Archimedes and the Burning Mirror

Probably no ancient tale has raised as much controversy as the story of the Greek inventor Archimedes using a giant mirror, or set of mirrors, to set fire to Roman ships attacking his home city of Syracuse in 212 B.C.. Did it actually happen? Scientists and scholars have come down on each side of this question. Sometimes their conclusions are based on the historical record (or lack of it), sometimes the researchers have actually tried setting up the test themselves using real mirrors and mock ships. In 2010, U.S. President Obama even challenged the hosts of the TV show Mythbusters to test the problem and come to a definitive conclusion. They did, but was their answer the correct one?

This engraving shows Archimedes using a large, parabolic mirror to make his attack, but it seems more likely he would have employed a number of smaller flat mirrors.

Let's start our exploration of the subject by going back to an account of what Archimedes supposedly did. Zonares and Tzetzes writing in the 12th century quoted from an earlier work (now lost) called the Siege of Syracuse, said:

> *When Marcellus [The Roman General] had placed the ships a bow shot off, the old man [Archimedes] constructed a sort of hexagonal mirror. He placed at proper distances from the mirror other smaller mirrors of the same kind, which were moved by means of their hinges and certain plates of metal. He placed it amid the rays of the sun at noon, both in summer and winter. The rays being reflected by this, a frightful fiery kindling was excited on the ships, and it reduced them to ashes, from the distance of a bow shot. Thus the old man baffled Marcellus, by means of his inventions.*

It is clear that, at least on the surface, the method described seems plausible. Plenty of school children have used a magnifying glass to concentrate the sun's rays onto a small piece of wood, setting it on fire. The same thing can be done with a small parabolic mirror which can take the sun's rays and reflect them onto a small point. The writers suggest that Archimedes did this on a grand scale with a huge mirror focusing it on ships anchored "a bow shot" from the wall of the city (perhaps 500 feet).

The ability of mirrors to concentrate the sun to obtain very high temperatures is well-known. A few years ago the U.S. Department of Energy, along with a group of businesses, constructed a solar "power tower" station in the Mojave Desert near Barstow, California, to demonstrate the feasibility of harnessing this kind of energy. The station consisted of an array of mirrors that reflected the sun to a tower in the center of the field. At the top of this tower was a large target that used molten salt to absorb the heat and transfer it to a water boiler on the ground.

The boiler created steam which then ran turbines and generators like a regular power plant to make electricity. The plant could produce 10 megawatts by using almost 2000 mirrors that would move under computer control, tracking the sun and reflecting its light to the tower.

The Solar II power plant near Barstow, CA, used almost 2000 mirrors and the heat of the sun to make 10 megawatts of power.

It's easy to imagine focusing those mirrors on a wooden ship instead of the tower and setting it ablaze. The target at the top of the tower can reach temperatures greater than 1,000 Fahrenheit, well about the autoignition point of most wood. However, each of the installation's mirrors was huge (430 square feet-which is a mirror over twenty feet long by twenty feet wide) and there were almost 2000 of them, probably not something Archimedes could have arranged given the technology at the time.

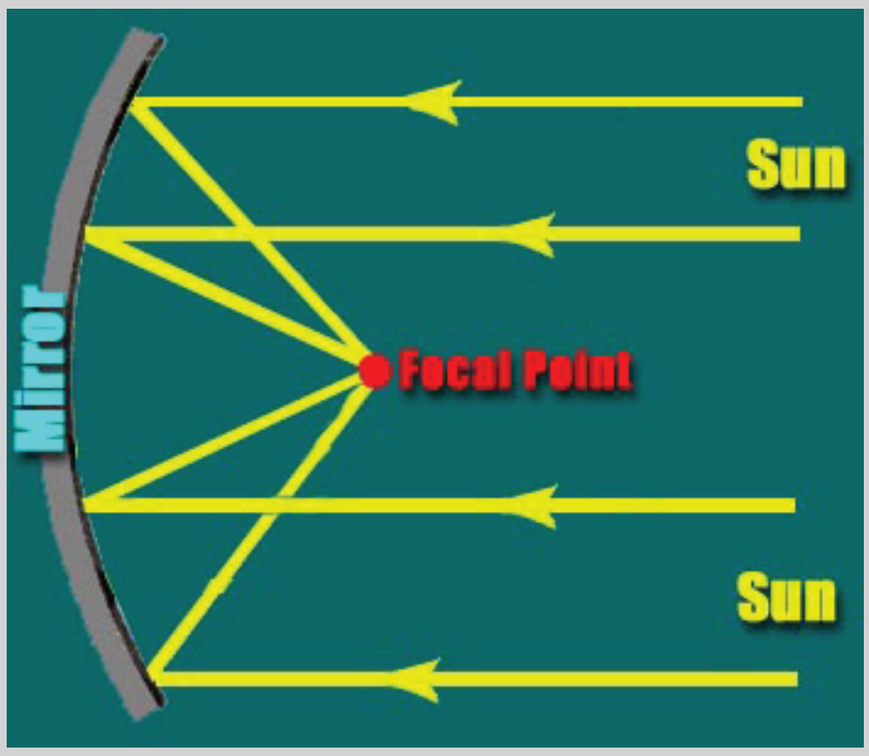
So the question isn't whether the sun could provide enough heat, it is whether Archimedes could have built a mechanism with the tools he had available at the time to concentrate enough sunlight to set the deck of a wooden ship on fire.

