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ARTICLE

Physics and Mathematics

The Power of Archimedes Death Ray

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Archimedes was one of the most famous mathematicians and inventors in Ancient Greece. He was born in 287 BCE in Syracuse, Sicily and died at the age of 76 (Toomer, 2023). Archimedes' inventions were later praised by many future inventors including Leonardo Da Vinci ("Archimedes", 2023).

Background

One of his most notable inventions was the Archimedes Death Ray. The Archimedes Death ray is seen as one of the earliest forms of harnessing the sun's energy and using it as a weapon. The Death Ray is made up of a series of large concave mirrors which are positioned to focus the sun's rays onto a single focal point. The Death Ray was designed to be put in a range from its target of 200-1000 feet (Clark, 2008). It is believed that the greatest historical use of the Archimedes Death Ray was during the battle of Syracuse from 213-212 BCE (English, 2023). In this event the Death Ray was used as a weapon against the Roman army that was advancing on the walls of Syracuse. The mirrors of the rays were positioned along the bay of Syracuse and were angled at the Roman ships (Matthews, 2017). Evidence suggests that combustion occurred rapidly, where the combined heat of the rays could cause the roman ships to ignite within minutes ("Archimedes Death Ray: Idea Feasibility Testing", 2005). Since ancient times, this technique has been used to light the Olympic torch at the start of every Olympic games. During a traditional ceremony, the sun's rays are bounced off a parabolic mirror, focusing the energy onto the Olympic torch and igniting it ("Olympic Torch lit in Olympia", 2008).

Objective

The goal of this project was to evaluate if the principle behind the Archimedes Death ray was plausible using a miniaturized experimental setup.

Hypothesis

I hypothesized that concave mirrors could be used to focus light energy onto a target and that the temperature of the target would increase further as the number of mirrors increased.

Materials & Methods

The experiment was carried out in one setting and in a controlled indoor environment where the ambient temperature was fixed to 21°C. The following equipment was purchased to accurately carry out the experiments (Figure 1): an Infrared Thermometer (INKBIRD, Infrared Thermometer Gun, Amazon), plastic clamps to hold the concave mirrors (EVORETO Action Figure Stand, Amazon.ca), a table clamp style heating lamp with a 50W and a 100W LED lamp (PETBODA Heating Lamp dual head, Amazon.ca), four concave mirrors (United Scientific 100MM focal length concave mirrors, Amazon.ca) and a piece of cardboard paper which was marked with a clear focal target zone.

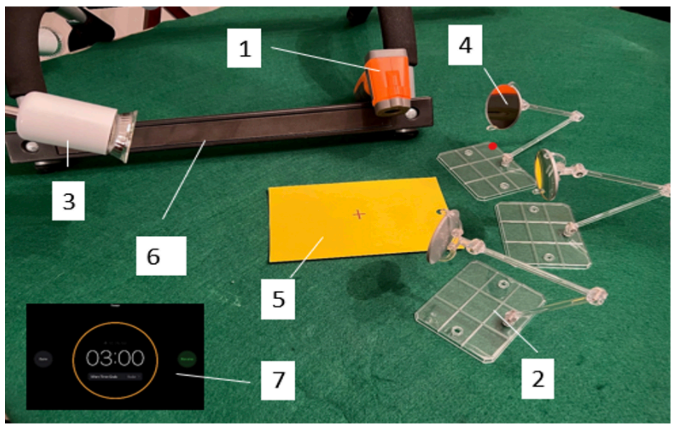

Figure 1. Experimental Setup. 1) Infrared thermometer, 2) Clamps, 3) Heating lamps (50W, 100W), 4) Concave mirrors (four), 5) Target paper, 6) Stand for thermometer, 7) Timer of 3 minutes.

