Chapter 4
Aerial Refractor Telescopes and the Development of Reflectors

Before the advent of the innovative achromatic lens, it was recognised that it should be possible to obviate the problems of spherical and chromatic aberrations by having a long focal length objective lens. This stemmed from an empirical observation that the image quality of a lens—remembering they were all of spherical section and made of crown glass—was improved by a decrease in curvature. Taken to the extreme limit, a flat piece of glass has neither spherical nor chromatic errors, but also no capacity to focus closer than infinity. By having reduced curvature and therefore a long focal length, the aperture ratio \( f \) decreases. The \( f \) value is created by the simple expedient of dividing the focal length by the aperture. Thus, the best images at the time were generated by long focal length lenses with a resulting very small aperture ratio (confusingly designated by a large number). Aperture ratios of 1:150 were not unknown at this time and were an inevitable result of only being able to produce long focal length lenses of relatively small diameter.

Since the dispersive power of a lens is a product of the material of which it is made, it remains constant regardless of focal length. Thus, as the focal length increases, so does the image. Consequently, the chromatic aberration has a smaller effect on the image. In a similar way, spherical aberration is reduced in proportion to the square of the focal length. The result of this is that a long focal length telescope will have a small aperture ratio, reduced spherical aberration and less intrusive chromatic aberration. The image will be large but of low brightness and contrast. Making these long focal length telescopes a productive instrument was very much a balancing act between these advantages and disadvantages.

In the 1640s, one of the longest tubed telescopes was constructed by Johannes Hevelius in Danzig. Hevelius was well travelled in his youth, having been brought up in a German speaking family and taught Polish in what was his home town of Danzig (Gdansk). He was educated in Leipzig, then went to France and England before returning to Danzig where he remained, firstly as a brewer in the family concern and then increasingly developing his astronomy. He owned (partly through marriage) a set of three joined houses, on the roof of which he built an observatory equipped with a Keplerian telescope of 46-m focal length, as well as many other
Instruments of high quality. This was quite an achievement, as the tube, made of wood and wire, was constructed by Hevelius himself. Not only was this one of the longest tubed instruments, but Hevelius was also among the first to realise that long instruments could be made that would overcome some of the practical shortfalls, spherical and chromatic, of single lens objectives.

By 1647, Hevelius had accumulated enough data using telescopes of around 3.5-m focal length to publish *Selenographia*. This was his first work and the first complete lunar atlas of the visible side of the Moon. It was illustrated with the Moon in all phases and with names to many features (Fig. 4.1).

During the 4 years in which he had been specifically investigating the Moon, Hevelius also managed to recognise and measure the Moon’s libration, the apparent oscillation of the Moon as it moves through its phases. After his first wife, Katharine Rebeschke, died, he married again. His second wife, Elizabeth Koopman, was a great support and coworker, appearing in woodcuts of the time seated at astronomical instruments. It is not known for certain how much of the work was hers, but she is now recognised as the first woman astronomer. The maps of the Moon that Hevelius produced were very much better than had previously been made of the Moon but were still limited by virtue of the telescopes and of the clarity skill of the observer. One of the other ideas that Hevelius publicized was his discovery of four comets. It was his observation of these which led him to believe that these celestial bodies follow a parabolic path around the Sun.

Although Hevelius started using relatively short telescopes for his observations, word came to him of the brothers Huygens, Christiaan and Constantijn, who were making magnificent telescopes of great length. These two had apparently decided that since the available telescopes were not as good as they would like, they should

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**Fig. 4.1** The full face of the Moon equally illuminated, from *Selenographia*, published 1647 (http://www.e-rara.ch/zut/content/pageview/160517)
make their own. This was at the time a relatively common event for scientists of all types, as there was a limited pool of manufacturers making a limited range of equipment. Very often, the devices were ornate and embellished to appeal to the eye, thereby optimizing value and profit for the manufacturer (Fig. 4.2).

