CENCO Physics Selective Experiments In Physics

• C.J. Overbeck Northwestern University • R.R. Palmer Beloit College • Marsh W. White The Pennsylvania State University

SPHERICAL MIRRORS

OBJECT: To study the laws of reflection of spherical mirrors, and to determine experimentally the focal length and radius of curvature of a convex and of a concave mirror.

METHOD: With the aid of an optical bench and its accessories the image formed by a spherical mirror is located, and from the measured distances of the object and the corresponding image from the mirror the focal length and radius of curvature of the mirror are calculated.

THEORY:
Definitions and Notation: A spherical mirror is a small section of a spherical shell. If the mirror surface is on the same side as the center of curvature of the sphere, it is called a concave mirror. If, however, the mirror surface is on the outside of the spherical shell, it is called a convex mirror.

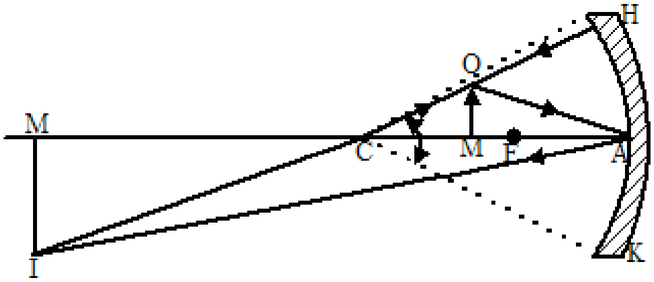

Fig. 1. Image formation by a concave mirror.

Let the center of curvature of the spherical reflecting surface HK (Fig. 1) be denoted by C. The axis of the surface with respect to a given point M is the straight line joining M with C, and the point A where the straight line MC (produced if necessary) meets the surface HK is called the pole or *vertex* of the surface with respect to the point M. If the point M is symmetrically situated with reference to the edges of the mirror, the axis is called the *principal* axis of the mirror. The angle HCK subtended at the point C by the edges of the mirror is called the angular aperture of the mirror.
When a beam of light from an infinitely distant object is incident upon a spherical mirror, it is either converged to a *real* focus somewhere in front of the mirror or diverged so that it appears to come from a *virtual* focus back of the mirror. The *principal focus* of a mirror is defined as the point through which a bundle of rays parallel to the axis of the mirror pass, or appear to pass, after reflection. The distance from the reflecting surface to the principal focus is called the *focal length*. When an object placed at one-point causes an image to be formed at another point, the two points are called *conjugate foci*. A real focus is one through which the beam of light actually passes, while a *virtual* focus is one to which the light only *appears* to go The corresponding images are likewise referred to as real and virtual. A *virtual* object is one toward which light converges before striking the mirror-for example, a point on the screen S in Fig. 8.
In the following treatment of spherical mirrors, this notation will be used:

u = object distance (measured from the object to the mirror)
v = image distance (measured from the mirror to the image)
f = focal length (measured from the mirror to the principal focus)
r = radius of curvature (measured from the mirror to the center of curvature)

The Convention of Signs: The object and image distances and focal lengths are considered positive if measured from *real* objects and *real* images and *real* foci, negative if measured from *virtual* objects and *virtual* images and *virtual* foci. The radius of curvature of a concave mirror is considered positive; of a convex mirror, negative.

Derivation of the Formula for a Spherical Mirror: In Fig. 1, let OM be an object in front of a concave mirror. A line drawn from O to I must pass through C, the center of curvature. To see that this is true, imagine a ray drawn from O toward the mirror-a prolongation of the line CO. It. will strike the mirror normally and be reflected straight back through O and C to the image which is at the point I. The angle OAM must be equal to the angle M' AI, since a ray OA after reflection must pass through I, and the angle of incidence must be equal to the angle of reflection. The triangles OAM and M' AI are similar, as are the triangles OMC and CIM. Taking the corresponding sides of the similar triangles,

