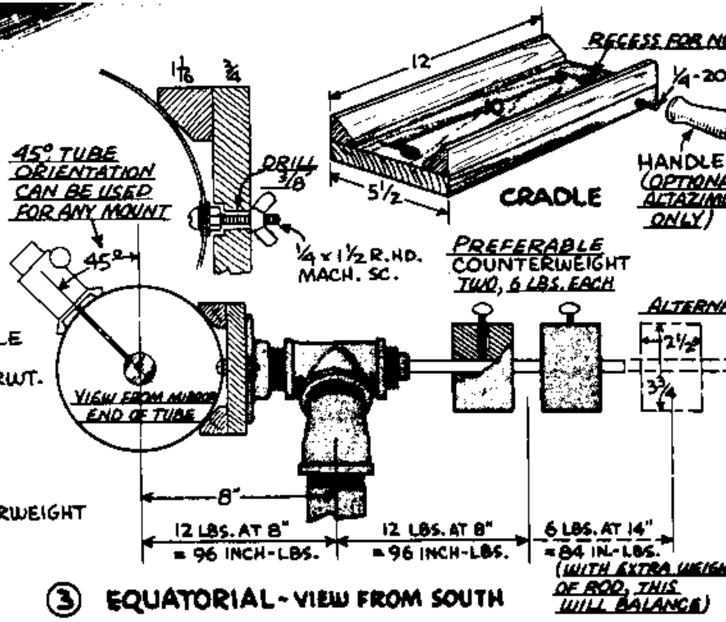
The diagonal mount is commonly made a part of the eyepiece holder although it can be made up as a separate unit and mounted independent of the eyepiece holder. The simplest way to attach the mirror to the diagonal support is by gluing, but this has the obvious fault of possible distortion. Taping is slightly better because this has enough "give" to relieve strains caused by warping or expansion. Mechanical fastenings are probably the best but they are always a fussy job to make and fit; like the clips on main mirror, they must support and hold the glass without pressure. A diagonal with a longitudinal adjustment is sometimes useful, and is easily made in the manner shown. If you use a wood support for the diagonal, it should be some stable, easily worked wood such as mahogany. Mounting by any method is simplified if the support is made the same exact size as the mirror. This means that for an elliptical diagonal, you must turn a cylinder of wood the same diameter as the width of the diagonal, and then slice this and cut at 45 degrees as shown.

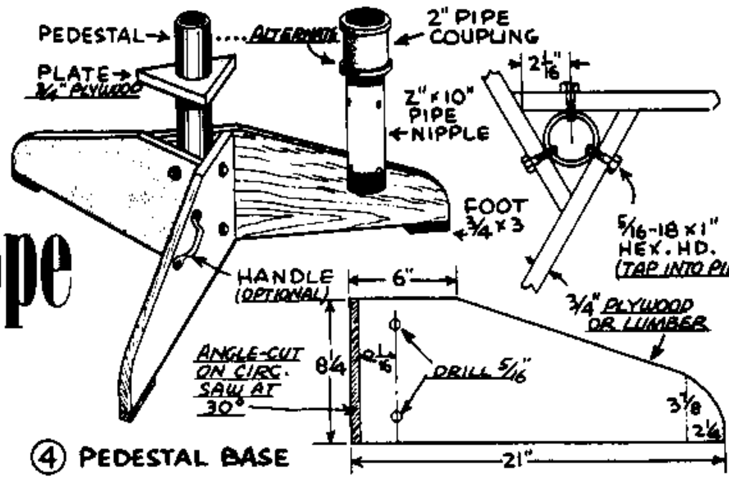
Make-your-own EYEPIECE HOLDER and DIAGONAL MOUNT



VARIOUS WAYS TO MOUNT THE DIAGONAL (ALL DIAGRAMS ½ FULL SIZE)