The telescopes which the Huygen brothers started making for themselves were relatively modest instruments, but in 1659 when Christiaan Huygens published *Systema Saturnium*, he included descriptions of some very long telescopes. Their initial instrument, built in 1655, had an objective diameter of about 5 cm and a focal length of 3.6 m. Although exact details of size are not available, the aperture ratio would be approximately 72. This was used first on Saturn, which at that time (March 1655) was situated such that the rings passed almost exactly through the pane of the Earth and so were impossible for them to see. With no rings to view, Christiaan Huygens looked more closely at the area of orbit and on March 25 discovered Titan, not only the largest of the Moons of Saturn but also the second largest moon of the Solar System, second only to Ganymede orbiting Jupiter. For comparison, Titan is also larger than Mercury, although only 40% as massive. By the end of 1659, the Huygens had created a 7-m telescope with which they could see an apparent tapering of the extremity of the rings of Saturn. These ansae were visible because the rings were still more or less edge on. Through both the 3.6-m and 7-m telescopes, Saturn was studied in great detail, culminating in publication of *Systema Saturnium* in 1659. As was normal at the time, scientific publications were written in Latin. This was for two reasons: the first to establish the credibility of the educated author, and the second so that it could be read by other scientists without the need for translation. This publication finally stated that the ring system was circular, not attached to the planet and also inclined to the ecliptic (Fig. 4.3).

Both Hevelius and Huygens were primarily involved in positional astronomy, although discoveries made regarding structures and features on close astronomical bodies, such as the Moon, were of very great significance to them. At the same time

**Fig. 4.2** Portrait of Christiaan Huygens by Bernard Vaillant around 1686. This is unusual for the time in being pastel on paper, when the popular medium of the time was oil on canvas (Huygensmuseum Hofwijck, Voorburg)
that Hevelius and Huygens were working, Giovanni Domenico Cassini was also working in astronomy. Besides accurate engineering of astronomical instruments he was involved in civil engineering works, most notably in flood defenses on the river Po at the invitation of Pope Clement IX. Although not directly associated with the Vatican, River Po runs entirely within Italy from East to West, discharging into the northern Adriatic. Cassini was famous in his time as much because of a telescope he installed at the Paris Observatory as any of his other engineering activities. This telescope was so spectacular that it even attracted comment from Moliere. Cassini took up his position at the Paris observatory on September 14, 1671, starting his observations the very next day. The observatory itself was not finished when he started his work, although the building process had started in 1667. He went on to discover four new satellites of Saturn and in 1675 demonstrated that the ring system was not uniform, but divided by a dark band. Interestingly, due to political unrest and lack of interest in the observatory itself, the first four people in charge of the Paris Observatory bore the Cassini name. It was only with the grandson of Giovanni Cassini, Cesar-Francois Cassini de Thury, that the official title of Director of the Paris Observatory became established in 1771 (Fig. 4.4).

It was fitting that in October 1997, the exploration of Saturn went one stage further with the launch of the Cassini-Huygens space probe. This immensely productive system landed the Huygens probe on Titan in January 2005, and then after several years in January 2017, Cassini was flown into Saturn itself, relaying information on the way down.

It was the remarkable discoveries made by Christiaan Huygens and his publications detailing observations of Saturn, as well as rediscovery of the Orion nebula, that solidified his fame. The Orion nebula had been originally noted by Johann
Baptist Cysat in 1618 while viewing a comet, his main area of interest. However, it was the rediscovery, which gave observational details, that gained widespread acknowledgement. Hevelius read the work of Huygens, and it was this that converted him to the idea of very long focal length lenses being used for astronomical telescopes.

Hevelius embarked upon the manufacture of very long telescopes as a means to increase his ability to observe the heavens. He was not an optician in the sense of being a lens maker, so these were either made locally or bought from dealers, while he made the tubes and mechanisms of manipulation. It should not be underestimated how complicated the process of construction these telescopes were. It was a complicated engineering project, with the fitting of the objective lens being left until the entire device was made and in position. Without modern materials, the options were few, and as a compromise between strength and weight, they had to be made of wood. Details were given by Hevelius in his volume *Machinae Coelestis* published in 1679, where the various options for construction were discussed.

By carefully making tubes in sections, Hevelius constructed telescopes of about 18.5 m, 21.5 m and finally one that was just short of 46-m focal length. The long focus lens for the 46-m telescope was made locally, others being bought elsewhere. It would seem from the point of view of Hevelius that employing a skilled lens grinder was by far the easiest part of constructing this immense telescope. The lens...
would be commissioned and expected to be completed while the mechanical parts of the telescope were being made.

