A SMALL, SIMPLE, BEGINNER'S TELESCOPE ANYONE CAN BUILD

Alan Binder & Ken Graun

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Alan Binder (AB) & Ken Graun (KG)

Part I: Introduction and Background

Introduction

Astronomy and telescope making are unique fields in the physical sciences because a person with no formal training can not only enjoy both as hobbies, but can also do professional level work. For example, many variable star observations are made by amateur astronomers, since there are far to few professional astronomers and they have far to little telescope observing time to continuously observe the myriad of variable stars in the nighttime sky. Similarly, amateurs contribute significantly to the search for comets, Near Earth Asteroids and Super Nova stars, as well as the study of features of Jupiter and Mars — just to mention a few. And many of these amateurs use telescopes they built themselves.

While amateur astronomy, both as a hobby and as an aid to professional astronomers, is booming, amateur telescope making is declining from its heydays in the 40s, 50s and 60s. This is mainly due to the numerous telescopes available from commercial vendors. This is, in our view, unfortunate, since making a telescope and observing with it is extremely satisfying and, when one can make the optics for a telescope, one is not limited to that which is available commercially, i.e., you can make a telescope to exactly serve your specific needs.

Figure I-1: A simple, 4-inch, 36-inch focal length (FL), Newtonian Reflector with a simple equatorial mount on a cement pillar in the atrium of AB's house. This telescope also has a tripod that AB uses when he is camping or wants to observe at a different location. Building this kind of telescope and mount requires only simple wood and metal working tools.

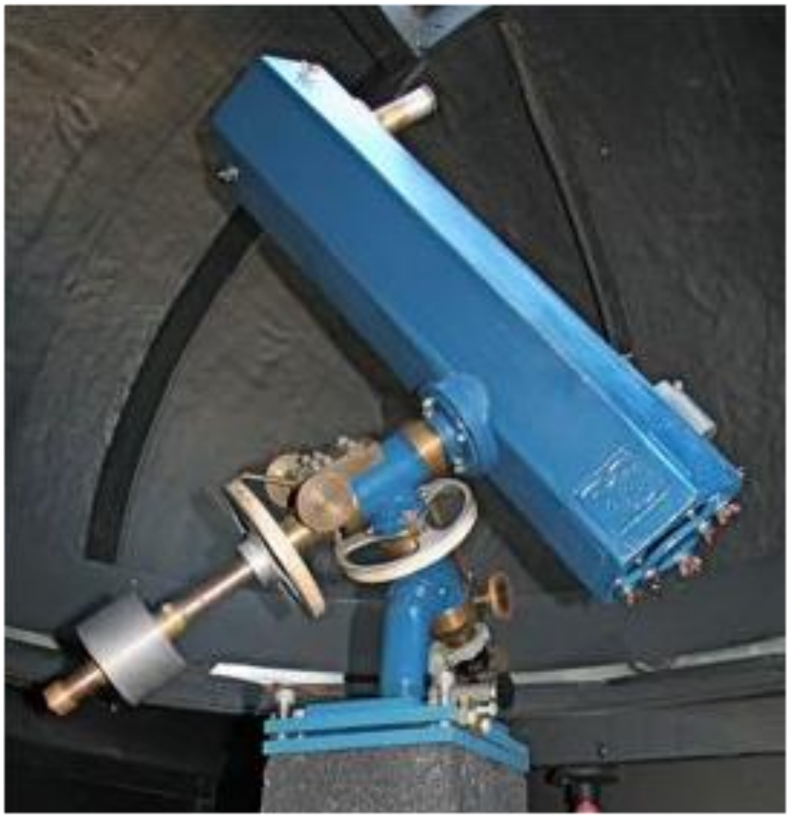

Figure I-2: A classic, 4-inch, 29-inch FL, Newtonian Reflector with a classic German Equatorial Mount, a clock drive, slow motion controls and setting circles in one of the domes of AB’s observatory. Building this kind of telescope and mount requires the use of a lath, a mill, and wood working tools.

Both authors have ground and polished mirrors and lenses for various telescopes over many decades. AB has made the mirrors for four, 4-inch Newtonian reflectors (e.g., Figures I-1 and I-2); three optical flats and a very long focal (46 foot) mirror for a solar telescope; a 4-inch Dall-Kirkham Cassegrain telescope; the 3-inch (2.8-inch clear aperture), 17-foot focal length lens and three Huygens eyepieces for a replica of the long-focal refractors of the mid-1600s (Figures I-3 and I-4); the lens and Kepler eyepieces for three replicas of the telescopes of the early 1600s, and the lenses and eyepieces for replicas of three of Galileo’s most famous telescopes (Figure I-5).

Figure I-3: AB’s 17-foot replica of the long-focal, non-achromatic refractors and mounts of the second half of the 17th century.

Similarly, KG has made the mirrors for one 6-inch and two 4-inch Newtonian telescopes and the lens and eyepiece for a Galilean telescope.

Figure 1-4: The single element, 2.8-inch clear aperture objective lens and the three Huygens eyepieces (50x, 100x and 150x) of AB's 17-foot replica telescope.

Figure I-5: Replicas of three of Galileo's telescopes made by the authors.

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As such, we can attest to the enjoyment we have had from the many 1000s of hours we have spent observing the Sun, the Moon, the planets and their satellites, comets, double stars, galactic star clusters, diffuse nebulae, planetary nebulae, globular star clusters and galaxies. Observations that were, and are, even more rewarding since we made the telescopes ourselves, telescopes that were designed to fit our observing needs.

It is with this background that we decided to write this instruction manual and make the accompanying video on how to make a small (1.5-inch), simple, refracting telescope for anyone who is interested in amateur astronomy and amateur telescope making and does not know how to start. By doing so, we hope to awaken the interest of people, especially young people, in these two fields of scientific endeavor—interests that could led to careers in either of these two fields in this age of space exploration.

How Useful is a Small, Simple Telescope?

There is a general misconception among those who have never looked through an astronomical telescope that leads to a question often asked; "Don't you have to have a big telescope to see anything?" The answer is a resounding "No." AB's first telescope was a 25x, 1½-inch, achromatic refractor his dad used for hunting! With it, AB observed the craters, marae and mountains of the Moon, lunar eclipses, sunspots and a solar eclipse, the phases of Venus, Jupiter and it's two main belts and its four major satellites, a few asteroids, Saturn's rings and Saturn's largest satellite—Titan, Uranus, Neptune, numerous double stars, the Orion Nebula and a few other diffuse or gaseous nebulae, several galactic star clusters, a planetary nebula, many globular clusters, the Great Andromeda Galaxy and a couple of other galaxies. To drive this point home, the reader can go to Appendix A to see a list some 130 objects he or she can observe with the simple telescope we describe in this manual.

However, one note of caution: You will never see, through *any telescope,* the detail of any celestial object that is captured, often in color, by a long exposure image, e.g. the beautiful pictures from the Hubble Space Telescope. The human eye is only capable of seeing, e.g., galaxies, gaseous nebulae and most globular star clusters, as gray patches of light even in modest sized telescopes. Also, the colors of Mars, the colors of the cloud belts of Jupiter and those of stars are just faint hues—not the brilliant reds, browns, etc. seen in pictures. The thrill of visually observing these objects is knowing what you are seeing, e.g., that that gray patch of light is the Andromeda Galaxy, our sister galaxy, consisting of several 100s of billion of stars located some 2.4 million light years away or that gray patch is the Orion Nebula, in which stars are being born as you are watching (so to speak).

As such, the simple, beginner's telescope we describe in this manual is designed to open to doors to the wonderful fields of astronomy and telescope making, not to compete with the Hubble Telescope, or even a modern, modest sized telescope.

The Development of the Telescope

It is generally accepted that the telescope was invented by a Dutch spectacles-maker, Hans Lippershey, in 1608. News of the invention spread from Holland to England and Germany and, finally, to Italy. Using the newly invented telescope, Harriot in England began observing the Moon as early as July 26, 1609; Simon Marius in Ansbach, Germany discovered the four "Galilean" satellites of Jupiter and named them in November 1609 and later the Andromeda galaxy; and in late 1909, Galileo in Italy began observing the Moon, the planets and the stars. However, it was Galileo who was largely responsible for spreading the word about the astronomical discoveries make by the newly invented telescope and hence he is frequently and erroneously credited with both the invention of the telescope and all of the early discoveries made with it—as a result, the type of telescope used by those earliest observers is called a "Galilean Telescope".

Galilean telescopes have either a plano-convex lens or a biconvex lens (so called positive lenses) as the main—or objective lens, with clear apertures of generally less than an inch and with focal lengths of up to several feet. The Galilean eyepiece is a plano-concave or biconcave lens (so called negative lenses) yielding magnifications of up to about 30x (Figure I-6a). However, one of the main disadvantages of a Galilean telescope with its negative eyepiece, is that the field of view is extremely small. When looking through the replicas of Galileo's telescopes we have made, the view is quite unpleasant, since it is like looking through a soda straw! This makes it difficult to find and track objects—even the Moon.

In 1611 Kepler made the first improvement to the astronomical telescope by suggesting that the negative Galilean eyepiece lens be replaced by a positive lens (Figure I-6b). The result of using a Keplerian eyepiece is that, for the same power as a Galilean telescope, the field of view is quite large and the view is very pleasant.

However, even after Kepler's suggested improvement of the early telescopes, two major defects remained. Since the objective lenses used were *single element* lenses (that is, they consisted of just one lens), they suffered from both spherical and chromatic aberration. In spherical aberration, the light rays near the center of the lens come to focus at a greater distance from the lens than the light rays at the edges of the lens (Figure I-7a). In chromatic aberration, the rays of

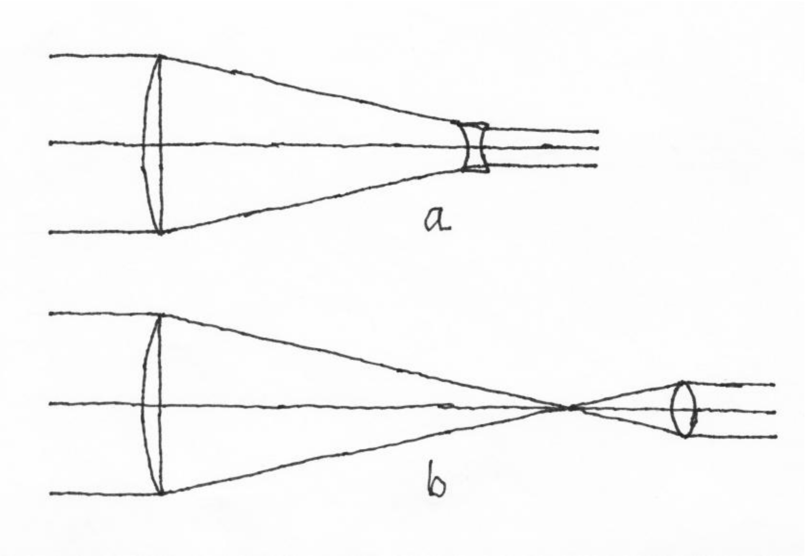

Figure I-6: (a) Optical configuration of a Galilean telescope with a single element, objective lens and a negative eyepiece lens; (b) Optical configuration of a Keplerian telescope with a single element, objective lens and a positive eyepiece lens.

light of different colors come to focus at different distances from the lens, e.g., the red light focus is longer that that of blue light (Figure I-7b).

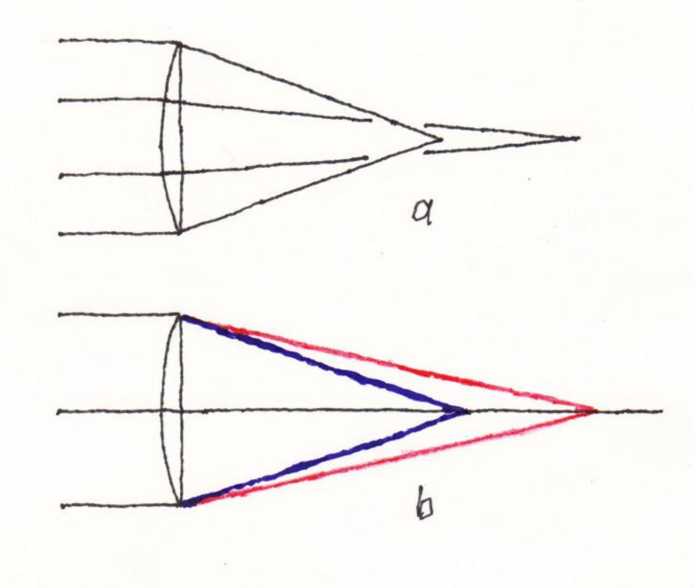

Figure I-7: (a) Ray traces showing the effects of spherical aberration on the focus points of rays passing through the lens near the center of a single element lens and those passing through the lens near the edges of the lens; (b) Ray traces showing the effects of chromatic aberration on the focus points of rays of blue light and those of red light.

These two defects of a single element lens means that the image produced is somewhat blurry. By the middle of the 1600s, astronomers and telescope makers, like Huygens and Hevelius, found that the effects of spherical and chromatic aberrations could be compensated for by making the focal length of the objective lens very long. However, both of these effects depend on the square of the diameter of the objective. Thus, while a 1-inch diameter objective with a focal length of 40-inches or more is essentially color-free, i.e., achromatic and essentially free from spherical aberration, the focal length of a 2-inch diameter lens must be 160-inches or more, that is, 13-feet to be nearly defect-free. As the reader can surmise, this solution to the aberration problems of single lenses via increasing focal lengths has it limits and led to telescopes of the second half of the 1600s having focal lengths of 100- to 200-feet, and even more, while still having objective lenses no larger than 6 to 8 inches in diameter, e.g., Hevelius’ 150-foot telescope (Figure I-8). Needless to say, telescopes of those lengths were very difficult to use, but as AB demonstrated with his 2.8-inch clear aperture, 17-foot replica of the telescopes of that era (Figures I-3 and I-4), modest sized telescope of that era were very capable astronomical instruments (Appendix B; Binder, 1992; Binder, 2010a; Binder, 2010b).

There are two other solutions to the problems of telescopes caused by spherical and chromatic aberration. First, if the objective lens is made with two lenses, one positive and one negative, with the two lenses made from glasses with different dispersions, i.e., different refractive indexes for the different colors of light, the resulting *two element* objective is nearly achromatic and free from spherical aberration, even for telescopes with very short focal lengths. However, this solution was not discovered until 1733 by Hall and, of course, making an achromat, as such lenses are called, is not a simple task.

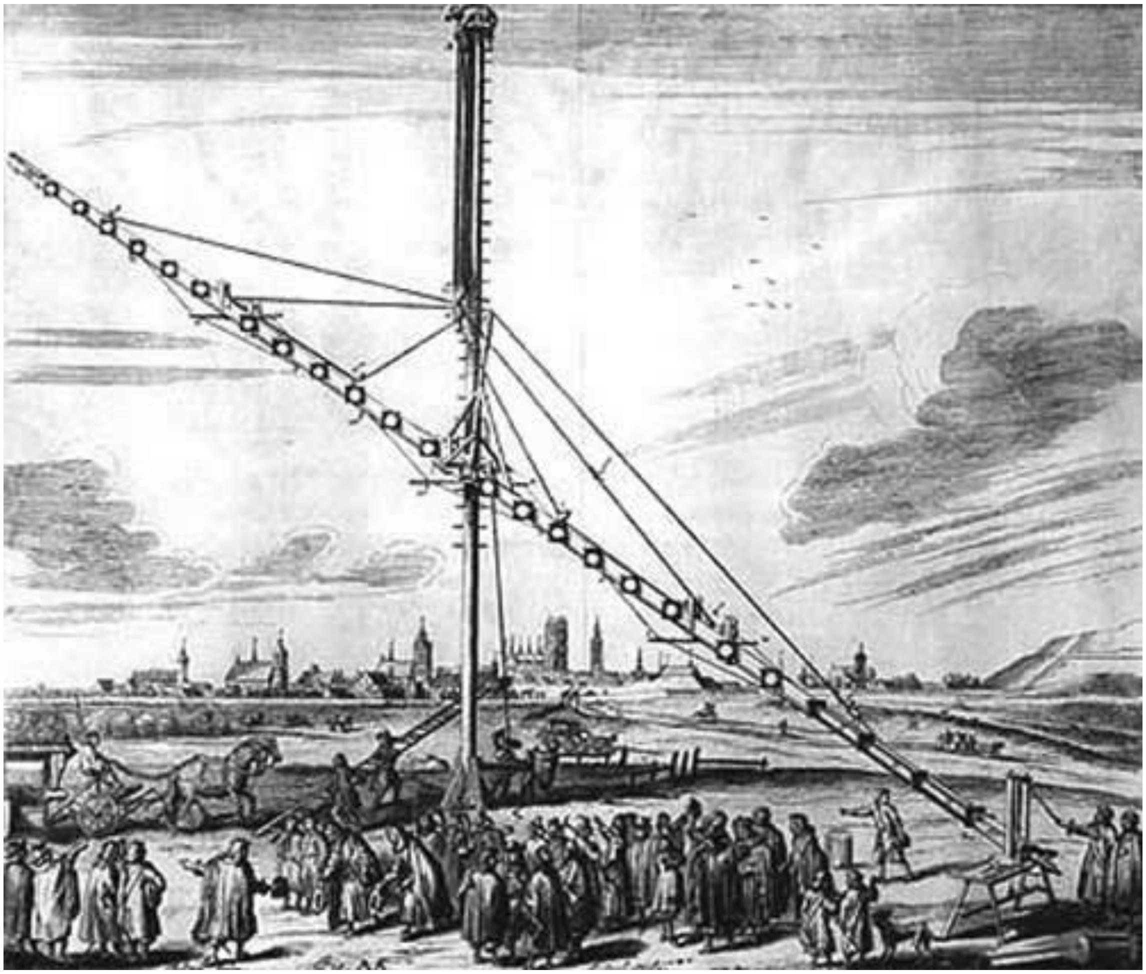

Figure I-8: Hevelius’ 150-foot telescope.

