

Optics: Lenses and Mirrors

Introduction

Mirrors reflect light while lenses transmit light. Both can form images, however. In this lab you will study spherical lenses and mirrors. A spherical surface is simply some portion of the surface of a sphere. It is characterized by its *radius of curvature, R*.

Equipment

Meter stick optical “bench”	Light source, object card	Spherical and cylindrical mirrors	Screen (white cardboard)
Lens holders	Convex lenses ($f = 10\text{-}30\text{ cm}$)	Concave lens ($f = -10\text{ to } -30\text{ cm}$)	Ruler for ray diagrams.

Theory

A spherical mirror is a section of a sphere. If the “shiny” side is inside the sphere it is a *concave* surface (Figure 1). If the mirror is on the outside surface then it is *convex* (flexed out). As with all mirrors, light reflecting from the surface obeys the law of reflection: the reflected angle is equal to the incident angle. The normal to a spherical surface passes through its radius. From this it can be shown that rays parallel to the optic axis of a concave spherical mirror will all be reflected towards the focal point (converging). Rays reflected from a convex spherical mirror will diverge away from a focal point behind the surface. (See Figure 2)

The *focal length* (distance to focal point) of a spherical mirror is given by

$$\frac{1}{f} = \frac{2}{R} \quad \text{or} \quad f = \frac{R}{2}.$$

Lenses form images by refracting light. A spherical lens can be made of any transparent material with a curved surface and an index of refraction that differs from the medium its in. For a lens with index of refraction n and spherical surface(s) of radius R_1 and R_2 which is placed in air, the focal length is given by

$$\frac{1}{f} = (n - 1) \left[\frac{1}{R_1} - \frac{1}{R_2} \right]$$

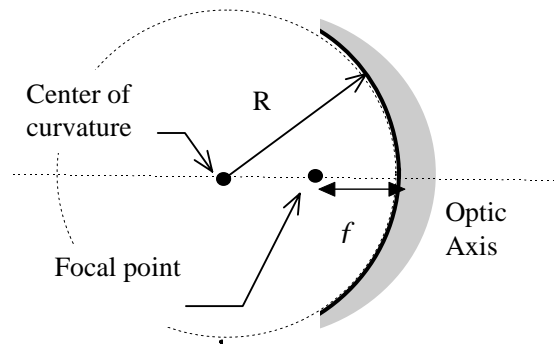


Figure 1: A concave spherical mirror.

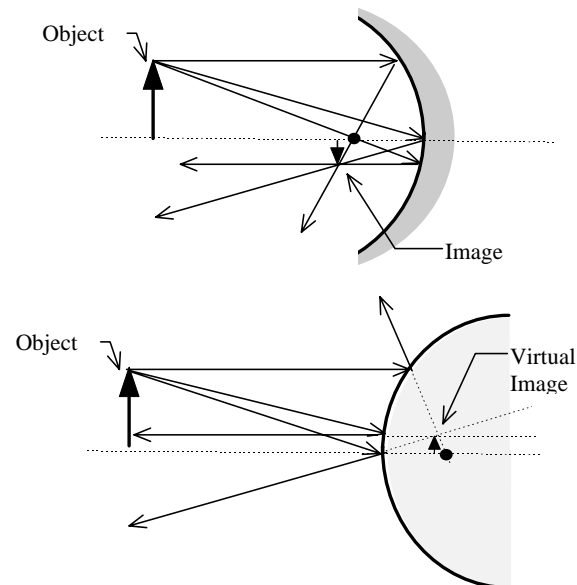


Figure 2: Concave converging mirror (top) and convex diverging mirror (bottom).

For a spherical lens, parallel light incoming to a lens with convex surfaces will converge on its focal point, while parallel light incident on a concave lens will diverge away from its focal point. (Figure 3) The *image location* for either mirrors or lenses can be found by a *ray diagram*. A ray diagram is constructed using the following rules for a converging (or diverging) lens:

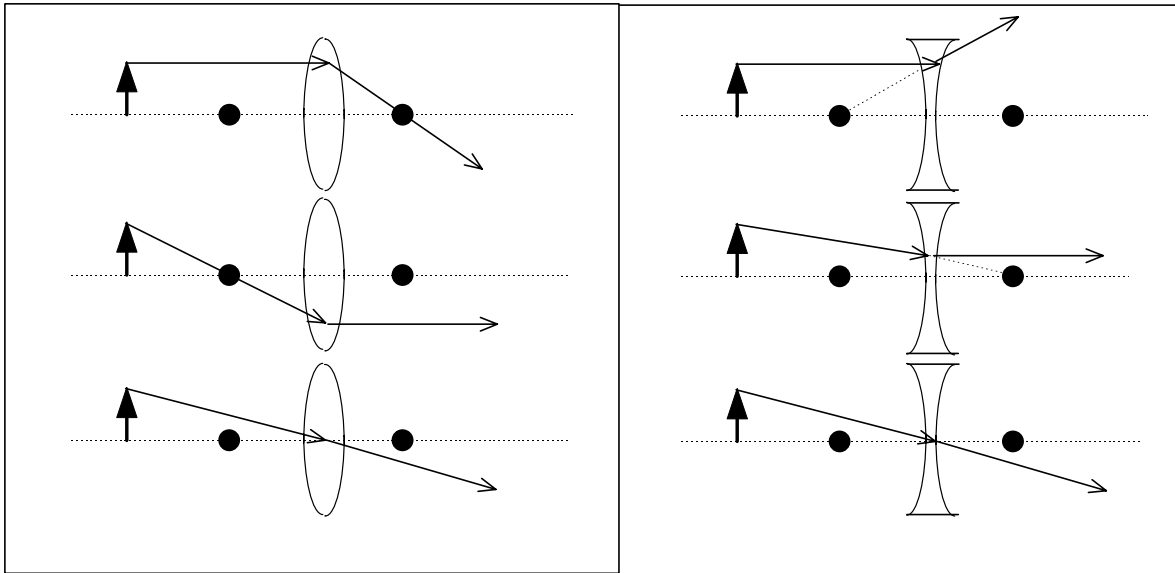


Figure 3: Converging (left) and diverging (right) lenses

Parallel incoming rays will be bent towards (or away from) the focal point.
 A ray incoming from (or towards) the focal point will be refracted so it is parallel.
 A ray through the center of a lens is unchanged.

These rays are shown in Figure 3. A real image is formed if these rays intersect. If they diverge when exiting the lens, a virtual image is found by tracing them back behind the lens. Similar rules apply to mirrors as shown in Figure 2.

The *magnification* of an image is the ratio of image height (h') to object height (h). Drawing similar triangles shows that this is equal to the ratio of image distance, i to object distance, p . The relationship between image distance, object distance and focal length is given by

$$\frac{1}{p} + \frac{1}{i} = \frac{1}{f} \quad \text{and the magnification by} \quad m = \frac{h'}{h} = -\frac{i}{p}$$

A negative magnification indicates an inverted image. Object distances are positive when on the incoming side of the lens (or mirror). Image distances are positive on the opposite side. Focal lengths are positive for converging lenses and negative for diverging lenses.

Procedure

Part A: Spherical Mirrors.

a) Finding the focal length and radius.

Light from an object located very far away is nearly parallel. This can be used to find the focus of a spherical mirror. Take a mirror and a white card to the window. Hold the mirror up to the light from the sun and adjust the position of the white card until the light is focused on it. (If it is night time use another light source far from the mirror). Measure the distance from the mirror to the card.

Have a second person repeat the measurement to check your accuracy. Average the results.

Calculate the radius of curvature of the mirror. Does your answer seem reasonable? Draw a ray diagram for the mirror showing the incoming light coming in parallel and converging on the focus.

b) Images in spherical and cylindrical mirrors.

Hold one hand up next to your face. Hold the spherical mirror so that this hand is farther than the focus.

Tilt the mirror til you see your hand. Describe what you see. Is the image upright or inverted? Smaller or larger?

Make a ray diagram for a spherical converging mirror and an object farther than the focus. Explain whether or not your diagram agrees with your observations.

Repeat these two steps using the convex side of the mirror as a diverging mirror. (You can look directly at your face instead of your hand now).

Look at the images in a flat mirror and a cylindrical mirror. What do you see? How does it compare to the spherical mirror? Explain why the image in the cylindrical mirror looks the way it does.

Part B: Spherical Lenses

Here you will set up the lenses on an optical bench and find the images of the light through a triangular aperture. First try to use a screen to find the image. If you cannot do this it may be a virtual image. In this case you can look through the lens to see the image but cannot actually measure the image distance. In each case you should record the relative size and orientation of the image.

a) Convex (Converging) Lenses

Measure image distances and observe the size and orientation of the image for the following cases using a +20 cm focal length lens: object distance = 5 cm, 10 cm, 25 cm, and 40 cm.

For the 10 cm and 25 cm object distances, draw a ray diagram (label everything in your diagram to explain what it is). The diagrams should be to scale and drawn accurately with a ruler. For each case compare your results to the ray diagrams.