Although making the parts were in themselves complex engineering, they were still defined by contemporary knowledge. Other parts of the process were not so clear. Mounting a lens in a tube of that length was difficult; the accuracy of alignment is crucial if the image is not going to be off centre. If it is off centre by even a fractional amount, the image loses clarity, as the centre of the lens becomes off centre in the image and all the advantages of a long focal length lens are lost. In a similar way, moving the entire telescope and maintaining the alignment with the shifting load on the telescope tube was a considerable achievement. Even with the greatest skill, this was to be a large and unwieldy piece of equipment of considerable mass. The mass in itself was a problem; strength in the supports was vital to stop flexing and allow for reliable alignment without the problem of swaying.

There are illustrations of the very long telescope that match with his description of its construction. Two flat pieces of wood were joined lengthways at 90° to each other to make a very long, straight, trough, several of these troughs were then joined to make the complete telescope length. This, then, was not an enclosed telescope: it was open on top, with the objective at one end and the eyepiece at the other. The whole construction then had to be hauled into the air by ropes and pulleys, suspended from a mast. While Hevelius makes light of the problems of controlling and using the telescope, reported details do imply that a rather more complicated technique was required than he suggested. Needless to say, it required more than one individual to accurately position the device (Fig. 4.5).

The 46-m telescope itself was open along the entire top edge and so only functioned at full performance when it was a dark and moonless night. Any extraneous light had to be shielded from the eyepiece. Along the length of the tube were a number of “stops” which limited the stray light available at the eyepiece and helped in alignment. These stops were also said to increase the rigidity of the instrument, but by virtue of its construction it is unlikely that it would have eased the twisting moment from an inadequately tensioned supporting wire. Another indicator of the complexity of operation of this telescope was that it required a large number of willing hands to hoist the telescope up the mast and to align it before observation could begin. With the structural changes due to temperature, humidity and wind, this particular long telescope, though famous and in many ways groundbreaking, did not make a significant contribution to astronomy simply because the scale of the device was beyond the available materials at the time.

The work of Hevelius was interrupted by a serious fire at his observatory on September 26, 1679, when by all accounts his books and most of his instruments were destroyed. We have two descriptions of the events and damage that took place when the fire caught hold. One was in a letter sent by D. Capellus to Peter Wyche, the British Consul, in which he describes Hevelius and his wife leaving the city for a sojourn in the country. Sending his groom back to town with his horses, his man sets a candle in the stable, which then set the place on fire. This burnt the entire frontage of the three buildings he owned and destroyed his laboratory at the front of the house. Most of his books, manuscripts and instruments were destroyed, along
with the observatory. Even so, Hevelius rebuilt enough equipment to view the great comet of 1680. In 1685, Hevelius published his *Annus Climactericus*. This covered the fire that did so much damage to his equipment in a very long preface that also included a list of his observations and views of stars and planets. Interestingly, the body of the book is directed to Henrico (Henry) Oldenburg, who was not only a founding member of the Royal Society in 1660, but was also the first Secretary to the society. More than that, this was the start of the Age of Enlightenment, when science and reason were rushing to the forefront of thought in all arenas. Thus, it is no surprise that when Oldenberg founded the *Philosophical Transactions* as editor, he introduced an innovation which is still used today—peer review. Experts were called upon to spread the intellectual load of the editor in an increasingly complicated world. This is, of course, the system we now rely upon completely for testing the veracity of scientific publications (Fig. 4.6).

While Hevelius was making long and unwieldy telescopes with a partial wooden tube, Huygens realised that given dark conditions, it was quite possible to do away with the tube altogether. This astute observation was nonetheless a radical one. So it was that the true aerial telescope was born. We have considerable written

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**Fig. 4.5** The 46-m telescope pictured in a woodcut from *Machinae coelestis*, 1673, by Johannes Hevelius. Houghton Library, Harvard University (Houghton Library, Cambridge Massachusetts)
documentation of the Huygens aerial telescopes, as well as sufficiently detailed drawings to be able to construct a modern version, mainly from his 1684 publication *Astroscopia Compendiaria Tubi Optici Molimine Liberata* (Compound Telescopes Without a Tube). Having made the technical leap regarding the structure of a telescope, Huygens was the first astronomer to completely dispense with a supporting tube. This, of course brought with it technical difficulties of its own regarding alignment, but perhaps not surprisingly, these were less problematic than constructing and controlling an immense structure like Hevelius had done.

One of the aerial telescopes that Huygens made was 37.5 m in length, with an objective of 19-cm diameter. It was smaller than the Hevelius 46 m, but given the right conditions was just as good for celestial observation. This particular 19-cm objective was significant both for its size and its clarity, and when Constantijn visited London, he presented the lens to the Royal Society.