Second, it was recognized very early that if a parabolic mirror could be ground and polished, it would be both achromatic and have no spherical aberration. However, the “*if”* was the problem, since no one initially knew how to grind and polish such a mirror and mirrors were made of *metal*, rather than glass, until the middle of the 1800s. Nevertheless, in 1668 Newton succeeded in making the first, small (1¼-inch diameter mirror with a 6¼-inch focal length) working reflecting telescope (Figures I-9a and I-9b), but it

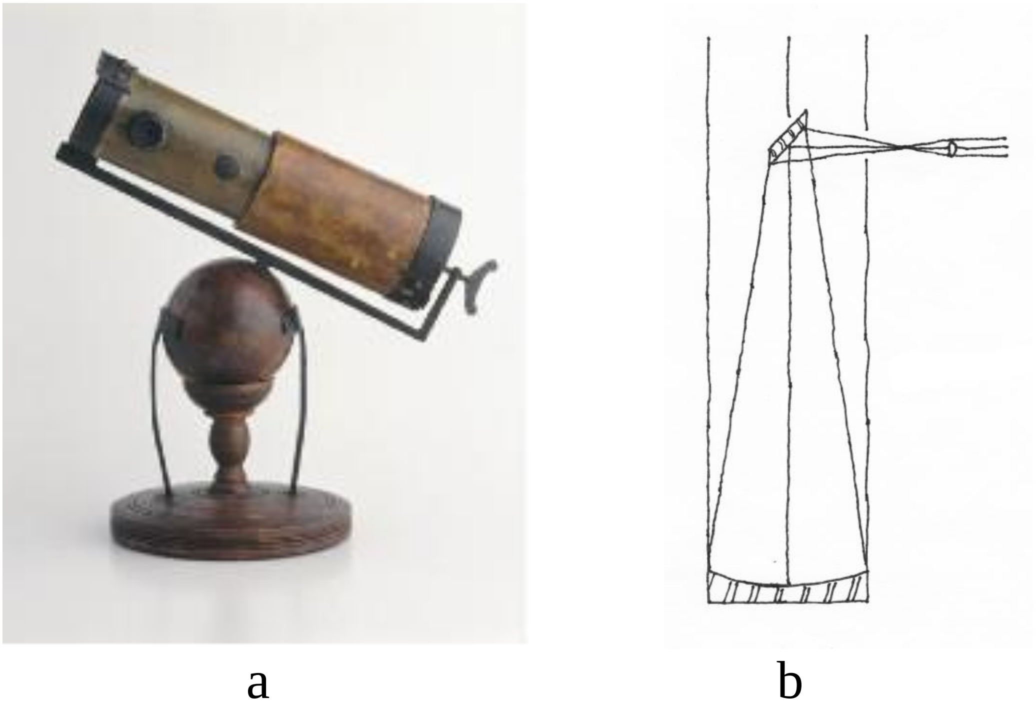

Figure I-9: (a) The first Newtonian reflecting telescope; (b) optical configuration of a Newtonian reflector.

was not until 1721 that Hadley make the first practical Newtonian telescope with a 6-inch diameter mirror of 62-inch focus (Figure I-10).

It is this Newtonian design that was the mainstay of the amateur telescope-making boom in the 1940s, 50s and 60s. However, though anyone can make a mirror for a Newtonian telescope, it does require a lot of time, effort and a learning period. And though the mechanical parts of a Newtonian can be very simple and made with simple tools (Figure I-1), most amateur telescope makers opt for a more sophisticated telescope that requires the use of a lathe and a mill (Figure I-2), unless one buys all the mechanical parts of the telescope and its mount.

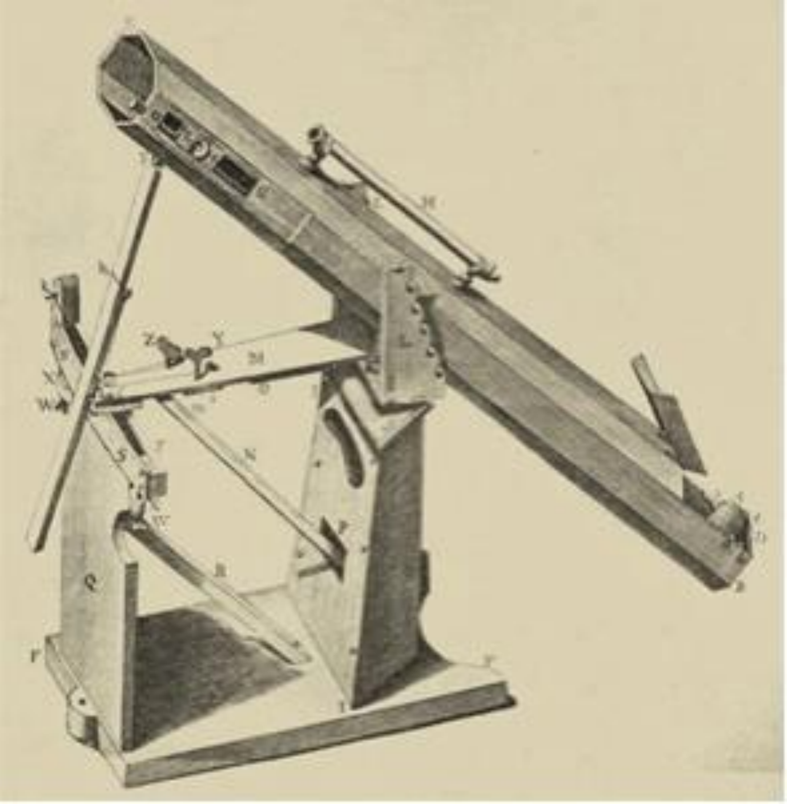

Figure I-10: Hadley’s 6-inch diameter, 62-inch focal length Newtonian telescope.

The above discussions of telescopes is sufficient for the purposes of this manual, but any reader who is interested in learning more about the development of the astronomical telescope should read King’s excellent book, “The History of the Telescope” (Appendix B). And anyone who is interested in making telescopes more advanced than the one described below should read any of a number of excellent books on telescope making, e.g., “Amateur Telescope Making, Book One” (Appendix B).

A Simple Telescope for the Beginner

Based on the years of experience the authors have had making and observing with telescopes, both modern and replicas of historical telescopes, we have designed a very simple, non-achromatic refractor with a simple mount that anyone can make in a short time using 1) the lens grinding and polishing kit we can supply, 2) items purchased from a hardware store and other stores and 3) simple tools.

The telescope optics consist of a single element (non-achromatic) plano-convex objective lens with a clear diameter of 1½-inch (1¾-inch full diameter) with a 60-inch focal length (FL) and two plano-convex, Keplerian eyepieces with 2-inch and 1-inch focal lengths, yielding 30x and 60x.

The kit (Figure I-11), which we supply via Ken Press for $20.00 plus $6.00 shipping (we make no profit - rather lose money on these kits), consists of the following:

1) Two 1¾-inch diameter plate glass, beveled blanks for making the objective lens,
2) Two 11/4-inch diameter, plate glass blanks and a curved template for making the 2-inch focal length eyepiece lens,
3) Two ¾-inch diameter, plate glass blanks and a curved template for making the 1-inch focal length eyepiece lens,
4) Two 1¾-inch diameter spindles; two 11/4-inch diameter spindles; and two, ¾-inch diameter spindles to hold the glass blanks while making the lenses,
5) Four little bags of grinding grit (#80, #220, #400, and #600 grit) for course and fine grinding,
6) One little bag of Cerium Oxide (CeO) for polishing,
7) One cup of optical pitch for polishing,
8) The wooden elements for the mounting cell of the objective lens,
9) The wooden elements for the two eyepieces, and
10) The wooden rings to hold the plastic drawtube in the telescope tube.

In addition to the materials provided in the kit, you will need to buy a number of items—and have access to several different, simple tools—to make the telescope tube and mount, as listed in each of the appropriate sections.

Figure I-11: The kit supplied by Ken Press needed to grind and polish the single element objective lens and the two Keplerian eyepiece lenses described in this manual. From left to right in each row:

Back row – plastic bags containing #80, #200, #400 and # 600 grinding grits and a plastic bag of CeO polishing agent;
Second row - spindles to make the 1¾-inch diameter objective lens, the 2-inch FL eyepiece lens and the 1-inch FL eyepiece lens;
Third row - two elements of the objective lens cell, the barrel for the 2-inch FL eyepiece, the barrel for the 1-inch FL eyepiece and plastic cup of polishing pitch;
Fourth row - two rings to hold drawtube in the telescope tube, the caps and templates for the 2-inch FL and the 1-inch FL eyepieces;
Front row - glass banks for making the 1¾-inch diameter objective lens, glass banks for making the 1¼-inch diameter, 2-inch FL eyepiece lens and glass banks for making the ¾-inch diameter, 1-inch FL eyepiece lens.

Part II: Making the Lenses

Getting Prepared

In order to grind and polish the lenses for your telescope, you will need:

1) A variable speed power drill, wood drill bits and a drill mounting,
2) A very small saucepan used to melt the pitch (the pan is a "throw away", it can not be cleaned),
3) A 6-inch wooden stick,
4) A 4- or 5-inch diameter, 1-inch deep plastic tub,
5) Modeling clay or other pliable material,
6) A small, wide mouth jar or plastic tub and its lid,
7) A small, glass or plastic bowl,
8) ¼-inch thick plywood*,
9) Single edge razor blades, exacto-knife or box cutter,
10) Masking tape,
11) A yardstick,
12) Stiff, white paper,
13) A clean, soft cotton handkerchief,
14) A plastic teaspoon,
16) Turpentine,
16) Elmer's glue,
17) Newspapers,
18) Paper towels
19) A hand lens or magnifying glass and
20) An old toothbrush.

- If you have thicker plywood (up to ½-inch) on hand, you can use it, since the thickness is not important.

Getting Ready

The first thing you must do is *read through all the sections on making the objective lens and the eyepieces lenses*. You need to do this because some of the activities you need to do to grind and polish the lenses, you have to do at the same time—even though we may describe them in successive paragraphs, i.e., familiarize yourself with the entire lens-making process before you start the process.

The second thing you should consider, as you start to make your simple telescope, is to keep a *logbook*. By doing so, you can keep track of how much time you are spending on each stage of grinding and polishing, what difficulties you are having and how you overcome them, what the focal lengths of the tools and lenses are as you proceed with your work, etc. This way you can avoid any pitfalls as you proceed and any if you decide you want to continue making telescopes after completing your first, simple telescope.

You will notice that the wooden elements of the objective lens mounting cell and the eyepieces in the kit are spray painted flat black. We provide them already blackened, since it is very important that the paint be *completely dry* before the lenses are placed in their mountings, thus insuring that the painted parts do not stick together, making it impossible to remove the lenses, if necessary (Figure II-1).

Also, if you want to, you can work on the tripod and telescope mounting while you are grinding and polishing the optics, but *do not* make the telescope tube until you have competed the optics. You need to know the exact focal length of the finished objective lens before you know how long to make the telescope tube.

Figure II-1: The two components of the objective lens cell and those of the two eyepieces that have been spray painted with flat black paint.

As shown in Figure II-2, the variable speed drill is mounted upside down in its mounting and the drill mounting carries a small platform with two holes. The first hole is just big enough so you can slide the platform onto the vertical mounting pole of the drill mount and the hole is “tight” enough so the platform stays put on the pole. The second hole is 1-inch in diameter. The platform is mounted just above the drill chuck with the 1-inch hole centered on the chuck— as shown in Figure II-2 and in the video.

The platform is made from ¼-inch (or thicker) plywood and the details of the platform are shown in Figure II-3.

Figure II-2: The variable speed drill (mounted upside down), its mount and the platform that together are used to do the optical work on the telescope lenses.

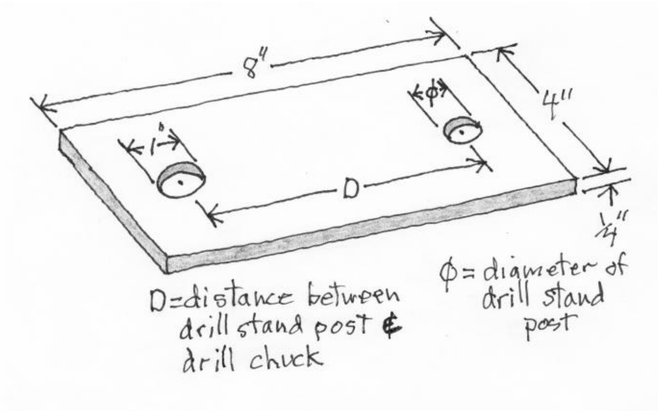

Figure II-3: The details of the drill platform.

Figure II-4 shows the shallow, plastic tub, with a ½- to ¾-inch hole in the bottom and a dam, made of play-dough, modeling clay or some similar pliable material, around the hole. This tub is located on the platform with its hole over the hole in the platform (Figure II-5), where it will keep water, grinding grit, grinding mud and/or polishing CeO from dropping down into the drill chuck and spinning off the rotating spindles and glass blanks on to their surroundings. We will call this tub the “catch tub”.

Figure II-4: The plastic “catch tub” used to catch grinding grit, mud, polishing CeO and water from dropping onto the inverted drill.

Figure II-5: The placement of the catch tub on the drill platform.

Making the Objective Lens

The first tasks in making the objective lens are to fine grind and polish its flat - or plano-side. While plate glass is flat enough so this step is not necessary when making the plano-convex eyepiece lenses, this is not necessarily the case for the objective lens. So, you will need to fine grind and polish the plano-side of the objective lens.

Before shipping the kit to you, we inspected the two, 1¾-inch diameter plate glass blanks for the objective lens and marked one with a T on both sides; this is the so-called “Tool” blank. The blank may have scratches on both sides, but that is of no concern. The second blank has a P on one side and a CV on the other. The P side is to become the plano-side of the lens and will be scratch free or only have very fine scratches that will grind out when you are fine grinding the plano-side. The CV side will become the convex side and may, or may not have more significant scratches—scratches that will grind out during the grinding processes.

Step 1 - Fine Grinding:

As shown in the video, place a piece of newspaper on a table or counter top (Figure II-6), fill the glass or plastic bowl with water, dip the tool (T blank) in the water, place the tool on the newspaper, sprinkle a little #600 grit on the tool's upper surface (you may want to put the grits in little plastic cups to make them easier to handle), and place the CV blank with the P side down on the tool. Press down hard while moving the CV blank straight back and forth by 1/3 of the diameter* of the blank, or just over ½-inch. Each such "back-and-forth stroke" should take about a ½-second, or so.

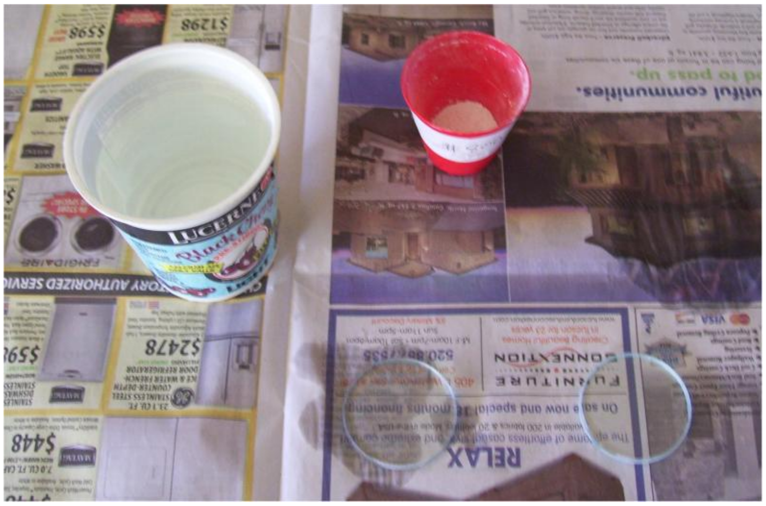

Figure II-6: Getting ready to start grinding the plano-side of the objective lens.

* **Note:** When grinding or polishing a lens or a mirror for a telescope, one uses a 1/3-diameter stroke because it creates a *spherical surface, which is what you want to produce*. If you use a longer or shorter stroke, the surfaces of the lens or mirror and their tool are no longer spherical.

Each successive stroke must be made at a different angle, so the center of the blank makes a star pattern as shown in Figure II-7 and after several strokes (8 to 10) you should have gone once around the star pattern. Simultaneously, while continuously changing the direction of the stroke, you must rotate the CV blank in your hand by about the same amount that you have rotated the stroke direction—*but in the opposite direction* as in Figure II-7.

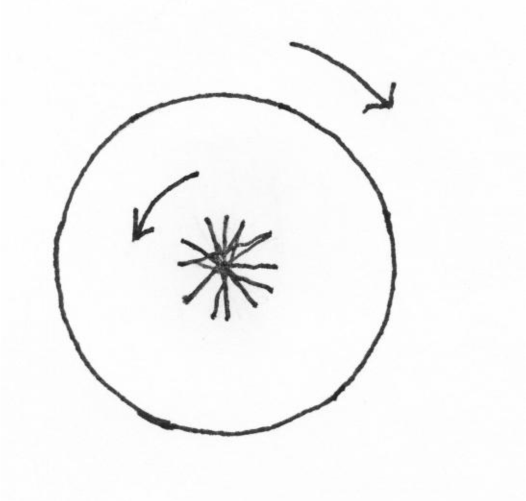

Figure II-7: Diagram showing the motions used in grinding and polishing.

Do not try to make length and direction of the strokes and rotations of the CV blank perfectly regular. The natural randomness of the strokes and two opposite rotations, along with the rotations themselves, insures that the grinding is symmetric with respect to the center of the blank.

As you are grinding, you will hear a grinding sound. As the grit breaks down to “mud”, the grinding sound will diminish and then it is time sprinkle more water and more #600 grit on the tool. The time it takes to grind the grit down to mud is called a “wet”.

But—before adding more grit, wipe the mud off the CV blank and inspect it. If, as expected, there are irregularities on the P side of the CV blank, the high parts of the irregularities will be fairly well ground while the low parts may still be polished. The idea is to do as many such wets as are necessary to have the P surface of the CV blank and tool *uniformly ground*, so all the irregularities are ground flat.

Now, the grinding process described above causes the upper blank (the P side of the CV blank) to become very slightly concave and the top of the tool to become very slightly convex. While this is how the curves for lenses and mirrors are generated, we do not want this to happen for the plano-side, since it must be flat. So, every minute or so, you must reverse the position of the tool and the CV blank on the newspaper and in your hand. As long as you spend about the same amount of time grinding with the tool on bottom of the CV blank as well as on the top, the P side of the CV blank will be essentially flat.

The fine grinding of the plano-side of the CV blank should take just a few minutes, but may take a longer. When the P side of the CV blank and the tool are uniformly ground, you are ready to polish the plano-side of your objective lens.

<u>Step 2 – Making the Pitch Lap</u>:

In order to polish the plano-side of the CV blank, you must attach the tool and the CV blank (which we will simply call the lens from this point on) to their spindles [Note: all the remaining optical work will be done using the spindles and the inverted drill] and make a pitch lap.

But first, completely wash off all the grit and mud from the tool and lens using the toothbrush. Throw the wet and "muddy" newspaper way and put a clean piece of newspaper on the work surface. Be absolutely sure to clean everything that could come in contact with the tool and lens or you might end up with scratches on your polished lens.

As shown in the video, put the optical pitch into a small saucepan and *very slowly* and at *low heat*, melt the pitch (which is very sticky). *Be sure to stir* the melting pitch with a wooden stick as the pitch is melting and do not let the pitch boil. Boiling causes the pitch to become too hard when solidified and this will cause scratches and irregularities on the optical surfaces of the lens.

When all the pitch has completely melted, remove the saucepan from the heat and set it on the newspaper. Take one of the two, 1¾-inch diameter spindles, dip its wooden surface in the melted pitch just deep enough to cover the raised ring on the outer edge of the wooden disk. Press the finely ground side of the tool on the pitch on the raised rim of the wooden disk of the spindle, making sure the tool is *centered on the spindle's central hole and is not tilted*.

If the tool is not centered or tilted and the pitch has hardened so the tool will not move, heat the tool and pitch under hot running water until the pitch softens and you can then center the tool and/or remove its tilt.