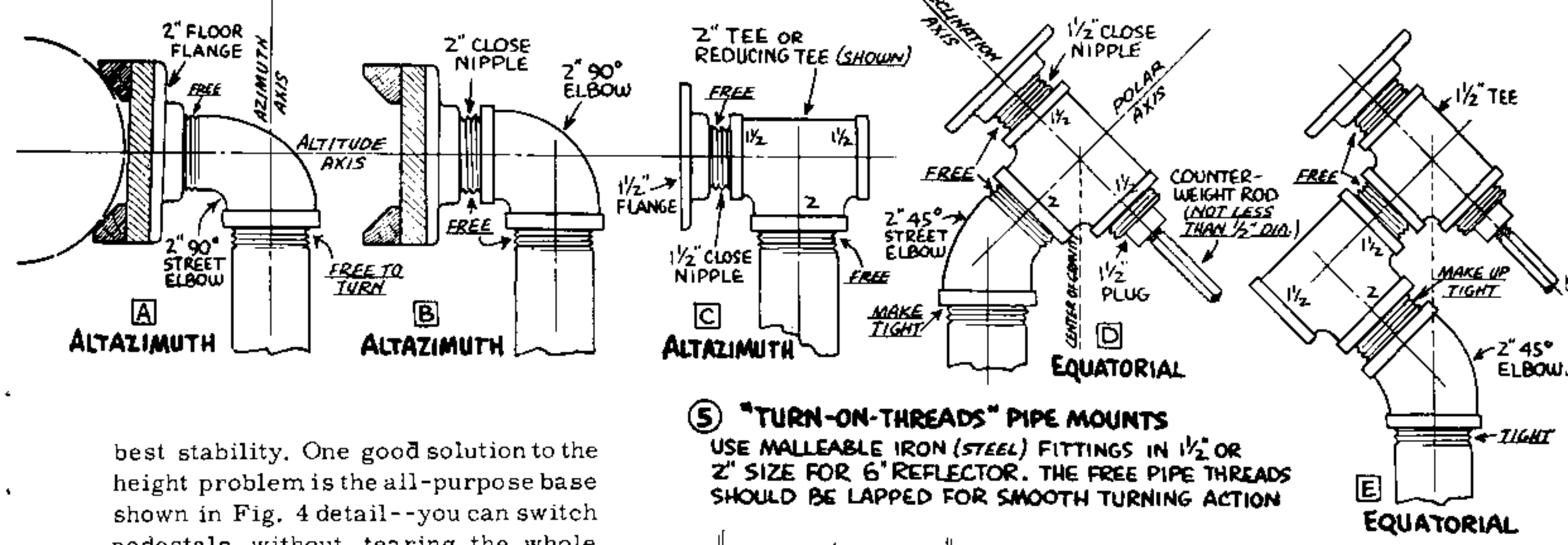
Mounting your telescope

YOU MAY eventually make something much fancier, but for a starter there is no better telescope mount than the turn-on-threads variety made of pipe fittings. With this kind of mount you get the needed mechanical movements by simply leaving the pipe fitting a little loose, free to turn. Much the same construction is used for both altazimuth and equatorial mounts. Both have two axes at right angles, but the primary axis of the altazimuth stands erect, Fig. 1, while the equatorial is tilted, Fig. 2.

Pipe and pipe fittings for a turn-on-threads mount suitable for a 6-inch reflector should be the 2-inch size, although in a pinch you can use 1-1/2-inch. Fig. 5-A shows the basic altazimuth made with the fewest number of parts. If you can't locate a street elbow, an ordinary elbow with a close nipple can be used, Fig. 5-B. It is always a good idea to start with the simpler altazimuth mount, but if you have your eye on an equatorial, then construction like 5-C lets you move right along to the equatorial, Fig. 5-D. All of these mounts have the center of gravity considerably off-center, but this is not an item of great importance. Sometimes you will see a turn-on-threads equatorial fitted with a gooseneck, Fig. 5-E, to put the weight directly over the pedestal, but on the whole this is over-building.

The free threads should be lapped-in for a smooth turning fit, this operation being done by applying a mixture of oil and fine abrasive (400-grit) and then applying your muscle to screwing and unscrewing the joint many times until you gain at least two full threads. The sludge is then removed with paint thinner, but you don't have to be too thorough since a little abrasive left in the joint is helpful for its mild braking action.

