Chapter 1

Getting Started

1.1 The Amateur's Telescope

Until the early part of the twentieth century, the amateur astronomer, with few exceptions, had to purchase his telescope. The telescope of choice was the refractor; however, economic circumstances often dictated the choice of a reflector because of its cost advantage. Except for the wealthy, who could afford to buy a Clark, Cooke, Brashear, Zeiss, or one of the other better makes. The amateur who wanted a refracting telescope had to be content with one having a very small aperture (usually about 60 mm or less).

In England, a book was published in 1920 containing a series of articles by Rev. Wm. F. A. Ellison called "*The Amateurs Telescope*." This book contained instructions for the fabrication of reflecting and refracting telescope optics.

In the early 1920's, Russell W. Porter and Albert Ingalls inspired a growing group of amateur telescope makers through the pages of *Scientific American* magazine. This led to a book, *Amateur Telescope Making*, edited by Ingalls and published by Scientific American in 1926. The book by Ellison was incorporated into this work. Unfortunately for the lovers of refractors, Porter and Ingalls settled on the mirror as the most viable medium for amateur telescope makers. This was probably because only one surface had to be fabricated and, perhaps more importantly, glass suitable for mirror making was readily, and inexpensively, available compared with the difficulty of obtaining optical glass suitable for lenses. The grinding of inexpensive telescope mirrors became quite popular during the depression years, and its popularity continued through the next several decades.

Through the 1970s, the reflecting telescope, purchased or home made, was by far the most popular instrument of the amateur astronomer. The appearance of an amateur made refractor at the Stellafane convention was an unusual occurrence. During this period, interest in the refracting telescope was kept alive by a few firms that specialized in small size refractors, such as Unitron, Brandon, and Jaegers.

In the 1980s, the Schmidt-Cassegrain telescopes made their commercial appearance in large numbers. The reflector remained the most popular amateur telescope spurred on by the increasing popularity of the Dobsonian mount. The Dobsonian mount started an aperture race that emphasized light gathering power over image quality. The objective of the game became trying to identify the most distant blob of light, regardless of whether it was really observed, or only noted as being a fleeting glimpse with averted vision. In the hubbub of large Dobsonians and compact Schmidt-Cassegrains, the refractor with its crisp, unobstructed, image regained some of its reputation as a fine telescope for the amateur astronomer. During this period the apochromatic refractor began to be appreciated for its color free images. There were two general types, the two-lens apochromat using special glasses or fluorite, such as those by Takahashi, and the three-lens apochromat that was developed by Roland Christen, founder of Astro-Physics Inc. During this decade, a substantial number of amateurs made achromatic refractors in the 3–6 inch aperture range using kits of materials and instructions developed by the author. The hobby of collecting antique telescopes (primarily refractors) began to gain a large number of enthusiasts.

The popularity of the refractor steadily increased during the 1990s and into the present (early 21st century). This was due, in part, to the superb performance of the best apochromats, but also to the beautiful clear images produced by the unobstructed aperture of a well-designed and well-made achromatic refractor.

It is unlikely that the refractor will ever again be a contestant in the quest for large aperture instruments, but it will continue to be a favorite among those who pursue the finest images.

With this book, you will learn how to grind, polish, and test your own achromatic refractor. Some well corrected designs are provided for your use. If you prefer to design your own, a straight forward method is presented that will lead directly to a well corrected design.

When one starts a new project, such as making a refracting telescope, there always seems to be an incredible number of things to be considered and resolved. Without some plan of action, the task can seem overwhelming. The objective of this chapter is to present a workable plan of attack and get you started making your lens.

- Determine the optical and mechanical characteristics of the finished instrument.
- Design the lens, or select one of the prescriptions from Chapter 12.
- Establish the glass blank specifications, and order the glass blanks.
- Design the lens cell.
- Modify the lens design based on the melt data provided with the glass (optional).
- Pre-form the blank if not purchased edged and surfaced flat and parallel.
- Grind the lenses to shape.
- Make optical flats (optional–with lens).
- Fine grind the four surfaces (and the flats).
- Polish the four surfaces (and the flats).
- Make, or purchase, the lens cell.

- Test and figure the flats and the lens.
- Make the tube assembly.
- Make the mounting.

A summary description of these operations follows. They are discussed in detail elsewhere.