Experimental Variables

The controlled variables in the study are the following: the distance from the light source to the mirrors, the distance from the light source to the target zone, the duration of the target zone under the heating lamp, the time of cooling down of the target zone following each experiment, and the distance from the infrared thermometer to target zone. The independent variables in the study were the number of concave mirrors used to focus the heat, and the power of the heat source. The dependent variable is the temperature of the target zone after 3 minutes of being under focused light.

Experimental Design

The experiment was carried out by attaching a heating lamp (50W LED light bulb) to the edge of a table and pointing it directly on the marked target zone (Figure 2). A stand was used to hold the infrared thermometer at a constant distance from the target zone and the temperature of the target zone was

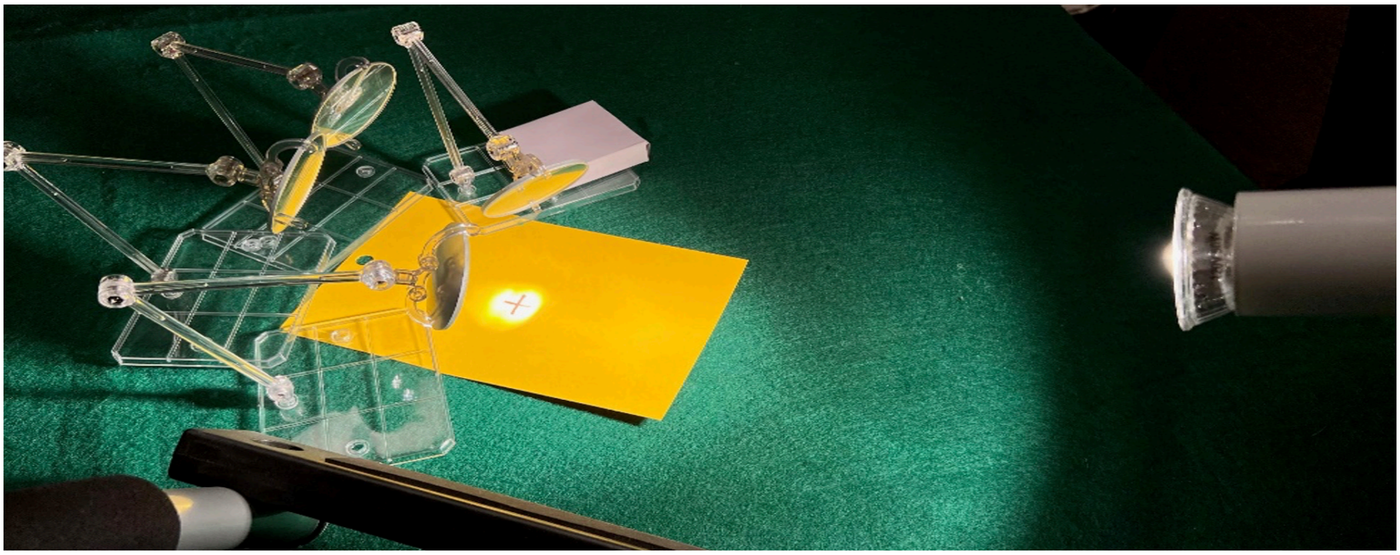

Figure 2. Sample of experimental setup.

measured in triplicate and used as a baseline temperature. The light source was then turned on for 3 minutes to warm up the target and the temperature at the target zone was measured in triplicate. Pilot experiments determined that 3 minutes of heating led to a constant temperature at the focal point. Four concave mirrors were then attached to clamps in preparation for the next series of experiments. After each test, the target zone was allowed to cool and reach its baseline temperature again (measured with infrared thermometer to confirm). The first mirror was positioned to reflect the light onto the target for 3 minutes and target zone temperature measured in triplicate. After the target zone was allowed to cool down, additional mirrors were added until a total of 4 were pointed at the target zone. The accuracy of the focal zone of each mirror was visualized by ensuring that the focus spot of the reflected light was consistently the same size between mirrors. Temperature measurements were taken after each trial in triplicate. This entire process was repeated using a 100W light bulb to receive a greater range of results.

