5. SPHERICAL MIRROR REFLECTION

STRUCTURED

Driving Question | Objective

What is the radius of curvature of the concave spherical mirror provided by your instructor? Use the principles of reflection and the spherical mirror equation to experimentally determine the radius of curvature of a concave spherical mirror.

Materials and Equipment

- PASCO Optics Track[1] or PASCO Dynamics Track with Optics Carriages[2]
- PASCO Basic Optics Light Source[3]
- PASCO Concave Mirror Accessory[4]
- PASCO Half-Screen Accessory[4]

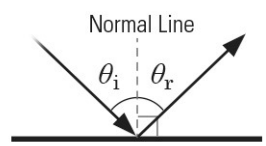
[1]www.pasco.com/ap28 PASCO Optics Track

[2]www.pasco.com/ap29 PASCO Dynamics Track Optics Carriages

[3]www.pasco.com/ap26 PASCO Basic Optics Light Source

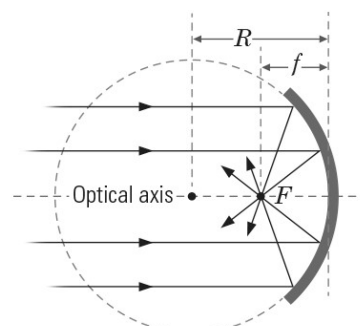
[4]www.pasco.com/ap32 PASCO Concave Mirror Accessory

Background



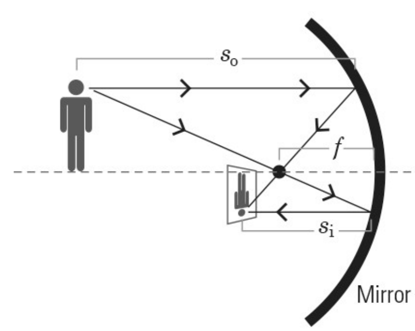
Light rays reflecting from a mirrored surface obey the Law of Reflection: the incident angle θ_i of a reflected light ray is equal to the reflected angle θ_r, where both angles are measured relative to a line normal to the reflecting surface.

$$\theta_i = \theta_r \quad (1)$$



In the case of a concave spherical mirror, the surface of the mirror is curved in the shape of a section of a sphere with radius R. (R is also known as the mirror's *radius of curvature*). Because of this curvature, light rays incident on a concave mirror, parallel to its optical axis, have incident angles that increase as the distance between the optical axis and the light ray increases. These varying incident angles cause the parallel light rays to reflect from the mirror and converge to one point F along the optical axis known as the *focal point*. The distance f from the mirror's surface to the focal point is known as the *focal length* and is equal to half of the mirror's radius of curvature:

$$f = \frac{R}{2} \quad (2)$$



If an object is introduced in front of a concave spherical mirror along its optical axis, beyond the mirror's focal length, an image of that object will form in front of the mirror. This image is said to be a *real image* because it forms where light rays converge onto a viewing screen. Images that are formed by diverging light rays (images that cannot be formed on a viewing screen) are said to be *virtual images*.

The following spherical mirror equation defines the position of the real image formed by a spherical mirror:

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \qquad (3)$$

where f is the mirror focal length, s_o is the distance from the mirror to an object (*object distance*), and s_i is the distance from the mirror to the point at which the image of the object is in focus (*image distance*). Using the variables in this equation, you will perform an investigation to experimentally determine the radius of curvature of a concave spherical mirror.

RELEVANT EQUATIONS

$$f = \frac{R}{2} \qquad (2)$$

$$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i} \qquad (3)$$

Procedure

SET UP

1. Lay the optics track flat on your lab table and mount the light source to it so that the "screen zero" (see the bottom of the light source for the screen zero indicator) is aligned with the 6-cm mark on the track. Make sure the crossed-arrow image on the light source points down the length of the track.

2. Mount the mirror to the track at the 20-cm mark with the concave surface of the mirror facing the light source.

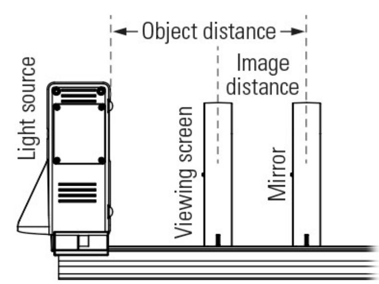
3. Mount the viewing screen to the track at some point between the light source and the mirror.

