Reconstructing the Magnifying Mirror of Archimedes

by Charles E. Hughes

About two years ago, after reading references to descriptions by classical writers of Greece and Rome, who wrote during the 1st and 2nd centuries B.C., I wondered if a telescope using a magnifying mirror could have been produced and utilized in that ancient time period.

You have probably heard the story about Archimedes, the Greek scientist from the city-state of Syracuse, in what is now Sicily, Italy. It is said that he invented a device to focus solar rays upon invading Roman ships to cause them to burn up. Archimedes lived from 287 B.C. to 212 B.C., and made important discoveries in physics and geometry, such as the principle of specific gravity. I surmised that his burning device was a large concave mirror, probably made of bronze.

William Curran

The author with his 34-inch mirror. Ancient observers could have made a similar mirror to produce a magnification power of 40.

Later, I found some more details on the Archimedes "burning mirror," in a book by Robert Temple entitled *The Crystal Sun,*[1] about optics in the ancient world. Temple reported that mirrors and lenses of glass and rock crystal have been found in archaeological excavations in Greece and Rome, and even back to Egypt and Babylon. More than 400 examples of magnifying lenses exist in museums today from Greece and Rome, although these are usually labelled as jewelry!

As for Archimedes burning up Roman ships, Temple says this is how it was done: A single giant mirror would be useless, as its focal length would be fixed and a ship could simply sail out of range. Instead, about 70 men were placed on the ramparts of Syracuse, facing the ships. Each man had a large mirror, which Temple says was a bronze shield, flat and highly polished. The men were arranged in a semi-circle with the open part facing the target, all focussing their reflections on one part of the ship. The result would be the same as that of a large concave mirror which had an adjustable focal length. Opening the semicircle a bit would lengthen the focus; closing up the array would shorten the focus. This was coordinated carfully to keep all of the mirrors focussed on the ship.

Archimedes in thought, depicted in a 1620 painting by Domenico Fetti, which is now in the museum Staatliche Kunstsammlungen in Dresden, Germany.

Temple reports that the Italians demonstrated this method in 1989 using Navy sailors and a large glass mirror, focussed by each sailor, to set on fire a small wooden boat. They wanted to prove that Archimedes had accomplished this, since Archimedes' feat was a proud tradition of Italy, and Italian history. However, this sheds little light on ancient magnifying mirrors.

I found more descriptions of ancient mirrors in *The Electric Mirror on the Pharos Lighthouse* by Larry Radka.[2] One such mirror was located in the tower of the famous lighthouse in Alexandria in the 2nd Century B.C. Radka claims that this mirror was used at night to project a beam out to sea to guide ships into the Egyptian port. In daytime, it served as a telescope to spot approaching ships. Radka says that the lighthouse used a carbon arc device as a light source, and that the mirror users had invented wet cell batteries to produce an electric current to run a carbon arc.

Perhaps this is so, but I don't wish to dwell on that aspect of the lighthouse, which is one of the seven wonders of the ancient world; I want to focus on possible telescopic mirrors. Radka gives references to ancient writings by Polybius, Pliny and Plutarch among others in his book.

Building a Magnifying Mirror

I decided to replicate a mirror similar to the above descriptions, although these reports were inadequate and I had to figure out for myself the possible form and characteristics of such a device.

If the ancients had magnifying mirrors, did they use them on the Moon and planets and perhaps discover things only later discovered in the 15th Century about the nature of the Solar System? For

A 17th Century engraving showing the siege of Syracuse with Archimedean mirrors focussed on the attacking Roman ships.

An engraving of the Lighthouse of Alexandria by Magdalena van de Pasee dated 1614, which is now in the Museum of Art, Rhode Island School of Design. The ancient Pharos lighthouse was 300 feet tall and considered to be one of the Seven Wonders of the World. It was destroyed by two earthquakes, in 642 A.D., and 1303 A.D.

example, did the planets like Jupiter have a round shape, did Venus have phases, did Saturn have rings, and the like? A large mirror of bronze, polished stone, or glass of about 40 power could reveal that.

