AMATEUR TELESCOPE MAKING

SCIENTIFIC AMERICAN PUBLISHING CO.

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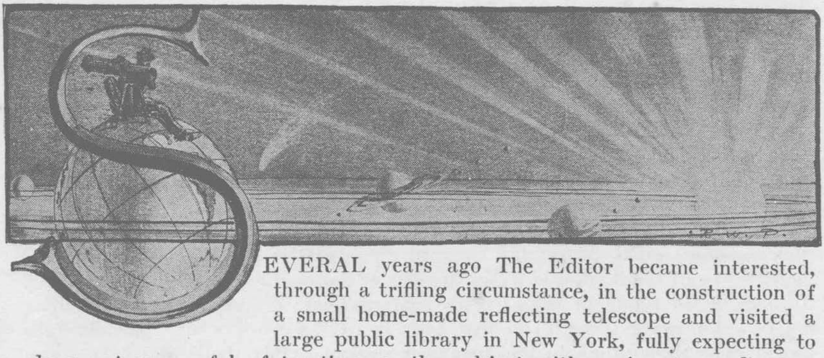
PREFACE



SEVERAL years ago The Editor became interested, through a trifling circumstance, in the construction of a small home-made reflecting telescope and visited a large public library in New York, fully expecting to draw out an armful of treatises on the subject with a view to reading up before attempting the venture.

Now it is a rare thing in these days of plentiful books and treatises on about everything under the sun, when one cannot easily lay hands upon at least a dozen books on a given subject, however obscure that subject may be; generally, in fact, the difficulty lies in eliminating all but the best one or two of them.

What, then, was The Editor's surprise on making the discovery that there was only one thoroughly practical book in the English language on telescope making for the amateur. By "practical" was meant a book which covered the subject in the detail which successful work demands and which bore the earmarks of preparation by someone whose experience in the art was not limited perhaps to the perusal of an encyclopedia article about it. That book was *The Amateur's Telescope,* most ably written by the Reverend William F. A. Ellison, Director of Armagh Observatory in Northern Ireland and veteran mirror maker. It proved to be a gold mine. With its aid work was soon commenced on a modest mirror of 6-inch diameter.

At this juncture The Editor discovered Russell W. Porter of Vermont. This gentleman, skilled by years of experience in the same work, gave willing ear to certain frantic appeals for assistance and advice, and in due course the little mirror was completed. And then a larger idea took shape. Why not, with the book by Ellison, the experienced assistance of Porter, and the pages of the *Scientific American,* attempt to popularize amateur telescope making as a widespread hobby? Such a hobby, it was thought, would be likely to make serious, dignified appeal to a rather unusual class of men. For it demands a modicum of skill and patience—enough to exclude the trifler (but not enough to have stumped hundreds of people in all walks of life who enjoy creating things of real beauty and worth with their own hands). Finally, the end-product would be an instrument capable of unlocking the majesty and grandeur of the whole visible Universe outside of this little mote we inhabit. The idea made appeal.

Largely to enlist the interest of the potential amateur the three articles which form the opening chapters of the present volume were prepared by Porter and were published in the *Scientific American.* There was no pretense that they were complete in themselves, for arrangements had already been made to reprint with them, between the same two covers, most of Ellison's work *The Amateur's Telescope,* obtainable only in Great Britain. In his excursion through these preliminary chapters the reader will therefore kindly bear in mind that the instructions for the various operations involved in making a paraboloidal mirror will be complete only when Porter's and Ellison's contributions have both been studied.

In taking up the work of telescope making without previous experience the beginner ought preferably to read this treatise twice—once to get the general lay of the land, and again to clear it thoroughly of mental underbrush. It may be advisable to skip, in this concentrative second excursion, all those parts not bearing directly on that portion of the work which logically falls to the tyro rather than to the advanced worker. Only those who have "been there" can speak with conviction concerning the inadvisability of starting with a large mirror. In the hypothetical race one beginner making first a 6-inch mirror and later a 12-inch, will finish both mirrors before another beginner could finish in satisfactory style a 12-inch mirror were it his first attempt. On the whole, it has been said with fair accuracy that a man who is handy enough to make a good radio or do his own automobile repairing, and who will exhibit patience, will succeed at mirror making. However, it is frankly not suitable work for those who have five thumbs on either hand.