4. Plug in the light source to turn it on.

COLLECT DATA

5. Slide the viewing screen up and down the optics track between the mirror and the light source until the image of the crossed-arrow target is in focus on the half-screen.

   NOTE: Depending on your setup, you may not see the entire image on the viewing screen. Also, the image may not be in perfect focus; however, the image location *is where the image is most focused. You may need to slide the screen back and forth through the image location until you can determine where the image is the most sharply focused.*



6. Using the graduated scale on the optics track, determine the object distance s_o and the image distance s_i. Record these values in Table 1 in the Data Analysis section below.

   NOTE: Object distance is measured from the position of the mirror to the front of the light source (the object), and image distance is measured from the position of the mirror to the position of the viewing screen.

7. Slide the mirror 3 cm farther from the light source. (Do not change the light source position.)

8. Slide the viewing screen up and down the optics track between the mirror and the light source until the image of the crossed-arrow target is again in focus on the screen.

9. Record the new object distance and image distance next to Trial 2 in Table 1.

10. Repeat the data collection steps three more times, increasing the distance between the mirror and the light source by 3 cm in each trial. Record the object distance and corresponding image distance for each trial into Table 1.

Data Analysis

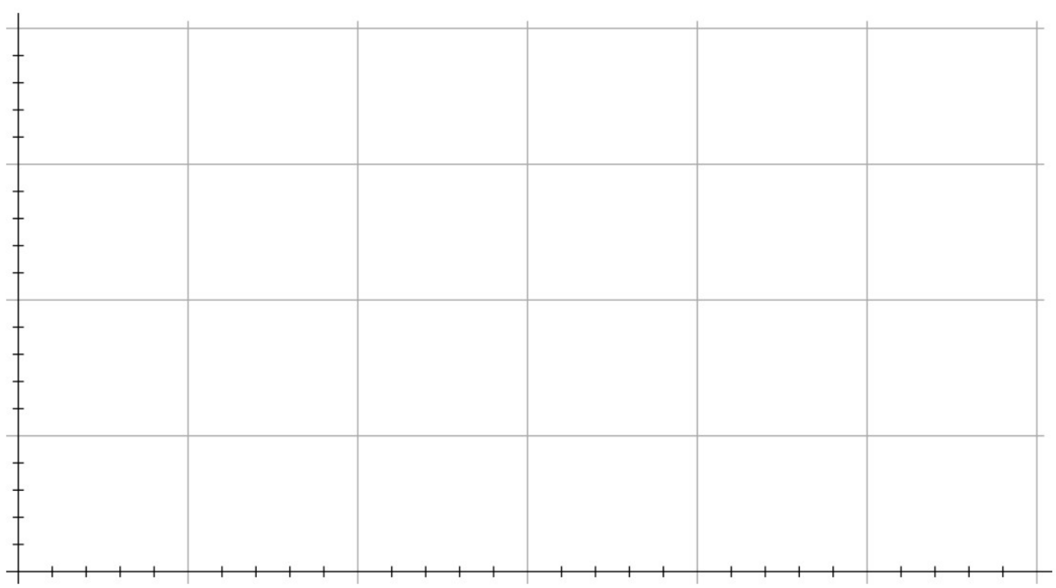
Table 1: Object distance and corresponding image distance using a concave spherical mirror

Trial	Object Distance s_o (m)	Image Distance s_i (m)	$1/s_o$ (m^{-1})	$1/s_i$ (m^{-1})
1				
2				
3				
4				
5				

1. Calculate the inverse of each object distance and image distance in Table 1. Record your results in the $1/s_o$ and $1/s_i$ columns of Table 1.

2. Plot a graph of $1/s_o$ versus $1/s_i$ in Graph 1. Be sure to label both axes with the correct scale and units.

Graph 1: Inverse object distance versus inverse image distance using a concave spherical mirror



3. Draw a line of best fit through your data in Graph 1. Determine and record the equation of the line here:

    Best fit line equation: ______________________________

4. Use the y-intercept from the best fit line to determine an experimental value for the radius of curvature R of your mirror:

$$y\text{-intercept} = \frac{2}{R}$$

Radius of Curvature R (m): ________________________

Analysis Questions

1. What is your experimental value for the radius of curvature R of your mirror, and how did you determine this value from your data?