Measure the image distances and magnifications for an object distance of 40 cm and lenses of focal lengths +10 cm, +20 cm (done above) and +30 cm.

For each case calculate the theoretical image distance and magnification and compare to your result.

b) Concave (Diverging) Lenses

Using a -20 cm focal length lens, find the images for object distances of +10 cm and +20 cm.

Record your observations, draw ray diagrams and do calculations as described above.

Part C: Making a telescope

A telescope magnifies images which are very far away.

A terrestrial telescope forms an upright image: Rays from the distant object are nearly parallel and are focused by a converging lens (called the Objective). Because the rays are nearly parallel, the image from the Objective is nearly at its focus. A diverging lens (called the Eyepiece) is placed inside the focal distance. The image formed by the Objective becomes the object for the Eyepiece, which then forms a much bigger, upright virtual image which can be viewed through the Eyepiece. If the focal point of the Eyepiece is near the focal point of the Objective then the final image should be very large.

A astronomical telescope forms an inverted image: Again a converging Objective lens focuses rays from very distant object. In this case a converging (called the Eyepiece or Occular) is placed outside the focal distance of the Objective and is used to form a final inverted virtual image that is magnified.

Construct a telescope. Describe it for your report.

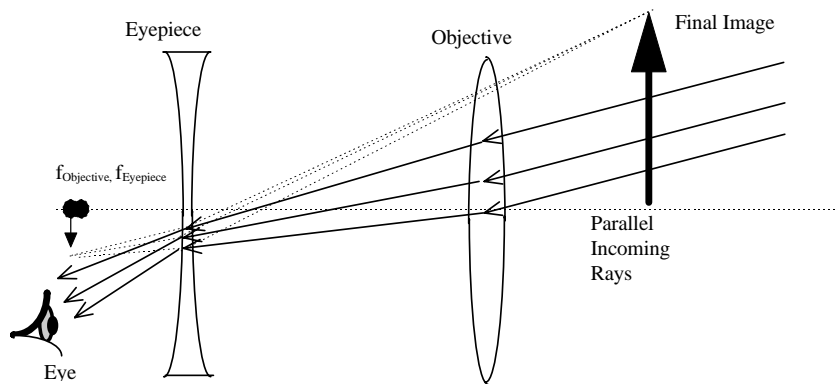


Figure 4: Terrestrial (Galilean) Telescope (not to scale)

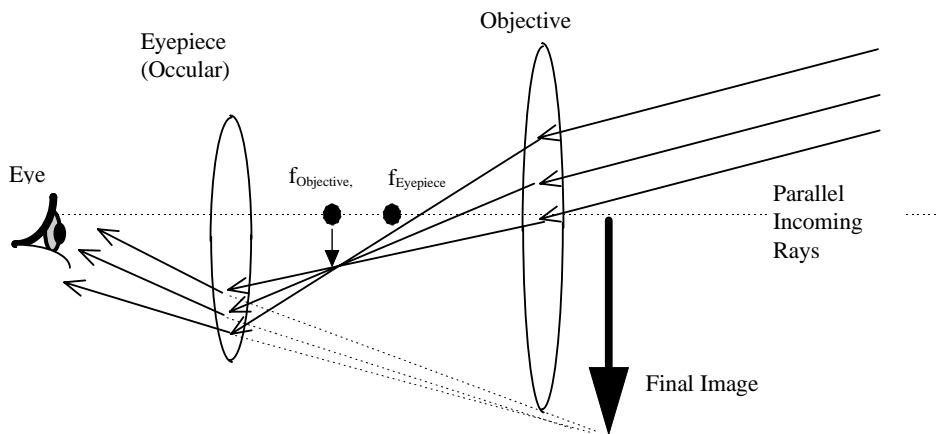


Figure 5: Astronomical telescope (not to scale)

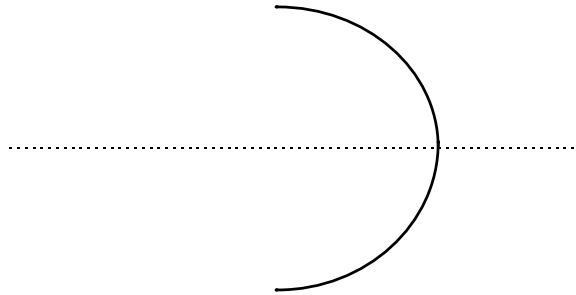
Part A: Spherical Mirrors.

Distance from mirror to screen when focused _____

Average: _____

Radius (calculated) _____

Ray Diagram (Draw accurately to scale and show several incoming rays, reflected rays, the focal point and the radius.)

