31 Concave Mirrors and Convex Lenses
Spy Glass

Purpose

To investigate the nature, position, and size of images formed by a concave mirror or a convex lens.

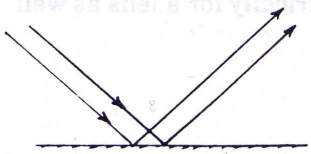
Required Equipment and Supplies

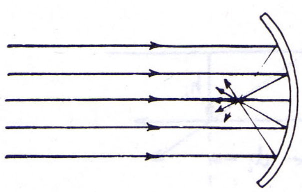
concave spherical mirror, or a convex spherical lens
cardboard
night light with clear 7-watt bulb
small amount of modeling clay
meterstick

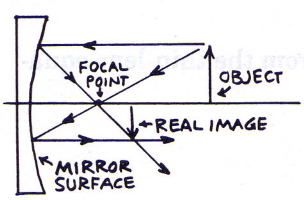
Optional Equipment and Supplies

Data Plotter graphing program (optional)
Apple II Series computer
2 convex lenses with a focal length of about 10 cm
1 convex lens with a focal length of about 50 cm

Discussion







The law of reflection states that the angle of reflected light is equal to the angle of the light's incidence upon a reflecting surface. Simply put, the angle of reflection equals the angle of incidence. Parallel light rays that strike a plane mirror head-on reflect directly backward and are still parallel. If the parallel rays strike the mirror at an another angle, all rays reflect at the same angle and the reflected rays that leave the mirror remain parallel. Incident parallel rays remain parallel so no convergence occurs. Without convergence, light rays cannot be brought to a focus and form *real* images. So a plane mirror cannot focus light rays and form real images. The images observed in a plane mirror are always *virtual* images. A curved mirror is different.

A *parabolic* mirror is able to focus parallel rays of light to a single point (the *focal point*) because of its variable curvature. A small *spherical* mirror has a curvature that deviates only a little from that of a parabolic curve and is cheaper and easier to make. Spherical mirrors can, therefore, be used to make real images as well as virtual images.

In the ray diagram for a concave mirror, Figure 31.1, the light gray right triangle near the mirror has a base very close to f and a height equal to the

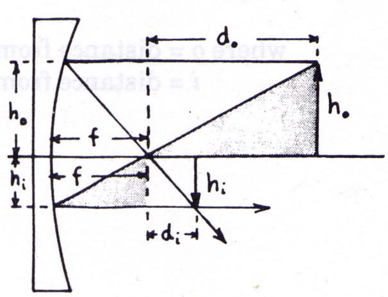


Figure 31.1

object height, h_o. The darker gray right triangle near the mirror also has a base very close to f and a height equal to the image height, h_i.

Since the two darker gray triangles are similar, the ratio of the heights equals the ratio of the bases:

$$\frac{h_o}{h_i} = \frac{d_o}{f}$$

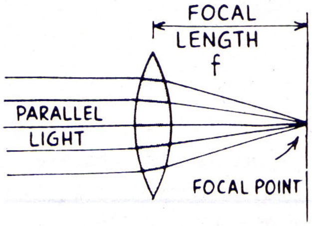
Also, since the two light gray triangles are similar:

$$\frac{h_o}{h_i} = \frac{f}{d_i}$$

Thus,

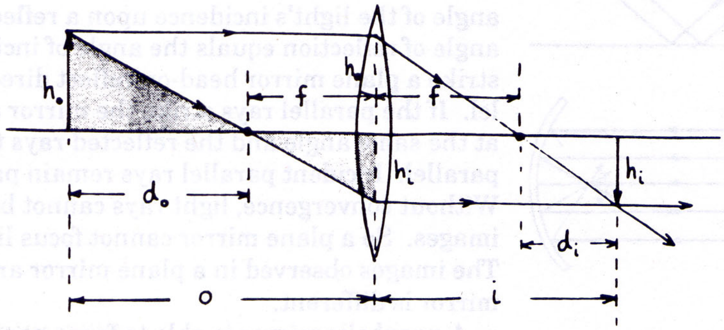
$$\frac{h_o}{h_i} = \frac{d_o}{f} = \frac{f}{d_i}$$

$$d_i d_o = f^2$$



Just as a curved mirror can reflect parallel light to a focus, a convex lens can refract light to a focus. A similar procedure can be used to analyze convex lenses. Instead of reflecting light from a mirror onto a screen, the light is refracted through the lens onto a screen.

The relationship $d_i d_o = f^2$ can be derived geometrically for a lens as well as for a concave mirror.