I happened to own a big glass tabletop, 34 inches in diameter, almost a meter wide and half an inch thick. My plan was to make this into a concave mirror with a 400-inch focal length, about 35 feet. This, I calculated, would yield a magnifying power of 40. The glass, if not coated with metal, as modern telescope mirrors are treated, would reflect about 20 percent of the incident light as a metalized glass mirror. This would be enough to see the moon clearly.

If the ancients had made a similar mirror of bronze, the metal of choice in 200 B.C. for large castings, the reflecting power would have been about 65 percent, much better than uncoated glass. But I had to use glass because I owned a glass disk. A disk of bronze that large would have cost thousands of dollars, and would need to be custom cast in a foundry.

So, I took my 34-inch diameter disk, bought about 20 pounds of tungsten carbide abrasive, and got a second piece of round glass, 14 inches in diameter, to serve as a grinding tool. The tool was wood with a glass face (which was less expensive that making it all glass). It was made up of six 14-inch plywood disks, 3/4-inch thick. A 1/2-inch thick glass coaster was glued with silicon rubber to the plywood to do the grinding. I then put the glass table on top of a 36-inch grinding table made up of many pices of 36-inch plywood spool faces, donated by a neighboring electrical supply company. The table had to be thick enough to keep the tabletop glass slab absolutely flat during the grinding of a concave face into it.

Standard Techniques

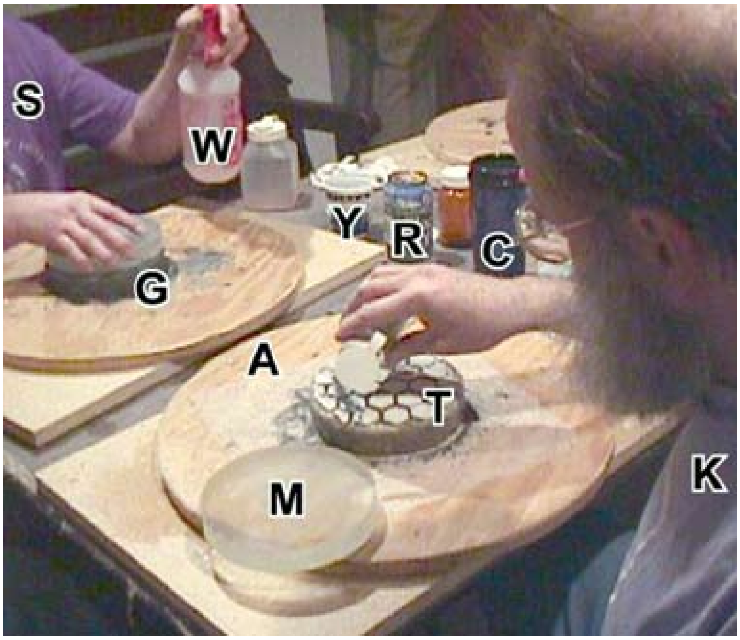
I was using standard mirror-making techniques scaled up, as described in *Scientific American*'s book on telescope mirror-making *Amateur Telescope Making—Book One*. I tried several ways to do the mirror; for example, placing the tool on top of the mirror blank, my glass tabletop. The tool was about half the size of the mirror. I expected trouble trying to evenly grind the concave shape, because the mirror was only 1/2-inch thick, a bit on the thin side. Ideally, my mirror should have been at least 1 inch thick, so I was pushing the envelope dangerously!

I placed a 36-inch rug section, cut round like the mirror under it, so that the mirror would grind evenly over the entire surface, avoiding multiple focal centers, or astigmation.

The grinding was begun on Feb. 17, 2008 and completed on Aug. 28, 2008. The grinding went through a number of grain sizes of tungsten carbide abrasive, which is as hard as diamond but cheaper; I went from large grain sizes down to a fine powder to smooth the mirror surface. Then I used a special tool coated with paper squares and cerium oxide as the polishing agent. All the ginding and polishing was done with water; no dust was produced.

I judged the progress of the work by putting a metal ruler across the diameter of the mirror and measuring the space under it, at the center of the mirror, with a leaf gauge. This value in inches was used in a math formula to calculate the focal length. The distance under the ruler is called the *sagitta,* and is inversely related to the focal length, the distance from the mirror to the point of convergence of the reflected light rays. The sagitta needed to be a bit less than a quarter-inch or about 0.230 inch to give me a 40-power mirror.