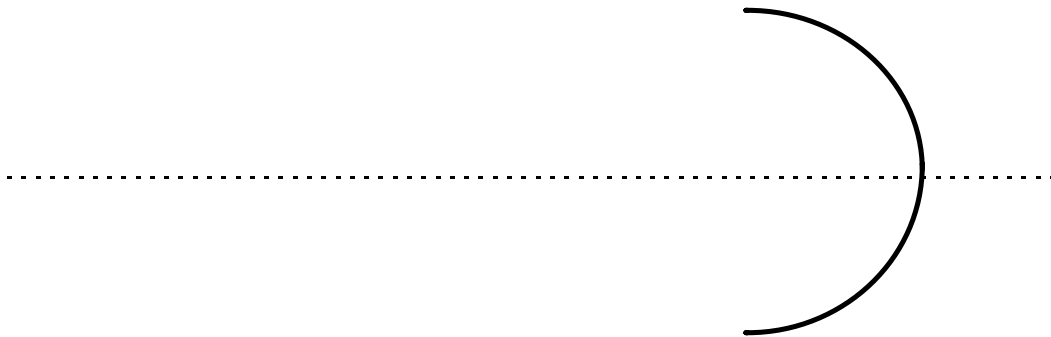


Images in Mirrors (USE THIS AS A TEMPLATE FOR ALL PARTS)

Converging Mirror, Object farther than focus:

Description of image (what your hand looks like!)

Ray Diagram (draw to scale using a ruler for straight lines!)



Does the diagram agree with what you saw? **EXPLAIN!**

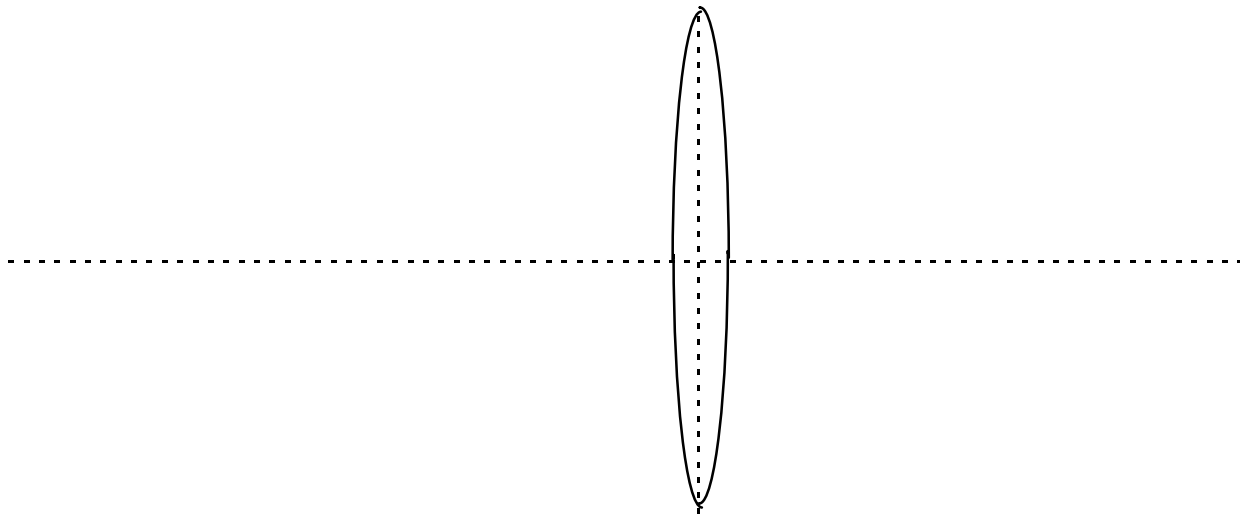
Part B: Spherical Lenses

USE THIS AS A TEMPLATE FOR EACH CASE Follow with discussion.

Converging Lens: Data and Calculations

Focal Length, f	Object Distance, p	Image Distance, i	Describe Relative Image Size	Image Orientation
Theoretical Image Distance			Theoretical Magnification, m	

Ray Diagram: Use a ruler and make the drawing to scale. Mark the focal points and label all rays.