A Parabolic Mirror

Many illustrators have pictured the old inventor using a single parabolic mirror a few feet in diameter to do the job. A parabolic mirror has a curved shape that will focus parallel light rays coming from a light source (like the sun) onto a single point (called the focal point) which is a set distance from the mirror (the focal length).

The problem with this scheme is that a single, solid mirror has a set focal length. This means that the ship you want to set to fire must be precisely the focal distance away from your mirror for such a scheme to work. Any closer or farther and the light isn't concentrated on a small point, but is instead spread out over a larger area. This in turn means that the resulting temperature will probably not be high enough to start combustion.

Since Archimedes couldn't control how far away Marcellus parked his ships, he couldn't anticipate where to set the focal point when he built his mirror. One way to get around this problem is to build such a large mirror that even if the focus point isn't precisely on the ship you still concentrate enough light on it to get it burning. The problem with this is that a single mirror the necessary size would be extremely hard to move and control with the primitive equipment Archimedes had.



A parabolic mirror focuses parallel light rays to a single point concentrating their power.

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Another problem with a large parabolic mirror is that the farther the focal point is away from the mirror, the less energy you can focus on it. For example, a one foot diameter parabolic mirror with a ten foot focal length can concentrate light from the sun by 10 times. However, a one foot diameter parabolic mirror with a one hundred foot long focal length would not concentrate sunlight at all. If the Roman ships were any distance from the mirror, say 500 feet, Archimedes would need a parabolic mirror at least 10 feet in diameter to just double the normal heat that the target would get from the sun itself. This would be far less than what would be needed to get a fire going.