It is now, as this preface to the second edition of the book is prepared, nearly three years since the popularization of the work was commenced by the *Scientific American.* The results have been most gratifying. Enthusiastic amateurs exist in every state and in many foreign nations. We are in constant correspondence with them, they call at the editorial offices when they are in the metropolis and we find their eager interest in the telescope making hobby a constant source of inspiration. Even the professional has now willingly joined hands with us; for no scientist is more unassuming and natural in his contacts with his fellow men of all stations than the professional astronomer. Perhaps familiarity with the scale of the Universe, and a knowledge of the comparative unimportance of man in it, help confer that boon which is denied to some whose existences are too closely rooted in the narrow confines of the earth. Thus we have, as the reader will see, the phenomenon of professional astronomers contributing to a book on a hobby for amateurs; and presently, we hope, some of these professionals will themselves take up telescope making and qualify as amateurs in their own right.

Before closing this section a short sketch concerning each contributor may prove to be of interest to the uninitiated reader.

Dr. Harlow Shapley, who contributes the Foreword, is Director of the extensive observatory at Harvard College and is widely known for his discoveries concerning the size of our Galaxy. He is one of America's foremost astronomers.

Russell W. Porter, author of Part I, and general collaborator with The Editor on the whole book, was born in Vermont and studied architecture at Massachusetts Institute of Technology. Following this he made eight trips to the Arctic with the Peary, Fiala-Ziegler and Baldwin-Ziegler expeditions, as artist, astronomer, topographer, surveyor, or collector for natural history. During the World War he was engaged in optical work at the United States Bureau of Standards. He is now Optical Associate of the Jones & Lamson Machine Company, too well known in the mechanical world to need further mention. He devoted much of his time there to the "screw-thread comparator" for the development of the optical parts of which he was originally responsible. We amateurs may well look to Porter as the leading genius of the American amateur telescope makers. His chapters on making a flat, a Cassegrainian telescope, and an eyepiece have never been duplicated, so far as The Editor knows, in any treatise. This is especially true of the chapter on the Cassegrainian, for it is believed that no similar instructions exist anywhere.

The Reverend William F. A. Ellison, around whose minute and explicit instructions for mirror making (Part II) the present volume was originally constructed, was formerly Rector of Fetherd-with-Tintern, but has been Director of the observatory at Armagh in Northern Ireland since 1918. This venerable masonry structure, or rather group of structures, including a residence and housing several telescopes, was built some time before the year 1800. Among the telescopes still preserved there is a six-inch reflector formerly owned by the well-known amateur astronomer King George III of England, of whom it might be said that he knew his stars better than his colonies. The Reverend Mr. Ellison took up telescope making as an amateur, and he still retains the amateur point of view. But the world, once it discovered the excellence of his mirrors, soon trod the traditional beaten path to his door to obtain them. The beginner, in making his first telescope, will find the bulk of his practical, working instructions in Ellison's treatise (pages 72-179) and should con these pages over and over.

Professor Charles S. Hastings of Yale, who contributes Part IV, has been intimately known to two generations of foremost optical workers. During many fruitful years he was one of a notable trio who together produced many of the world's largest and most famous telescopes. Of the trio, Dr. Hastings calculated the optical curves and contributed the necessary theoretical work; MacDowell, of the famous Brashear organization in Pittsburgh, contributed the craftsmanship; while Brashear himself popularized the work, also attending to the human and other relations involved.

Dr. George Ellery Hale, who describes solar research with the remarkable spectrohelioscope which he has developed, has frequently been characterized as America's foremost astronomer. Until his health recently forced him to lighten his chosen work, he was Director of the great Mt. Wilson Observatory. To list, even in outline, his honors and achievements would demand an entire page. The interested reader will find them mentioned in "Who's Who." Dr. Hale, whom all the world regards as a professional, likes to regard himself as an amateur. He is keenly enthusiastic concerning the interest recently aroused in amateur astronomy through the channel of amateur mechanics, and only the limitations of his strength forbid him from lending direct assistance to the humblest beginner.