Next dip the second spindle in the hot pitch, but again, just deep enough to cover the raised ring on the outer edge of the spindle's wooden surface and stick the lens to the spindle—but in this case, stick the *CV side (the still polished side)* of the lens to the spindle—leaving the finely ground plano-side free and making sure *it is centered and not tilted*.

Now, once the pitch has cooled, use a single edged razor to trim off the pitch that has oozed out from the space between the glass blanks and the wooden spindle.

Pour ¼-inch to ½-inch of water in a small, wide mouth jar or tub and pour the CeO polishing powder in the water. Stir the mixture of water and CeO with the plastic spoon until all the CeO is suspended in the water to make a slurry. Put the lid on the jar or tub and keep it on except when the CeO slurry is being used.

Cut a 6- to 7-inch long, ¾-inch wide strip from a piece of newspaper and rap it around the tool and the top of its spindle and fasten it with a little masking tape—thereby making a dam ¼-inch tall around the top of the tool (see video).

Put the bolt of the spindle holding the tool, with the paper dam, through the holes in the plastic tub and platform and into the inverted drill's chuck. Tighten the chuck, making sure that the top of the tool is horizontal (see the video and Figure II-8). Take the saucepan with the pitch (the pitch should still be melted—if not, re-melt it) and pour the melted pitch onto the tool's surface until the pitch completely fills the dammed space to the point where the pitch bulges a little bit over the paper dam, but not so full that the pitch runs over the dam.

Let the pitch cool to the point where it is no longer a thick fluid, but is still a little soft — this may take several minutes. As long as the pitch has a shiny surface, it is still too fluid to proceed. As the pitch cools, the edges will start to take on a dull luster. When the entire surface is slightly dull, you can proceed.

Now comes the difficult part, getting contact between the pitch lap and the finely ground surface of the lens.

Stir the CeO slurry in the bottle and spoon a little of the CeO slurry on the surface of lens, coating its entire surface with slurry. As shown in the video, holding the lens/spindle by the lens (not by the bolt), gently place the finely ground face of the lens on top of the pitch and slowly move the lens/spindle around using the same stroke/rotation combination used in the fine grinding.

Figure II-8: Getting ready to make the pitch lap.

If the pitch is still too hot and soft, it will ooze out over the paper dam. In this case, stop moving the lens, leave the lens exactly centered on top of the pitch lap (or just lap from this point on) and let the pitch cool a little longer.

If, or when, the pitch has just about the right hardness, you will be able to press harder and harder on the lens and the pitch's surface will very slowly yield and make better and better contact with the finely ground surface of the lens. Keep moving the lens around on the forming lap and pressing down moderately hard, until the pitch has completely hardened. Slide the lens off the lap and you will see the pitch has a dull, flat surface out to its edge.

However, if the outer most edge of the lap is shiny, you do not have contact all the way to the edge and/or if the surface of the lap is irregular or has bubbles that form shallow holes in the lap, remove the lap/spindle from the chuck, warm the lap and the lens under hot, running water a few minute to soften the pitch. As shown in the video, you can work the lap and lens together, by hand, by pressing the lens down onto the lap and continue moving and pressing the lens down on the lap until contact is achieved under the hot running water. You may need to add CeO slurry to keep the lens from sticking to the lap. Repeat this procedure until you have good contact between the lens and the lap.

Slide the lens off the lap. If, as is probably the case, the pitch has oozed over the edge of the paper dam and the dull, flat surface of the lap extends beyond the edge of the glass tool, you need to trim the lap. Take the masking tape off the paper dam, wet the paper and remove as much of the paper dam as possible without disturbing the pitch. Then, harden the lap by putting it in crushed ice and water for a few minutes. Using a single edge razor, trim the excess pitch off the edge of the lap (see the video) until the lap's diameter is the same as the glass tool, i.e., 1¾-inchs in diameter.

Using a single edge razor, cut two channels (following the pattern in Figure II-9)—about 1/8 of an inch wide and nearly that deep in the surface of the lap (see video).

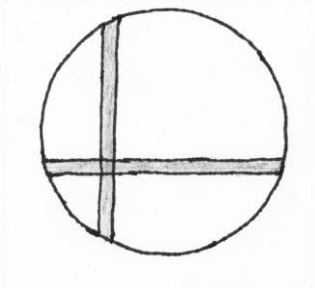

Figure II-9: The pattern of the channels you are to cut in the lap.

Take note of the fact that, as you are trimming the lap and cutting the channels, the pitch you are trying to cut off may chip off, rather than be smoothly cut off. Regardless, the pitch chips tend to stick to you fingers, the surface of the lap and anything else they come in contact with. You can trim the lap and cut the channels "out-of-doors" and let the chips fall where they may, or do the trimming and channeling under running, ice cold water. In either case, when you are finished trimming and channeling, wash your fingers and the lap in cold water—this will remove most of the annoying pitch chips. If that fails, wipe your fingers and anything else with pitch chips stuck to it, but *not the surface of the lap*, with a paper towel that is moistened with a little turpentine.

Please Note: Making a good lap, getting good contact between the lap and the lens, trimming and channeling a lap takes practice and getting the feel of how pitch reacts. You may not get it right the first or even second try, so don't worry about having to remake the lap.

Step 3 – Polishing the Plano-Side of the Lens:

Warm the newly made lap by running *very warm water over it and the lens* for a few minutes and put the lap/spindle back in the chuck. Stir the CeO slurry. Spoon some of the CeO slurry on the warm lap and, holding the warm lens/spindle at the edges of the lens (see video), press the lens down on the lap with a modest amount of pressure and, using the same ½-inch stroke and rotation of the lens you used during fine grinding, start polishing the plano-side of the lens *by hand*. Doing this for 20 or 30 seconds will help get good contact. *Then* turn on the variable speed drill with a spin rate a few revolutions/second* and continue polishing. As the CeO slurry either begins to get dry or as the slurry is used up, add more slurry.

* **Note**: *There is a tradeoff between spin rate, how fast the grinding or polishing goes and your ability to control the motion of the lens or lap during the grinding or polishing.* The faster the spin rate, the faster the grinding and polishing will go, i.e., the less time it will take do the grinding and polishing. *However*, as the spin rate gets higher and higher, there is a rate above which you cannot control the motion of the tool, lap or lens you are holding in you hand while trying to use the required stroke (e.g., Figure II-7) to do the grinding and polishing, i.e., you cannot keep the tool, lap or lens on its spinning counterpart. This problem is made worse if the tool, lap or lens on the spinning spindle is not well centered and is tilted. *You will have to find, via trial and error, the best spin rate to use while making the lenses for your telescope.*

Stop polishing after about 10 to 15 minutes, remove the lap/spindle from the chuck and put the lens/spindle in its place. Just as you did during fine grinding, you need to reverse the positions of the lap and lens every 10 to 15 minutes to insure the plano-side is flat.

But, before you put the lens/spindle in the chuck and proceed with polishing, wipe the CeO slurry from the lens using the side of you arm (see the video, assuming your arm is clean and not sweaty) and inspect the lens by looking at the reflection of a light bulb from the lenses surface. You will see that the lens has begun to polish, though the polishing might not be totally uniform, i.e., it may be polished more at the center or along the edge. This is OK now, but, if this condition persists after 30 or 40 minutes of polishing, you need to reheat the lap and lens under hot running water and get better contact between the lens and the lap, as described in the section on making the lap, before continuing.

Assuming that (as will often be the case) the lens is polishing fairly uniformly after your first 10 to 15 minutes of polishing and your first inspection, put the lens/spindle in the drill chuck and do another 10 to 15 minutes of polishing with the lap on top of the lens, adding CeO slurry when necessary and using the same ½-inch stroke and rotation. Continue polishing this way—reversing the positions of the lap and lens every 10 to 15 minutes and inspecting the polish of the lens.

It will take from 1½ to 3 hours (*depending on how fast the spindle is rotating*) to completely polish the plano-side of the lens. However, since polishing is a little tedious, you will probably want to break up your polishing work into 15- to 20-minute sessions. Also, as you are polishing, the two channels you cut into the lap's surface may partially close because of the heat generated by polishing. When you see that the channels have partially closed, you will need to reopen them with the single edge razor. Finally, after you have had a break and/or reopened the channels and want to start polishing again, *remember to warm the lap and lens under running warm,* water before starting each 15- or 20-minute polishing session.

After about an hour or so of polishing, the plano-side may look completely polished to the naked eye, but if you use a hand lens or magnifying glass to look at the surface in reflected sun- or lamp- light you will see that the surface has numerous fine pits. Keep polishing until the pits are gone.

Also, though ideally the polishing should be uniform over the plano-surface of the lens, our experience is that this is not always the case. If, as stated above, the lens is polishing well at the center, but not on the edge, or visa versa, and this persists even after getting good contact between the lap and lens - and after polishing for an hour or so, you will have to do one of the following:

A) If the lens is polishing well at the center but not at the edge, use a *¾-inch or even a 1-inch stroke* and/or have the stroke go over the lens towards the *edge of the lens* rather that over its center (see video), i.e., concentrate the polishing at the *edge* of the lens.

B) If the lens is polishing well at the edge but not at the

> center, put the lap/spindle in the drill chuck and continue polishing *with the lens on top* and the lap on the bottom. Use a *¾-inch or even a 1-inch stroke*, but have the stroke go over the *lens' center* (see video), i.e., concentrate the polishing at the *center* of the lens.

Once the plano-side of the lens is completely polished, you need to remove the lens from its spindle and stick it back on the spindle with the *newly polished plano-side stuck to the wooden ring on the spindle, with the CV side free*. You must also remove the lap from the tool before you proceed.

Figure II-10: Removing the lens from the spindle is made simple by setting the lens/spindle in a bowl of crushed ice for several minutes.

The easiest way to remove the lens and tool from their spindles and getting the lap off the tool is to set the lens and the lap and its tool in a bowl of crushed ice (Figure II-10 and the video). Because of the differences in the thermal contraction of the glass of the tool and lens and that of pitch, the lenses and lap will become unstuck in several minutes. The lens/tool/lap will slide apart, usually with a little force, but if they don't, you will either have to wait for them to get colder on the ice and/or push harder. If that does not work, strike the glass lens or tool with a heavy wooden stick.

Once the lens is off its spindle, re-melt the pitch in the saucepan, dip the spindle in the pitch as described earlier and stick* the *newly polished, plano-side of the lens to the spindle, with the CV side free*—being sure the lens is centered on the spindle and not tilted. Then put the lens/spindle back in the chuck of the inverted drill and tighten the chuck.

*** Note:** Or, as shown in the video, just hold the pitched side of the spindle over the source of heat and re-melt the pitch on the spindle and then stick the *newly polished, plano-side of the lens to the spindle, with the CV side free.* Also, as often happens during grinding and/or polishing, the tool/lap or lens may come off its spindle. If so, heat the pitch on the spindle and stick the tool/lap or lens back on its spindle.

It is possible, that, due to the ice, the lap may also have become unstuck from the tool. If the lap does slide off the tool, put the lap back in the saucepan, since the pitch of the lap can be re-melted with the rest of the pitch in the pan.

If the lap does not come free from the tool, lay it down on a piece of newspaper and use a single edge razor to cut and chip the lap off the tool. As above, put the chunks of pitch back in the saucepan for re-melting. Wipe the surface of the tool with a paper towel moistened with turpentine to clean off any remaining pitch stuck to the tool's surface.

Step 4 – Grinding the Convex Side of the Lens:

Step 4a – Rough Grinding with #220 Grit:

Because the shallowness of the convex curve needed to make the objective lens with a 60-inch focal length is so slight (0.012-inches), rough grinding is done using #220 grit.

Put the lens/spindle in the chuck of the inverted, variable speed drill and tighten the chuck. Turn the variable speed drill on with a spin rate of a few revolutions/second. Put a newspaper down next to the inverted drill and its mount. Set the bag of #220 grit and a small bowel of water on the newspaper.

As shown in the video, sprinkle some water on the slowly spinning lens and then sprinkle some #220 grit on the lens. Hold the tool/spindle by the wood of the spindle, press the tool down hard on the lens and – *in principle* – use the 1/3 diameter- or just over ½-inch- stroke, to start grinding, while frequently rotation the lens the way you did while fine grinding and polishing the plano-side of the lens.

We say "in principle" use the 1/3 diameter stroke, because that will give you a spherical surface. However, when roughing out the curve one can use several different methods to save time and effort (e.g., see the section on rough grinding the strongly curved eyepiece lenses below). In the case of the objective lens with its very shallow curve, you could use the 1/3 diameter stroke and generate the desired curve in about an hour and in the process grind off nearly 1/16th of an inch of the thickness of the lens blank! To reduce the time required to do the rough grinding, you should use a ¾-inch or even a 1-inch stroke for the first 15 to 20 minutes of rough grinding. Then return to using the 1/3 diameter or about a ½-inch stroke for the rest of the rough grinding to get the lens' surface spherical.

As you start rough grinding, the #220 grit will quickly grind down to mud. When it does, leave the mud on the lens and tool and add more water and grit and keep grinding.

After 10 minutes of rough grinding, stop and wash off all the mud from the *tool*. As shown in the video, make a focus tester from a yardstick with a piece of stiff, white paper taped vertically to the end of the yardstick as a focus target. As in Figure II-11 and the video, go out doors (assuming it is during the day) and point the yardstick towards the Sun, with the end with the paper target pointing towards the Sun. Wet the tool's surface and hold the tool on the yardstick about 30 inches from the end with the paper target. Move the yardstick and/or tool around until the reflection of the Sun off the wet surface of the tool is on the paper target. Since the tool is slightly concave, it will form a very rough image of the Sun on the target. Move the tool closer and closer to the target. If the rough image of the Sun gets smaller, move the tool even closer until the blurry image starts to get sharper and then starts to get bigger and blurry again. Go back and forth until you find the distance from the tool to the target where the Sun's image is the sharpest and smallest—that will be the *tool's focal length*.

Figure II-11: Measuring the focal length of the tool.

Alternatively, if the image of the Sun gets bigger when you first move the tool closed to the target, move the tool farther from the target and keep moving it farther and farther until you have found the distance from the tool to the target where the Sun's image is smallest and sharpest—that will again be the focal length of the concave tool.

Three points: First, the concave tool will dry off quickly during this testing, so you will have to keep wetting it.

Second, the determination of the focal length of the concave tool will be quite inaccurate at this stage—there will be at least a few of inches of uncertainty.

Third, the focal length of the convex *lens* itself will be nearly 4 times the focal length of the *tool*. For example, if the first rough check of the focal length of the tool is 25 inches, then the focal length of the lens is about 96 inches.

The goal of the rough grinding is to get the focal length of the lens to be about 75 inches, so you need to keep rough grinding until the *tool's focal length* is about 20 to 22 inches. It should take 20 to 40 minutes of rough grinding to get the focal length of the tool in this range.

If you over shoot and the focal length of the tool is less than about 20 to 22 inches, put the tool/spindle in the drill chuck and grind with the lens/spindle on top until tool's focal length is about 20 to 22 inches. When you have reached that point, you are done with rough grinding.

A word of warning – in the case of the long focal lens you are making, just a *few minutes of grinding* will change the focal length of the tool by *inches*. So, as you are getting close to the desired 20- to 22-inch focal length of the tool, stop and test the focal length every few minutes and keep track of the time spent and focal length of the tool in your log book.

When the tool has about a 20- to 22-inch focal length, you are ready to start fine grinding.

Step 4b – Fine Grinding with #400 Grit:

Take the lens/spindle out of the chuck, take the catch tub off the platform and carefully clean all the grit and mud off them and also off the tool/spindle under running water, using the old toothbrush. Wipe off the platform and chuck with a moist paper towel. Close the bag of #220 grit and put it away, wash out the water bowel and throw the old newspaper way.

Put the catch tub back on the platform, put the lens/spindle back in the chuck and tighten it, put a clean newspaper next to the drill and mount. Put the little bag of #400 grit and the bowel with clean water on the newspaper.

Start the drill at the same spin rate, sprinkle some water and #400 grit on the lens and start the fine grinding, using the same 1/3 diameter stroke and lens rotation motion as before. Add new grit and water as necessary. Test the focal length of the tool every five minutes or so using the Sun and the yardstick/paper target. Your goal is to get the focus of the tool down to 18- to 19-inches.

15 minutes of fine grinding with #400 grit will remove all the pits generated by rough grinding with #220 and the focal length of the tool should be close to the desired 18 to 19 inches. If not, continue grinding with #400 grit with the *tool on top* if the focal length is *longer than about 18- to 19-inches* or with the *lens on top* if the focal length is *less than about 18- to 19-inches*, until the focal length of the tool is 18- to 19-inches.

Step 4c – Fine Grinding with #600 Grit:

Repeat all the steps under Step 4b, except use #600 grit and get the tool's focal length to be 16- to 17-inches. If not, continue grinding with #600 grit with the *tool on top* if the focal length is *longer than 16- to 17-inches* or with the *lens on top* if the focal length is much *less than about 16- to 17- inches,* until you get the focal length of the tool to be 16- to 17-inches. Now you have a finely ground, slightly convex lens surface ready for polishing.

One final note: due to the inaccuracies in measuring the focal length of the tool and hence that of the lens during rough and fine grinding, the focal length of the lens, when fully polished may be up to several inches longer or shorter that the desired 60 inches. We will comment more on this towards the end of the following section.

Step 5 – Polishing the Convex Side of the Lens:

As in the above steps, wash and clean all the surfaces, the lens- and tool/spindles and the catch tub.

Then follow the instructions given in "Step 2 – Making the Pitch Lap", starting with the paragraph that begins with "Cut a 6- to 7-inch long, ¾-inch …." given above—with the one exception.

When pouring the melted pitch on the top of the tool to fill the space formed by the paper dam and the top of the tool, fill that space *only up to the top of the paper dam*. Do not fill it to the point where the pitch bulges a little bit over the dam. When you press the lens (covered with CeO slurry) down on the warm pitch, the convex surface of lens will first come in contact with the pitch's surface in the middle and, as you continue to push down and move the lens around, the contact surface will slowly spread out towards the edges of the lap and lens. In doing so, the pitch will bulge over the edge of the dam by itself. Other than that, follow the instruction given in that section and when the lap is cooled, trimmed, channeled and has good contact, you are ready to polish the convex surface of the lens.

Polishing the convex side is done in the same way as the plano-side was polished—as described in "Step 3 – Polishing the Plano-Side of the Lens"—except, keep the lap on top and the lens on the bottom during all the polishing - unless the lens is not polishing uniformly. If so, follow the instructions in that section to correct the situation.

Now, after you have polished for 10 to 15 minutes, you will see that the surface is beginning to polish. In fact, after only 10 to 15 minutes, the polish is good enough so you can accurately measure the focal length of the lens using the Sun. If you choose to, you can remove the lens from its spindle – or if and when the lens comes free itself and before you re-pitch it to its spindle - you can clean the CeO off the lens and measure its focal length. Use the Sun or the nearly full Moon, a stiff, white paper target, and a carpenter's ruler or two yardsticks taped together, to determine the exact focal length of your slightly polished objective lens (see video). You should be able to measure the focal length with an accuracy of an inch or two and the focal length will probably be within a few inches of the desired 60 inches, i.e., somewhere between 55 and 65 inches.