2. What are factors that might have caused error in your measured value for radius of curvature? Explain how each factor you list could be avoided or minimized.

3. Ask your teacher for the actual value of the radius of curvature of your mirror, and then calculate the percent error between your experimental value and the actual value.

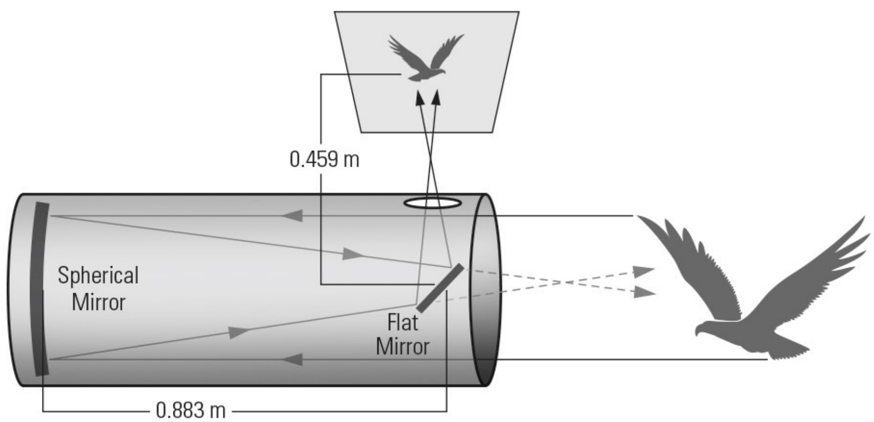
$$\text{Percent error} = \left|\frac{\text{Actual} - \text{Experimental}}{\text{Actual}}\right| \times 100$$

4. What do you predict happens to the image distance from a concave spherical mirror as the object distance grows very large (much larger than the image distance)? Justify your answer: use mathematical reasoning or data from your experiment, or both, to support your answer.

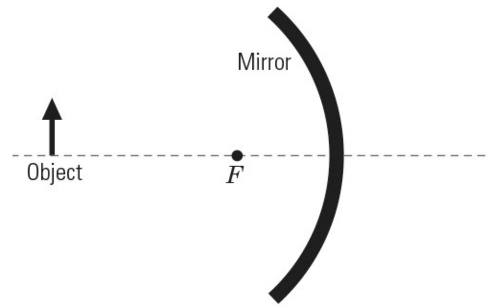
Synthesis Questions

1. In 214 BC, Archimedes invented a large spherical-type mirror used to focus the sun's intense rays onto far away enemy boats, which would eventually light them on fire. If the boats were travelling in a nearby channel approximately 1,000 m from the river bank, what would the radius of curvature of his mirror need to be? Show your work.

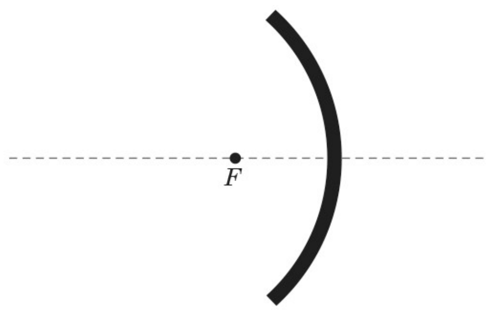
2. The image below shows the position of two mirrors inside a reflector-style telescope. Light from far-off objects enters the body of the telescope through the opening on the right. That light is reflected off a spherical mirror in the back of the telescope and then again off a flat mirror that redirects the light to a screen where the image of the object appears in focus. Given that the image of the eagle on the screen is in focus, and the actual eagle is 726 m away from the spherical mirror, what is the radius of curvature of the spherical mirror?



3. Sketch a ray diagram showing the image produced by the concave spherical mirror below. Is the image real or virtual? How do you know?



4. Is it possible for a concave spherical mirror to produce a virtual image of an object? Sketch a ray diagram that supports your answer.



5. In most applications of concave spherical mirrors (including this activity) it is assumed that all light rays travelling parallel to the mirror's optical axis are reflected through the mirror's focal point; however, this is an approximation that applies only to light rays traveling near the mirror's optical axis. In a few sentences, explain why a concave spherical mirror does not reflect all light rays travelling parallel to its optical axis through its focal point.