Although others would produce aerial telescopes of greater than 100 m in length, it was the Huygens brothers who made the greatest use of the idea of aerial telescopes, and it was them who first recognised the importance of clear skies for making observations. Christian noted that even on clear nights, stars twinkled and the
edges of the planets seemed to move. It would have been easy to put this observation
down to instability in the viewing system, but he was an astute observer and warned
against blaming the instrument for difficulties in observation.

It is known that at least three of the lenses ground by Huygens arrived in London:
the one described above; one in the possession of Newton at 51.9-m focus; and one
belonging to Reverend G. Burnet, of 64-m focal length. Both of these found their
way to the Royal Society as large aperture lenses, but it is the first which has a more
interesting history. This 19-cm diameter lens with a focal length of 37.5 m, which is
still with the Royal Society, gave the Committee some considerable problems in
finding a proper place for it. They tried finding a suitable building to mount it on for
zenith measurements, but they could not find one tall enough. They even considered
the possibility of using the scaffolding of St. Paul’s Cathedral. This was deemed
unsuitable, and so it remained unused for some years until James Pound, a member
of the clergy, borrowed the lens and mounted it on a maypole at Wanstead on the
outskirts of London, the pole having been removed from the Strand in London.
Although it was useable, the same problems attended this construction, in that
although it was recognised that the lens was of very good quality, the vibration
when in use made it very difficult to use and consequently limited its practical
value. This problem was repeated when Henry Cavendish mounted the lens for
comparison with a Dollond achromatic. Almost 150 years after the Royal Society
received it, another attempt to mount the lens was made, but it was seen as too dif-
ficult and so was dropped as a project, since when the lens has been in the collec-
tion, unmounted. It should be noted that while we give measurements in metres,
these are not exact values. The problem is not merely one of Huygens or his contem-
poraries figuring a glass to such an accurate and precise focal length, but more so
one of units. In the 1684 publication by Huygens *Astroscopia Compendiaria Tubi
Optici Molimine Liberata*, Huygens refers to telescopes of 34 pedo longo, that is,
34 ft long and later 70 ft. We do not know for certain what sort foot he was referring
to. Until the metric system was introduced, local units were used for weights and
measures in commerce. This variation from place to place was of no particular sig-
nificance when trade was local, but when it attempted to give details as Huygens did
to an international audience, the value of the unit became significant. Until Napoleon
introduced the metric system into the Netherlands, there was no agreed standard for
what a foot was. In general, it was about the same as the English foot of the time,
which makes it 30.48 cm, but this, too, is overly precise. Not having a standard
length meant there could not be a standard measure, so any foot that was used would
only approximate to this value. It is the standardisation of measurements of this sort
that has allowed us to have pieces of equipment made by different people on differ-
ent continents that fit together perfectly.

The problem of lining up the objective and eyepiece was the primary problem
with these very long devices, and the longer they became, the more difficult it was.
With bright objects such as planets, it was possible to project an image onto a sur-
face that could be used to align the eyepiece. With lower luminosities, more convo-
luted techniques were used. These refracting telescopes were without doubt difficult
to use and required a great deal of practice and learnt skill. Very often, it was only
the originator of the instrument who could get the best out of the telescope, or in some cases anything at all.

Manufacturing the lenses for these very long instruments was in itself a highly skilled task, the manner in which it was done arousing some considerable interest at the time. This was primarily because they started with ordinary glass blanks but ended up with very superior lenses. This was again very much associated with learnt skills rather than a new and unusual method. It was still at this stage an artisan activity, perfected over years, with as many techniques as there were practitioners, starting with making the polishing tool to be used on the glass blank. For example, while Newton thought that putting too much pressure on the metal grinding tool while it was being polished would cause it to distort or wear unevenly, Huygens thought that great force was required to aid the tool polishing process. When the tool had been polished to a suitable finish, the glass could be introduced to the tool, which was usually more than twice the diameter of the lens. This allowed for rotation to spread the wear over the whole tool evenly, solving the problem of the tool wearing faster than the glass. Emery powder was used as the grinding abrasive, consisting mainly of aluminium oxide and other hard mineral species. This could be worked so that the larger particles worked their way to the edge of the grinding tool where they could be removed, gradually making the mixture finer and finer. Eventually, the mechanical grinding and integrated polishing could be finished off with cloth polishers. The time that this process took was considerable.