1.2 Mechanical and Optical Characteristics

Deciding what the mechanical and optical characteristics will be is a very fundamental consideration. These decisions will affect everything related to the cost, fabrication, and use of your refractor. The optical design will, of course, affect the image formed by the lens. The glass selection will impact the cost of the blanks as well as the ability to correct the various image aberrations. The aperture will affect the light grasp and resolving power of the lens that will, in turn, effect the maximum image magnification. The focal length, along with the aperture, will establish the *f*-ratio, but it also establishes the size of the telescope tube. The telescope tube, in turn, impacts the size and cost of the mounting. The controlling parameter in all of these decisions is, as you might expect, the aperture. In practical terms, a refracting telescope with an aperture of 4 inches or less can be considered conveniently portable. Once the aperture gets to be 6" or larger, portability becomes an increasingly more cumbersome proposition. The large aperture refractor is more suited to a permanent observatory installation. Even for a permanent observatory installation, you are strongly advised to carefully consider the cost and size constraints before embarking on the construction of that dream large aperture refractor. Attempting a large aperture instrument, without first making a smaller (approximately 4" aperture) instrument, is to embark upon a perilous, and possibly expensive, journey. This first telescope can be used as your portable telescope or as a guide’scope if you decide to build a larger instrument later.

1.2.1 Lens Design

Lens design is discussed in excruciating detail in Chapter 16, and Chapter 17. From the standpoint of initial considerations, the aperture and focal length are the most critical parameters. Lens design has come a long way since the advent of the computer, and the amateur designer of today can work through a design with a degree of detail unimaginable by the designers of yore who slaved over log tables and were generally content to calculate a restricted fan of meridional rays and perhaps one or two skew rays. You can use or scale one of the prescriptions given in Chapter 12 if designing lenses is not of interest to you.

1.2.2 Ordering Glass

Ordering the glass blanks involves specifying the glass type, form, optical quality, and size. The glass type will be one of the catalog glasses of the vendor. The form will be a function of what the vendor has available and may be as a molded blank (pressings), strip glass, or as cut blanks (machined to diameter and thickness). As discussed in Chapter 3, the preferred way to buy your glass is as cut blanks, edged round and ground to thickness. Design of the blanks is discussed in Section 17.6 and a sample ordering specification is given in Figure 3.1.1.

1.2.3 Lens Cell Design

It is well to start on the design of your lens cell before starting work on the glass. The final design and fabrication of the cell can be undertaken at this time or delayed until you have progressed a little further. If you are buying edged blanks, you will have to design the cell to fit the blank diameter. If you are going to edge the blanks yourself, you can make the cell to fit the blanks or vice versa. The design should consider the diameter of the proposed telescope tube as well as how the lens will be constrained in the cell and how the lens in its cell will be “squared on” to the center line of the tube. The proposed cell material should also be given consideration at this time. Lens cell design detail is covered in Section 13.1.

1.2.4 Modify the Lens Design

When you receive your blanks and melt data certification, you will want to check that they comply with your specifications. The melt data sheet will probably indicate that the index and partial dispersion values are slightly different than the catalog values you used in calculating the design. These differences should be small and technically insignificant except for an apochromat, where small differences can be very important. You may want to “tweak” your design to accommodate the actual values.

1.2.5 Pre-form the Blanks

The next step, after receiving and inspecting your blanks, is to pre-form them to the proper diameter, cleanup the surfaces, establish the proper blank thickness, and make the two faces parallel to each other. If you buy cut blanks, most of this work should be done for you; however, you must make sure that both blanks are round and of the same diameter and the two faces are indeed parallel with each other by measuring the edge thickness. Manufacturing tolerances are sufficiently broad that you will probably have to do some surface grinding to make the them parallel. You can readily work the edge thickness to the required parallelism tolerance. Even if you buy cut blanks with a ±0.002" diameter tolerance, you may encounter the unlikely situation where one is at the + extreme and the other is at the – extreme. To remove only a few thousandths from the diameter, cut a strip of metal (a tin can will do) a bit wider than the thickest blank and about two inches longer than the blank circumference. Bend over tabs at the ends for a hand grip, so that the band has about a quarter inch gap when wrapped around the blank. With the blank and band resting on a flat surface, charge the band with moist #120 grit and, holding the tabs, move the band back and forth to grind the edge of the blank. Periodically rotate the blank within the band. Measure frequently. If you can mount the blank on a rotating spindle, the job will go much quicker. Be sure to wear heavy gloves to keep your hands from being cut. If the blanks are received out of the specified tolerance range, they should be returned to the vendor for correction.

1.2.6 Grind the Lenses to Shape

Once you are satisfied that your blanks meet the requirements discussed above, it is time to start shaping the four spherical surfaces using coarse (#80) abrasive. If you have not done so before, put a nice bevel (approximately 1⁄16") on each edge. This bevel is extremely important because it will help prevent chipping of the edge during the grinding steps. The bevel will wear away as you shape the glass, so it will be necessary to renew it before it disappears. When you get to the #220 grit fine grinding stage, the bevel should be allowed to get smaller so that the final bevel is about 1⁄32". Mark the blank edge with the glass type (e.g., BK7) and an arrow pointing to each surface with the surface number identified (R_1, R_2, etc.). A vibro-tool is a very convenient tool for this purpose. You should similarly mark each grinding tool edge with the number of its mating surface (T_1, T_2, etc.). This is a good time to mention that you should positively identify that you have the proper tool and mating lens surface in position to work before starting to grind. It is not too hard to have the wrong surface of the bi-convex crown blank up when you start to work after a "cleaning up" session. A few seconds of grinding R_2 with T_1 will result in a flat spot that will take some time to remove. To minimize cleanup time and to avoid the possibility of introducing a coarser grit scratch on a finer ground surface, rough grind all four surfaces to their target radius and thickness before proceeding to fine grinding. While shaping the surfaces (rough grinding), you must continue to monitor and, if necessary, correct the edge thickness. Once you start fine grinding, it will not be possible to do anything more than keep the edge thickness in control.