If the focal length of the lens is a *just a few inches longer that 60 inches,* continue polishing with the *lens on the bottom and the* *lens on top* – this will shorten the focal length by a couple of inches.

If the focal length of the lens is a *just a few inches shorter that 60 inches,* continue polishing with the *lap on the bottom and the lap on top* – this will lengthen the focal length by a couple of inches.

Or, if the focal length is longer than 65 inches or shorter than 55 inches – or if you just want to get the focal length closer to the desired 60 inches - we recommend (*but you do not have to do so*) that you go back to fine grinding with #600 grit. You will have to remove the lap from the tool and, as during fine grinding, grind with the tool over the lens to shorten the focal length or grind with the lens over the tool to lengthen the focal length of the lens. Remember that a few minutes of grinding, even with #600 grit, will change the focal length by inches – so test the focal length of the tool every few minutes. When you have gotten the focal length of the tool to the desired 16- to 17-inches, you are ready to make a new lap and start polishing again.

Completely polishing the lens should take 1½ to 3 hours. When the lens is completely polished, remove it from its spindle using the crushed ice method as described earlier. Clean the CeO off the lens under running water and, if any pitch it stuck to the lens, remove it with a paper towel moistened with turpentine. Then wash the turpentine off. You can use Windex and a soft cotton handkerchief to give the lens its final cleaning.

Again, using the Sun or the nearly full Moon, a stiff, white paper target, and a carpenter's ruler or two yardsticks taped together, determine the exact focal length of your newly finished objective lens. You should be able to measure the focal length with an accuracy of about ½ of an inch and the focal length of the lens will probably be within a few inches of the desired 60 inches, or at least somewhere between 55 and 65 inches. Do not be concerned if the focal length is not exactly 60 inches, you just need to know what the focal length is to be able to make the telescope tube the correct length.

Finally, though you will want to have your lens completely free from scratches and pits, if there is a small scratch or two or a few pits on the objective lens, they will not affect the performance of your telescope.

Regardless, you now have a beautiful objective lens of your own making. So, we congratulate you.

Making the 2-inch and 1-inch Focal length Eyepiece Lens

Grinding and polishing the eyepiece lenses are done in essentially the same way you did for the convex objective lens. The differences are described in the following.

First, as indicated in the first paragraph in the section on "Making the Objective Lens", the surfaces of the plate glass blanks are flat enough so you do not need to grind and polish their plano-sides as you did for the objective lens.

Second, we have marked the 11/4-inch diameter and the ¾-inch diameter blanks that are to be used for the tools with a T. We have marked the 11/4-inch diameter and the ¾-inch diameter blanks that are to be used for the lenses with a CV on the sides to be ground and polished and P for the sides that will be the plano-sides and that are free from scratches.

Third, as seen by the curves of the templates for the convex sides of the lenses, the convex sides of both eyepiece lenses are very strongly curved, i.e., you have to grind off a lot of glass during rough grinding to make these eyepiece lenses. So rough grinding will be done with #80 grit and fine grinding will be done with #220, #400 and #600 grits.

Fourth, since the curves on the convex sides of the eyepiece lenses are so strongly curved, the stroke you will use during the rough grinding is different from that used while making the objective lens and that you will use during the fine grinding stages and polishing of the lenses. Previously, you mainly used a 1/3-diameter stroke, going back and forth over the *center* of the lens, tool, or lap, while rotating the lap, tool or lens in your hand and, as noted above, that stroke produces the desired spherical surface on the lens. However, if you use a 1/3-diameter stroke going back and forth over the *center* of the lens during rough grinding when the desired convex curve is very strongly curved, it will take a long time to reach the required curvature and the lens will become too thin. To avoid these problems, start rough grinding using the 1/3-diameter stroke while rotating the tool in your hand, ***but the stroke should not go over the center of the lens—rather it should pass nearly over the edge of the lens – i.e., as close to the edge as possible*** (Figure II-12a). As discussed in more detail below, towards the end of rough grinding, the center of the stroke must pass closer and closer to the center of the lens (Figure II-12b), until at the end of rough grinding, the stroke passes over the center of the lens (Figure II-12c). This will insure that the rough ground surface of the convex lens is spherical.

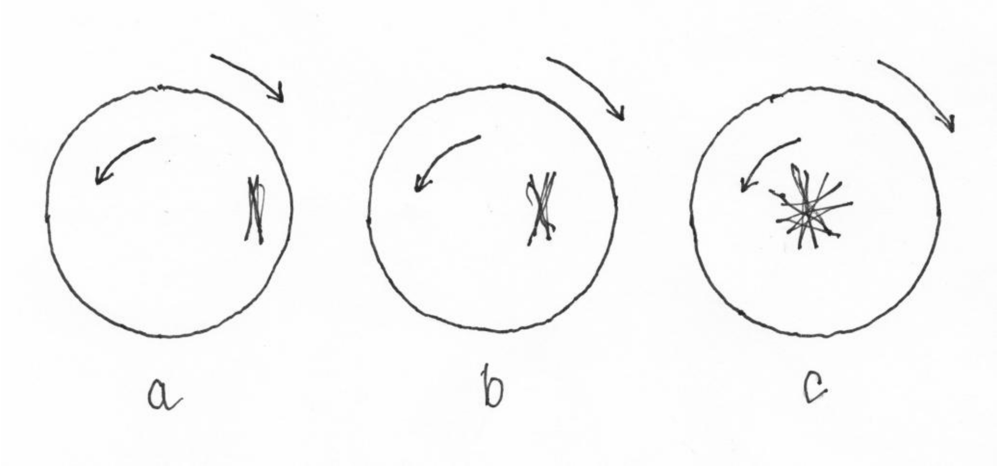

Figure II-12: (a) Diagram of the movement of the center of the tool over the lens used during most of rough grinding the eyepiece lenses; (b) Diagram of the movement of the center of the tool over the lens used towards the end of the rough grinding of the eyepiece lenses; (c) Diagram of the movement of the center of the tool over the lens used at the end of rough grinding the eyepiece lenses.

Fifth, because of the force applied during, especially, rough grinding, the lens (and possibly tool) will most probably come loose from its spindle. When this happens, take the spindle out of the drill chuck, wash all the grit and mud or CeO from the lens and spindle, hold the pitched side of the spindle over the hot heating element until the pitch has melted and then re-stick the lens (or tool) to the spindle.

Finally, since each lens will go through the same grinding and polishing steps, you can save time and effort cleaning up everything between each grade of grit or before making the laps and polishing, by doing each step on both lenses before going to the next step, e.g. first rough grind the 1¼-inch diameter lens with #80 grit and then rough grind the ¾-inch diameter with #80 grit before cleaning up and start fine grinding with #220 grit. Then do the fine grinding with #220 grit on both lenses, clean up everything and then go on to #400 grit, and then #600.

Step 1 - Sticking the Blanks to their Spindles:

As you did while making the objective lens, melt the pitch in the saucepan, dip a 1¼-inch diameter spindle in the melted pitch just deep enough to cover the raised wooden ring on the spindle and stick the 1¼-inch diameter *tool* (T) blank to it. Be sure the blank is exactly centered on the spindle and that it is not tilted. Do the same for the 1¼-inch diameter *lens* blank with the P side stuck to the spindle and the CV side free. Repeat these steps for the ¾-inch diameter tool (T) and lens (CV, P) blanks and their spindles.

Step 2 – Rough Grinding:

Put the catch tub on the platform, put the 1¼-inch diameter lens/spindle in the drill chuck, tighten the chuck and start the drill turning at a few revolutions/second.

Spread a clean newspaper out next to the inverted drill and its mount, place the water bowl and the bag of #80 grit on the newspaper, sprinkle some water and #80 grit near the edge of the rotating lens and, holding the tool/spindle by the tool blank, start rough grinding while pressing down with a lot of pressure.

As discussed on the previous page, use a ⅓-diameter stroke, which in the case of the 1¼-inch diameter lens is a little less than a ½-inch stroke—with the ***stroke centered very, very near, the edge of the lens*** (see video)—***and press the tool down very hard on the***

lens. Also, for the first several wets you should slightly tilt the tool so only the center of the tool is in contact with the edge of the lens. This will help start grinding off the edge of the lens. After a few wets, the tool will naturally tilt this way as you keep the stroke passing over the edge of the lens.

After 15 to 20 minutes, i.e., after many wets of fresh #80 grit and water, stop the drill, wipe off the mud from the tool and lens and inspect both of them. A shallow depression will have formed at the center of the tool and the edges of the lens will have been somewhat ground off. Grind another 15 to 20 minutes, keeping the center of the tool very near the edge of the lens as shown in the video, and check the lens and tool again. The central hole in the tool will be deeper and wider and the edges of the lens will be ground off further. As you proceed in this way the concave depression in the tool will have become deeper and wider—and the ground part of the edge of the lens will have deepened and widened. After about 1 hour of grinding the 2-inch focal length lens (and ½ of an hour for the 1-inch focal length lens), you can use the template to determine how close you are to having the correct curvature of the lens. The lens may still have a flat, un-ground spot at its center and the tool may still have un-ground edges. Continue grinding and testing this way, until A) the concave depression has reached the edge of the tool, B) the convex surface of the lens extends all the way across the lens so there is no flat, partly reflective spot in the middle of the lens and C) ***the curve of the lens exactly fits the template, as in Figure II-13***. Rough grinding to this point will probably take less than 2 hours for the 2-inch focal length lens and less than an 1 hour for the 1-inch focal length lens.

Also, during rough grinding of eyepiece lens, a lot of the fresh #80 grit will fall off the lens and collect in the catch tub along with the mud. Since rough grinding of the eyepiece lenses takes a lot of #80 grit, you can periodically scoop up some of this grit and dump it back on the lens rather than always adding fresh grit from the bag of #80 grit (but don’t bother to do this for the finer grits).

In addition, you can minimize the amount of fresh grit that fall off the lens into the catch tub after the tool begins to be concave during rough grinding with #80 grit (and later during the fine grinding stages) as follows. Hold the tool with the concave side up and sprinkle the fresh grit on the wet surface of the concave tool.

Now, to make sure the curves of the lens and tool are spherical, grind another 15 or 20 minutes as you move the center of the stroke closer and closer to the center of the lens, as shown in Figure II-12a and b. Check to insure that ***the curve of the lens exactly fits the template, as in Figure II-13.***

At this point you are finished rough grinding the 1¼-inch diameter lens and its radius of curvature is that required for the correct focal length, i.e., the template fits it.

Do not bother to clean up, just take the 1¼-inch diameter lens/spindle out of the chuck of the drill and replace it with the ¾-inch diameter lens blank/spindle. Then, using the ¾-inch tool blank/spindle and the #80 grit, start rough grinding the ¾-inch lens in exactly the same way as you did the 1¼-inch diameter lens—using a 1/3-diameter stroke (1/4 of an inch) near the lens' edge and the ¾-inch template to test the curvature of the ¾-inch diameter lens.

When you have finished rough grinding the ¾-inch diameter lens, clean both lens/spindles, both tool/spindles, the catch tub, etc. and get set up with clean newspaper, #120 grit and clean water for fine grinding.

Steps 3, 4, and 5 - Fine Grinding with #220, #400 and #600 grits:

Proceed with fine grinding with the three grades of grit of both lenses in exactly the same way you did the convex side of the objective lens, cleaning up properly between each successive grade of grit and use the 1/3-diameter stroke over the center of the lens while rotating the tool/spindle in you hand as the lens rotates at a few revolutions/second on the inverted drill. You must spend a minimum of 15 minutes of fine grinding with each grade of grit for each lens.

As you are fine grinding with each grade of grit, you should check the curvature of the lenses with its template once or twice to see if you have excellent contact between the convex surface of the lenses and its template, as in Figure II-14. When you finish fine grinding, you must have excellent contact between the lenses convex surfaces and their tool, as shown in Figure II-13—if you do, the focal lengths of the lenses will be very close to the desired 2 inches and 1 inch.

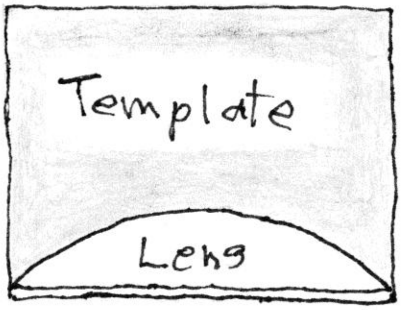

Figure II-13: Diagrams that show the contact between the template and the convex side of an eyepiece lens at the end of each stage of fine grinding.

When you have fine ground the lenses with each grade of grit for at least 15 minutes—if you have excellent contact between the lenses and templates, clean everything up as usual and prepare to go to the next stage of grit.

Though very unlikely, if for any grade of grinding, the curvature of the convex side of the lens becomes too steep, i.e., you only have contact between the lens and its template at their centers (Figure II-14***), put the tool/spindle in the drill chuck and, holding the lens spindle in you hand, grind with that grade of grit until you again have achieved contact.***

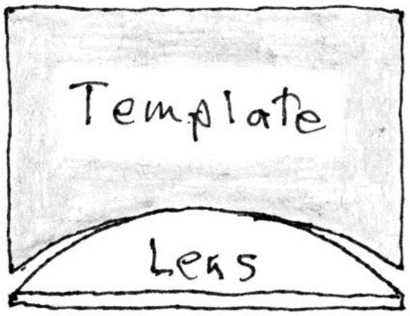

Figure II-14: Diagram showing the incorrect contact between the template and the convex side of an eyepiece lens if you have over-ground the lens and need to correct for this by grinding further with the tool/spindle in the chuck of the drill and the lens/spindle in you hand.

Step 6 – Polishing:

Make pitch laps for each of the lenses in nearly the way you did for the objective lens. But, there is no need to cut the two shallow channels in the laps for lenses as small as the ones you are now making.

When the laps are finished, use the CeO slurry to polish the lenses. During polishing, keep the lens/spindle on the bottom, i.e., in the drill chuck, and hold the lap/spindle in you hand.

Polishing the 11/4-inch diameter lens and the ¾-inch diameter lens should take about an hour or so and 30 minutes or so, respectfully (depending on the rotation rate of the spindle).

When you have finished polishing both lens, remove them from their spindles, using the crushed ice method, clean the lenses of CeO and pitch and you are done making the telescope optics.

Since you measured the focal length (FL) of the objective lens when you finished it earlier, you can calculate the actual magnification for each eyepiece using the formula:

Magnification = (FL of Objective)/(FL of Eyepiece)

For example, if the focal length of the objective lens is 62-inches, the magnification or power of the 2-inch and 1-inch eyepieces would be 31x and 62x, respectively. Now clean the eyepiece lenses they way you clean the objective lens.

Congratulation, you now have three beautiful lenses you have make yourself. The hardest part of your journey is behind you and you are ready to assemble your telescope.

Part III: Making the Telescope

Telescope Tube Materials

Assuming the focal length of your objective lens is between 55- and 65-inches long (if not, email one of us for instructions), you will need to buy the following materials to make the telescope tube:

1) One, 2-inch ID (Inside Diameter), 36-inch long* mailing tube**,
2) Two, 2-inch ID, 30-inch long*** mailing tubes**,
3) One, 2-inch ID, 18-inch long**** mailing tube**,
4) One, 1½-inch OD (Outside Diameter), 12-inch long, Flanged Tailpiece, plastic tube (Lasco brand, from, e.g., Ace Hardware Store),
5) A can of clear Krylon spray paint,
6) Scotch Tape,
7) Cotton balls,
8) 6- to 8-inch long stick of wood.
9) Elmer's glue and
10) Black construction paper.

* Actual length is 37 inches.
** You can buy the tubes from the Post Office, a UPS Store or a Staples store.
*** Actual length is 31 inches.
**** Actual length is 19 inches.

Getting Ready

Before you handle the optics in preparation for the final assembly, wash your hands to remove all the oils from your skin, oils that could leave smudges on your lenses. Then, again, carefully clean the three lenses with Windex and a soft, clean, cotton handkerchief.

Assembling the Two Keplerian Eyepieces

As shown in Figure III-1 and the video, lay the eyepiece lenses on their respective black, eyepiece barrels with their *convex-sides facing into the barrels*. Then slide the eyepiece caps onto the eyepiece barrels to keep the lenses in their places. If a cap is too loose, tape pieces of Scotch Tape on the outside of the barrel, where the eyepiece cap slides onto the barrel, until they fits snugly. The barrels must fit in the caps very tightly, so there is no danger of the lenses falling out—but not so tightly that you cannot remove them when (or if) you want to clean the lenses.

Figure III-1: Mounting an eyepiece lens in its barrel.

A word of caution: Wood (even painted wood) swells and shrinks as the humidity changes. So, even if the eyepiece caps fit tightly on the barrels (with – or without Scotch Tape), as the humidity drops, the caps may come loose and the eyepiece lenses may fall out. To avoid this, *you must put Elmer's Glue along the junction of the cap and the barrel* (see the video). This will eliminate the danger of the caps becoming loose and the eyepiece lens falling out. But, if you ever need to take the lenses out of the mounts, you can cut the glue with a single edge razor or exacto-knife and pull the cap off the barrel to free the eyepieces lenses to clean them.

Now, get the 1½-inch OD, 12-inch long, flanged tailpiece plastic tube that will be the drawtube of your telescope. As shown in the video, cut the flange off the end of the tube and file or use sandpaper to smooth the cut end.

Also, as shown in the video, cut a 4½ x 10½-inch piece out of a sheet of black construction paper and wrap the piece around a broomstick to make a cylinder that is small enough to slide into the plastic drawtube. Use a little Elmer's glue to glue the black construction paper inside the drawtube, with one end of the construction paper tube flush with one end of the plastic drawtube. The purpose of this black paper tube is to prevent light from reflecting off the shiny white interior of the plastic drawtube into the eyepieces.

Now insert each eyepiece into the end of the drawtube that is free from the black paper. The eyepieces should fit snuggly, but not tightly in the drawtube (see video). Again, because of the swelling and shrinking of the wooden eyepiece barrels – and because there may be slight differences in the IDs of the various tubes, your eyepieces may fit too loosely or too tightly in the drawtube. If the eyepieces are too loose, wrap some Scotch Tape around the barrel(s) until they fit snuggly in the drawtube. If they are too tight, use sandpaper to sand them down until they slide snuggly into the drawtube.

Making the Telescope Tube

The 2-inch ID, cardboard tubes have white plastic caps at each end. Save these caps and use one of them for the telescope's dust cap and two others for the dust caps for the two eyepieces, when you are not using the telescope. We have made the diameter of the wooden eye-lens caps of the eyepieces just big enough so the white plastic caps will easily slide onto the eye-lens cap - once you have cut out the little part of the plastic that is there so you can get a grip on the cap to remove it from the mailing tube.

We have found that if the 2-inch ID, cardboard tubes used to make the telescope tube are left in direct sunlight for long periods of time and if the tubes get wet from dew (or rain), they will warp. To minimize this, it is necessary to strengthen the telescope tube by inserting a second tube (we call it the “inner-tube”) inside the main tube (that we call the “outer-tube”), as described below.