Results

There was a steady increase in the temperature of the target zone as more concave mirrors were added (Table 1). Interestingly, the addition of a single mirror made a detectable increase in the target zone temperature compared to the heating lamp shining on the target alone. As seen in Figure 3, the blue bars represent the temperature of the target zone using a 50W bulb while the red bars represent the target zone's temperature with a 100W bulb. It is noticeable that the greatest increase in temperature is between heat + 3 mirrors to heat + 4 mirrors. This occurred both for the 50W and 100W bulbs. It is evident that when the more mirrors were added the higher temperature was reached and that the greatest temperature jump was with the addition of a fourth mirror.

Discussion

Overall, the results show that the use of a mirror to focus light increases the target temperature greater than what a nearby light source was able to do alone. This is quite remarkable as it suggests that light is going in all directions and that the shape of the concave mirror focuses the light waves onto a single point. As the number of mirrors increased so did the

Table 1. Experimental results showing the effect of heat strength and number of mirrors on target temperature.

	Experimental Condition										
	Heat OFF	Heat ON		Heat + 1 mirror		Heat + 2 mirrors		Heat + 3 mirrors		Heat + 4 mirrors	
	--	50W	100W	50W	100W	50W	100W	50W	100W	50W	100W
Temperature trial 1 (°C)	21.0	26.4	27.1	28.0	35.2	29.9	39.5	33.0	43.2	41.0	53.4
Temperature trial 2 (°C)	21.2	26.5	27.5	28.4	35.2	30.0	40.1	32.5	44.0	40.2	53.0
Temperature trial 3 (°C)	20.9	26.3	27.0	28.2	34.4	30.2	39.3	32.6	42.9	42.0	54.0
Average temperature (°C):	**21.0**	**26.4**	**27.2**	**28.2**	**34.9**	**30.0**	**39.6**	**32.7**	**43.4**	**41.0**	**53.5**

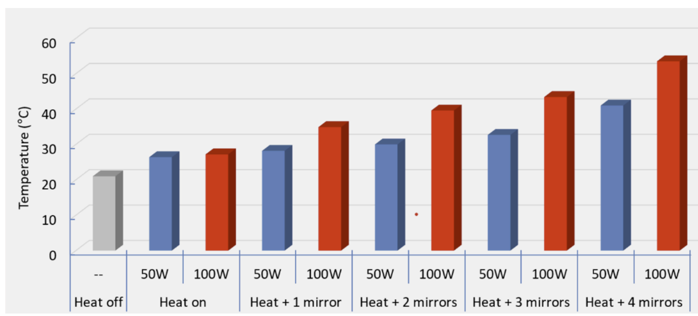

Figure 3. The effect of increasing the number of mirrors to focus energy after 3 minutes of heating using 50W (blue) and 100W (red) heat sources on the average temperature of the target compared to baseline temperature (grey).

temperature of the target zone. Increasing the power of the light source greatly increased the temperature of the target zone for each of the mirrors. Doubling the number of mirrors to reflect the energy did not double the target zone's temperature. In evaluating the data further by looking at the relative change in temperature from baseline of the 50W heat source only, the magnitude of change of adding additional mirrors led to an approximate 2°C increase with each additional mirror up to 3 mirrors at which point the addition of the fourth mirror led to an 8°C jump in temperature at the target zone. When evaluated in the same manner for the 100W heat source the change in temperature with each mirror was 4°C up to 3 mirrors and an additional 10°C with the 4th mirror.

