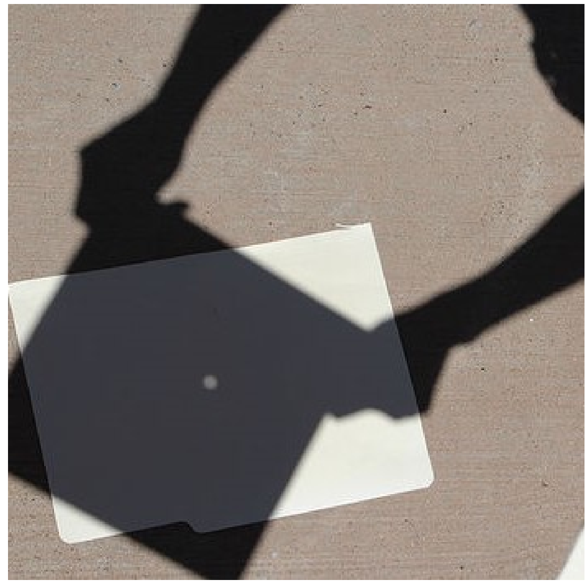
Pinhole Projector

Workshop

Construct a pinhole projector to introduce participants to the basic properties of light. This tool can then be used to view eclipses or other bright sources.



NASA JPL

Number of Participants: Unlimited

Age Range: Middle School (ages 11-13) and up

Duration: 10-20 minutes

Difficulty: Level 1

Materials Required:

- Chipboard or a cereal box
- Aluminum foil (10 x 10 cm)
- Graph paper
- Thumbtack
- Ruler or measuring device
- Scotch tape
- Screen or sheet of white paper
- Scientific Calculator

Setup:

1. Remove an 8 x 8 cm square from the center of the chipboard. Cover the square with a single piece of aluminum foil and use tape to secure it to the board.
2. Gently pierce the foil with the thumbtack.

Presenter Brief:

A primary goal of this demonstration is to outline geometric optics by explaining why an image is formed. Most descriptions involve highlighting that light travels in a straight line (rays) and that an image is formed because there is a one-to-one relationship between a given source point and an image point. In this case, because the hole is so small, a given image point only receives light from one part of the object. Relate this to how the eye works.

Note: Be familiar with basic principles of diffraction but diffraction should not be noticeable in this example because the pinhole is most likely too large.

Vocabulary:

- Diffraction – Splitting of light due to interactions of electromagnetic waves with physical media.
- Aperture – An opening (usually a circle) that light passes through.

Physics & Explanation:

Middle (ages 11-13) and general public:

If a pinhole is placed in the path of light, some of the rays will pass through it. These rays can be projected onto a screen to form an image of the light source. The source can be any object reflecting light, like a person, or any object giving off its own light, like the sun.

From any given point on the sun, light rays are emitted and travel in straight lines in all directions. When the rays encounter the pinhole, only some will pass through. Since the light rays intersect at the aperture, the projected image will be flipped from the original.

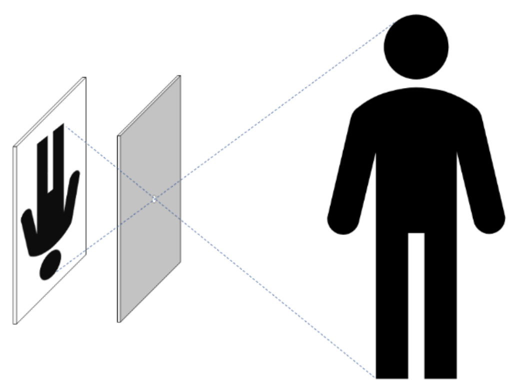


Figure 1

Instruct participants remove an 8 cm x 8 cm square from the center of their board. Cover the opening with aluminum foil and secure with tape. Next, gently pierce the foil in the center with a thumbtack. A small hole is desired: smaller holes will be dimmer, but have sharper focus. Collect thumbtacks after everyone has made their pinhole.

Assist participants in using their projector to project an image of the sun on their screen or blank sheet of white paper.

🔑 An image of an object can be projected using a pinhole.

If possible, replicate (by live-sketching or printing beforehand) Figure 1 to illustrate why the image is flipped.