$$CM/CM' = OM/IM' \qquad (1)$$

and

$$MA/M'A = OM/IM' \qquad (2)$$

Hence

$$CM/CM' = MA/M'A \qquad (3)$$

But from the figure it is easily seen, in terms of the above notation, that

$$MA = u \qquad (4)$$
$$M'A = v \qquad (5)$$
$$CM = r - u \qquad (6)$$

and

$$C'M = v - r \qquad (7)$$

Substituting these values in Eq. (1), it follows that

$$(r-u)/(v-r) = u/v \qquad (8)$$

Clearing of fractions,

$$rv - uv = uv - ur \qquad (9)$$
$$rv + ur = 2uv \qquad (10)$$

Dividing this equation by *uvr*,

$$1/u + 1/v = 2/r \qquad (11)$$

is the desired equation.
If the incident light is parallel, i.e., from a very distant object, $1/u = 0$ and $v = f$, the focal length. Hence

$$2/r = 1/f \qquad (12)$$

Consequently in Fig. 1 the distance *AF*, which is one half of *AC*, is the focal length f.
In the foregoing derivation it has been implicitly assumed that all the rays from the object point O which strike the mirror will pass the point I. This is found to be true only when the rays strike the mirror near the axis. It is only for a group of rays from O near the axis that the image at the point I is sharply defined.

Magnification: From Fig. 1 triangles IM' A and OMA are similar, hence $IM'/OM = M'A/MA$. The ratio of the size of the image IM' to the size of the object OM is called the magnification *m*, hence

$$m = v/u \qquad (13)$$

APPARATUS: The required apparatus consists of an optical bench with three carriages (Fig. 2), together with an extra carriage, for supporting accessories at various positions on the bench, a hooded screen, a combined object and image screen, two lens and mirror clamps, an object holder with 40watt lamp, a double convex lens of about six-inch focal length, and a concave and a convex mirror.

PROCEDURE:
Part I. Focal Length of a Concave Mirror:
By Coincidence: Place the concave mirror N in the holder B mounted on a carriage of the optical bench, with the concave surface of the mirror toward the source of light and the object O (Fig. 3). Use a combined object

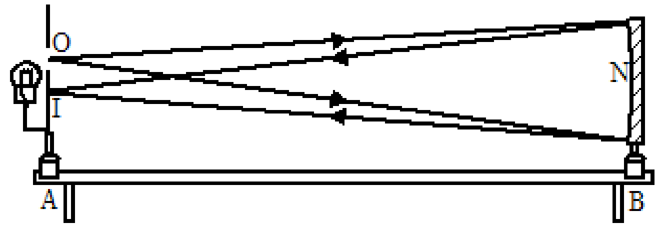

Fig. 3. Image I of an object O placed at the center of curvature of a concave mirror.


(a) (b)
Fig. 4. Object and Image Screen (a) for use in Holder (b).

and image screen consisting of an illuminated arrow and a white screen with partition between (Fig.4).
Starting near the combined object and image screen (which is mounted in the holder A), slide the mirror along the bench away from A until a sharp image I of the arrow is formed on the screen. Note and record the position of the mirror.
Next move the mirror farther away and approach the position of sharp definition of the image from the opposite direction and again note the position of the mirror. The distance from the mirror to the average of these two positions will give the radius of curvature *r* of the mirror.
By Conjugate Foci: Place a small white screen I (a white card will do) in the holder C between the object 0 and the concave mirror N (Fig. 5). The top of the white screen should be just below the bottom of the object. Find the image formed on the white screen when the mirror is 50cm from the object.
Measure both object and image distances and use these distances to compute the radius of curvature *r* and the focal length *f* of the mirror. Repeat these measurements with the mirror 80cm from the object, and again when it is at 120cm from the object, and from each set of readings compute *r* and *f*.


Fig. 2. The Optical Bench

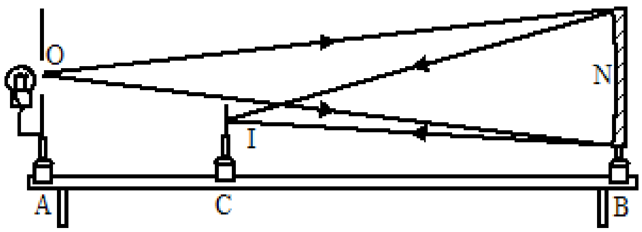

Fig. 5. Image I and object O at conjugate focal points of a concave mirror.