1.2.7 Optical Flats (Optional)

It is the opinion of the author that the fabrication of a set of optical flats will be well rewarded. There are alternate methods of testing your lens but they lack the convenience and precision of testing with a flat. Making and figuring flats is a challenging exercise. The practice will stand you in good stead preparatory to finishing your lens. Testing a refractor with a flat is rigorous because you will be figuring the lens to the familiar uniform (null) shadow of a sphere at the center of curvature. The flat should be at least the same diameter as your lens. Detailed instructions for grinding and figuring flats are given in Chapter 14. You can save a lot of clean-up time if you make the flats along with the lens, using the same grit size for all of the surfaces as you go.

1.2.8 Fine Grinding

After the shape of the two lenses is established using the coarse abrasive, it is time to cleanup and start the fine grinding process using a series of successively finer abrasives. The objectives during these fine-grinding stages are:

- Remove scratches/pits remaining from the coarser grit.
- Maintain uniform edge thickness.
- Work the lens center thickness toward the design target.
- Work the surface radius toward the design target.
- Maintain a spherical surface shape.

After each stage of fine grinding, it is necessary to have a thorough cleanup. This is one of the reasons for suggesting that you do all four lens surfaces (and the flats, if you are making them) using one grit size before going to the next smaller grit. Also, carefully measure and record the following items for each surface before starting the next fine grinding stage:

- Surface radius.
- Center thickness.
- Edge thickness.

1.2.9 Polish the Lenses

After the last stage of fine grinding, the surface radius and center thickness should be at their final design targets. Radius, thickness, and parallelism will experience only very tiny, almost immeasurable, changes during polishing. Now it is time for a final cleanup and to make your laps. Details of lap making and the polishing operation were covered in Chapter 8. Polishing will take several hours for each surface (note that flats or test plates must be well figured but need not be brought to a full polish). With polished, transparent, lenses, pits will show up more prominently than you may be used to in mirror making. Make sure the surfaces are fully polished before starting to figure the lens. You will probably find that you will want to go back and do more polishing on the first lens surface after you have finished polishing its mate on the other side.

1.2.10 Lens Cell

If you have not acquired your lens cell by now, you should have it before starting the testing and figuring operation. Having the cell available now will save the time and effort involved in making a temporary fixture to hold the lens while you are testing it.

1.2.11 Testing and Figuring

The next, and final, step is the fascinating, and sometimes frustrating, task of testing and figuring your lens. Before doing anything else, figure the concave surface of the flint lens (surface three) to a perfect sphere using the knife-edge test. You should also precisely determine its surface radius. After you have satisfied yourself that surface three is as good as your are going to get it, it is time to assemble your polished lens in its cell and start to test and figure the total lens. If you have made and figured test flats, this is the time to collect your reward. The experience gained in making the flats will apply as well to figuring the lens surfaces, and the availability of a full diameter flat will allow rigorous testing of your lens with the convenience and relative comfort of a test bench. If your design is correct, there are only three items to be checked and, if necessary, rectified. These are the focal length, spherical aberration, and surface irregularities, including turned edges. If your design is correct, and if you have brought the surface radii to their target values, there is no reason focal length should differ from the design focal length by more than a small fraction (0.2%) of the design focal length. Spherical aberration should be corrected to as close to a null figure with the knife-edge test, and straight bands with the Ronchi test, as you can reasonably get it. The quarter wave tolerance for spherical aberration is given in Section 17.4. Test plates are the only way the amateur can test the surface figure of convex lens surfaces. In the absence of test plates, and unless there is some reason to suspect otherwise, work on surface four to start the process of correcting spherical aberration, as well as zonal irregularities. We select surface four because the strong curvature of surfaces one and two tend to hold a spherical shape more effectively than the small curvature of surface four. Clear up any bumps or ridges before worrying about spherical aberration. If it turns out that working on surface four doesn't seem to be doing any good, select another surface, and see if working on it helps. Details on testing and figuring are covered in Chapter 11. When you have eliminated surface irregularities and corrected spherical aberration to your satisfaction, your lens is finished. Congratulations!

1.2.12 Tube Assembly

You can no longer put off the task of making your tube assembly. This will be discussed in Chapter 13. If you have finished your tube and mounting, you can star test your lens instead of, or to supplement, bench testing. If you have carefully worked your lens surfaces to the proper radii, you may very well decide that your lens is close enough to perfect and stop at that point.