Ten years ago, the favored base for a portable telescope was the familiar wood tripod, but today 90% of all small reflectors are supported by a pedestal base. The homemade version, Fig. 4, has three wood legs fastened to the pipe pedestal with machine screws. If you work this one leg at a time, spotting holes, drilling and tapping, you will get a tight assembly which needs no other fastenings. How high to make the pedestal is always a problem. A pedestal 32 in. high for an altazimuth or 28 in. for an equatorial is about average, but since people come in assorted lengths it is not possible to suit everybody. In any case, you favor staying fairly close to the ground for

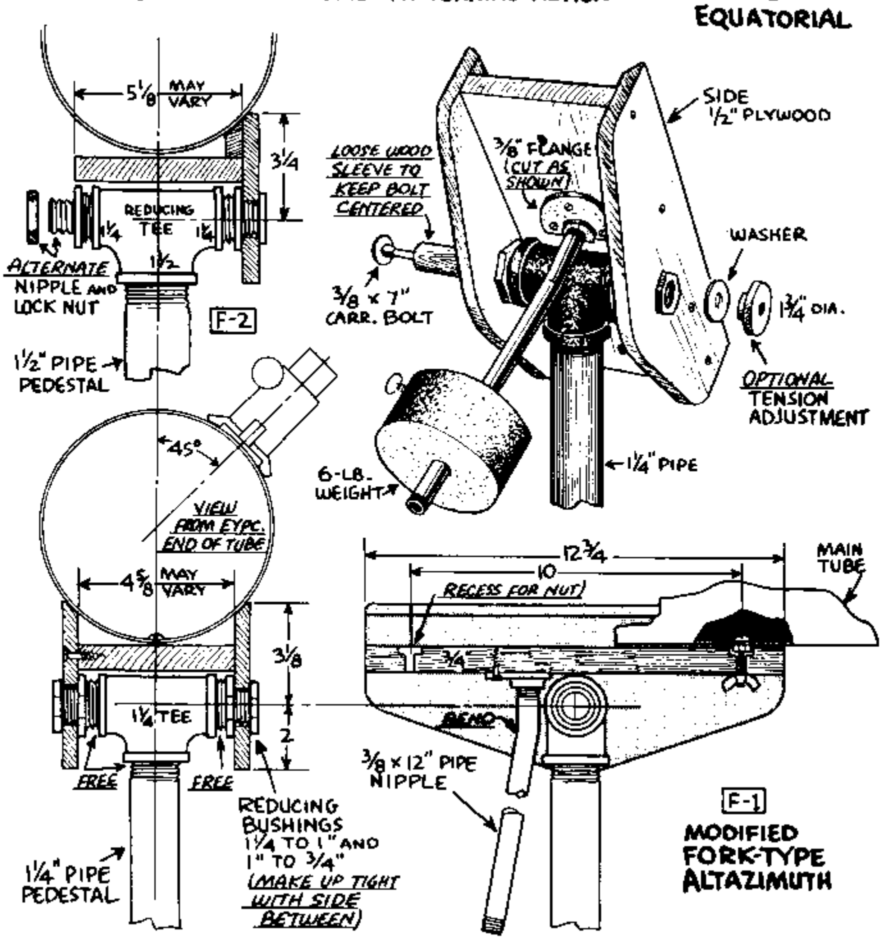


⑤ "TURN-ON-THREADS" PIPE MOUNTS
USE MALLEABLE IRON (STEEL) FITTINGS IN 1½" OR 2" SIZE FOR 6" REFLECTOR. THE FREE PIPE THREADS SHOULD BE LAPPED FOR SMOOTH TURNING ACTION

best stability. One good solution to the height problem is the all-purpose base shown in Fig. 4 detail--you can switch pedestals without tearing the whole assembly apart.

The equatorial shown in Fig. 2 is the popular German-type with primary polar axis providing a single outboard support for the secondary declination axis, which in turn provides a single outboard support for the telescope cradle. The other popular type of mounting is the fork type which provides a double support for the secondary axis. The fork principle can be applied to a turn-on-threads mount in the manner shown in Fig. 5-F. In use, the free thread on one side of the central tee unscrews while the opposite end tightens. A carriage bolt passing through the tee to a threaded knob allows putting a little squeeze on the threads to provide a tension adjustment. Although it requires a counterweight, this mount is nicely balanced and can be used successfully on a lightweight pedestal.