Dr. Elihu Thomson, whose article on the theory of the polishing operation appears as a part of the Miscellany, is known equally well to science and to industry for his long list of researches and discoveries involving both. The invention of electric welding is but one of more than five hundred inventions credited to him. Though engaged in the active direction of the great Research Laboratories at Lynn, Massachusetts, to which the General Electric Company has given his name, he has never lost interest in one of his early hobbies—amateur telescope making. In past years he has made several refractors, including, of course, the objective lenses for them.

Professor G. W. Ritchey, a few of whose remarks appear in the Miscellany, is without doubt the world's most expert mirror maker, his largest piece of work being the 100-inch mirror at Mt. Wilson Observatory. Though engaged in exacting research on a new attempt to reach greater powers of telescopic magnification, he is nevertheless keenly interested in the popularization of the work among amateurs.

Clarendon Ions, who tells how to convert a Model T Ford into a telescope, is a Southern business man who for many years has made amateur optics his hobby. He is connected with the unique Southern Cross Observatory at Miami, Florida, devoted wholly to engaging the interest of the public in astronomy.

John M. Pierce, who tells how to make a simple telescope, is Director of Vocational Training in the Springfield, Vermont, High School—work involving machine shop practice in a large measure. He is a graduate of the Carnegie Institute of Technology in Pittsburgh and is a member of the original group known as the Telescope Makers of Springfield.

A. W. Everest, who describes the HCF polishing lap, is connected with the General Electric Company at Pittsfield, Massachusetts. Highly original himself, it is not remarkable to those who know him that he has hit upon an original method of hastening a previously fatiguing task. He has made at least eight excellent mirrors and knows whereof he writes.

And now, let us take up the actual work.

New York, July, 1928.

Albert G. Ingalls,
Associate Editor, Scientific American.

FOREWORD

By HARLOW SHAPLEY, Ph.D., Director, Harvard College Observatory

"I set myself to work", wrote the great Christian Huygens, one of the earliest of amateur telescope makers, who, inspired by Galileo's telescopic revelations, proceeded to reveal celestial marvels on his own account, and in 1659 unravelled the secret of Saturn's rings—"I set myself to work with all the earnestness and seriousness I could command to learn the art by which glasses are fashioned for these uses, and I did not regret having put my own hand to the task".

"And now that I, too, have fashioned some glasses," the amateur instrument maker may inquire, "what next?"

Three things are next; the first is inevitable, the first two are natural, and all three are possible. The first is to feel satisfaction that you have created something with your own hands. The second is to indulge your curiosity, and incite that of your friends, by using your equipment on the objects for which it is designed; but, in so doing, keep in mind that pride of manufacture is justifiable, but that humility and wonder are the appropriate attitudes in contemplating the stars.

The third privilege of the amateur, who has followed the book and his own intuition in constructing astronomical tools, is to use his product advantageously for science. To do so effectively, he must be sincere and have both freedom and spirit. Assuming that you who read this are so gifted, I shall make some suggestions.

First, if you have "fashioned some glasses" into a telescope of three inches aperture or larger, you can do valuable work on variable stars. The American Association of Variable Star Observers would welcome you to its international membership, give you instructions, charts and encouragement. And if you are of the right stuff, within a few months you should become, in your extra evening hours, one of the contributors toward the solution of some major astronomical problems, such as the nature of stellar variability and the evolution of stars.

If the Earth and the Moon attract you more than the remote telescopic stars, and if you have access to accurate time by observatory clock or radio, you are invited to learn the simple technique of occultations—that is, the accurate timing of the eclipsing of stars by the Moon. It is only of late that we have come to realize the important work that the serious amateur astronomer can do in helping to determine the Moon's position by observing the predicted occultations. Your observations will be directed and studied by professionals; and you will be aiding in a fundamental research—the measurement of irregularities in the rotation of the Earth and the lengthening of the terrestrial day.

