Physics 12 Laboratory
Mirrors and Lenses

In this experiment, we will examine the types of images formed by concave and convex spherical mirrors, and bi-concave and bi-convex lenses.

The radius of curvature *R* of a spherical mirror or lens is related to its focal length f by

$$R = 2f \qquad (1)$$

The sign of the radius of curvature and the focal length depends on which side the center of curvature is with respect to the surface of a mirror or lens: positive for concave mirrors and bi-convex lenses; negative for convex mirrors and bi-concave lenses. Object and image distances are related to the focal length by the following equation,

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f} \qquad (2)$$

where o is the object distance from the lens or mirror, and i is the image distance. If an object is “infinitely far” away (meaning that $1/o$ is negligible compared to $1/i$ or $1/f$), then

$$i = f \qquad (3)$$

Images are either “real” or “virtual”. A real image is formed when light from a source is focused in front of a concave mirror, or focused opposite the source side of a bi-convex lens. A virtual image occurs when reflected or refracted rays of light do not actually converge to form an image, but the human eye interprets the diverging rays as coming from an image behind the surface of a concave mirror, or on the source side of a bi-concave lens. The sign of the image distance is positive for real images, and negative for virtual images.

When light from a source is focused at the image distance, the image can be either magnified or de-magnified, and either upright or inverted. The magnification of an image is defined by a ratio of the image height (h’) over the source height (h) or by taking the negative ratio of image distance over object distance:

$$M = h'/h \qquad (4)$$
$$= -i/o \qquad (5)$$

The sign of the magnification in equation (5) denotes whether an image is upright (positive) or inverted (negative).

PART I. MIRRORS

Convex mirror measurements

The radius of curvature of a mirror or lens can be measured using a spherometer a device with three fixed posts and a central screw that can be turned in and out. To use the spherometer, place the device on a flat surface, such as the frosted glass piece, and adjust the turnscrew until the center screw tip just touches the surface. Record the “flat” reading of the circular scale, which shows tenths and hundredths of revolutions. Also measure the center to center distance between the center post and one of the three outer legs. (Let this distance be “a.”)

“Flat” reading of spherometer: ___________________ divisions

a = ________________________ mm

Now center the spherometer on the concave mirror and adjust the center screw until it just touches the mirror surface. NOTE: While one partner adjusts the center screw, the other partner(s) should notice how many complete revolutions take place during the adjustment. Record the “concave” reading of the spherometer, then compute the change in reading, taking into account the number of complete revolutions that occurred.

“Concave” reading of spherometer: ___________________ divisions

Difference in readings: _____________________ divisions

Number of complete revolutions = ______________ revs

Fraction of revolution based on difference in readings: ________________ revs

Total revs from “flat” to “concave” reading: ___________________ revs

Convert the difference to millimeters using the fact that the spherometer is scaled to 2 revolutions per millimeter.

x = __________________ millimeters for concave mirror

Obviously the curvature of the concave mirror is related to the difference between the two spherometer readings, which we have called x. From the definition of a circle, one can find that the relationship between depth x, and radius of curvature, R, is given approximately by

$$R = \frac{a^2}{2x}$$

Use this relationship and equation (1) to compute the focal length of the concave mirror.

f = R/2 = $\frac{a^2}{4x}$ = _________________ mm for concave mirror

Now you are ready to investigate the images formed by a concave mirror.

Focal length of concave mirror measured from real image of an infinitely distant object

The mirror can be mounted on the optical bench using the holder with spring-loaded arms. (Be careful with these arms, since they can spring shut and propel the mirror.) Mount the mirror on the optical bench at the 0 cm end of the bench and aim it so that its concave side is aimed at some distant tree or building outside the window (i.e., aim it at an "infinitely far" object). Next, mount a white card and flat round glass piece in a lens holder and place it on the bench in front of the mirror, making sure its height is slightly below the mirror's so that light can reach the mirror. Slide the card holder toward and away from the mirror until a sharp image of the object is formed on the screen.

By equations (2) and (3), this image distance is the focal length of the mirror. Record this "optical" value of f and compare it to the value of f found using the "geometrical" method earlier.

f = i = _______________ cm = ____________ mm for concave mirror by optical method

average value of f from optical and geometric methods: _______________ mm

percent difference between optical and geometric values of f: _______________ %

Concave mirror: Image formation when object is outside focal length (o > 2f)

Now we will form a real image of an object that is not "at infinity." Place the light source on the bench at the 50 cm point. This will be our object.

Locate the image of this object by sliding the white screen back and forth along the bench, as before. Measure the image and object distances. Measure the image and object heights (top to bottom of arrow) using calipers. Record the measured values, and complete the calculations in the tables below. Then describe the characteristics of the image as indicated.