SHAFT EQUATORIALS. More conventional mounts are made with rotating shafts turning in sleeve bearings



PIPE

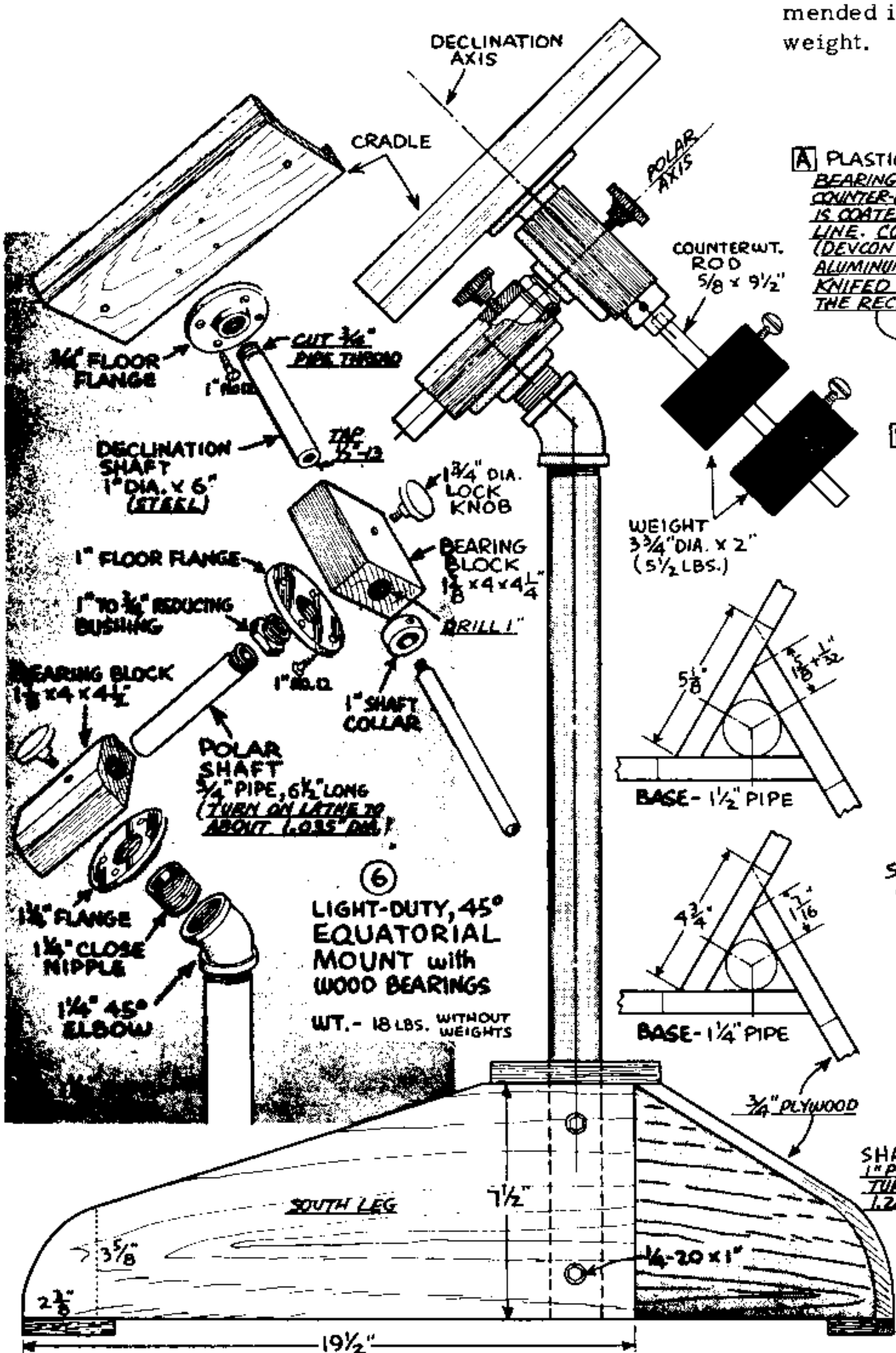
STANDARD WEIGHT STEEL PIPE, BLACK OR GALVANIZED