Second, if you have fashioned (or bought) and mounted a very rapid photographic lens, in which the ratio of focal length of aperture is 3.0, or 2.0, or even less, you are invited to join the select ranks of astronomical sportsmen and go gunning for photographs of shooting stars. Photographing the shooting stars costs no more than trout fishing in the Adirondacks, or hunting mountain sheep in the Rockies, or angling off Catalina Island; but it should have much the same appeal and difficulty, and a greater thrill when success arrives. It is not hard to see shooting stars and make unreliable visual observations of them; but it is an art, mastered by few amateurs or professionals, to photograph the elusive intruders in our upper atmosphere and thereby make permanent and accurate records. We must have more meteor photographs. One hundred thousand plates in the Harvard collection have been examined, and have revealed only a few hundred meteor trails. They form the most important collection of such data in the world, and the importance lies largely in the fact that astronomers now see the great significance of meteors in the problems of interstellar space, of comets, and asteroids, of the nature of nebulae, and of the origin and maintenance of starlight. Meteors are fundamental and little known; they are the game of the astronomical sportsman, and if he can work with others of his kind, so much the more important his contribution.

Third, if you have fashioned some contrivance for the better recording of meteor paths observed visually among the stars, then you should get acquainted with the American Meteor Society, and the work it tries to do. You will find that there is good systematic work to be done in that field without camera and without telescope.

In summary, if you have the time and spirit for it, you can crown the zeal you have displayed in making an astronomical instrument by using it intelligently and constructively on important projects. If you communicate your earnest astronomical aspirations to any of the observatories, you will be freely counselled. The professional astronomer has gained too much from the amateur in the past to disregard him at this time, when many useful contributions can be made by the man whose hobby is astronomy. But remember that constructive work is only one of three privileges of the amateur telescope maker. The second may be the most important—to look into the heavens with uncovered head and humble heart.

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CONTENTS

AMATEUR TELESCOPE MAKING

Part I.

CHAPTER I.

Mirror Making for Reflecting Telescopes

By Russell W. Porter, M.S.
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In the reflecting telescope, *the mirror's the thing.* No matter how elaborate and accurate the rest of the instrument, if it has a poor mirror, it is hopeless. Conversely, a good mirror, even if it is crudely and simply mounted, makes a powerful and efficient astronomical tool.

We are concerned in this chapter with the shaping of the telescope mirror.

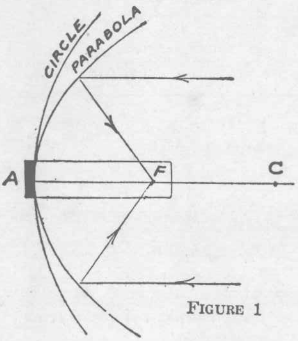

Figure 1

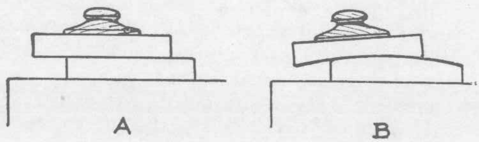

Figure 2

Figure 1. THEORY OF THE MIRROR. *Many find it difficult to understand why the focal length is only one-half of the radius or distance to the center of curvature, while in the shadow test the light is focused at the center of curvature. In the first case the rays are coming from a star, at almost infinite distance, and are therefore virtually parallel, while the rays that reach the mirror from the pinhole are divergent (radii). In this diagram, let us imagine we could grasp the two parallel rays indicated and actually pull their right-hand ends together until they touched the point C. As we drew them in, the angle at which they would now meet the mirror's surface would change, and since light is reflected away at the same angle at which it strikes a mirror, the reflected rays would shift at the same time from F to C, at double the distance of F.*

Figure 2. WHY THE CURVES DEVELOP. *The upper disk tends to hollow out because at the extremities of the strokes the abrasive effect on both disks is increased. This is due to the overhang and to the consequently increased pressure on the central portion of the upper disk, as well as the marginal part of the lower.*

This consists solely in giving one side of it a concave, polished surface. This surface is to be so very nearly spherical that we shall first attempt to make it precisely so; and at the very last we shall alter it to the kind of surface familiar to us all in automobile headlight reflectors, and known among the highbrows as a paraboloid of revolution.

Such an automobile headlight has the property of throwing out from a concentrated source of light placed at a focal point near it, a beam of parallel rays. (See Figure 1.) We shall, however, use this reflector the other way around, that is, by receiving parallel rays of light from a distant object (star); and by reflecting them from a properly curved mirror we shall bring them to a point or focus (F, Figure 1).