Some other experiments have used the Archimedes Death Ray including the MythBusters experiment which created a life size representation of what they believe the Archimedes Death Ray to be. A major difference from my experiment and the one done by MythBusters is that they used multiple mirrors hanging on a single stand whereas I used multiple stands ("Skulls In The Stars", 2008). In historical depictions the mirrors were all single curved sheets about the size of a person and there were hundreds scattered around the bay of Syracuse. I aimed to create a more realistic and accurate depiction of historical events. Although the MythBusters team showed that the use of mirrors increased the target temperature significantly, they concluded that combustion using the Archimedes Death Ray was not possible and not a viable means of destruction for its time. Another team from The Massachusetts Institute of Technology (MIT) also tried to replicate Archimedes designs through experimentation and simulation and found that the principle of the Death Ray was plausible ("Archimedes Death Ray: Idea Feasibility Testing", 2005). The authors found that the use of multiple polished bronze mirrors with variable focal lengths to create a larger focal target zone could have improved the efficiency of the burn. They also found that cloudy days could affect the outcome. However, they found that regardless of the wood type or moisture content of the wooden ships, combustion could occur in less than 11 minutes. Similarly, I concluded that it is possible to increase the target temperature with additional mirrors, but my experiment was not designed to create combustion. Based on my experimental findings, I agree with the MIT group and believe that with a strong enough heat source and larger, multiple mirrors all focused at a perfect angle, combustion could be possible.

One of the limitations of this technology is that it may not work during cold months of the year, or if the light source is obstructed such as with cloudy skies. In addition, the practical application of this technology would be influenced easily by a change in the distance from the light source to the target area which would clearly have an impact on the efficiency of the rays such as with moving ships in a wavy sea. In addition, we do not know if the Greeks had a method of locking the Roman ships in place using underwater nets or strategically placed rocks or if they targeted a particular part of the ship to create combustion. Given that there is no archeological evidence supporting these theories we can only speculate.

Conclusion

In conclusion, these series of experiments showed that the principle behind the Archimedes Death Ray is certainly possible and hence I accept my original hypotheses that concave mirrors can be used to reflect and concentrate light given off from a light source. As the number of reflective mirrors increases, so does the temperature of the target. Altering the strength of the light source also increased the temperature of the target. However, for it to function properly and cause combustion of large objects such as wooden ships, it would require a very powerful light source and many large mirrors. The historical descriptions of the use of the Death Ray in ancient Syracuse is plausible, however no archeological evidence of the Archimedes Death ray has been found besides what is recorded in the books of Ancient Philosophers.

References

Archimedes. (2023, August 12). In *Wikipedia, The Free Encyclopedia*. Retrieved 19:31, August 13, 2023, from https://en.wikipedia.org/w/index.php?title=Archimedes&oldid=1169915078

Archimedes Death Ray: Idea Feasibility Testing. (2005) MIT Department of Engineering. https://web.mit.edu/2.009_gallery/www/2005_other/archimedes/10_ArchimedesResult.html

Clark, J. (2008, September 29). *What was Archimedes' death ray?* HowStuffWorks. https://history.howstuffworks.com/historical-figures/archimedes-death-ray.html

English, T. (2023, July 20). *7 remarkable inventions from Archimedes that shaped history*. Interesting Engineering. https://interestingengineering.com/lists/7-amazing-inventions-from-archimedes

Matthews, R. (March 21, 2017). Siege of Syracuse. Encyclopedia Britannica. https://www.britannica.com/event/Battle-of-Syracuse-214-212-BCE

Olympic Torch lit in Olympia (2008, March 23) https://olympics.com/en/news/olympic-torch-lit-in-olympia

Skulls In The Stars. (2010, February 7). *Mythbusters were scooped - by 130 years! (Archimedes Death Ray)*. Mythbusters were scooped - by 130 years. https://skullsinthestars.com/2010/02/07/mythbusters-were-scooped-by-130-years-archimedes-death-ray/

Toomer, G. J. (2023, November 7). Archimedes. Encyclopedia Britannica. https://www.britannica.com/biography/Archimedes

ABOUT THE AUTHOR BRENDEN SENER

My name is Brenden Sener, I am going into Grade 8 and I love science, video games and hanging out with my friends and playing with my dog. I hope that in the future I will be able to contribute to society in a meaningful way.