Since light rays move in straight lines, the ratio between the diameter of the sun and the diameter of the image is equal to the ratio between the distance from the Earth to the Sun and the distance from the screen to the projector, as shown in Figure 2.

$$\frac{Diameter\ of\ Sun}{Diameter\ of\ Image} = \frac{Distance\ from\ Earth\ to\ Sun}{Distance\ from\ Screen\ to\ Projector}$$

$$Diameter\ of\ Sun = \frac{Distance\ from\ Earth\ to\ Sun \times Diameter\ of\ Image}{Distance\ from\ Screen\ to\ Projector}$$

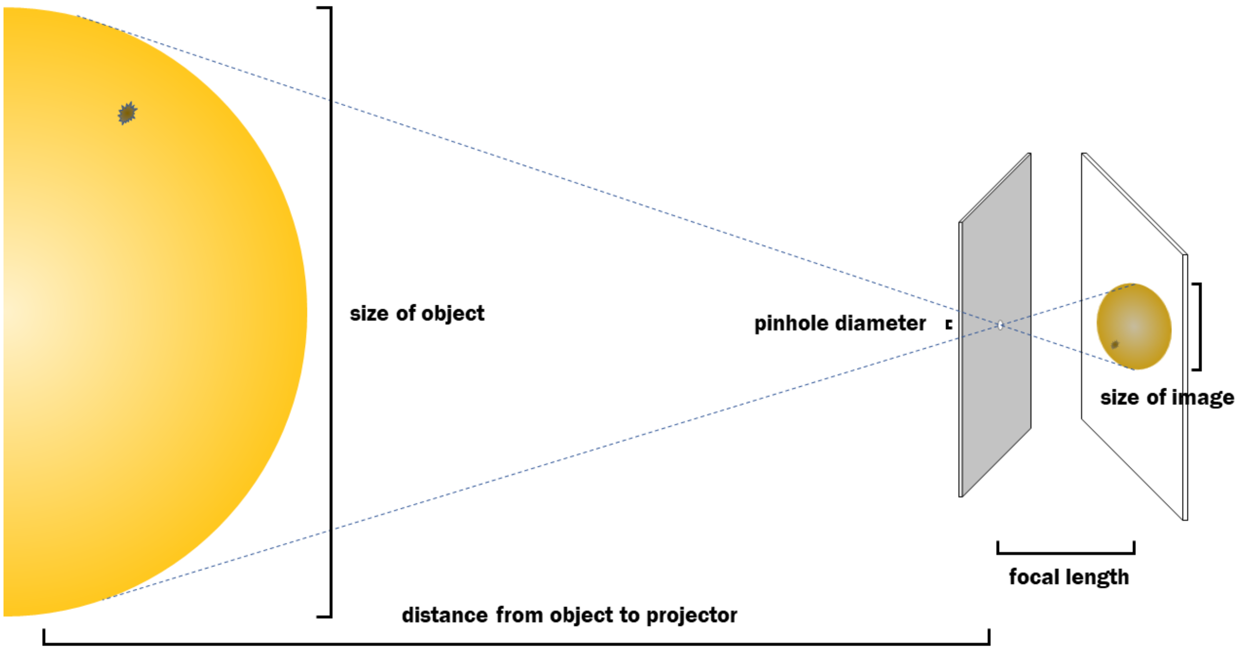


Figure 2

Now use the graph paper as your screen and measure the diameter of the projected image. Next, measure the distance between the screen and the projector. The average distance from the Earth to the Sun is $149.6 \times 10^6\ km$.

> As a group or individually, calculate the diameter of the sun. Compare the answer to the correct value of $1.39 \times 10^6\ km$ and discuss the reasons for any discrepancies.

🔑 Light rays move in straight lines.

High School (14 +):

After completing the previous section, you should notice that the distance between the pinhole and the screen affects the clarity of the image. After optimizing the image clarity, measure the distance between the screen and the pinhole. The optimal distance is known as the pinhole focal length (f). The focal length depends on the radius of the pinhole (r) and the wavelength of light (λ) passing through the hole:

$$f = \frac{r^2}{\lambda}$$

Since the distance between the pinhole and the screen is easy to measure, we can calculate the size of the pinhole using the wavelength of sunlight. (While multiple wavelengths constitute sunlight, we can use the approximation of $550\ nm\ or\ 0.00055\ mm$).

Solve the equation for the pinhole radius r and calculate the radius of the pinhole in mm. *Note: Double the radius to get the diameter.* Is this a reasonable value? What factors would cause your answer to be off?

$$r = \sqrt{f\lambda}$$

Placing the pinhole at the focal length will project the best image of the sun.

Additional Resources:

- The Physics Teacher article http://aapt.scitation.org/doi/pdf/10.1119/1.2340648
- The Pinhole Camera https://cral.univ-lyon1.fr/labo/fc/cdroms/cdrom2004/cd_venus/documents/pinhole/pinhole_imaging.html

Useful Equations:

Geometric Optics	$\frac{Size\ of\ Object}{Size\ of\ Image} = \frac{Distance\ from\ object\ to\ projector}{f}$
Pinhole Focal Length	$f = \frac{r^2}{\lambda}$

$r = radius\ of\ pinhole$

$\lambda = wavelength\ of\ light$

$f = focal\ length - the\ distance\ at\ which\ light\ from\ an\ optical\ component\ converges$