Concave mirror; o > 2f

Object distance, o (mm) measured	Image distance, i (mm) measured	Object height, h (mm) measured	Image height, h′ (mm) measured	Magnification, from =h'/h

Focal length, F (mm), (average value)	Image distance, i (mm) calculated from eqn (2)	percent diff between calc and meas values of i	Image height, h′ (mm), predicted from h' = |-i/o| h	percent diff between calc and meas values of h'

Characteristics of the image:

_________ real? __________ virtual?

________ upright? _________ inverted?

________ magnified? ________ de-magnified?

Concave mirror: Image formation when object is inside focal length (o < f)

Now move the light source closer to the concave mirror to a position less than its focal length. Notice that there is nowhere you can place the frosted glass to capture the image formed in this situation. This is because the light rays are reflected from the mirror in such a way that they diverge, rather than converge to a focus. Your eye will interpret the diverging rays as coming from a virtual image of the source, located behind the mirror. Holding your head near the source, look into the mirror to see the virtual image. The instructor or assistant will describe a "parallax" method for deciding whether the image you see is closer to you or farther from you than the surface of the mirror.

Summarize the characteristics of the image:

_________ real? __________ virtual?

________ upright? _________ inverted?

________ magnified? ________ de-magnified?

Convex mirror: Image formation

Now reverse the spherical mirror so that the convex side is facing the light source. By experimenting with the relative positions of the source and mirror, you will find that there is no condition under which a convex mirror forms a real image it can only form a virtual image. Observe and describe the virtual image.

Characteristics of the image:

_________ real? __________ virtual?

________ upright? _________ inverted?

________ magnified? ________ de-magnified?

PART II. LENSES

Notice that there are three lenses on your table, two that are bi-convex and one that is bi-concave. You will find that the bi-convex lens has the same optical properties as a concave mirror. The convex lens and concave mirror are converging systems (and are assigned positive focal lengths); they can form either a real or a virtual image, depending on the object distance. In contrast, the bi-concave lens and convex mirror are diverging systems (and are assigned negative focal lengths); they can form only a virtual image of the object.

Bi-concave lens: Image formation

Convince yourself that a bi-concave lens is a diverging system by viewing near and far objects. Notice that no real images can be formed (no image can be captured on a screen). Also notice that when you view the object through the lens, a virtual image between the object and the lens is formed.

Summarize the characteristics of the image:

_________ real? __________ virtual?

________ upright? _________ inverted?

________ magnified? ________ de-magnified?

Bi-convex lens: image formation with object inside or outside focal point

Using the large-diameter bi-convex lens on your table, find its focal length by the same "optical" method you used to find the focal length of the concave mirror. Then describe the images formed by a bi-convex lens when an object is outside or inside the focal length.

Large-diameter lens
f from image distance when object is "infinitely far": _______________ mm

Characteristics of the image when o is very large ($o > 2f$):	Characteristics of the image when o is inside the focal length ($o < f$):
_____ real? _____virtual?	_____ real? _____virtual?
_____upright? _____inverted?	_____upright? _____inverted?
_____magnified? _____de-magnified?	_____magnified? _____de-magnified?

Now repeat the "f" measurement using the small-diameter bi-convex lens at your table.

Small diameter lens:
f from image distance when object is "infinitely far": _______________ mm

PART III. BUILDING A TELESCOPE

Place the large-diameter convex lens (the "objective" lens) near one end of the optical bench so as to form a real image of a distant object on your white card. Now place the small-diameter convex lens (the "eyepiece" lens) with its focal point at the location of the real image formed by the objective. Remove the white card.

You have just constructed a simple refracting telescope. Put your eye near the eyepiece lens, and you will see an image of the object outside the window.

Describe the image:

________ upright? _________ inverted?

________ magnified? ________ de-magnified?

Compute the angular magnification of your telescope using $m = f_o / f_e$, where f_o and f_e are the focal length of the objective and eyepiece lenses, respectively.

m = __________________.

Your name ____________________________ Date ______________________

Group names ____

PRE-LAB EXERCISES

1. Derive the approximate relationship between R, a, and x: $R = a^2/2x$.

2. Use the mirror/lens equation to show that for a converging lens or mirror ($f>0$), i is positive (corresponding to a real image) if $o>f$, and i is negative (corresponding to a virtual image) if $o<f$.

3. Show that for a diverging lens or mirror ($f < 0$), i is negative no matter what the value of o.

Appendix: Set-up instructions

Number of stations:

Because of the difficulty of seeing past another group of students, try to use just three setups (of three students each, if necessary).

Equipment:

Each lab station should have, from SR1:

Optical bench
Light source, 3B3
Two lens holders, 3B3
Digital caliper, 1A5 (try not to use solar-powered ones, they require o'head lights)

From box 1, 3A2:
Spherometer
Concave/convex mirror, focal length 20 cm

From box 2, 3A2:
Biconcave lens
Biconvex lens, large-diameter, approx 50 cm focal length
Biconvex lens, small-diameter, approx 5 cm focal length
Cards to label concave and convex lenses
Round flat glass, white card

Parallax trick: To help students see virtual images, have them hold their head near the source and look toward the lens or mirror at the image. Have them close their right and left eyes in alternation. When using a convex mirror, the image will shift very little compared to a spot on the mirror, indicating it is far from the eye – behind the mirror. When using a concave lens, the image will shift a lot, indicating it is close to the eye than the lens -- on the same side of the lens as the source.

Caution during "lens" exploration. The shiny surfaces of the lens also act as curved mirrors! So there are additional images due to reflection beyond the "primary" one formed by refraction. Make sure students are looking at the "primary" one.