Assuming the focal length (FL) of your objective lens is, as expected, between 55- and 65-inches, the length of the outer-tube (L_{OT}) and the length of the inner-tube (L_{IT}) are given by the following formulas:

$$L_{OT} = \text{FL} - 4\text{-inches and}$$

$$L_{IT} = \text{FL} - 12\text{-inches.}$$

As demonstrated in the video, the best way to cut the tubes to the correct lengths is to wrap a piece of paper around the tube where it is to be cut, making sure that the ends of the paper exactly overlap and use a piece of masking tape to secure the paper. Now, using the edge of the paper as a guide and using an exacto-knife, a box cutter or a single edge razor, carefully, and with only a little force, make a shallow cut all the way around the tube, *exactly* following the edge of the paper. Cut around the tube again, with a little more force, to make the cut a little deeper. Keep cutting around the tube, each time with a little more force and each time making the cut deeper. After several such circuits, you will have made a very clean cut through the tube.

Now, you will make the outer-tube of the telescope using the two, 31-inch long, 2-inch OD tubes. We use the 61-inches focal length (FL) objective lens made for the telescope shown in the video and figures of this manual as the example of how to proceed. Using the formula given above, the length of the outer-tube (L_{OT}) is (61 – 4) or 57-inches. Since the two 31-inch tubes have a total length of 62-inchs, we cut 5-inches off one of the 31-inch long tubes to make the “front section” of the telescope’s outer-tube. Note that the 5-inch segment cut off the 31-inch tube may be use as the dew cap (see below).

Next, you will make the inner-tube using the 37-inch and 19-inch, 2-inch ID tubes. Again, using our 61-inch FL lens as the example and the formula given above, the length of inner-tube (L_{IT}) is (61 – 12) or 49-inches. The 37-inch and 19-inch tubes have a total length of 56-inches. The excess length should be cut from the 19-inch tube, so we cut 7-inches off the 19-inch tube to make what we call the “short segment” of the inner-tube and kept the 7-inch segment for possible use as the dew cap (see below).

Next, as shown in the video, use an exacto-knife or a box cutter to cut a ¾-inch wide strip from the side of both the 37-inch long inner-tube and the short segment inner-tube, that together will be the inner-tube of your telescope tube.

Regarding the 5- and 7-inch residual segments cut from the tubes, as described below, either segment can be used for the “Dew Cap” of your telescope, so called because it prevents dew from forming on the objective on a cold, damp night—and protects the objective from dust.

Now you are ready to start making your telescope. But first **note**: Before you proceed, make absolutely sure the two parts of the black, objective cell and the two unpainted wooden rings *easily slide* into the 2-inch ID tubes. If they do not, sand or file them down until they do *easily slide* into the 2-inch ID tubes. Also, check to insure that the inner-tube sections easily slide into the outer-tube sections before proceeding.

Make a swab from a 6- to 8-inch long wooden stick, a cotton ball or paper towel and string or tape (see video). As shown in Figure III-2 and the video, saturate the swab with Elmer’s glue and swab a wide ring of glue around the inside of the *front segment* of the outer-tube of the telescope – starting 2-inches down the tube and extending as far down the tube as you can.

Figure III-2: Swabbing Elmer's glue in the front end of the outer-tube section of telescope tube.

Next, as in the video, smear Elmer's glue on one end of the short segment of the inner-tube. Then:

A) Hold the inner-tube segment by the end that is free from glue and squeeze it so the cut edges are close together;

B) Hold the front segment of the telescope outer-tube in your other hand and – *being very careful not to let the glue on the inner tube get on the inside of the outer-tube* - insert the glued end of the longitudinally cut inner-tube segment into the front of the front segment of the telescope outer-tube as far as you can;

C) Stop squeezing the inner-tube and let it open back up until it and the glue on its end press against the inside of the front section of the telescope's outer-tube.

D) Now, and *as shown in the video, rapidly push* the inner-tube all the way into the outer-tube and the quickly use the 37-inch long inner-tube section, to push the front section inner-tube further down towards the front of the outer-tube, until the end of the inner-tube is *2-inches down into the end of the outer outer-tube – but no closer to that end of the outer tube segment.*

E) Now, let the glue *completely* dry.

Similar to what is shown in Figure III-2 and the video, again saturate the cotton ball with Elmer's glue and swab a ring of glue ½-inch wide around the inside of the front section of the outer-tube starting about ¼ of an inch down into the tube. Now, get the 1½-inch long, back segment of the flat black, wooden objective cell, *that has a 1/8-inch tall, 1¾-inch ID retaining ring cut into one end* and slide the end of the wooden segment *without the retaining ring* into the tube to where the Elmer's glue is, i.e., until ¾-inch of the cell, *with the retaining ring*, is sticking out of the tube, see Figure III-3. Wait until the glue has dried.

Figure III-3: The correct position of the back segment of the objective cell in the front end of the telescope tube, with the 1/8-inch tall, 1¾-inch ID retaining ring visible.

The Dew Cap: You can use either of the pieces of 2-inch ID tube cut off the 31-inch tubes to make the dew cap, which should be between 4- and 6-inches long. If both of these segments are longer that 6-inches, cut one of them to the proper length.

Now, take the second 1½-inch long, front segment of the objective cell and slide it part way into the dew cap tube. It should fit snugly, but not so tight that it cannot slide further into the dew cap with a some force. If it is too loose, tape some Scotch Tape on its outside to make it fit better. *Do not use Elmer's glue in the dew cap*. This part of the objective cell *must* be able to slip back and forth to properly hold the objective lens in its proper place in the cell. When the segment fits correctly, push it further into the dew cap until it is about ½ of an inch inside the dew tube.

Hold the objective lens with its convex side up (see Figure III-4 and the video) in one hand and hold the front section of the telescope tube with the part of the objective cell with the retaining ring sticking out in the other hand. Lay the lens in the retaining ring. The ring's ID is a little larger than the lens' diameter, so the lens will fit loosely in it's cell and the lens will stick out of the cell by 1/16 to 1/8 of an inch.

Figure III-4: Inserting the objective lens, with its convex side up, into the retaining ring of the objective cell.

Next, take the dew cap and slide the end, in which the front segment of the objective lens cell is located, down on the part of the objective cell that is sticking out of the telescope tube and that is holding the lens in the retaining ring (see the video). As always, the dew cap must fit snugly so it won't fall off, but not so tightly that it cannot be slid down onto the objective cell. Again, if the dew cap fits too loosely, use Scotch Tape to make it fit snugly. Assuming the dew cap fit is correct, keep pushing it down until the dew cap touches the top of the telescope tube. As you are pushing down, the inner part of the objective cell will come in contact with the objective lens and, as you push farther, the inner part of the cell will slide back, but keep pressure on the objective lens to hold it in place, see Figure III-5.

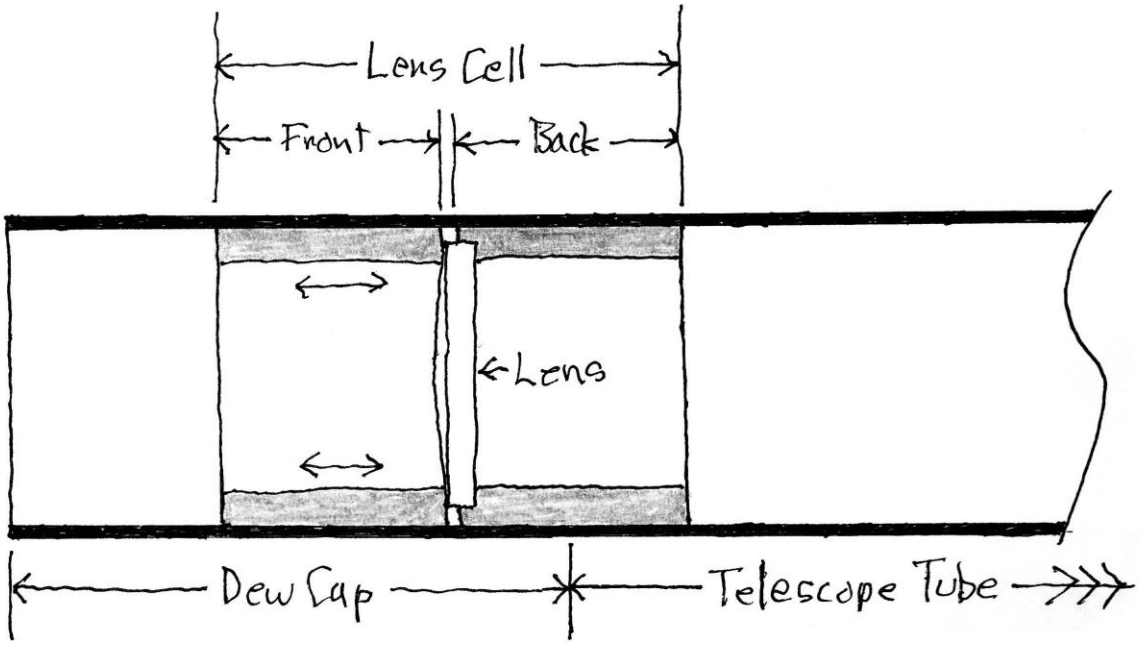

Figure III-5: Diagram showing how the front segment of the objective lens cell and the dew cap hold the objective lens in its place in the telescope. Remember that only the 1½-inch long, back, ring segment of the cell is glued to the 2-inch ID, telescope tube, while the 1½-inch long, front, ring segment of the cell has a slip fit inside the 2-inch ID, dew cap so the ring can push against the lens to hold it in place.

To make the back segment of your telescope tube, get the second, 2-inch ID, 31-inch long tube and the two, unpainted, ¾-inch wide wooden rings. Using the swab, swab a ring of Elmer's glue about 4-inches down one end of the tube. As shown in the video, push one of the wooden rings down into the tube and into the glue some 4-inched down in the tube. Next, swab glue on the inside of the tube about ½ of an inch inside the end of the tube, as shown in the video. Next, slide the second wooden ring into the end of the tube until it's end is flush with the end of the outer-tube and simultaneously into the glue (as in Figures III-6 and III-7 and the video). Set this aside and let the glue completely dry.

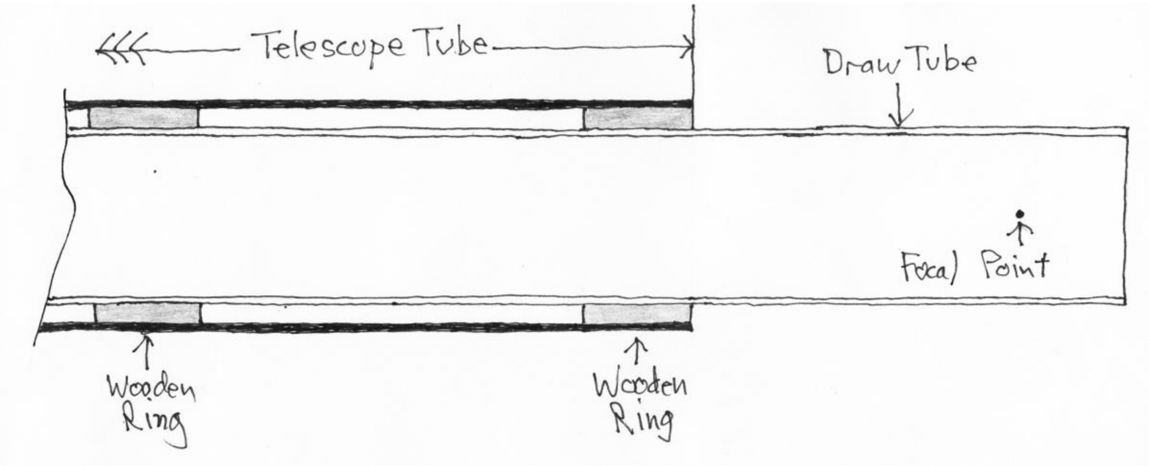

Figure III-6: Diagram showing where the focal point of the objective lens should be located, i.e., 3-inches behind the backend of the 2-inch ID, telescope tube and within the 1½-ID drawtube that holds the eyepieces.

Figure III-7: Photo of the back end of the telescope tube with the second wooden ring in place, flush with the end of the telescope tube.

When the glue is dry, insert the 12-inch long, 1½-inch OD plastic drawtube into the wooden rings of the back segment of telescope (Figure III-8). Make sure that the end of the drawtube that has the black paper tube extending all the way to the end of the drawtube is the end that is going inside the wooden rings. Push the drawtube in until about 4-inches of the tube is sticking out of the back of the telescope tube.

Figure III-8: Inserting the drawtube into the back of the telescope tube.

Take the 37-inch, 2-inch ID tube with the ¾-inch wide cut out you completed earlier, see Figure III-9, and as shown in the video, squeeze this inner-tube so the cut edges touch and insert it into the back of the front segment of the telescope tube until it abuts against the front segment of the inner-tube you glued in place earlier. Now, squeeze the part of the inner-tube sticking out the back of the front section of the telescope tube and slide the back section of the telescope tube (with the rings and draw tube) onto the inner-tube sticking out of the front section of your telescope. If everything has been done correctly, you will be able to slide the back section of the telescope tube all the way onto the inner-tube until the back and front sections of the outer-tube abut against each other, as in the video. If this is not the case, then you need to trim off enough of one end of the 37-inch long inner-tube so the two parts of the outer tube do abut against each other.

Figure III-9: The segments of tubing after a strip, ¾ of an inch wide, has been cut from them.

Next, you need to test your entire telescope with the two eyepieces to check if everything is correct.

Take your telescope and go outside and slide the 2-inch FL Keplerian eyepiece into the drawtube. Lean the telescope on something solid, point the telescope towards a far off object (tree, building, etc. at least a mile away) and slide the drawtube and/or the eyepiece in and out until you get a sharp focus. Next, replace the 2-inch FL eyepiece with the 1-inch FL eyepiece. If both eyepieces come to sharp focus, without needing to slide the drawtube in or out by more than a couple of inches, everything is ok. If not, then you need to check the FL of the objective lens and your calculation of the lengths of the tubes and correct any errors.

Once everything is correct and before you proceed finishing the telescope tube, take the drawtube out of the main tube, the dew cap off the tube and the lens out of its cell and store them in a safe place.

As in the video, remove the 37-inch segment of the inner-tube from both parts of the outer-tube. Now:

A) Smear Elmer’s glue on the part of this inner-tube that slides into the front part of the outer-tube;
B) Hold that tube segment by the part that is free from glue and squeeze the cut tube until the cut edges are close together.
C) Hold the front segment of the telescope tube in your other hand and *rapidly insert* the glued inner-tube segment into the back of the front segment of the telescope tube until it butts up against the part of the inner-tube already glued in place;
D) Stop squeezing the inner-tube section and let it open back up until it and the glue on it press against the inside of the back of the front section of the telescope tube, see Figure III-10;
E) Rotate the section around a little to get it firmly seated in the front segment of the tube, see the video.

Figure III-10: Sliding the longitudinally cut segment of tubing in the front segment of the telescope tube.

Now, smear the part of the inner-tube segment sticking out of the front section of the telescope tube with Elmer’s glue and, following the same steps given above, slide the back segment of the telescope tube back onto the glued section of the inner-tube (as in Figure III-11) until the front and back segments of the outer-tube are flush against each other. Sight along the telescope tube and roll it on a flat table or counter top *to be absolutely sure the tube segments are straight*. If they are not straight, twist the tube segments to get them straight. When the tubes are straight, wipe of any glue that might have oozed out of the junction between the two segments of the tube with a damp cloth.

Figure III-11: Joining the back segment of the telescope tube to the front segment of the telescope tube.

When the glue had dried, put the dew cap back on the telescope. Put the dust cover on the front of the dew cap, and plug the hole for the drawtube in the back of the telescope with a wad of paper. Now you are ready to seal or paint the tube.

We recommend that you leave the outside of the telescope white, i.e., the original color of the cardboard tubes. If you decide to leave the tubes white, you may also want to paint the back of the wooden ring at the back of the end of the tube white. This is up to you. Alternatively, you can spray paint the telescope tube any color you want, but if you leave the telescope white, it will be easier to sight along the telescope tube to find objects in the dark of the night. If you want you keep the tubes white, you need to seal them by spraying the entire outside (except the dust covers) of the tube with clear Krylon spray paint to protect the cardboard from the moisture of the night (or any rain if you forget to take the telescope inside after using it). You should give the tubes ***several*** coats of Krylon (or colored paint) to ensure that the tube is well protected against moisture (or rain), otherwise moisture from dew or very high humidity may cause the telescope tube to warp.

When the Krylon (or colored) spray paint is completely dry, take the dew cap off, put the objective lens back in its cell, put the dew cap back on the telescope tube, take the paper plug out of the back of the telescope, slide the drawtube back into the wooden rings until about 4 inches of it are sticking out and put the 2-inch FL eyepiece back in the drawtube. Now you have a beautiful telescope of your own making.

There are three things you need to do to care for your telescope:

First, when not using it, keep the dust cap on the objective end of the telescope to keep dust and dirt from getting of the objective lens on the telescope;

Second, when you are not using them, keep the dust caps on the eyepieces and;

Third, do not leave the telescope out in the sunlight or outside overnight when you are not using it. Despite the protective coating of Krylon or paint, the cardboard tube may warp from the heat of direct sunlight if exposed to the sun for prolonged periods of time and due to dew forming on it during the night. So keep the telescope indoors when not in use.

Part IV: Making the Mounting

In order to build the telescope mount and tripod, in addition to the variable speed power drill, wood and metal drill bits, a countersink bit, wood clamps and/or heavy weights and a drill mounting mentioned in Part II, you will need to buy (or have or have access to):

1) A table saw or a miter box and a miter saw,
2) A 1-inch x 6-inch pine board* about 2-feet long,
3) Six, 1-inch x 2-inch x 8-foot long, pine laths**,
4) A piece of ¼- to ½-inch thick plywood about 1 x 1-foot,
5) 75, 1½ -inch long, number 10, flathead wood screws
6) A 3-inch long, 3/8-inch diameter, full threaded hexhead bolt,
7) A 3/8-inch hexnut,
8) A 2-inch diameter, ½ -inch washer,
9) Two 3/8-inch, lock washers,
10) A 1¼-inch diameter, 3/8-inch washer,
11) A 3/8-inch wingnut,
12) Two 2½-inch long, 5/16-inch diameter, full threaded hexhead bolts,
13) Four 5/16-inch hexnuts,
14) Four 5/16-inch, lock washers,
15) Four 5/16-inch washers,
16) A 5/16-inch wingnut,
17) Six 3-inch long, ¼-inch, hexhead bolts,
18) Six ¼-inch hexnuts,
19) Twelve ¼-inch washers,
20) Three ¼-inch wingnuts, and
21) Two, 14-inch long cable ties.

Notes:
* A 1-inch x 6-inch board is really ¾-inches thick and 5½-inches wide and will be referred to as such in the following.
** 1-inch x 2-inch pine laths are ¾-inches thick and 1½-inches wide and will be referred to as such in the following.

Unless you made the mounting while you were making the optics and the telescope, you are ready to do so now. But, before you start, there are several things you must know and do to make the mounting.

The first thing to take *serious note of is*: Without a *solid mount*, any telescope—no matter how good the optics are—is nearly useless. If your mount is not well made and solid, you will have a hard time pointing the telescope at an object and an even harder time keeping the object in the field of view and when it is in the field of view, the telescope will be shaking so you won't really see much. So make sure you follow our instructions and make your mount ***SOLID***.