BLACK PIPE AND FITTINGS ARE CHEAPEST, EASY TO PAINT... GALVANIZED LOOKS GOOD WITHOUT PAINT

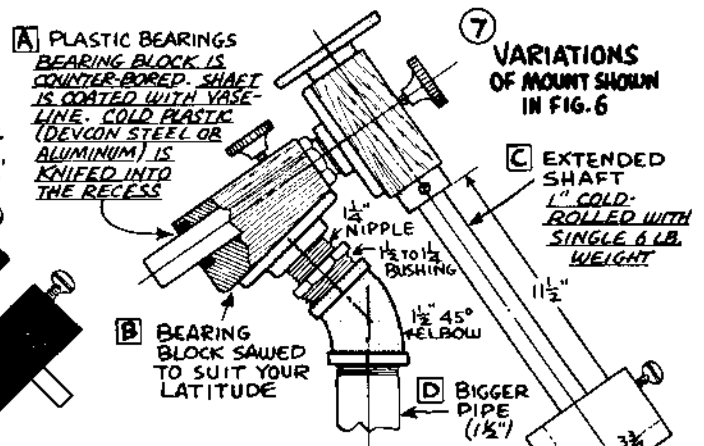
NAME SIZE	OUTSIDE DIA.	INSIDE DIA.	WALL	THREADS PER INCH	WEIGHT PER FOOT
⅛"	.405"	.269"	.068"	27	.24 LBS.
¼"	.540	.364	.088	18	.42
⅜"	.675	.493	.091	18	.57
½"	.840	.622	.109	14	.85
¾"	1.050	.824	.113	14	1.13
1"	1.315"	1.049"	.133"	11½	1.68 LBS.
1¼"	1.66	1.380	.140	11½	2.27
1½"	1.90	1.610	.145	11½	2.72
2"	2.375	2.067	.154	11½	3.65
2½"	2.875	2.469	.203	8	5.79
3"	3.50	3.068	.216	8	7.58
3½"	4.00	3.548	.226	8	9.11
4"	4.50	4.026	.237	8	10.79

of metal, plastic or wood. Minimum specifications are about 1 in. dia shafts in bearings spanning at least 4 inches. The simplest construction makes use of solid wood bearing blocks, Fig. 6. For shafts, you have a choice of steel, brass or aluminum bar stock, which is truly round, but you must cut the pipe thread, or, you can use pipe shafts which are already threaded but you must machine round. Fig. 6 design shows both. The holes through the bearing blocks can be worked on the drill press, preferably followed by hand reaming to exact size. You can improve a wood bearing block considerably by using bearings of Devcon plastic steel or aluminum, Fig. 7.

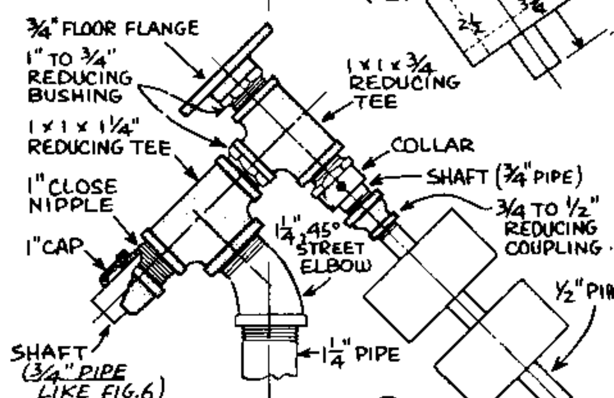
The most common type of construction makes use of pipe and pipe fittings. Dozens of variations are possible. Tees are used as bearing housings and reducing bushings make the bearings. These parts are assembled permanently and bored straight through from one end to the other. Ream or grind if you have the equipment; otherwise you can get a fair fit by lapping with 400 or 600-grit abrasive grains with oil lubricant. Fig. 8 design departs from the construction mentioned by using a pipe cap as the end bearing for the polar shaft. This is fitted permanently in place and then bored. Fig. 9 is a medium-duty design recommended if you want fair stability without too much weight.