Assuming that the ancients did not know how to make a telescope ocular or the magnifying lens near the eye, the mirror would have to be 40 power, using



Courtesy of Springfield (Vermont) Telescope Makers, Inc.

Grinding telescope lenses at a Stellafane telescope-making course. To cut a spherical concave surface into a mirror blank, a full-size tool is rubbed against the blank, with a wet grit mixture, to abrade the glass. (It also abrades the tool, which becomes convex.) The mirror blank M is sitting to the side on plywood turntable A, while mirror maker K is sprinkling silicon carbide grit (black particles) onto tile tool T from a plastic salt shaker in his hand (attached cap hides the holes). Mirror maker S chooses to apply grit from a yoghurt cup Y with a plastic spoon. The grit is kept wet with water (to lubricate the grit and trap glass dust) from a spray bottle W.

Mirror maker S is grinding with one hand, mirror on top, with a solid glass tool G on the bottom; he will rotate the mirror and tool in opposite directions, frequently and at random angles to insure grinding strokes will curve the entire surface of the mirror and tool. One charge of grit and water, called a wet, lasts about 10 minutes in rough grinding. Rough grinding will take 4 to 6 hours in total for a mirror this size.

For more photos and descriptions of grinding, see http://stellafane.org/tm/mc/index.html

only the naked eye. This required that my mirror have a focus about 10 times greater than a modern telescope mirror, which needs a focus of only 3.5 feet, instead of 35 feet.

I did not carry out the polishing to a perfect finish, but stopped when there were still pits on the surface from the grinding operation, but the mirror was reflective enough to test on the Moon and terrestrial objects.

The Accident and Take #2

In September 2008 during testing, the mirror fell from the test stand onto a nearby tool box, and broke into several pieces! I was determined to succeed with this mirror, however, so I gathered up the fragments, keeping the largest to experiment with, to see if the shattering had ruined the optical properties. It had not; the fragment approximately 20-inches square worked normally, although it was of irregular shape.

I ordered another piece of glass from American Glass Company in Hackensack, N.J. for $150; made a new tool; and started the process all over again. The new mirror, which I called Archimedes 2, or Archie-2, was completed by August 2009.

Next, I started to build a mounting for the mirror. My idea was to make an octagonal box with side trunions, only 12 inches deep and mounted on a square cart which would be movable on caster wheels (see photo, p. 47). The mirror is mounted in a cell at the rear of the octagonal box. It is free to move from vertical to horizontal and to rotate a complete circle.

The whole apparatus was painted a bright red and moved to the basement of my workplace in September 2009 to be tested. I determined the focal length of the mirror by holding a flashlight in front of the mirror, and backing away, moving the light from side to side until the light filled the mirror, and no motion could be detected in the flashlight reflection. This was found to be 405 inches, about 35 feet, which was the length of focus I had planned upon.

The 35-foot focus would give the mirror a power of enlargement of 40, using the naked eye alone. I tested the mirror on distant terrestrial objects outdoors, and it magnified them 40 times. The mirror was employed by pointing it at the target and interposing the observer facing the mirror, 35 feet from the front, at the focus. The magnified object seemed to appear in, or slightly in front of, the mirror.

On Jan. 29, 2010, a full Moon about 10 degrees above the northeastern horizon was imaged. I could make out the "seas" on the disk, which was round, sharp, and fairly bright in the mirror. Two other persons present confirmed the sighting and took a photo of the image with an electronic camera. The photo details were less sharp than what we saw with the naked eye.

Unlike a conventional telescope image, where an eyepiece is used to enlarge the image and is only in clear focus over an inch or two, the Archie 2 image stays in focus throughout the entire distance of the focal length; it gets larger until maximum magnification is reached at 35 feet.

The Archie 2 observations show that a concave mirror of extreme focal length can serve as a telescope, using only the mirror and the human eye. It is likely the ancient observers could have done just that.

Footnotes

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1. London: Century Books, 2000.
2. Parkersburg, W. Va.: The Einhorn Press, 2006.

More Articles by Charles Hughes On Telescope Making

Making Your Own Telescope
21st Century, Spring 2004

"Constructing a Very Large, Short Focus Telescope"
21st Century, Fall 2005

"John Dobson Debunks the Big Bang"
21st Century, Spring-Summer 2006