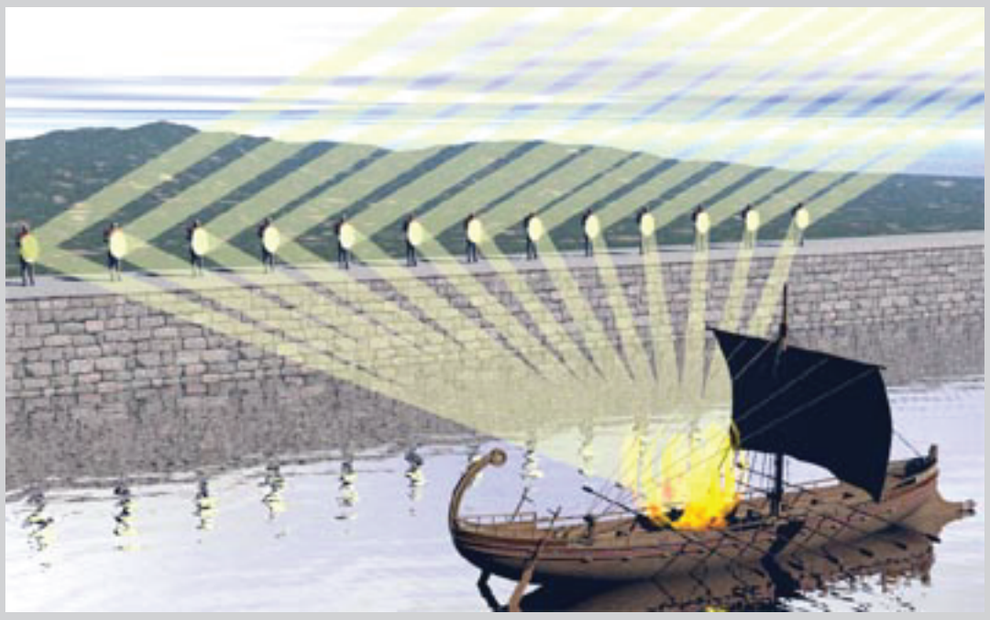
Multiple Mirrors

All this seems to make it much more likely that Archimedes instead used a number of small, flat mirrors instead of one, big, parabolic one. Each of the mirrors could be used to focus sunlight to a small spot on the target. Together they would form a shape roughly the same as one huge parabolic mirror. To do this he might have equipped hundreds of soldiers with mirrors. Working together, with each man adjusting his own mirror, they might have been able to focus enough light on a single point on a ship to get it burning.

This approach is exactly what a number of attempts to reproduce Archimedes achievement have used. Apparently in 1973 a Greek scientist, Dr. Ioannis Sakkas, became curious about whether Archimedes could really have used a "burning glass" to destroy the Roman fleet and set up an experiment involving 60 Greek sailors each using an oblong 3' by 5' flat mirror to focus light on a wooden rowboat 160 feet away. According to sources he had no problem getting the wood to catch fire very quickly.

In 2009, as an exercise in design, a class at MIT decided to try and reproduce the Archimedes weapon using 127 one foot by one foot mirrors. They were successful in getting a mocked up ship made out of red oak to start burning after ten minutes of exposure to direct sun. Their experience, however, showed some flaws with the idea of using this as a weapon.

The problem with using individual mirrors is that each of them has to be aimed at the target (a specific point on the ship) at their own particular angle from the sun. If you handed one person a mirror and asked him to reflect the sunlight to a location, it is easy for him to do. He simply uses the bright spot formed by the mirror's reflection as a guide to aiming at the target. If you give one-hundred people mirrors and try to do the same thing, however, you have chaos. One hundred mirrors means one hundred bright spots and nobody is sure which spot is theirs.



Soldiers using multiple flat mirrors could concentrate light on a ship, but could they really get it hot enough to burst into flame? (Copyright Lee Krystek, 2011)

With some training and perhaps the use of an aiming device this problem can be minimized. A more difficult problem to solve is the length of time needed by the MIT crew to get a fire going. Ten minutes is a long time to keep your attention focused on aiming a mirror at distant point while the chaos of battle is going on around you. Plus the length of time necessary to get anything burning could easily be stretched out even further if the enemy took the simple defensive measure of splashing water on your target area to cool it down.

In 2010 the Mythbusters television show attempted to use 500 flat mirrors controlled by 500 volunteer middle and high school students to reproduce the burning mirror legend. Despite an hour of focusing the sun on a sail (which should have had an ignition point of only about 500 degrees Fahrenheit) they could only get the temperature up to about 230 degrees. Even more significant is that they used modern silver mirrors do this. Polished bronze mirrors, more typical of what would have been available in Archimedes day, would have been 30 percent less efficient, resulting in a lower temperature.

The Mythbusters conclusion was that although in theory setting a ship on fire with mirrors might be possible, it seems an unlikely method to be used in battle. Jamie Hyneman, one of the Mythbusters hosts who was stationed aboard the mock ship during the experiment, observed that while the ship did not burst into flame he found the dazzling brightness of the mirrors disconcerting and suggested that Archimedes might have simply used them to confuse the enemy and disrupt their ability to see their opponents.

Others have suggested that while the mirrors might not have been able to set the ships on fire, they might have been very effective in harassing the crew of the ship. Having a light beam focused on you that could raise your skin temperature to over 200 degrees would be extremely unpleasant.

Eary Accounts without Mirrors

Given that it seems that mirrors are an impractical way to set a ship on fire, perhaps it makes sense to look at the accuracy of documents that claim that Archimedes actually did this. The quote we looked at earlier was written 1,400 years after the fact. It says that it is quoting an earlier work, but that early work is now lost so we can't really see the source material itself.