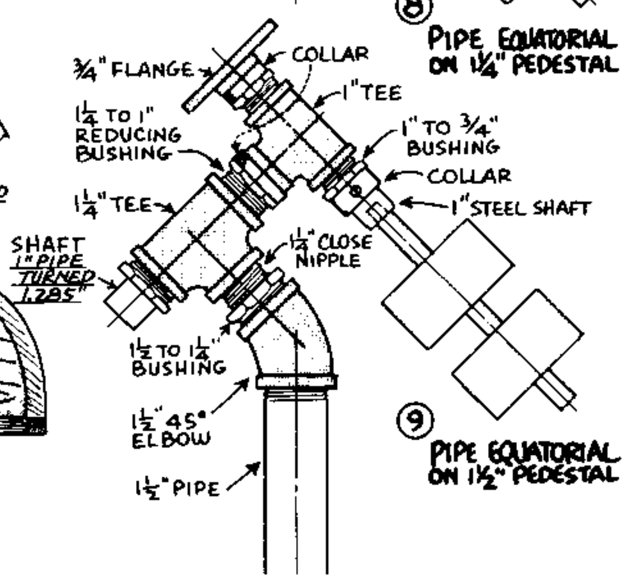
6
LIGHT-DUTY, 45° EQUATORIAL MOUNT with WOOD BEARINGS
WT. - 18 LBS. WITHOUT WEIGHTS