Using a slightly different technique of lens grinding, Campani in Italy produced what were recognised as some of the finest long focus aerial telescope lenses available. The way he did this was based on grinding a flat piece of glass into a concave tool so that when it was used against a glass blank it would produce a convex lens. These lenses, made and figured by Campani, were a favourite of Cassini, who used them extensively in the telescopes at Paris Observatory. It was with Campani lenses that Cassini discovered two of Saturn’s satellites, Tethys and Dione, both first seen in 1684 using telescopes of 30.50-m and 41.5-m focal length.

It is interesting to note that the use of aerial telescopes declined quite quickly as shorter focal length achromatic lenses became available. Since these broadly solved the problem of spherical and chromatic errors that the long focal length aerial telescopes had tried to cure, there was no longer any need for the immense structures associated with these devices and the sheer practical problems of manipulating them. Shorter telescopes were easier to use, and the images they produced intrinsically had a much better contrast and brightness. It was the low contrast, which is inevitable from these long lens systems, which caused Huygens to note that observations could be interfered with by extraneous light. Although not significant at that time, it was going to be progressively more of a problem over time.

During the 18th century, Newton’s ideas, primarily those of universal gravity and optics, became a major part of astronomy and the construction of telescopes. This new knowledge moved astronomy in two different directions. The first was trying to make sense of the movements of planets and stars as they were observed in terms of Newtonian mechanics. The second was observational, searching for new celestial bodies and making catalogues of the visible stars and planets. This was fueled by
the developments in telescopes with the very large aerial instruments and achromatic lenses, and also the developments in reflective surfaces that were starting to make reflector telescopes a reality. At the same time that the production of reflector telescopes became possible and they slowly became better instruments of much simpler design than refractors, production of larger lenses was also becoming possible.

There were many issues associated with long focus telescopes, some of which as we have seen were resolved by the introduction of achromatic doublet lenses and non-spherical lenses. However, one issue remained. Stubbornly resistant to any change in optical quality and correction of aberration was the amount of light that could be collected by these instruments. The objective lenses were too small. As time went on, it became possible to construct supporting equipment and housings that could be moved on what we would now recognise as modern bearings, keeping the telescope steady and on target throughout the night. At the same time, a shift followed in the way in which the telescope was described. By the middle of the 19th century it was no longer normal to describe a telescope by the focal length of the objective. Instead, it became the practice to describe a telescope by the diameter of the objective lens. This shift in emphasis reflected the move away from trying to make detailed analysis by magnification towards detailed analysis by optical resolution. This was paralleled by changes in construction of microscopes, where many initially thought that magnification could resolve anything but then moved towards a realisation that magnification without contrast could reveal nothing about their specimen.

So it was with telescopes that the need to see further and with greater acuity resulted in a search for methods to create larger diameter lenses that could gather enough light to make the previously invisible, visible.

The advent of techniques to create glass in large enough volumes to make larger lenses opened up new possibilities. This was based on the work of Pierre Louis Guinand, who developed some of the basic techniques that helped scale up glass manufacture for lenses. Up until about 1880, it was really only possible to obtain lenses made of one of two types of glass, crown or flint. The movement into other glass types was started by the exceptional work of Otto Schott. The son of Simon Schott, a maker of window glass, he went on to study the chemistry of glass and how they could be changed by addition of other elements. So it was that he invented borosilicate glass and came to understand how it was possible to change refractive index with additions of metals. After demonstrating a lithium additive to Ernst Abbe, they set up a close collaboration in which it was said that if Abbe wanted a glass for one of his lenses of a specific refractive index, Schott could provide it. It was not long before many different glass types were available using all sorts of metal additives, such as zinc, antimony, barium and magnesium. By the end of the 20th century, so sophisticated had the chemical definition associated with the optical nature of glass become that now the exact mixture depended upon whether the lens was designed for visual use or photography (Fig. 4.7).

This was an important point, as by the end of the 19th century it was widely recognised that there were three principal instruments in astronomy: the telescope,
spectroscope and camera. This changed in the following century but at the time was quite an accurate assessment of the situation. It should be noted that without the telescope, the other two instruments would be of little use. During the same century as large lenses became available, materials of sufficient strength and rigidity also appeared, so that the enormous weight of these lenses could be supported in a permanent structure.