Our curve, however, is so small a portion of this widely sweeping parabola (the black area represents the mirror) that it is extremely shallow, and so it nearly coincides with the superimposed spherical curve. At first, therefore, we shall seek to hollow out a spherical curve, later deepening it very slightly into the paraboloid.

Since the angle of incidence of a reflected beam of light is equal to the angle of reflection, the parallel, arriving rays will be reflected approximately to a focus whose length may be regarded as one-half of the radius of curvature, C-A, Figure 1.

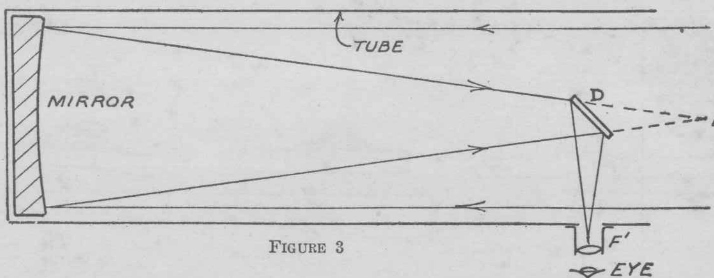

FIGURE 3

FIGURE 3. WHY A DIAGONAL IS NEEDED. *Without it the rays would theoretically come to a focus at F, where the observer's head would eclipse the light from the object. The diagonal mirror, or a prism, reflects them to F'.*

Enlarging the mirror of Figure 1, A, we have in Figure 3 the essentials of the Newtonian, reflecting telescope. Light from a distant object falls down the tube to the mirror, and normally would, by reflection, produce an image at the focus, F. The converging rays are, however, intercepted at D by a small diagonal mirror or prism that delivers them to a lens called an eye-piece at the side of the tube, where the image is examined.

I will take as our standard, a mirror six inches in diameter, having a four-foot focal length. The beginner is not advised to essay a larger mirror for his first effort, since his difficulties will be found to multiply quite disproportionately as the diameter increases. If two flat glass disks (A, Figure 2) are ground together, one over the other, with an abrasive between, lo and behold!—the upper one becomes concave, the lower one convex. This is because the center receives constant wear, while the outer portions, overhanging part of the time, receive less wear. In the illustration the length of stroke is somewhat exaggerated.

A straight, back-and-forth stroke, in which a given point on the upper disk moves across one-third the diameter of the lower, has the property of holding the two surfaces spherical. This is due to the fact that spherical surfaces are the only ones which remain in continuous contact at every point when moved over each other in any direction. This fact is a veritable godsend to the amateur—and to the professional, too, for that matter—for he may go confidently forward through the different stages of grinding and

FIGURE 4

PREPARING THE PITCH LAP

Melted pitch is being poured on the convex, upper face of the tool. Note the temporary collar of wet paper, which acts as a retaining wall for the pitch until it cools. Tool and mirror should previously have been placed in luke warm *water. If pitch is poured on a cold tool it will "set" so rapidly that there will be little time to make it conform to the curve of the mirror. But if the two disks are somewhat warm, there will be about ten minutes time in which to make a lap that will preserve good contact. Thus the worker may "take it easy" and do it correctly. Keep cold drafts away from the job. Warm water striking cold glass is not likely to break it, but cold water striking warm glass may.*

polishing with the knowledge that his mirror will come out nearly as it will be when it is finally deepened into a paraboloid.

The depth of the curve increases with grinding, and it is gaged with a template of the proper radius. Since by our rule, the radius, A-C, Figure 1, of the curve of the glass is twice its focal length A-F, a template is made from tin, with a radius of twice 48 inches, or 96 inches. Therefore a stick of wood (not a string, which would be elastic) should be tacked to the floor at one end so as to pivot, and a knife point held at the opposite end, or a sharpened nail driven through at the proper distance, should be used to scratch the desired curve to which the tin should be cut. For our six-inch mirror the hollow will come to about .05 inch deep.