The relationship can also be derived algebraically from the thin-lens equation

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

where o = distance from lens to object
i = distance from lens to image

Since d_i and d_o are distances from the focal point to the object and image, then for objects and images beyond the focal point

$$o = f + d_o$$
$$i = f + d_i$$

Thus, the thin-lens equation becomes

$$\frac{1}{f+d_o} + \frac{1}{f+d_i} = \frac{1}{f}$$
$$f(f+d_i) + f(f+d_o) = (f+d_o)(f+d_i)$$
$$f^2 + fd_i + f^2 + fd_o = f^2 + fd_i + fd_o + d_i d_o$$
$$f^2 = d_i d_o$$

In this lab, you will investigate how well these theoretical ideas are born out by experiment.

Procedure

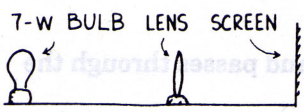


Figure 31.2

Step 1. The distance from the center of a lens to the focal point is called the *focal length, f.* Measure the focal length of your lens by converging parallel light to a point on a screen. Use the filament of a lit, clear 7-watt bulb as a source of parallel light and a piece of cardboard as a screen. Record your measurement below to the nearest 0.1 cm. Also record the number of your lens.

focal length f = ______ cm

lens number = ______

Data Table 31.1

d_o (cm)	d_i (cm)

Step 2. The rays of light striking your lens from the bulb may not be parallel. What effect, if any, would this have on your measured value for the focal length? What effect would moving the light source farther away have? Move it farther away, and record the focal length to the nearest 0.1 cm. (If a better source of parallel light is available, use it to find the focal point of your lens.) Record your measurement to the nearest 0.1 cm.

focal length f = _____ cm

Step 3. Position the lens two focal lengths away from the light source to form an image on a screen on the other side of the lens as in Figure 31.2. The distance between the focal point and the object is the object distance, d_o, and the distance between the focal point and the image is the image distance, d_i. Record the distances d_o and d_i in Data Table 31.1. Move the lens 5 cm farther away from the light source, and reposition the screen until the image comes back into focus. Record the distances d_o and d_i in Data Table 31.1. Repeat these 5-cm movements five more times, recording d_o and d_i each time.

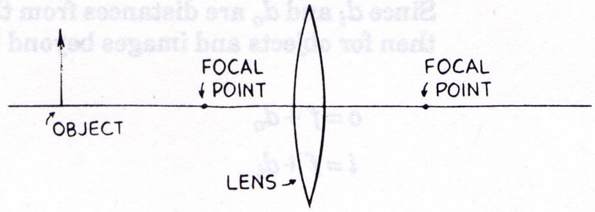


Figure 31.3

Step 4. Plot d_i vs. d_o, using different powers of each to discover what powers of d_i and d_o make a linear graph and thus a direct proportion. If available, use *Data Plotter* to plot your data.

1. What mathematical relationship exists between d_i and d_o?

Step 5. You can locate the position of the image of the object in Figure 31.3 using the ray-diagram method. Draw the path of the light ray that leaves the tip of the arrow parallel to the principal axis.

2. Where does this ray go after it is refracted?

Draw the light ray that leaves the tip of the arrow and passes through the focal point.

3. Where does this light ray go after it is refracted?

Now draw the paths of these two light rays after they are refracted. At the point where they cross, an image of the tip of the arrow is formed.

Step 6. Use the ray diagram method to locate the image of the object in Figure 31.4. Draw the path of the ray that leaves the tip of the arrow parallel to the principal axis and is refracted by the lens. Trace another ray that heads in the same direction as if it *originated* from the focal point and is refracted by the lens.

4. Do the refracted rays *actually* cross?

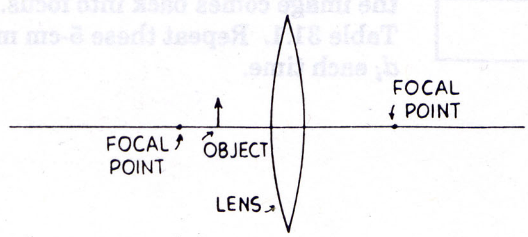


Figure 31.4

5. Where do they appear to cross?

6. Could the image be projected onto a screen?

7. What is meant by the thin-lens approximation? Draw a diagram that illustrates your answer in the space below.

Going Further

The Microscope and Telescope

The microscope and telescope both magnify objects, but in different ways. Microscopes magnify small objects that are nearby. The first compound microscope was constructed by a Dutch spectacle-maker, Zacharias Janssen, in 1590. Anton Leeuwenhoek built a microscope in the mid 1600's with a magnification of 270.