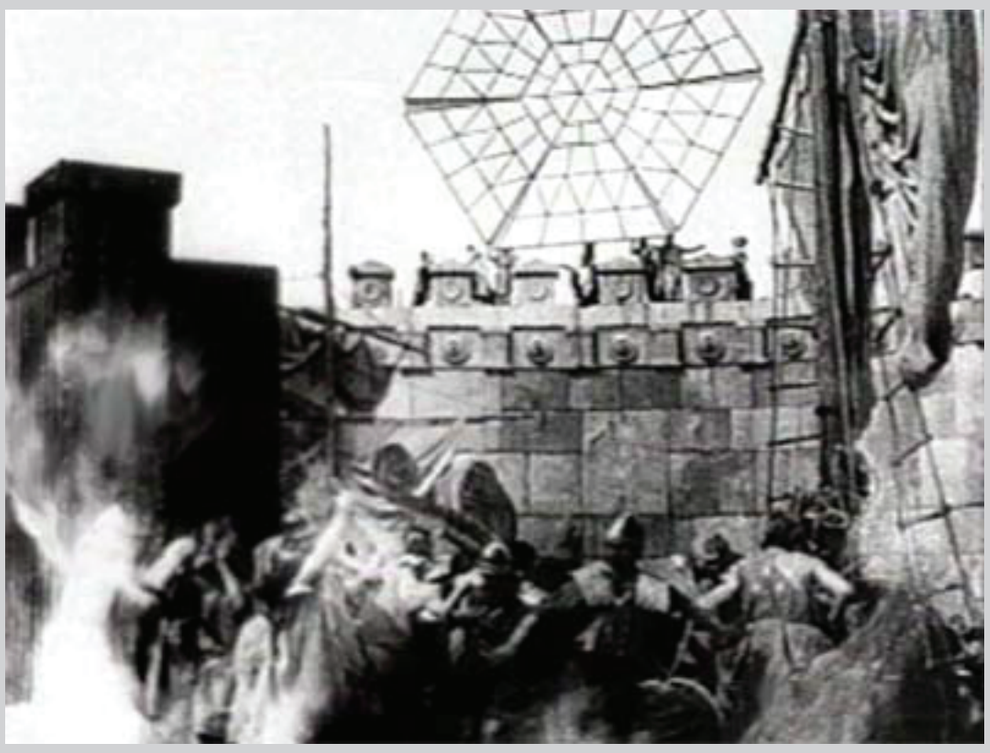
Greek fire was thought to be a form of sticky petroleum that would be set on fire. It could be delivered in a jug, or sprayed on with a siphon as shown here.

Writers contemporary to the era, like Polybius, Livy, and Plutarch, never mention the use of mirrors to set ships on fire, though they do discuss other of Archimedes defensive devices. In particular they tell about "The Claw of Archimedes" which was apparently a crane that stuck out far over the city wall and would use a grappling hook to catch the Roman ships, lift them and overturn them.

Two second century A.D. writers, Lucian of Samosata and Galen of Pergamon, do say that Archimedes set fire to the Roman ships, but don't say exactly how. This has led to speculation that the inventor may have employed a different method than mirrors: Greek fire.

Greek Fire?

Exactly what Greek fire was is a bit of a mystery to historians today. Sources tell us it would burn on water and some sources even tell us it would be ignited by water. A number of researchers, however, suspect that Greek fire was actually a thick, sticky form of petroleum. While such a material wouldn't actually burst into flame on contact with water, neither would water work as a particularly effective extinguishing agent, and might actually spread the flames. The easiest form of delivery would have been a pot filled with the stuff that has a lit wick sticking out of the top. When cast onto a ship, the pot would break open spilling out the liquid which would be set on fire by the flame. The arrangement would act precisely like an ancient version of a molotov cocktail.



Archimedes sets fire to a ship using a huge mirror made up of many flat segments in this silent film from 1914.

Another of Archimedes defensive designs supposedly deployed during the battle was a form of catapult. It would be easy to envision one of these machines pelting the Roman ships with pots of Greek fire and reducing them to ashes. If at the same time Archimedes was also employing mirrors to confuse and blind the enemy, an observer of the battle might be confused about what had caused the fires.

So did Archimedes set ships on fire at the Siege of Syracuse? We may never be sure of the truth. He certainly could have attempted it, though many of the facts we have today seem to suggest he might have not been as successful as the legend says. The history of the era probably supports this conclusion. If the Romans had found burning mirrors an effective defense during the battle, there is little doubt that they would have figured out how to add such a weapon to their own arsenal, which they never did.

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