The lower disk of glass is fastened to a pedestal or to a weighted barrel so that one can walk around it in grinding, or it may be held be-

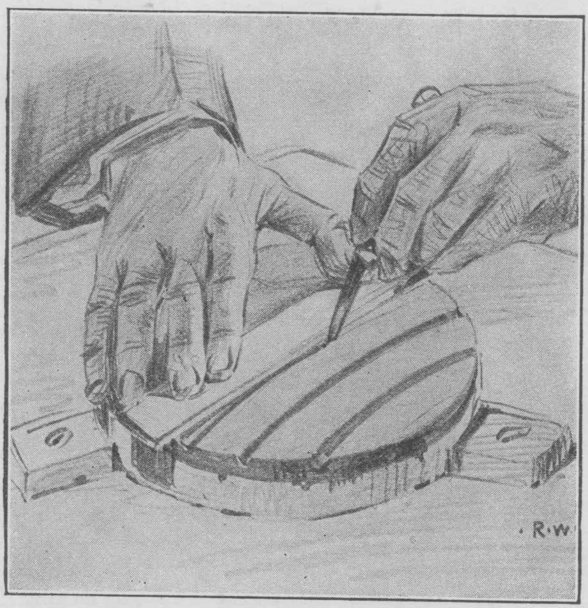

FIGURE 5

CUTTING CHANNELS IN THE PITCH LAP

Use a flexible straight-edge and a sharp knife. Keep everything wet, to minimize sticking of the pitch. In spacing the channels, precision serves no particular purpose. Do not center them, in any case. After the lap is formed and the channels are cut, leave the mirror on the lap until the tool, pitch and mirror have regained uniform room temperature. It should then be "cold pressed," or weighted, to insure the establishment of an even contact, which may have been disturbed during the cooling process.

tween one removable and two fixed buttons on the corner of a stout bench or table. (See frontispiece.) Using melted pitch, a round handle is attached to the upper disk, which is first heated in cold water to a slightly unpleasant warmth for the hand, taking care that no cold water drops fall on the warmed disk, for they might break it.

The grinding is done by placing wet carborundum grains of successively finer sizes between the two disks, care being taken after each size is used to wash all parts of the work entirely free of the larger sized grains, which would otherwise scratch the disk. The strokes are straight forward and back, the center of one disk crossing that of the other. The glass also rotates bit by bit in the hands, in order to present a new direction for each stroke; and from time to time, in order to prevent the wearing of the glass unsymmetrically, the worker shifts positions around the pedestal; or, if working on a bench, he turns the lower disk, called the "tool" (we shall discard this tool at the end) to a new position.

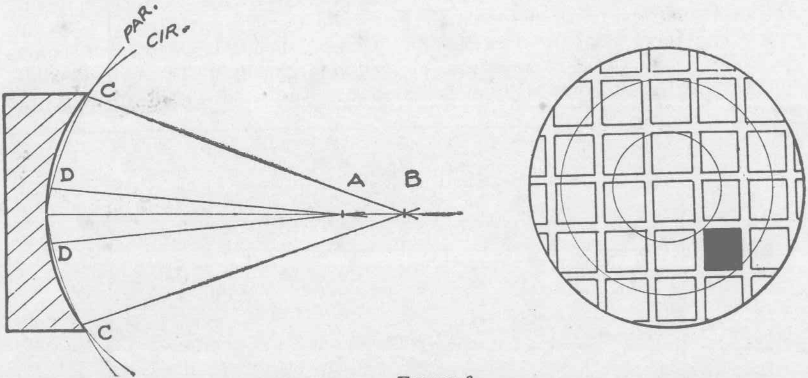

FIGURE 6

HOW MUCH HAVE WE PARABOLIZED?

The radius of a parabola shortens as its vertex is approached. Therefore the zone of the parabola near the edge, C, C, may be regarded (in practice) as part of a sphere with radius C-B. The central zone is regarded as part of a smaller sphere (shorter radius) with radius D-A. In the shadow test we can actually measure the distance A-B with a scale, and from this we can work out the amount that we have deepened or parabolized the center of our spherical mirror.

A TYPICAL PITCH LAP FOR A SIX-INCH MIRROR

The black square represents a facet removed from the lap in an effort to treat a depressed zone. Thus there would be less abrasion over the path traveled by this region as the mirror was rotated in polishing, and a zone (see rings on drawing) would tend to be raised above the general level of the glass.