Telescopes magnify large objects that are very distant. A Dutch optician, Hans Lippershey, was refused a patent in 1608 for his invention which used two lenses in combination. Galileo, having heard of Lippershey's invention, built his first astronomical telescope in 1609. Although it was a relatively crude instrument capable of modest magnification (33X), he made many important discoveries. In this activity, you will devise lens arrangements for both a compound microscope and an astronomical telescope.

A compound microscope has two stages of magnification. First, the objective lens produces a magnified real image of the object with $o_1 \geq f_1$ as shown in Figure 31.5. The second lens, called the eyepiece, magnifies the image further. The object of the eyepiece is the image formed by the objective.

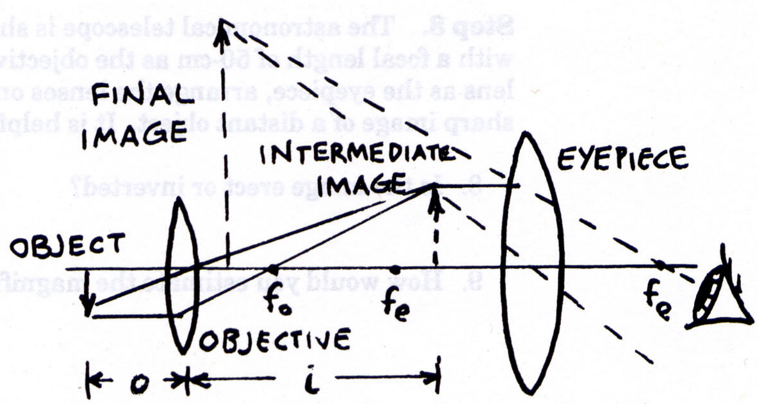


Figure 31.5

The linear magnification, M_1, of the objective lens is $-i_1/o_1$, and the angular magnification, M_2, of the eyepiece lens is 25 cm/o_2. The total magnification, M, is

$$M = M_1 M_2 = \frac{i_1 \cdot 25}{o_1 o_2} \text{ cm}$$

The total magnification is the product of M_1 and M_2 because the eyepiece uses the image of the objective as its object.

In principle, any magnification may be obtained with any two converging lenses; in practice the magnification is severely limited by lens aberrations.

Procedure

Step 7. Mount two convex lenses with focal lengths of about 10-cm with a piece of modeling clay as a lens holder. You can use a meterstick as an optical bench. Using the filament as the object, adjust the position of the objective lens until the object is in focus. Move your eye close to the eyepiece lens, then slowly move back. At one position the field of view seems to just fill the eyepiece lens. This is the optimum position for the eye, called the "exit pupil." Position the two lenses to obtain a sharply focused and magnified image of the filament. Calculate the total magnification, M, of your microscope.

$M =$ ________

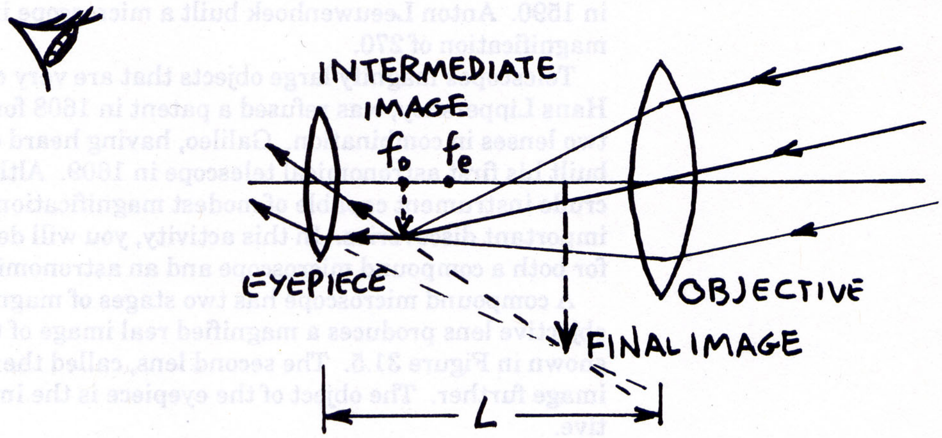


Figure 31.6

Step 8. The astronomical telescope is shown in Figure 31.6. Using a lens with a focal length of 50-cm as the objective lens and the 10-cm focal length lens as the eyepiece, arrange the lenses on a meterstick until you obtain a sharp image of a distant object. It is helpful if the object is well illuminated.

8. Is the image erect or inverted?

9. How would you estimate the magnification?