The second thing is: Since your telescope is over 5-feet long, the tripod must be tall enough so you can comfortably view celestial objects. Our rule of thumb is—make the tripod legs as long as the distance from the floor to about your upper chest.

The third thing is: Do you want to varnish or paint the wooden parts of the mounting or leave them unpainted? If you want to varnish or paint (whatever color you want) the mount, do so after you have constructed its parts, but before you have finally assembled them. Also, make sure you *do not* paint or varnish the various *bolts, nuts and washers* that together make the vertical and horizontal axes of the mounting and those that hold the legs to the tripod leg support and the tripod platform to the legs.

The fourth thing is: You will need a ***table saw and/or miter box and miter saw*** to make the wood cuts true and accurate, otherwise the tripod parts - and especially the telescope yoke and saddle parts - will not fit together properly and that will weaken your telescope mounting markedly.

The fifth thing is: You need to smooth each wooden element of the mounting with a wood file and sandpaper after you have cut it to shape.

Finally, there are three parts to the mounting—the tripod, the yoke and the saddle.

The Tripod

<u>The Tripod’s Leg Support</u>

Draw to scale the pattern called “Top” in Figure IV-1 on a piece of ¾-inch thick piece of pine board that is at least 5¼-inches tall and 6-inches wide and cut out the hexagonal top of the leg support. Drill the 3/8-inch diameter central hole through the wood, drill six pilot holes for the screws through the wood using a 3/16-inch drill bit as shown on the patterns, and then countersink the screw holes.

Take a ¾-inch by 1½-inch lath and cut three, 2-inch long pieces off of it. Using the pattern in Figure IV-2, drill a ¼-inch hole in each of the three pieces of wood. Draw to scale the pattern labeled “Bottom” in Figure IV-1 on the bottom of the hexagonal leg support and use Elmer’s glue to glue the three pieces of wood onto the bottom of the hexagonal part of the leg support. Use wood clamps or heavy weights to tightly hold the glued parts together. Let the glue dry.

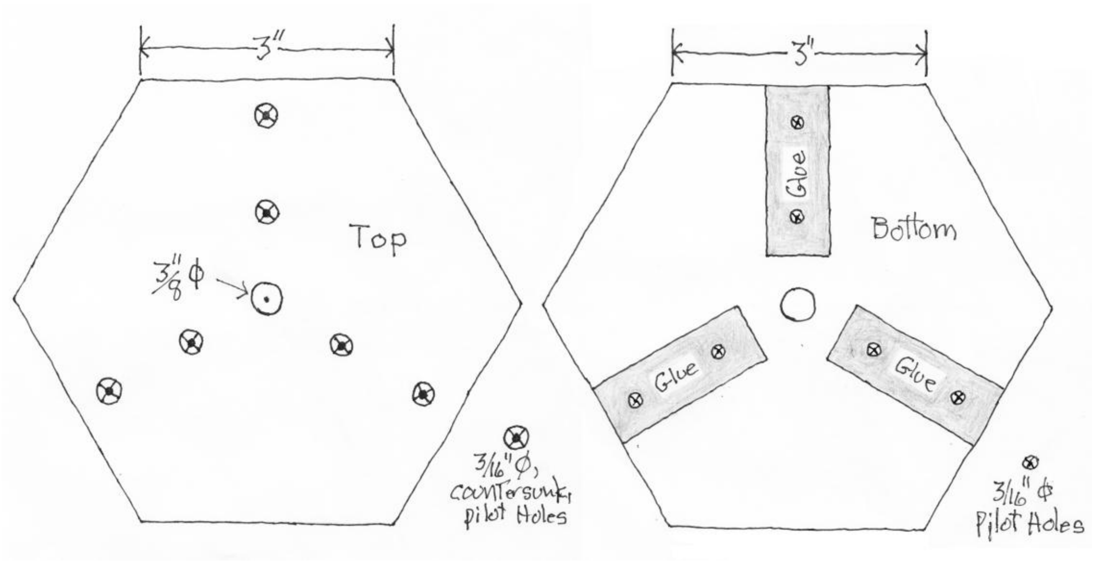

Figure IV-1: Patterns for the top and bottom of the tripod leg support.

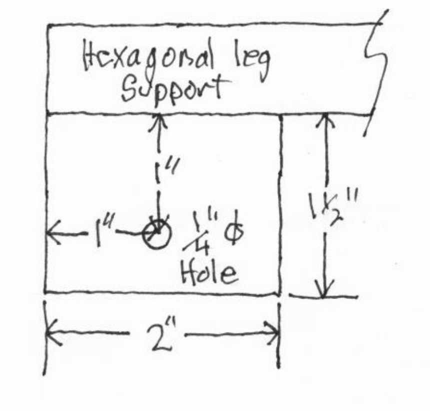

Figure IV-2: Pattern for the drill holes in parts of the tripod leg support.

Use a 1/8-inch diameter drill bit to drill pilot holes (one each for the six drilled and counter-sunk screw holes in the hexagonal leg support top) ¾-inch deep into the wood of the three leg supports glued to the bottom of the hexagonal leg support (Figure IV-3 and the video). Using six, #10 flathead wood screws, screw the three leg supports *very tightly* to the hexagonal leg support top.

Also, using a dark ink pen, number the outward facing end of the three leg supports: 1, 2 and 3. When you make the three legs, you will also number them 1, 2 and 3. Thus, you will not mix up which leg goes on which support.

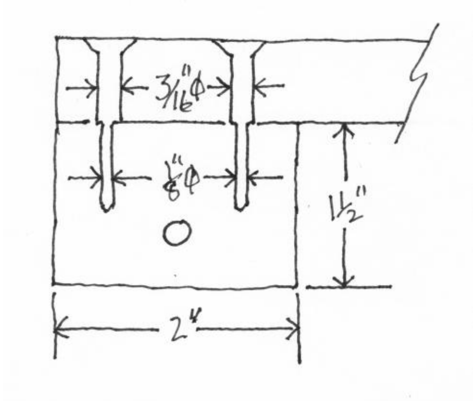

Figure IV-3: Diagram for drilling the pilot holes in parts of the tripod leg support.

Now put a lock washer on the 3/8-inch by 3-inch hex-head stove bolt and insert the bolt into the 3/8-inch diameter hole in the bottom of the hexagonal leg support (Figure IV-4). Put a 3/8-inch lock washer and a 3/8-inch hex-nut on the bolt sticking out the top of the hexagonal leg support and tighten the nut on the bolt as tight as possible. *Make absolutely sure the nut and bolt are very, very tight before proceeding*. **This bolt is the vertical axis of your mount.**

Figure IV-4: Photo of the positioning of the 3/8-inch stove bolt in the leg support and support ring.

Using the pattern in Figure IV-5 and a 2-inch hole saw, cut a 2-inch diameter disk out of ¾-inch thick board, and, using a 1-inch wood drill, drill a 1-inch diameter hole in its center. Also, drill three, 3/16-inch diameter pilot holes in the wooden ring and countersink the holes. Then, using Elmer's glue, glue this wooden ring to the top of the hexagonal leg support so the ring surrounds the hex-head nut holding the bolt and the pilot holes are not over the three leg supports on the bottom side of the leg support (Figure IV-4). Press down hard on the ring to insure there is good contact between the ring and the hexagon leg support as the glue dries.

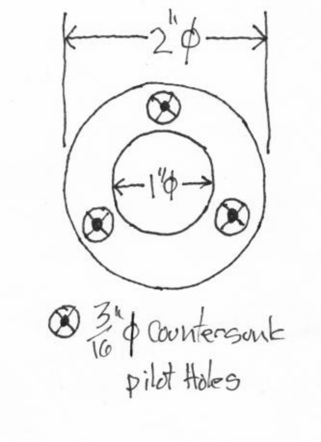

Figure IV-5: Pattern for the wooden disk for the top of the tripod leg support.

When the glue is completely dry, use a 1/8-inch diameter drill bit to drill pilot holes (one each for the three drilled pilot holes) ¾-inch deep into the wood of the hexagonal top of the leg support (see the video). Using three, #10 wood screws, screw the ring *very tightly* to the hexagonal leg support top (Figure IV-4).

The Tripod's Legs

Using the various ¾-inch by 1½-inch laths, cut three pieces of lath 6-inches long, nine pieces of lath 3-inches long and six pieces that are as long as the distance from the floor to about the middle of your upper chest.

Using the pattern in Figure IV-6, trim three of the 6-inch long pieces of lath to make the feet of the three legs.

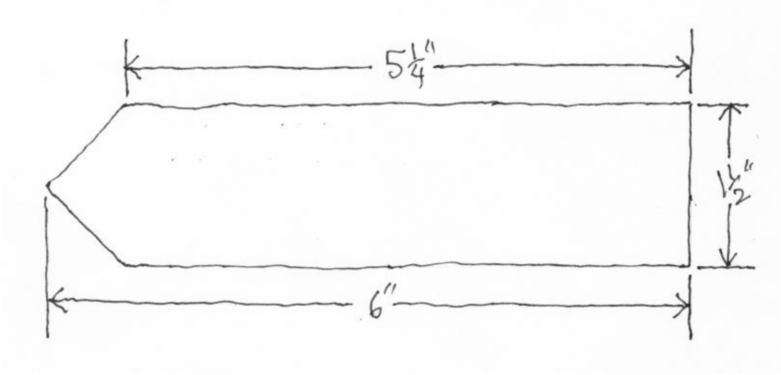

Figure IV-6: Pattern for trimming the 6 inch long pieces of wood to make the feet of the tripod legs.

Using the pattern in Figure IV-7, drill a 1/4-inch hole in *one end* of each of the six, very long laths. The ends of these very long laths with these ¼-inch holes will be the top of the three legs (also see Figure IV-8).

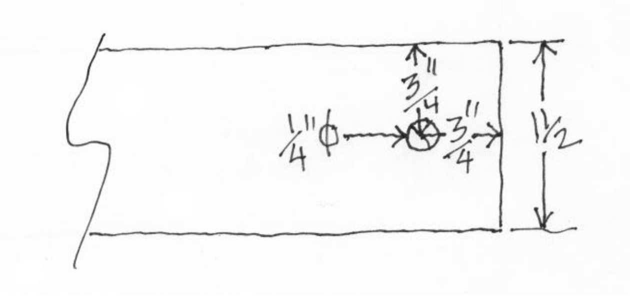

Figure IV-7: Pattern for drilling the ¼-inch holes near the tops of the six long pieces of wood that will make up the legs of the tripod.

Using the pattern labeled “R” in Figure IV-8, drill eight 3/16-inch diameter pilot holes, labeled “S”, countersink the holes in *three* of the long pieces of ¾-inch by 1½-inch lath and finally drill ¼-inch holes at the points labeled “P” and “Q” in the lath. Now, using the pattern labeled “L” in Figure IV-8, drill eight 3/16-inch diameter pilot holes, countersink the holes on the *reverse side* of the lath. Finally drill ¼-inch holes at the points labeled “P” and “Q” in the remaining *three* long pieces of ¾-inch by 1½-inch lath. If you have correctly done this, the drill patterns in the six pieces of lath will be as shown in Figure IV-9 when they are placed side by side in three pairs (one pair for each leg).

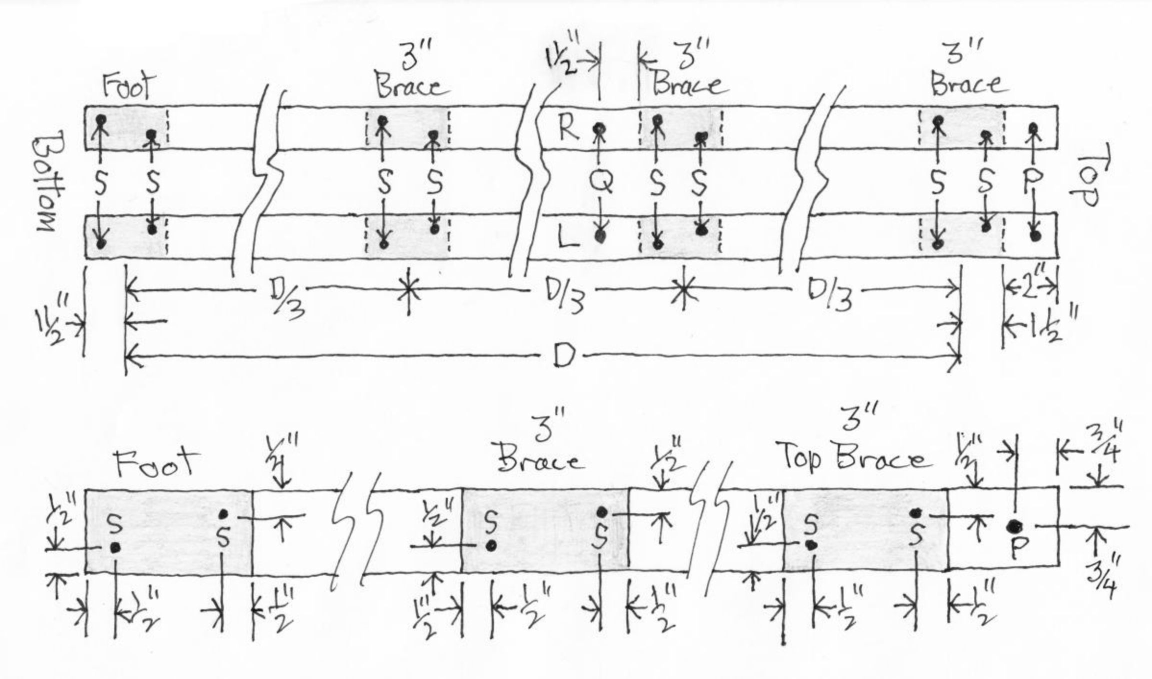

Figure IV-8: Top two drawings - pattern for drilling the holes in the six long pieces of wood that will make up the three legs of the tripod; Bottom drawing - details of the pattern for drilling the holes in the six long pieces of wood that will make up the three legs of the tripod.
Note that the ¼-inch diameter holes Q are drilled on the centerline of the laths (e.g., see Figure IV-7 for P).

Do the following to assemble each of the three legs: Lay one of the two long laths of a leg pair with it counter-sunk drill holes downwards on a flat surface. Spread Elmer's glue: A) on one side of the upper 3 inches of the 6-inch long leg foot; and B) on one side of each of the three, 3-inch long pieces of lath we call leg braces. As shown in the video, place the glued side of the leg foot and the three 3-inch leg braces on the long pieces of lath. Press down very hard to very tightly squeeze the glued pieces together. Next, spread glue

Figure IV-9: Photo of how the three pairs of long leg boards should look after drilling (and countersinking) the hole in the boards.

on the exposed sides of the top 3 inches of the leg foot and the three 3-inch long braces. Place the second long piece of lath of the leg on the glued surfaces and again press down very hard. Now, rotate the leg so it is standing on an edge and, using four wood clamps, clamp each of the glued wooden pieces tightly together. Let the glue dry.

Use a 1/8-inch diameter drill bit to drill a pilot hole ¾-inch deep into the lath in each of the eight drilled and counter-sunk screw holes of the leg foot and the three leg braces of each leg. Turn the leg over and drill the pilot holes for the eight drilled and counter-sunk screw holes on that side of the leg. Screw sixteen, #10 flathead wood screws *very tightly* into the sixteen screw holes.

Repeat the above process to make the other two legs.

As shown in Figure IV-10, slide the top of one of the legs over a leg support on the bottom of the hexagonal leg support, so the 1/4 -inch holes in leg and the leg support coincide. Put 1/4 -inch washer on the 1/4-inch, 3-inch long hexhead stove bolts, slide the bolt through the holes, put 1/4-inch washer on the protruding bolt and put two hexnuts on the bolt. Use two crescent wrenches to very securely tighten the bolt and nuts on the leg. Repeat the process for the remaining two legs. Adjust the legs so they are at about a 30 degree angle to the vertical and that the top of the hexagon leg support is level.

Figure IV-10: Photo of joining the legs to the tripod support structure.

Now, using a dark ink pen, number the legs, 1, 2, and 3, corresponding to the numbers on the outward facing end of the three leg supports.

The Tripod's Platform

The purpose of the tripod platform is three fold. First, the platform strengthens the tripod, making it very strong and solid. Second, it serves as a place to store the telescope dust cap, your star charts, observing book (see section on observing) and anything else you may need while observing. And third, it is a secure place where you can keep the eyepiece you are not using at the moment.

Using the pattern in Figure IV-11, cut the platform shelf from a piece of ¼- to ½-inch thick plywood, at least 9-inches wide and 10-inches tall, drill the six, 3/16-inch diameter pilot holes and countersink them. Using a 1½-inch wood drill bit, drill two holes in the shelf; these holes will hold your eyepieces when they are not in use.

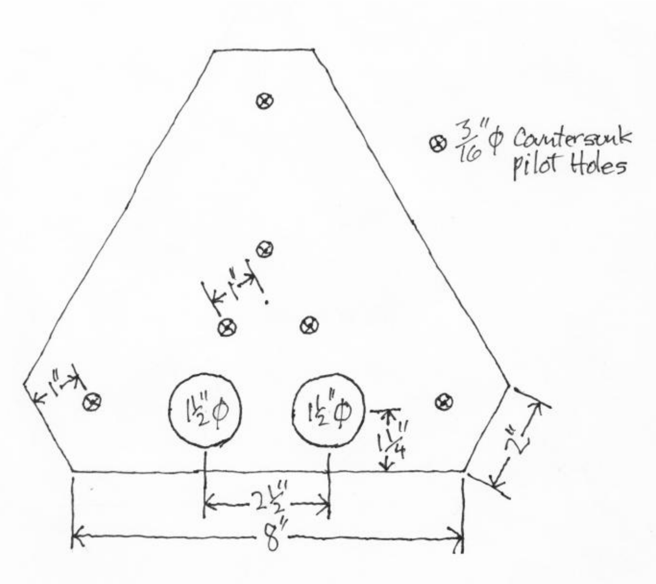

Figure IV-11: Pattern for the shelf of the tripod.

Now cut three 16-inches long pieces of lath from the ¾-inch by 1½-inch wooden laths to make the platform supports. Drill ¼-inch holes in each platform supports using the pattern in Figure IV-12. Using three ¼-inch, 3–inch long hex-head stove bolts, three ¼-inch wing nuts and six ¼-inch washers, loosely bolt the supports onto the tripod legs using the holes drilled at "Q" in each leg (see top section of Figure IV-8 and the video). The supports should be long enough to nearly touch at the center axis of the tripod, but not so long that they overlap. If they do overlap, spread the tripod legs until the supports just touch at the center.

