Giuseppe Molesini

Telescope Lens-Making in the 17th Century: The Legacy of Vangelista Torricelli
In the early days of instrumental optics, the know-how of lens-making was shrouded in secrecy. A remarkable exception can be found in a letter from 1643, in which the Italian lens-maker Vangelista Torricelli gives his correspondent directions on optical shop practices.

At the dawn of the 17th century, optical technology was almost exclusively devoted to mirrors and spectacle lens making. Spectacles had been around since the late 13th century for correcting farsightedness, but the introduction of lenses for correcting myopia was relatively recent in the 1600s. The availability of both positive and negative lenses laid the groundwork for the advent of the telescope.

At that time, optical shop practices to produce spectacle lenses were well established and known to artisans in various European cities. However, when it came to telescope lens-making, and particularly the objective, the inadequateness of the fabrication process became evident. Although Galileo succeeded in obtaining high-quality telescope lenses, it was the result of a careful selection among many pieces that had been fabricated by the best artisans of the time. It was only around the middle of the 17th century that telescope lens-making evolved into a reliable process in which quality lenses could be obtained consistently as a result of specific fabrication procedures.
The passage from spectacles to telescope lens making is not known in detail, as documents and descriptions are missing in the historical record. Most steps probably occurred in the shops of unknown artisans who kept their achievements secret in order to maintain a competitive edge. As a first and remarkable exception, a letter from Vangelista Torricelli, a lens-maker from Florence, details the state of the art in telescope making to his correspondent Raffaello Magiotti in Rome. The letter is dated December 4, 1643.

Who was Vangelista Torricelli?
Vangelista (or Evangelista) Torricelli was born in Rome in 1608. He was a disciple of Benedetto Castelli, who was in turn a follower of Galileo. Among his major achievements are the discovery that air has a specific weight, and that a vacuum is formed inside a tube of appropriate length filled with mercury—a finding that pioneered the invention of the barometer. In fact, the Torr (the pressure unit that is equal to 1/760 of a standard atmosphere) is based on Torricelli’s name.

Torricelli was invited to Florence in 1641; he assisted Galileo during the last three months of Galileo’s life. He was then nominated to the position of Mathematician of the Grand-Duke of Tuscany, and he continued his studies until his premature death in 1647 at the age of 39.

Torricelli started his lens-making work in 1642, and it did not take him long to achieve full mastery of his craft. To this day, optical testing is still carried out on some of his remaining lenses. Making large high-quality, long-focal-length lenses was a significant task at that time. The court of the Grand-Duke was interested in maintaining its supremacy—which was rooted in the telescope of Galileo and the fame of his discoveries. Torricelli’s approach to telescope lens-making built upon spectacle-production technology; having a solid scientific grounding, he could single out the critical points of the process and devise appropriate remedies.

17th century lens-making
In the standard craft of 17th-century spectacle-making, lenses were obtained from glass plates or pre-forms; a circular shape was created by edge chipping with cutters and pincers. Roughing was made with wet sand on appropriate tool plates, so that most of the excess material was removed and the surfaces acquired a figure close to the final one. More precise grinding to the desired figure and reduction of the roughness was made with spoltiglia (a slurry of emery powder in water that is made by successively eliminating the sediment) on a metal tool plate.

To this purpose, the lenses were attached to a wooden handle by means of hot pitch. The artisan had to press and drive the handle against the tool plate until the pits and scratches produced at roughing were consumed. The final polishing was done by scrubbing against a cloth smeared with tripolo (a fine powder of silicon dioxide). The operation was carried out by hand, or with the help of a turning machine that rotated a disc on which the cloth was secured. At the end, the lens was detached by imparting a sharp stroke to the handle.

The process described by Torricelli in his letter differs from the one I just described mainly in the grinding stage. As for the tool plate, it consisted of a disc of glass, of the same size or a bit larger than the lens to be ground. The tool plate was preliminarily deepened by means of a smaller disc of glass with sharp emery, abrading more about the center than the edge. The shape of the tool plate did not need to be particularly regular because, due to wear, “Nature itself makes it most perfect, where the art could never attain.”

As for the lens, it was attached to a handle. However, the handle was significantly lower and wider than it is in the art of spectacle making, being driven by the palm instead of the fist. Torricelli used a muller of lead, so that its weight relieved the artisan from pressing. The grinding action with spoltiglia was continued until the roughing marks disappeared and beyond, with the artisan moving the muller around in a random manner and describing “irregular and extravagant movements, i.e., coils, scrolls, circles, and mostly diameters,
many and in all directions.” The operation was only terminated when the remaining *spoltiglia* became greasy—“like butter.” The lens surface was then lightly polished with *tripolo* on stretched cloth against a hard background, just to remove the remaining haziness; Torricelli realized that the figure does “matter very much, and the polishing very little.”