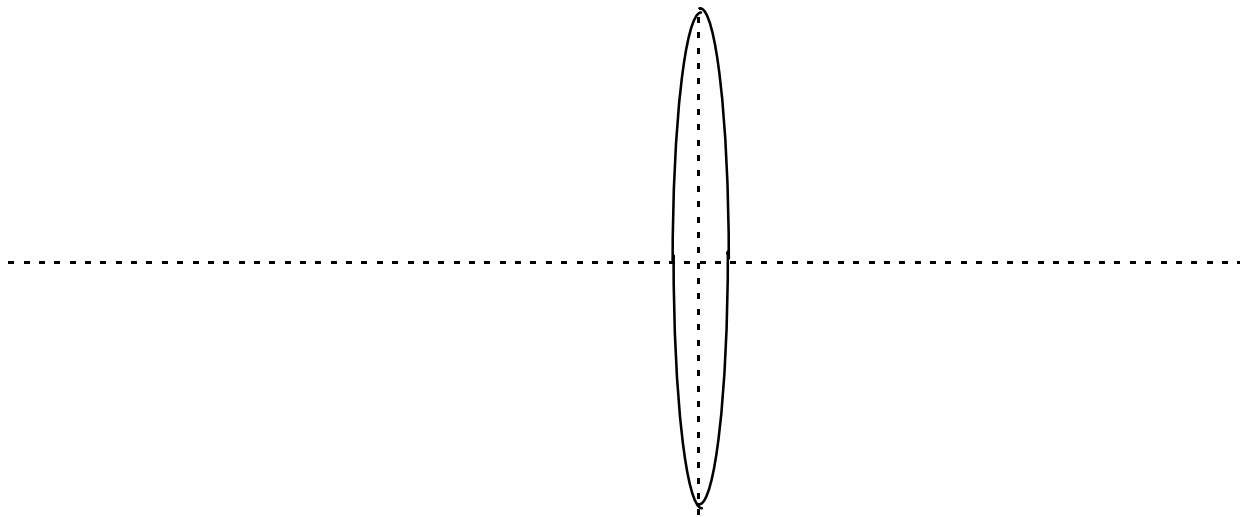
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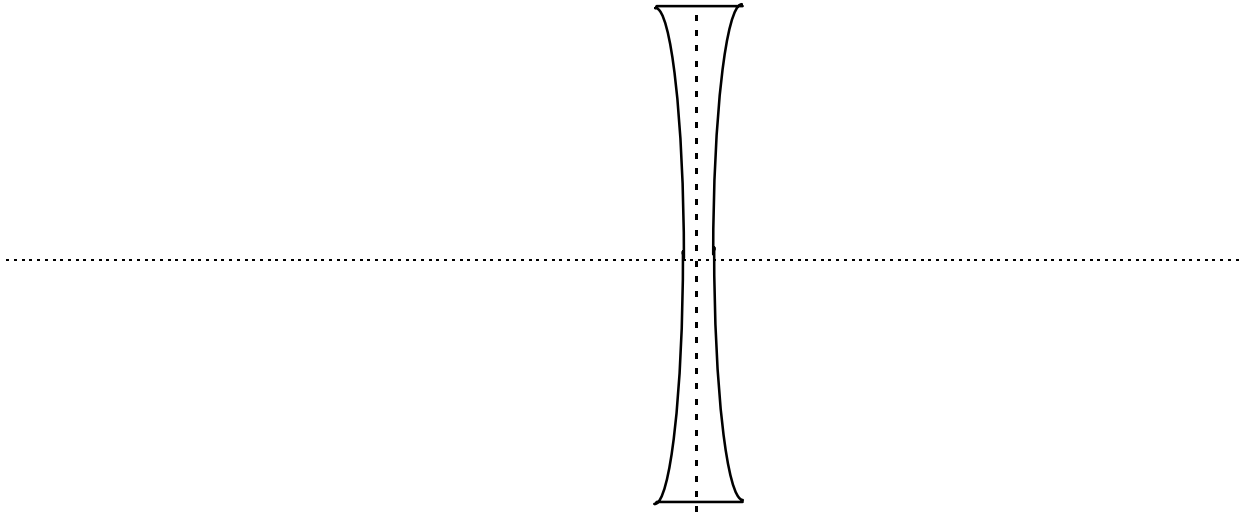
Part B: Spherical Lenses

USE THIS AS A TEMPLATE FOR EACH CASE Follow with discussion.

Diverging lens: Data and Calculations

Focal Length, f	Object Distance, p	Image Distance, i	Describe Relative Image Size	Image Orientation
Theoretical Image Distance				Theoretical Magnification, m

Ray Diagram: Use a ruler and make the drawing to scale. Mark the focal points and label all rays.



Part B: Spherical Lenses

USE THIS AS A TEMPLATE FOR EACH CASE Follow with discussion.

Diverging lens: Data and Calculations

Focal Length, f	Object Distance, p	Image Distance, i	Describe Relative Image Size	Image Orientation
Theoretical Image Distance				Theoretical Magnification, m

Ray Diagram: Use a ruler and make the drawing to scale. Mark the focal points and label all rays.