Part II. Focal Length of a Convex Mirror:

By Coincidence: Mount the convex lens L on the optical bench in the support D nearest the combined object and image screen at A (Fig. 6). Leave the carriage at C empty,

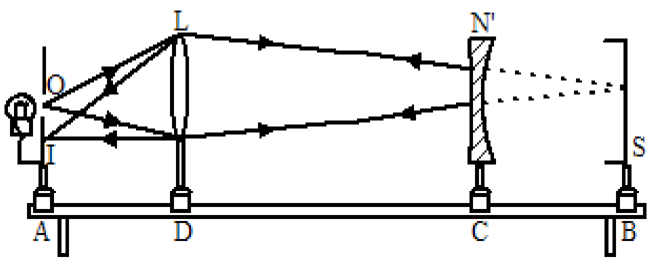

Fig. 6. Illustration of the coincidence method of finding the radius of curvature of a convex mirror.

and mount the white hooded screen S (Fig. 7) on the support B. Form an image on the hooded screen placed about 80cm from the illuminated object O.

Now support the convex mirror N' at C between the lens and hooded screen, and adjust its position until an image I is formed just beside the object O. If the radius of curvature is greater than the distance from the hooded screen to the lens, no sharp image can be formed on the screen and it will be necessary to refocus, increasing the distance between the object and the hooded screen. Determine the distance between the mirror and the hooded screen with the screen in a different position. Obtain a second set of readings. Observe *r* and calculate *f* from each set of observations.

By Conjugate Foci: Place the convex lens L 40 to 50cm from the object O (Fig. 8), and with the hooded screen S locate the image formed. Note in this case that the image rays are highly convergent. Insert the convex mirror N' about

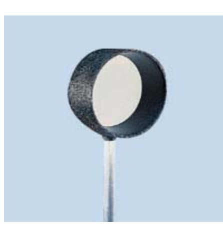
Fig. 7. Hooded Screen

10cm in front of the hooded screen and adjust its position until an image I is formed on apiece of white paper P held on and partly covering the nearest face of the convex lens.

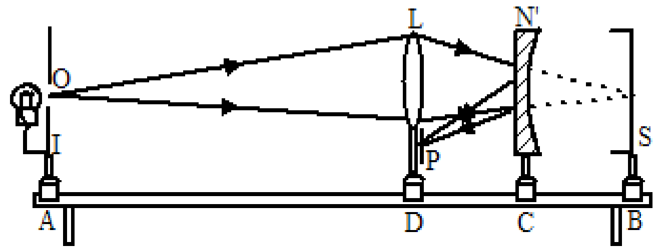

Fig. 8. Illustration of the conjugate foci method of finding the focal length of a convex mirror.

Record the lens to mirror distance *v*, the mirror to hooded screen distance u, and from these compute *f* and *r*. The wire gauze may be preferred as an object in this arrangement. If so, it may be inserted in the holder shown in Fig. 4 (b).

Interpretation of Data: Arrange in tabular form the observed and calculated values of *r*, *u, v* and the values of *f* calculated from Eq. (12) for both mirrors. Compute an average value of the focal length of each mirror.

QUESTIONS: 1. Make a construction showing the size and position of the image formed by a concave mirror, having a radius of curvature of 3in, of an object 1/2in long placed 4 inches in front of the mirror. Make full sized drawing.

2. A candle is placed 3ft in front of a concave mirror having a focal length of 1-1/2ft; where is the image, and how large?

3. How far must a man stand from a concave mirror having a focal length of 2ft in order that he may see an erect image of his face just twice its natural size?

4. An object 10cm high is placed 15cm in front of a spherical convex mirror with a radius of curvature = 6cm. Calculate the position and size of the image and give a drawing of the construction.

5. The radius of curvature of a convex mirror is 16in. Where is the image of an object 4ft from the mirror? If the object is 6in long, how long is the image?