Making large lenses is still a long and complicated business, fraught with all the problems one would expect when handling molten material at 1600 °C. In the 18th and 19th centuries, it was even more difficult and dangerous. When the lens makers art was at its peak—before the advent of computer controlled design and manufacture—there were few companies that could handle the making and casting of a uniform glass blank of high quality. The three major glass makers who could produce the volume of glass in one piece were all in Europe: Edouard Mantois in Paris, Schott Glassworks in Jena and Chance Brothers in Birmingham. Glass production at Chance has moved to Malvern in Worcestershire, but as a company they were both innovative and capable of making a large range of products from glass. It was Chance Brothers who made the glass for the Crystal Palace at the Great Exhibition in London in 1851 and the opalescent glass for the clock faces fronting the tower that houses Big Ben in London. The glass works of Mantois later became Société Parra-Mantois. In 1894, A. Clark and Edouard Mantois wrote in some detail in *L’Astronomie* how his works made the large glass blanks required for the large lenses, which were becoming objects of national pride and local competition for the largest and best.
Looking at contemporary details that are available from different sources, the systems used were broadly the same between different manufacturers. Unlike during the times of Guinand, when he and his wife controlled all of the processes and kept the details of their work secret in the manner of an old fashioned Guild, the broad techniques were no longer secret. The methods used may have been very similar, but the details were different. One thing they all had in common was that the production of large lenses was difficult and time consuming.

This technical difficulty started with the laying of the furnace. This has to be robust, as it was heated continuously on a scale of days rather than hours. Within the furnace there will be a crucible made of fire clay, this already being heated to show up any imperfections, like enclosed air, which may cause it to split in extreme heat. The crucible in the furnace was gradually heated to the required temperature. This had to be done over several days so as to obviate the problem of thermal shock causing splits and cracks.

There had been methods of measuring the temperature of furnaces available since the 18th century, when Josiah Wedgwood introduced his system of measuring thermal shrinkage. This was a simple system, where standard clay pieces were fired in the furnace to be measured, removed, cooled and tested on a tapered slope to see how far it would move down the incline before becoming wedged. As shrinkage of the clay is dependent upon temperature, the greater the shrinkage, the further down the slope the clay can move. The temperature would then be read from the side of the slope. Later developments involved matching colour, for example the colour change of a quartz crystal. The colour of the furnace interior was by far the commonest method of judging the temperature, and this was usually done by eye by an experienced furnace man.

When these first large lenses began to be made, it was generally accepted that anything up to 30 hours of steady heating was required to charge the vessel without it cracking or the furnace bricks breaking. Because a number of different components are added to the mix to make the glass, they tend to separate based on their specific gravity. This was stopped by continuous stirring with a ceramic rod, as described by Guinand. Removal of the pot when the mixture was at the right temperature (when the viscosity was just right) was a dangerous time for the workers, as the crucible was white hot and fragile. Added to this, the crucible could be stuck to the bottom of the furnace with glass spillage, so it needed working loose at the base. After careful maneuvering of the crucible, the glass was poured into a mould.

The process does not stop with the glass entering the mould; the nature of glass makes it necessary for the temperature to be controlled even as the glass cools down. The coefficient of expansion of glasses depends on many factors and is not linear across a large temperature range, so in brittle material such as glass, quite small thermal changes can result in fracture. This is true even though the coefficient of expansion may not be as great as for metals, but metals are ductile even at room temperature, while glass is not. The result of this was that the glass, now in a mould, had to be moved to a pre-heated cooling oven. This was sealed and gradually cooled over a period of 4–6 weeks, after which there was a solid block of hopefully homogeneous glass with neither flaws nor cracks. However, it was not possible to see if
this was the case when the glass was first removed from the oven. The surface was
milk white from slag and micro scratches, so a piece had to be removed by cutting
and polished until the interior could be judged for quality. If it seemed that only a
portion of the block was free of internal stress and bubbles, it was only this part that
was then cut from the block. This uniform piece of glass could then be put into a
crucible in the rough shape of the final objective. With very large lenses, besides the
need for two objectives of different glasses to be made, it could take many attempts
to achieve the uniform quality of glass that could be used to make the blank. We are
lucky in having, from the works of Mantois in Paris details of the time for produc-
tion of the 91-cm objective lens for the Lick Observatory in the USA, which was
finished by Alvan Clark in Massachusetts. There were two lenses made to form the
single objective, and the total time require was 4 years from start to finish. This was
in part because the initial melt was carried out 20 times, each cycle requiring a
month in the cooling oven before optical inspection for quality could start.

References

French).
Hevelius, J. 1647. Selenographia.
Leers.