Each grade of abrasive is used long enough to remove the coarser pits by the preceding grade, and it will save much time and labor in the polishing if a small quantity of wash 6F ("sixty minute") emery is used after the Number 600 carborundum.

All the preceding work is covered in great detail by Ellison in "The Amateur's Telescope," Part II of the present book, which at this time is the only modern work of this nature available in America.

The bench and both disks are now thoroughly washed in order to remove all traces of grit, preparatory to polishing.

Pitch is melted over a stove. It is tempered by adding (not over the fire) sufficient turpentine until a cooled sample placed between the teeth will just "give" slowly without crumbling, or will show a slight indentation of the thumb-nail under moderate pressure. The pitch is poured (Figure 4) over the tool, which has been warmed in water, and dried, and when it is partly cool, the glass is wetted (in warm water) and pressed down on the pitch until perfect contact is obtained between glass and pitch. V-shaped channels an inch apart are now cut across the pitch at right angles to each other, to allow free access of the rouge and water to all parts of the glass. Do not center this system of channels or you may produce zones in the mirror. See Figure 6.

Rouge mixed with water is now substituted for the carborundum and the polishing is carried on to completion, using the same strokes as in grinding. The time thus far consumed in grinding should be about five hours; polishing may require nine hours, divided into "spells." Through all these operations Ellison goes with painstaking care, anticipating the pitfalls into

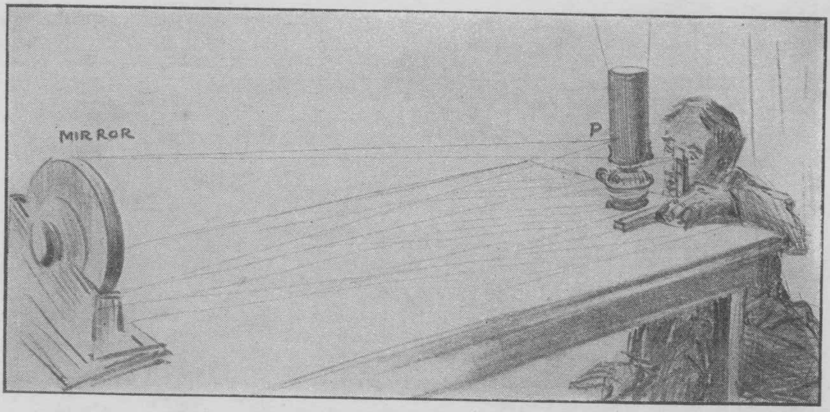

FIGURE 7

MAKING THE SHADOW TEST

The mirror does not necessarily have to rest on the same surface with the lamp and knife-edge, but all three should rest on stable supports which will not vibrate after the hand is removed from the knife-edge.

which the tyro inevitably falls. Were I to emphasize one caution over another, it would be the care required in preserving complete contact between the glass and the pitch lap surfaces while polishing.

If one-third strokes have been maintained in grinding and polishing, the surface of the glass will be nearly spherical. How shall we find out? The method I shall now describe is one of the most delicate and beautiful tests to be found in the realm of physics. By it, imperfections of a millionth of an inch on the glass can be detected, and all the tools required are a kerosene lamp and a safety razor blade! This method of testing mirrors, called the Foucault knife-edge test, was unknown until about 1850; before that time mirror makers were groping in the dark. Even the great Herschel

—father of the reflecting telescope—did not know when his mirrors were right, except by taking them out and trying them on a star.

If an artificial star made by a tiny pinhole (use a needle point) in a

FIGURE 8

MAKING THE KNIFE-EDGE TEST

The semi-circle in the foreground is the back of the mirror, with its handle, set in a simple wooden frame-work which can be made of a packing box cut down. Beyond is the lamp with metal chimney pierced by a needle hole; also the knife-edge. The latter consists simply of a dulled safety-razor blade or any strip of metal set in a split stick of wood which is driven into a hole in a block of wood. This crude equipment serves as well as if it were elaborated with more complicated devices.

tin chimney on a kerosene lamp (an electric lamp will not be suitable) were placed at the center of the sphere of which the mirror's curve is a very small part, all of that portion of the light that emerges from the pinhole and strikes the mirror, is reflected back to the pinhole; for these light rays