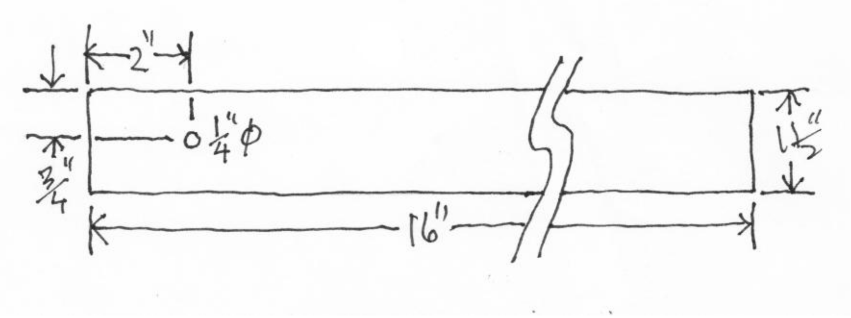

Figure IV-12: Drill hole pattern for the three platform supports.

Now, using a dark ink pen, number the three platform supports, 1, 2, and 3, corresponding to the numbers on the outward facing end of the three leg supports and the legs themselves.

Following the video and Figure IV-13, carefully aligning the platform shelf on one of the three platform supports so the support is exactly centered under the two screw holes on the platform shelf. Insert a soft lead pencil in each of the two screw holes, mark where the hole fall on the support. As in the video, using a 1/8-inch drill bit, drill screw pilot holes ¾-inch deep *exactly centered* at each of the two pencil marks on the top of the platform support. Now, using two #10 screws, screw the platform onto the support. Following the video, repeat the process for the other two platform supports.

Figure IV-13: Photo showing how to prepare for gluing and drilling the pilot holes in the three shelf supports.

When you are finished with the shelf, the tripod is done, unless you want to varnish or paint it. If you do want to varnish or paint it, disassemble it and paint each part separately before reassembling the tripod. If you varnish or paint the tripod, make sure you redo the *numbering* of the legs, their supports and the platform supports.

The Mounting's Yoke

Using a table saw or miter box and miter saw, cut two pieces 2-inches wide and 7-inches long and two pieces 2-inches wide and 5-inches long from the ¾-inch thick pine board, following the pattern Figure IV-14. Then drill two 3/16-inch diameter pilot screw holes and countersink them in the two 7-inch pieces and then drill a 5/16-inch hole at the other end of each piece. Following the video, put Elmer's glue in the ends of ***one of the 5-inch long pieces***. Lay that piece on a flat surface. Place the two 7-inch long pieces, with the counter sunk screw holes facing outwards, on the glued ends of the 5-inch piece and squeeze the pieces of lath together. Now place the ***unglued*** 5-inch piece between the other ends of the 7-inch long pieces and use wood clamps or heavy weights to put pressure on the 7-inch long pieces (Figure IV-15) so they fit tightly to the 5-inch pieces.

Note: The second 5-inch long piece, which is *not glued* to the 7-inch long pieces, is used *only* to keep the yoke true and is removed when the glue on the other end is dry.

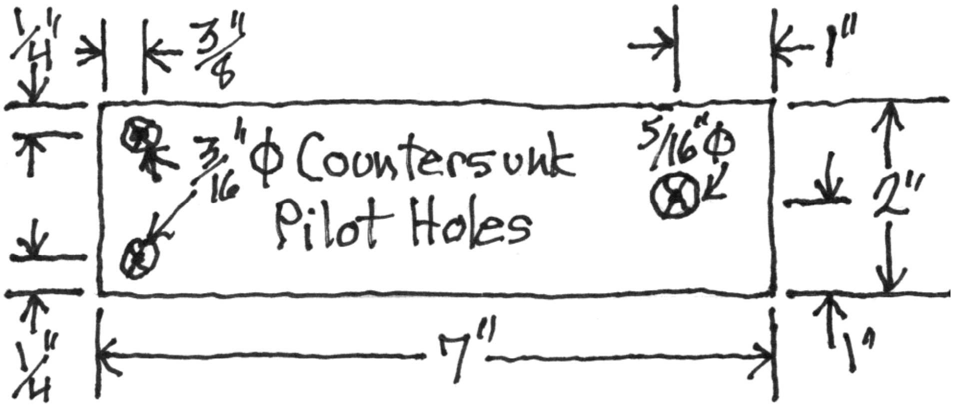

Figure IV-14: Size of the wood and the pattern for drilling the screw holes in two of the pieces of wood that make the yoke.

Figure IV-15: Photo showing the weighting of yoke parts

When the glue is dry, take off the wood clamps or weight and using a 1/8-inch drill bit, drill two pilot holes ¾-inch deep into each of the 5-inch long piece. Then use four #10 wood screws to very tightly screw the 7-inch long pieces to the 5-inch long piece. Now your yoke is finished (Figure IV-16), unless you want to varnish or paint it.

Figure IV-16: The finished yoke.

As in video, put a 2-inch diameter, 3/8-inch washer on the part of the 3/8-inch stove bolt sticking out the top of the tripod, slide the bottom of the yolk onto the 3/8-stove bolt, put a 3/8-inch washer over the stove bolt and then screw a 3/8-inch wing nut onto the bolt.

When you want to clamp the telescope in one position, you tighten this wing nut and when you want to move the telescope in azimuth (left and right), you loosen the wing nut. Now the yoke is finished.

The Telescope's Saddle

Following the patterns in Figure IV-17, use the table saw or miter box and miter saw and a 2-inch diameter hole saw, cut two 2-inch x 3½-inch saddle side-pieces and four 2-inch x 3 1/8-inch saddle end-pieces from the ¾-inch thick pine board. Using the pattern in Figure IV-17, drill two 3/16-inch pilot holes in each of the four saddle end-pieces and countersink the holes. Then drill a 5/16-inch hole in the center of each of the two saddle side-pieces.

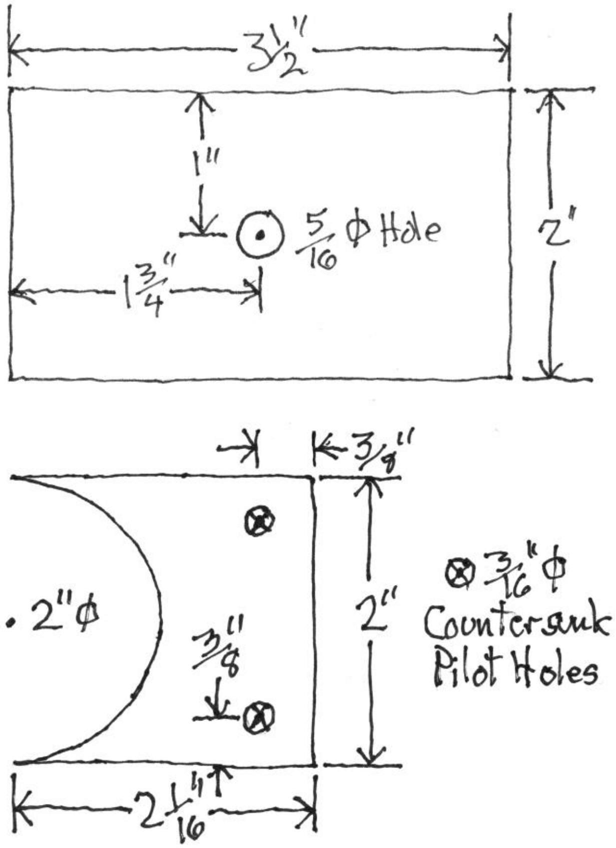

Figure IV-17: Patterns for cutting the telescope saddle parts and for drilling the holes in the four saddle end pieces of wood.

Wrap some medium grained sandpaper around the telescope tube and sand the arcs cut in the wood of the four end-pieces until the tubes fit *snuggly* in the wooden four end-pieces.

Following the video, put Elmer's glue on the 2-inch wide ends of the 3½-inch long saddle side-pieces of wood, lay those pieces of wood on a flat surface. Squeeze the four saddle end-pieces of wood, with the counter sunk screw holes facing outwards, onto the glued ends of the two saddle side-pieces and clamp the pieces together.

When the glue is dry, take off the wood clamps and, using a 1/8-inch drill bit, drill the pilot holes ¾-inch deep into each end the two saddle side-pieces. Then use eight #10 wood screws to very tightly screw the 2-inch wide saddle end-pieces to the two saddle side-pieces. Now the two parts of your saddle are finished, unless you want to varnish or paint them.

As in Figure IV-18 and the video, put 5/16-inch lock washers on the two 5/16-inch, 2½-inch long, hex-head stove bolts and insert the bolts with the lock washers into the 5/16-inch holes in the inside of the side-pieces of the two saddle parts. Then place 5/16-inch lock washers and 5/16-inch hexnuts on the two stove bolts and, using two crescent wrenches, tighten, very tightly, the 5/16-inch hexnuts onto the stove bolts.

As in Figure IV-18 and the video, put a 5/16-inch washer on the stove bolt of each saddle part, insert the stove bolt of each saddle part into the 5/16-inch hole in the top of each prong of the yoke, put a 5/16-inch washer on each stove bolt sticking out the side of each yoke prong and then screw two 5/16-inch hexnuts on one of the bolts and a 5/16-inch wing nut on the other bolt. **These two 5/16-inch bolts form the horizontal axis of your mount.**

Figure IV-18: Mounting of the two 5/16-inch stove bolts in the two sides of the saddle.

When you want to clap the telescope in one position, you tighten the wing nut and when you want to move the telescope in altitude (up and down), you loosen the wing nut. Now the saddle and the entire mount are finished (Figure IV-19).

Figure IV-19: Photo of the finished saddle parts mounted in the yoke.

Mounting the Telescope on the Mount

Find the balancing points of the telescope, first with the 2-inch FL eyepiece and then with the 1-inch FL eyepiece in the drawtube, when the eyepieces are focused on a very distant object. The differences in these two balancing points will be very small. Using the average of these two balancing points as your point of reference, slide the telescope into the saddle until the balancing reference point is in the middle of the saddle.

Take two, 14-inch long cable ties and wrap one around each end of the saddle to secure the telescope in the saddle. In order to get the cable ties as tight as possible, you will need to shape each tie to the shape of the saddle by bending each tie, where it crosses each corner of the saddle, with your fingers and then secure the cable ties very tightly, using a pair of pliers, as all shown in the video.

Congratulations, now you have completed your simple telescope (see title page) and are ready to start using it as soon as it is night and the Moon, planets and stars are out.

Part V: Getting Started Observing

WARNING—DO NOT USE YOUR TELESCOPE TO LOOK AT THE SUN. If you do, you may blind yourself. You can observe the Sun safely by projection as described in the note in Appendix A.

Also, when you are not using your telescope, 1) put one of the plastic caps, that came with the mailing tubes, in the front of the dew cap to keep dust from getting on the objective lens, 2) cover the eyepieces with the plastic dust caps, and 3) keep the telescope indoors, otherwise the sun and the weather may warp the cardboard tube so it is no longer straight.

Now, as you are getting ready to start observing, you will find it very useful and rewarding if you keep a logbook of your observations. Use this logbook to record:

A) The date and time of the observations,
B) The telescope used (lens diameter and focal ratio—the focal ratio is simply the focal length of the lens divided by the lens' diameter, in this case it is 60-inches/1.5-inches and is written as F/40),
C) The magnification used,
D) The transparency of the sky (from 1 to 5, where 1 is very hazy and 5 is completely clear),
E) The seeing (from 1 to 5, where the image is blurry and 5 the image is sharp and steady),
F) A drawings of what you saw and
G) Comments about what you observed.

There are a few other important facts about your telescope you need to know.

First: As you may already know, the average human can see stars down to the 6th magnitude in a clear, dark, country sky with no Moon out. Your 1½-inch telescope will let you see stars down to about the 9th magnitude under these conditions. However, the objects we have listed in Appendix A are generally limited to those brighter than about 8th magnitude, which you will most probably be able to see under good conditions—if you live in the country or a small town, but not a big city (where you will have trouble even seeing the brighter stars and planets).

Second: The theoretical resolving power of a perfect 1½-inch telescope is 3 arc-seconds (1 degree has 60 arc-minutes and each arc-minute has 60 arc-seconds). However, since your telescope has a single element, non-achromatic lens, we expect that its resolving power will probably be about 5 arc-seconds.

For comparison, the Moon's apparent diameter is about ½ of a degree or about 1800 arc-seconds and its real diameter is 2160 miles. So your telescope's resolution corresponds to about 6 miles on the Moon.

Another example is Jupiter, whose apparent maximum diameter is nearly 50 arc-seconds, so you will be able to see jovian features nearly as small as 1/10th the diameter of Jupiter.

Given that the best resolution we expect your telescope will have is about 5 arc-seconds, the list of, e.g., double stars, in Appendix A is limited to those stars that are separated by more than 5 arc-seconds. However, when observing double stars, the difference in the brightness between the primary (brighter) and secondary (dimmer) star also has an effect on ones ability to resolve the two stars. The theoretical resolving power of a lens (or mirror) is valid only if the two stars are of equal brightness. The dimmer the secondary star is with respect to its primary, the farther apart the two stars have to be to be able to see the secondary in the glare of its brighter primary.

Also, dim objects like diffuse nebulae and galaxies are hard to recognize unless they are bigger than a few arc-minutes, or more than 10 times the resolution of the telescope.

The first object you will probably look at is the Moon. Start with the 2-inch FL eyepiece that gives you 30x and has a FOV of nearly 1.1-degrees, i.e., about two times the diameter of the Moon.

At first, you may have trouble even finding the Moon, but with a little patience and *practice* you will get the Moon in the field of view, learn to keep it there and get it in focus—and then, at 30x, you will see the craters, mountains, marae and other detail of the lunar surface. Next, put the 1-inch FL eyepiece, which as a FOV of nearly 0.5-degrees in the telescope and at 60x you will see even more detail. With more and more *practice* you will find it easier and easier to locate not only the Moon, but also the brighter planets and stars in the sky and then the dimmer and dimmer ones.

If you already know the constellations and have “Sky and Telescope” and/or “Astronomy” magazine(s), you already know where and when to observe the planets of our solar system. But, in order to find the majority (but not all) of the double stars, galactic star clusters, diffuse nebulae, planetary nebulae, globular star clusters and some of the galaxies beyond our own Milky Way (listed in Appendix A), you will not only need to know the constellations (see below), but you will also need to use star charts. Star charts are essential for anyone who is serious about observational astronomy and there are a number of excellent books that you can use to learn where these various objects are in the sky, several of which have been written by KG and are available from Ken Press.

If you do not yet know the constellations and don’t get “Sky and Telescope” and/or “Astronomy”, you will need to start learning the constellations if you want to get the full use of your telescope and want to fully enjoy astronomy. There are many books and tools you can use to learn the constellations. One such tool is a planisphere that you can get from Ken Press. Alternatively, the constellation book recommended by AB is “The Stars” by Rey (Appendix B).

If you are just starting to learn the constellations and do not know where the planets are in the night sky, point your telescope to the brightest objects in the sky and:

If the object is a star, it will appear as a point of light at both 30x and 60x.

If the very bright object is whitish, has a disk, even at 30x, and has up to four medium bright stars, more or less, in a line on either side of the disk, you have “discovered” Jupiter and it four brightest satellites. To be certain it is Jupiter, look at it on a following night and if it is Jupiter, you will see that the satellites have changes positions. If you see less than four satellites, one or more are either behind Jupiter (occulted by Jupiter), or in eclipse in Jupiter’s shadow or are in front of Jupiter (transiting Jupiter).

If the bright object is yellowish, shows a small disk and has a ring around it—you have “discovered” Saturn and its Rings.

If you look at a very bright star to the east in the morning sky or to the west in the evening sky and it has the gibbous shape of our Moon a few days before or after full Moon, or has a half-moon shape, or has a crescent shape, you have “discovered” Venus. Venus goes through its phases, from full to crescent in the evening sky and from crescent to full in the morning, each in about nine months. Take note of the fact that, because Venus is so bright, it is best viewed when the sky is still very bright soon after sunset and shortly before sunrise. If the sky is too dark, the glare of Venus will be so bright that you will have difficulty seeing its phase.

If you look at a bright, reddish star in the night sky and it has a small disk, then you have “discovered” Mars. However, most of the time during its 26-month observational cycle, Mars is too small to show a disk, so, until you know your way around the constellations, you will have trouble identifying Mars.

Once you have learned the constellations and have more observing experience, you will be able to locate most, if not all, of the objects we have listed in Appendix A, assuming you do not have city lights bothering you.

We note here that the lists in Appendix A do not include every object you might be able to observe with your simple telescope. For example, we have resolved some double stars as close as 4 arc-second (e.g., Alpha Gemini or Castor which has a separation of 4.6 arc-seconds) using the telescope shown in the illustrations of this manual, but our ability to do so is a result of our having decades of observing experience. So, with time, you may be able to add to the list of double stars given in the appendix. Also, there are many dim and small deep sky objects (e.g., planetary nebulae, globular clusters and galaxies, almost all of which are dimmer than 6th magnitude) that are within reach of your telescope, but not in the lists in Appendix A. They are excluded from the lists because they are not close enough to a star (visible to the naked eye) you can use as a reference so you can find the dim object. The following two paragraphs illustrate this point.

There are just two planetary nebula that we have listed in Appendix A - the famous Ring Nebula in Lyra and the Dumbbell Nebula. The Dumbbell is fairly bright and big (8th magnitude and 5x8 arc-minutes) and is relatively easy to find, while the Ring Nebula is dimmer and smaller (9th magnitude and about 1 arc-minute is diameter) and you would miss it if it were not located halfway between two fairly bright stars is Lyra. Even so, you will find it hard to identify the Ring Nebula. There are several additional planetary nebulae that are about as bright, or brighter than the Ring Nebula, and about the same size, but they are all located far from any naked eye star and thus are very difficult to locate and identify with your simple telescope.

Further, we have listed the faint (8th magnitude and small (3 arc-minutes in diameter), elliptical, satellite galaxy (M32) of the Great Nebula (galaxy) in Andromeda (M31, 5th magnitude, 20x60 arc-seconds), because the former is just visible right next to the latter. However, if M32 were not right next to M31, you would have great difficulty finding it with your simple telescope. As is the case with the planetary nebulae cited above, there are several galaxies with magnitudes of 8 and 9 that are not listed, because they are not near a reference star and are thus very difficult to locate and identify.

In contrast to galaxies, planetary nebulae and diffuse nebulae, many globular clusters are relatively easy to find and identify, even if the brighter ones are not near a naked eye star. This is because many are large (several to tens of arc-minutes in diameter), fairly bright and have a characteristic, fuzzy ball shape that, once you have observed several of them, you will easily recognize them.

In addition, there are many open or galactic star clusters that are within the reach of your simple telescope, but are not listed in the appendix. As you might guess from their name, these clusters of young stars are found in—or close to—the Milky Way (our galaxy). Since (as you will see in your telescope), there are numerous stars in the Milky Way, it is often difficult to identify a galactic cluster that is located in the Milky Way from the background Milky Way stars. This is the case unless the cluster is very compact and its stars are relatively bright. Thus, most of the galactic clusters listed in the appendix are adjacent to the Milky Way, e.g., the Praesepe (M44) and the Pleiades (M45). But, with experience, you may be able to locate some of the galactic clusters in the Milky Way that are not in our list in Appendix A.