The size of the tool plate at the grinding stage was approximately equal to that of the lens, and this was a significant detail: In this condition, the random movements imparted by the artisan were such that the two surfaces being abraded—the lens and the tool plate—formed a pair of spherical surfaces, one concave and the other convex. The latter process was clearly understood by Torricelli, being based on the geometrical properties of the sphere as the locus of the points at the same distance from the center: Wear in fact takes away the bumps and valleys and equalizes the surfaces; he could then say that “neither an Angel could impart to the glass a figure more perfectly spherical.”

In the letter, Torricelli bestows some secret particulars to Magiotti, the major one being his use of a small tool plate to generate spherical surfaces and his advice “not to use fire.” The latter refers to the standard practice of attaching the lens to the muller by means of hot pitch, thereby causing lens bending by thermal expansion at the blocking stage, followed by a release of the strain when the lens is detached. Torricelli recommends instead the use of wax, which is a cold glue.

History reports of a final secret, regarding a subject that had only been confided to the Grand-Duke. A document of the time reported by Paolo Galluzzi states that Torricelli’s last secret consisted of polishing the lens on a thin plate of lead or tin laid on the same tool plate that served for grinding. Such an approach was similar to the innovation that was attributed to Newton in 1721—using a pitch layer for polishing.

Without further ado, I present Torricelli’s letter, which reveals so much of the optical shop practices of the time. It is one of the most fascinating documents even written about optical technology.

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**Excerpts from Torricelli’s letter to Magiotti, dated December 4, 1643**

*Note: The authors comments are in brackets.*

Please then know that the tool plate is very easy to make; and Nature itself makes it most perfect, where the art could never attain.

One takes a piece of flat glass, or raw, round, and just large as much as the glass to be worked, or a little bit more. One attaches to it something heavy, so that the hand does not drag it around during the work; I use a disc of lead, or a brick or other thing. After this, I start to deepen it with a small glass also flat and sharp emery. While deepening it I don’t keep anything else than that the glass, by which I deepen it, passes more often about the center than the edges of the future tool plate. On the whole, before one hour has passed (even if the glass were raw) I have deepened a tool plate for a telescope of three arms and half [approximately 2 m], worked out on both sides [equiconvex objective]: intending though that the tool plate should have a diameter not larger than 1¾ florentine *piastra* [approximately 7 cm; *piastra* was a silver coin about 42 millimeters in diameter].

Please don’t have scruples about the tool plate, because it suffices that it is deepened grossly, and then working the glass it is made perfect by Nature itself.”

[continued]
“When then the glass is ground everywhere, one stops adding spoltiglia, but continues working with the residual that has remained between one glass and the other, and also on the rim.”

“As to the smallness of the glass tool plate said above, i.e., that it has to be equal to the glass to be worked, Your Lordship has to consider it a great secret.”

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been noticed by myself with so much of evidence, that I have touched it by hand, and could tell Your Lordship also how, but I skip it for brevity. Now I attach the glass in this manner: I take a muller of lead of this proportion; to the flattened side A I apply a disc of inside or other fine yielding cloth, so that the glass touches against a soft layer; then above the said cloth I dress the muller with a very stretched glove skin and I fasten it most tightly with the string CD; then I daub the side of the said skin A with red wax, warm and spread very thin. In this manner the glass (unless it is wet) will always attach provided it is well cold; and in case it is needed, one gives a rub to the said skin with a ball of the same red wax, which will attach very strongly.

As a consequence the glass is not going to be strained, but when it is detached from the muller it maintains the same figure it receives from the tool plate. In addition to this Your Lordship will have the convenience of starting to test the glass if it works well or badly as soon as one starts to polish, and will have the possibility of detaching and attaching it hundred times without any damage, and rather with benefit. Since when one uses the pitch, the rule is not to detach it until it is finished. As regards the invention of the muller of lead it is not mine, but it is very good; because when doing the fine grinding it is not necessary to push down the hand almost at all, but the lead itself does it almost alone; also in the polishing it helps a lot: and so that it better makes its service we have the mullers that are almost two inches more in diameter than the glass itself, so that they press down somewhat more. And please notice that making the muller very tall is bad because it plays lever and makes the glass to lose its balance. When Your Lordship will try these inventions (which are only two: small tool plate and not to use fire) I assure you will make good glasses, even if the bulk material were bad [sic]; and none will ever turn out bad at all, but always more than middling. As to the very good ones, then, they are lucks; and it is necessary to bring together many things, the figure, the material, the polishing. The observation has taught me that in the glasses the figure matters very much, and the polishing very little. The reason is this. I have tested many glasses of mine that were just starting to get transparent, and I have seen that in spite of the very coarse grain they had, they anyway did well because the figure was good. Others then, polished like diamonds, because of a bit of unimaginable failure that is in the figure, they do nothing. I ask you to keep secret what I write you, in particular that of attaching, because it is a thing no one suspects about, and there is nothing that spoils more the glasses, when though they are not very big.