7
VARIATIONS OF MOUNT SHOWN IN FIG. 6



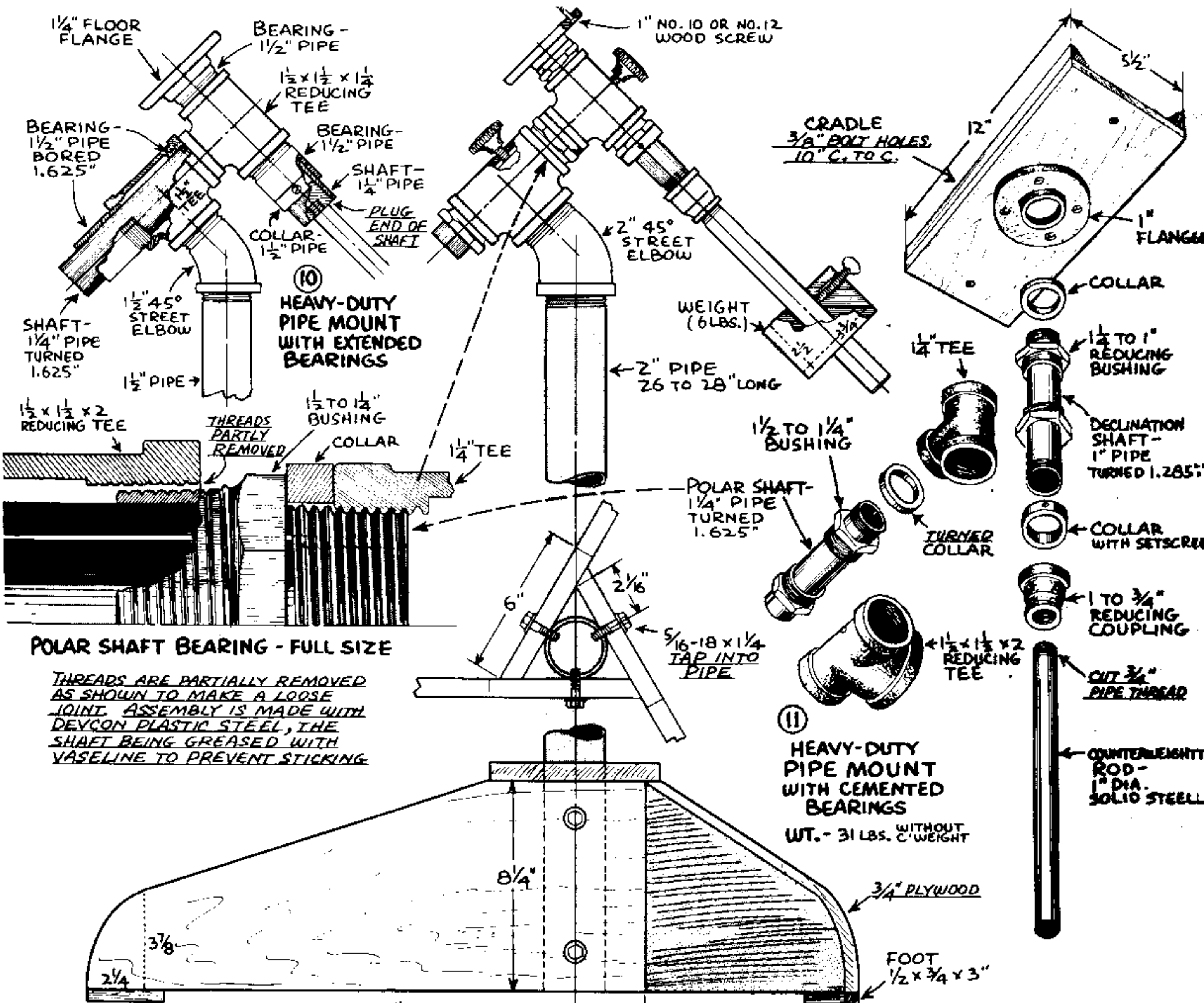
8
PIPE EQUATORIAL ON 1¼" PEDESTAL



9
PIPE EQUATORIAL ON 1½" PEDESTAL

The only difficult part of making a pipe equatorial is the boring job, the 4 or 5-inch depth being near maximum for average home workshop equipment. An alternate is to rough-bore the bearings separately .015 inch undersize, after which the assembly is made and the bearings hand reamed straight through to exact fit. Another solution is to use short sections of pipe as bearings, Fig. 10. You still have the straight-through boring job but it is easier to chuck and easier to bore. A third method is to use cemented bushings, Fig. 11. In this construction, the threads are partially removed from both the bushings and pipe tee with straight cuts to make a loose joint. The bushings are bored and fitted separately to fit the shaft, and the final assembly is made with adhesive cement, such as DEVCON plastic steel or aluminum. It is also practical to eliminate the bushings entirely, using bearings of plastic steel or aluminum in somewhat the same manner as Fig. 7. If the plastic bearings are thin-wall, the more liquid F-2 grade of Devcon plastic aluminum is preferable.

Avoid anything heavier than 2-in. pipe fittings if you expect to transport your mount from basement to backyard for each observing session. Cast iron legs can be purchased separately from Edmund; fit them to a stub pedestal of 2-1/2-in. pipe, and then extend to any desired height with reducing coupling and 2-in. pipe.



ADDENDUM

Throughout this book, we have discussed primarily 6-inch reflecting telescopes. They are the size most commonly made and used by amateur astronomers because of their relative lightweight, ease-of-construction, and portability. However, some of the more experienced readers may wish to try their hand in making 8, 10 or even 12 inch mirrors.

These mirrors have increased surface areas with similar f/ratios and will take additional time to excavate. Surface area is not as important, however, as change in f/number. The sagitta is really the same as the correction:

$$\frac{r^2}{2R}$$

The amount of glass removed is a function of abrasive, manpower and time. The following chart provides average times for grinding f/8 mirrors of various diameters.

In grinding a mirror, almost any method you can dream up is an old, tried system. The professionals use diamond grit generators that are costly, but produce mirrors with very little labor expense. Manufacturers of mirrors with numbers of similar curves often sag the curved shapes with heat.

Cast iron tools, preformed to curve, will also reduce grinding time. Adding a motor eliminates more hand work. Note, however, that these methods are not for amateurs.

There are rougher grades of abrasives, crushed steel for example, that will produce a curve faster. But it takes initiative and experience to efficiently profit by them. The sand blasting equipment used by glass engravers and tombstone manufacturers can help save time and is useful in making short radius mirrors.

Only experience in using the techniques described in this book, as well as the methods you develop in grinding, will make each new surface you work an increasingly pleasant exercise.

AVERAGE GRINDING AND POLISHING TIMES

Diameter (Inches)	Surface Area (Sq. Inches)	Grinding Time (Hrs.)		Polishing Rouge * (Hrs.)	Figuring Rouge (Hrs.)	Total (Hrs.)
		Rough #80	Fine #120 – #305			
6	27	4	6	10	10	30
8	54	6	8	12	10	36
10	81	8	10	14	10	42
12	108	10	12	16	10	48

*** NOTE: Barnsite or Cerium Oxide will polish much faster than rouge.**