Finally, from our experience, we are sure you will enjoy learning to use your home made, simple telescope to observe the Moon, the planets and the binary stars and deep sky objects of our universe listed in this manual. We hope the experience you have making your own telescope and observing with it, will encourage you to grind, polish and figure telescopic mirrors for much more capable telescopes like those shown in Figures I-1 and I-2. Such telescopes will give you much better views of the objects listed in Appendix A and will allow you to locate many more such objects, as well as see fine detail on the Moon, Mars, Jupiter and Saturn. We also hope that this experience will encourage you to choose astronomy, optics or planetary science as a career.

Appendix A:
Astronomical Objects that can be Observed with this Simple, Beginner's Telescope

Solar System Objects:
Sun* – Sunspots, Solar Eclipses, Transits of Mercury.
Mercury - Phases.
Venus – Phases.
Moon – Craters, Mountains, Marae, Lunar Eclipses.
Asteroids** – A few of the brightest ones.
Jupiter – Its two main cloud belts and its four brightest satellites.
Saturn and its Rings.
Uranus.**
Comets.

Notes:
* *Do not look at the Sun directly with your telescope or you could be blinded*. But you can look at the Sun by *projection* as follows: Cut a 1 9/16-inch diameter hole in a stiff piece of paper 6 or so inches square. Slide the paper over the drawtube of the telescope and push it flush against the back of the telescope tube. Put the 30x eyepiece in the drawtube and focus the eyepiece on a very distant object. Point the telescope towards the Sun and hold a white sheet of stiff paper, again 6 or so inches square, several inches behind the eyepiece. Refocus the eyepiece until the sun's image is sharp. You will see a 3- or 4-inch diameter image of the Sun projected on the white paper and you (and any companions) will see sunspots (if there are any on the Sun when you observe) and/or watch a partial solar eclipse and/or a transit of Mercury in comfort and with no danger to you eyesight.
** Located and followed only with the aid of star charts. Since Uranus and the brighter asteroids are only as bright as sixth or seventh magnitudes and are too small (Uranus is less than 4 arc-

seconds in diameter and the largest asteroids are less than 1 arc-second in diameter) to show a disk, you will only know if you have found them by noting (and drawing) their positions with respect to nearby stars on successive nights and seeing them move from night to night.

Double Stars:

The following table of double stars gives the following information:

The <u>Constellation</u> the stars are in,

The <u>Name</u> of the star,

<u>RA</u> – the Right Ascension Coordinate of the stars in hours (h) and minutes (m),

<u>Dec</u> – the Declination Coordinate of the stars in degrees north or south (-) of the celestial equator,

<u>PA</u> – the Position Angle of the secondary (dimmer) star with respect to the primary (brighter) star given in degrees and measured counterclockwise from celestial north,

<u>Sep</u> – Separation of the secondary star from the primary star measured in arc-seconds,

<u>M_1</u> – Magnitude of the primary star, and

<u>M_2</u> – Magnitude of the secondary star.

Constellation	Star	RA	Dec	PA	Sep	M_1	M_2
Aries	Gamma	1h 53m	19	0	7.5	4.5	4.6
	Lambda	1h 58m	24	47	36.7	4.8	6.7
Bootes	Iota	14h 16m	51	32	38.7	4.8	7.4
	Delta	15h 15m	33	78	103.8	3.6	7.9
	Mu	15h 24m	37	170	107.1	4.3	7.1
Cancer	Iota	8h 47m	29	308	30.7	4.1	6.0
Canes Venatic	Alpha	12h 56 m	38	229	19.3	2.9	5.5
Canis Major	h 3945	7h 17m	-23	52	26.8	5.0	5.8
Capericornus	Alpha	20h 18m	-13	292	381.2	3.7	4.3
Cassiopeia	SHJ 355	23h 30m	59	268	75.8	4.9	7.2
Cententarus	3	13h 52m	-33	106	7.9	4.5	6.0
Cepheus	Delta	22h 29m	58	191	40.6	4.2	6.1
Cygnus	Beta	19h 31m	28	55	34.7	3.4	4.7

Delphinus	Gamma	20h 46m	16	266	9.1	4.4	5.0
Draco	Nu	17h 32m	55	311	63.4	4.9	4.9
	Psi	17h 42m	72	15	30.0	4.6	5.6
Eridanus	Theta	2h 58m	-40	90	8.4	3.2	4.1
	f	3h 49m	-38	217	8.4	4.7	5.3
Hercules	95	18h 2m	22	257	6.3	4.9	5.2
Hydra	Tau1	9h h 29m	-3	5	66.2	4.6	7.3
Lepus	Gamma	5h 44m	-22	350	96.9	3.6	6.3
Lyra	Epsilon	18h 44m	40	174	210.5	5.0	5.3
	Zeta	18h 45m	38	150	43.8	4.3	5.6
	Beta AB	18h 50m	33	150	45.4	3.6	6.7
Monoceros	8 Epsilon	6h 24m	5	29	12.1	4.4	6.6
	Beta AB	6h 29m	-7	133	7.1	4.6	5.0
Orion	Delta	5h 32m	0	0	52.8	2.4	6.8
	Σ 747	5h 35m	-6	224	36.0	4.7	5.5
Puppis	Kappa	7h 39m	-27	318	9.8	4.4	4.6
Scorpius	Beta	16h 5m	-20	20	13.6	2.6	4.5
	Nu Aa-C	16h 12m	-19	337	40.8	4.2	6.6
Serpens	Theta	18h 56m	4	104	22.3	4.6	4.9
Taurus	88	4h 36m	10	300	69.1	4.3	7.8
	Tau	4h 42m	23	214	63.0	4.2	7.0
Ursa Major	Alpha	11h 4m	62	204	381.0	2.0	7.0
	Zeta	13h 24m	55	153	14.3	2.2	3.9

Open or Galactic Star Clusters*:

The following table of open or galactic clusters gives the following information:

The Constellation the galactic cluster is in,
The Name of the cluster,
RA – the Right Ascension Coordinate of the galactic cluster in hours (h) and minutes (m),
Dec – the Declination Coordinate of the galactic cluster in degrees north or south (-) of the celestial equator,
Dia** – Rough estimate of the diameter of the galactic cluster in arc-minutes,
Mag*** – Rough estimate of the magnitude of the galactic cluster.

Notes:

* Because Open Clusters are usually large and their stars are often dim, many of those listed here are easier found and observed with binoculars rather than with your simple telescope.
** The diameters and number of stars vary by, at least, a factor of 2 in different catalogs.
*** The magnitudes vary by up to 2 magnitudes in different catalogues.

Constellation	Name	RA	Dec	Dia*	Mag*
Auriga	M 36	5h 37m	34	12	6
	M 37	5h 53m	33	20	5
	M 38	5h 29m	36	20	6
	NGC 1857	5h 21m	39	9	7
Cancer	M 44 [1]	8h 41m	20	90	4
Canis Major	M 41	6h 47m	-21	30	6
Gemini	M 35	6h 10m	24	30	5
Hydra	M 48	8h 15m	-6	40	5
Monoceros	NGC 2244	6h 33m	5	40	5
	NGC 2264	6h 42m	10	20	4
	NGC 2301	6h 53m	0	15	6
Ophiuchus	NGC 6633	18h 28m	6	20	5
	IC 4665	17h 47m	6	50	6
Orion	NGC 1981	5h 36m	-4	30	4
	Iota Orionis	5h36m	-6	30	4
Perseus	M 34	2h 43m	43	30	6
	NGC 869 [2]	2h 20m	57	30	5
	NGC 884 [2]	2h 23m	57	30	5
Puppis	M 47	7h 37m	-15	20	5
	M 93	7h 45m	-24	20	7
	NGC 2451	7h 46m	-38	50	3
Sagittarius	M 18	18h 21m	-17	7	8
	M 23	17h 58m	-19	25	7
	M 24	18h 15m	-18	4	4
	M 25	18h 33m	-19	35	6
	NGC 6530 [3]	18h 5m	-24	10	5
Scorpius	M 6	17h 41m	-32	25	6
	M 7	17h 55m	-35	60	5
	NGC 6231	16h 55m	-42	15	5
	NGC 6281	17h 6m	-38	10	7
Serpens	M 16 [4]	18h 19m	-14	25	7
Taurus	M 45 [5]	3h 48m	24	100	2

NGC 1647	4h 47m	19	40	6
NGC 1746	5h 5m	24	45	6

Note:

[1] Praesepe or Beehive

[2] Double Cluster in Perseus

[3] Associated with the Lagoon Nebula, M 8

[4] Associated with the Eagle Nebula, M 16

[5] Pleiades

Diffuse Nebulae:

The following table of diffuse nebulae gives the following information:

The Constellation the diffuse nebula is in,
The Name of the diffuse nebula,
RA – the Right Ascension Coordinate of the diffuse nebula in hours (h) and minutes (m),
Dec – the Declination Coordinate of the diffuse nebula in degrees north or south (-) of the celestial equator,
Size – Size of the diffuse nebula in arc-minutes, and
Mag* – Magnitude of the diffuse nebula.

Note:

* The magnitudes vary by up to 2 magnitudes in different catalogues.

Constellation	Name	RA	Dec	Size	Mag
Orion	M 42 [1]	5h 48m	-5	66	5
	M 43 [2]	5h 36m	-5	17	9
	M 78	5h 48m	0	7	8
Sagittarius	M 8 [3]	18h 5m	-24	40x90	6
	M 17 [4]	18h 22m	-16	10x40	7
Serpens	M 16 [5]	18h 19m	-14	30	7

Notes:

[1] The Great Orion Nebula

[2] Detached knot of the Great Orion Nebula

[3] Lagoon Nebula, Associated with Open Cluster NGC 6530

[4] Omega or Swan Nebula

[5] Associated with Open Cluster NGC 6611

Planetary Nebulae:

The following table of planetary nebulae gives the following information:

The Constellation the planetary nebula is in,
The Name of the planetary nebula,
RA – the Right Ascension Coordinate of the planetary nebula in hours (h) and minutes (m),
Dec – the Declination Coordinate of the planetary nebula in degrees north or south (-) of the celestial equator,
Size – Size of the planetary nebula in arc-minutes, and
Mag* – Magnitude of the planetary nebula.

Note:

* The magnitudes vary by up to 2 magnitudes in different catalogues.

Constellation	Name	RA	Dec	Dia	Mag
Lyra	M 57 [1]	18h 54m	33	1	9
Vulpecula	M 27 [2]	20h0m	23	5x8	8

Notes:

[1] Ring Nebula

[2] Dumbbell Nebula

Globular Star Clusters:

The following table of globular star clusters gives the following information:
The Constellation the globular star cluster is in,
The Name of the globular star cluster,
RA – the Right Ascension Coordinate of the globular star cluster in hours (h) and minutes (m),
Dec – the Declination Coordinate of the globular star cluster in degrees north or south (-) of the celestial equator,
Dia – Diameter of the globular star cluster in arc-minutes, and
Mag* – Magnitude of the globular star cluster.

Note:
* The magnitudes vary by up to 2 magnitudes in different catalogues.

Constellation	Name	RA	Dec	Dia	Mag
Aquarius	M 2	21h 34m	-1	7	6
Canes Venatici	M 3	13h43m	28	16	6
Capricornus	M 30	21h 41m	-23	6	8
Centaurus	NGC 5139	13h 28m	-47	30	4
Columba	NGC 1851	5h 15m	-40	5	7
Coma Berenices	M 53	13h 13m	18	13	8
Corona Australis	NGC 6541	18h 8m	-44	6	6
Hercules	M 13	16h 42m	36	23	6
	M 92	17h 17m	43	8	7
Hydra	M 68	12h 40m	-27	9	8
Lepus	M 79	5h 25m	-25	9	8
Lupus	NGC 5986	15h 47m	-38	5	8
Ophiuchus	M 9	17h 20m	-19	4	8
	M 10	16h 58m	-4	8	7
	M 12	16h 48m	-2	10	8
	M 19	17h 3m	-26	6	7
Pegasus	M 15	21h31m	12	12	7
Sagittarius	M 22	18h 37m	-24	18	6
	M 28	18h 26m	-25	6	8
	M 54	18h 56m	-30	6	9
	M 55	19h 41m	-31	15	7
	M 69	18h 32m	-32	4	8

	M 70	18h 44m	-32	4	8
	M 75	20h 7m	-22	3	8
	NGC 6723	19h 1m	-37	7	6
Scorpio	M 4	16h 25m	-27	20	8
	M 62	17h 2m	-30	6	7
	M 80	16h 14m	-23	7	8
	NGC 6388	17h 37m	-45	4	7
Scutum	M 11	18h 52m	-6	14	6
Serpens	M 5	15h 19m	2	13	6

Galaxies:

The following table of galaxies gives the following information:
The Constellation the galaxy is in,
The Name of the galaxy,
RA – the Right Ascension Coordinate of the galaxy in hours (h) and minutes (m),
Dec – the Declination Coordinate of the galaxy in degrees north or south (-) of the celestial equator,
Size – Size of the galaxy in arc-minutes, and
Mag* – Magnitude of the galaxy.

Note:
* The magnitudes vary by up to 2 magnitudes in different catalogues.

Constellation	Name	RA	Dec	Size	Mag
Andormeda	M 31	0h 43m	41	20x60	5
	M 32	0h 43m	41	3	8
Centaurus	NGC 5128	13h 26m	-43	9	7
Hydra	M 83	13h 28m	-30	8	8
Sculptor	NGC 253	0h 48m	-25	6x22	7
Ursa Major	M 81	9h 56m	69	10x18	8

Appendix B: Reference Books, Papers and Magazines

All About Telescopes, S. Brown, Edmund Scientific Co., Tonawanda, NY, 1975.

Amateur Telescope Making - Book One, Ed. A.G. Ingalls, Scientific American, Inc., NY.

Astronomy (magazine), Kalmbach, Publishing Co., P.O. Box 1612, Waukesha, WI 53187-1612.

Atlas of the Moon, C.A. Wood and M.J. Collins, Lunar Publishing, UIAI Inc., Wheeling, WV

Binary Star Measurements with a 17th Century, Long-Focal, Non-Achromatic Refractor, A.B. Binder, Journal of Double Star Observations (e-journal), Vol. 6, #4, Oct. 1, 2010b.

Burnham's Celestial Handbook, Vol. I, II & III, Dover Publications, Inc., New York.

Double Stars for Small Telescopes, S. Hass, Sky Publishing Co, Cambridge, MA.

Gleanings for ATM's: A Telescope of the 17th Century, A.B. Binder, Sky & Telescope, pp. 444, April, 1992.

Making Your Own Telescope, A.J. Thompson, Sky Publishing Co, Cambridge, MA.

Moon Map, Sky Publishing Co, Cambridge, MA.

Sky & Telescope (magazine), Sky & Telescope Media, 90 Sherman St., Cambridge, MA 02140-3264.

Stargazer, F. Watson, D A Capo Press, 2005.

The History of the Telescope, H.C. King, Sky Publishing Co, Cambridge, MA.

The Next Step—Finding and Viewing Messier's Objects, K. Graun, Ken Press, Tucson, AZ.

The Performance Characteristics of 17th Century Long Focus, Non-Achromatic Refractors, A.B. Binder, The Journal of the Antique Telescope Society, Issue #31, Winter 2010a.

The Stars, H.A. Rey, Houghton Mifflin Co, Boston.
What's Out Tonight, K. Graun, Ken Press, Tucson, AZ.
21st Century Atlas of the Moon, C.A. Wood and M.J.S. Collins, Lunar Publishing, UIAI Inc. Wheeling WV, 2012.

The Authors

Alan Binder, PhD, is a Lunar and Planetary Scientist, a Spacecraft Design and Systems Engineer and a Mission Director with 50 years of experience in the exploration of the Moon and planets. He was a Principal Investigator on the Viking Mars Lander Camera Team—Viking made the first successful, unmanned landings on Mars in 1976 - and the father, Principal Investigator and Manager of the Lunar Prospector spacecraft that orbited the Moon for 19 months in 1998 and 1999 and made the first global maps of the Moon's composition, magnetic and gravity fields and found evidence for water ice in the lunar polar regions. Dr. Binder is the founder and Director of the Lunar Research Institute and the founder and CEO of Lunar Exploration Inc. He has authored and co-authored over 100 scientific paper and has authored *Lunar Prospector: Against All Odds*, the complete story of his Lunar Prospector Mission, and *Moonquake*, a science fiction story based on real lunar science and real engineering. Both books are available from Ken Press via this website.

Ken Graun was born and mostly raised in Milwaukee, Wisconsin where he obtained his bachelor's degree in math and physics. Later and elsewhere, he obtained a master's degree in psychology. He has had a strong interest in astronomy as far back as he can remember, spurred on by the space race in the early 1960's that eventually landed men on the Moon. Although he started to grind his first mirror, a 6-inch, in 9th grade, he did not complete it until 30 years later. Instead, he assembled a few telescopes by purchasing and making parts. Just before the year 2000, Mr. Graun wrote his first book on astronomy, *What's Out Tonight*, and since then has written a dozen more, including star charts, all geared towards beginners. Just after finishing his first book, he finally completed that first mirror and two more to win telescope making awards at the annual Riverside Telescope Making Conference. Today, he continues to write and enjoys teaching math and physics at community colleges. But, one of his favorite things is to show the night sky to those wanting to learn.

We met about ten years ago (2004), when Ken agreed to publish Alan’s book, *Lunar Prospector: Against All Odds*, (and a few years later *Moonquake*) and since then have been the best of friends. We have spent countless hours observing and discussing telescopes, astronomy, lunar and planetary science, the space program, physics, science in general, politics, etc.—essentially most every topic in the universe at large. It is through our mutual interests in telescope making and astronomy that we decided to write this manual, make the accompanying video and provide the kits to encourage you to start making telescopes and observing our fascinating universe.

Conclusions

As indicated in Part I, we have written this manual and make the video and kits for anyone, from youngsters to adults of any age, who has a ***serious interest*** in telescope making and astronomy, but does not know how to get started. As indicated on page 16, the $20.00 we charge for each kit is much less that the cost of the materials provided in the kit and does not take into account the fact that we spend several hours making the wooden parts for the telescope and cutting the six glass blanks for the three lenses included in each kit. As such, we ask that you purchase a kit ***only if you have a serious interest*** in making the simple, astronomical telescope we describe and ***are willing to spend 8 to 10 hours*** grinding and polishing the objective lens and ***4 to 6 hours*** grinding and polishing ***each*** of the eyepiece lenses, plus the ***several hours*** you will spend making the telescope tube and the telescope mount and tripod. If you do, we firmly believe that the ***25 to 30 hours*** required to make your telescope, the lessons learned while making it and all that you will learn using your astronomical telescope are well worth the effort. Thus, we encourage you to order a kit and start the journey. And please note that we will support you as much as possible in your endeavor to complete the telescope. Thus, if you have questions or are having difficulty with any part of the topics covered in this manual, please feel free to contact either of us via the following email addresses:

abrbprospector@earthlink.net
ken@kenpress.com

Also, we are interested in any comments—good and bad—you might have about A) the experiences you had in making your telescope, B) the experiences you are having observing with your telescope and C) how many of the objects we have listed in Appendix A you have been able to observe.

Finally, we thank Alex Miramontez, Vice-President of the Glaz-Tech company here in Tucson for providing us, gratis, with the plate glass we use to make the blanks and tools for the lenses you made using this manual, thereby helping us to keep the cost of the kit as low as possible.