

Module 1 : Reflection from Plane and Spherical Surfaces

This module is designed to help you to:

- explain the phenomenon of reflection from plane surfaces and curved spherical surfaces;
- verify the laws of reflection, i.e.,/the incident ray, reflected ray and the normal at the point of incidence are coplanar and the angle of incidence is equal to the angle of reflection;
- explain how the number of images formed between two plane mirrors is dependent on the angle between the plane mirrors;
- apply the concept of sign convention and mirror equations in the formation of images for objects kept at different positions in case of convex and concave mirrors.

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9.1.1 Introduction

Ray optics is studied, and developed, on the basis of our intuitive notion that light propagates along a straight path. This notion of straight-line propagation seems an obviously valid notion on the basis of our usual daily life observations. We ordinarily do not observe light bending its path anywhere during its passage from one point to another.

A ray of light encountering a different medium may move back into the same medium or enter the second medium. The former is called *reflection* and the latter is called *refraction*, which is characterized by a change in the velocity of light.

In this module, we shall discuss reflection and refraction of light from plane and curved spherical surfaces. In the process, we shall get to know about the formation of multiple images of an object by way of its reflection from two mirrors inclined at a particular angle between each other. We shall also study the formation of images by spherical surfaces by applying the relevant equation connecting the object and image distances, the focal length and the radius of curvature.

9.1.2 Reflection

Reflection may be viewed as the bouncing back, of a ray of light, in the same medium when this light ray encounters a surface separating the original medium from another medium.

According to the laws of reflection of light,

1. The incident ray and the reflected ray and the normal at the point of incidence, all lie in the same plane.
2. The angle of reflection is equal to the angle of incidence.

(i.e., $\angle r = \angle i$)

Activity 9.1.1

Verify the laws of reflection by drawing a ray diagram on a sheet of plane paper, using a plane mirror and pins/laser light.

Clearly indicate the incident ray, reflected ray, normal at the point of incidence, angle of incidence and angle of reflection.

Activity 9.1.2 Ray tracing to find the image of a point object kept in front of a plane mirror (laser light may be used).

Consider a point object P kept in front of a plane mirror. We need to find the position of the image formed by this plane mirror. We use the laws of reflection for constructing the ray diagram.

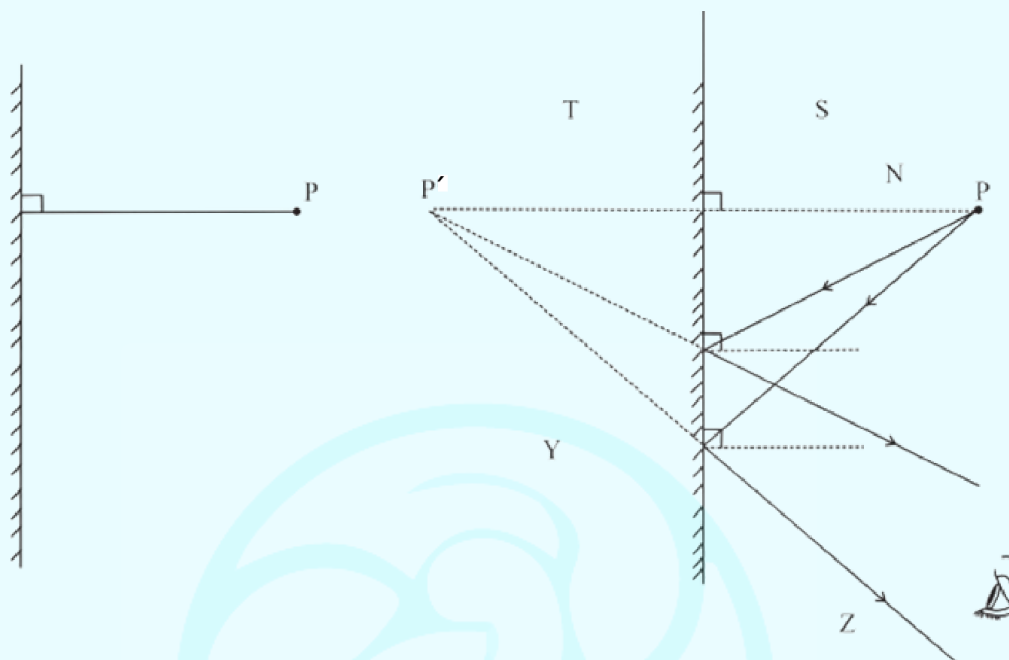


Fig. 9.1.1 Ray diagram for image of a point object in front of a plane mirror

Take any two rays originating from the object P directed towards the mirror. The mirror would reflect them according to the laws of reflection, that is $\angle r = \angle i$. To an observer, the reflected rays appear to come from a point P'. The object point P, as seen through the mirrors, appears to be at P'. We say that the point P' is the image of point P as formed by the plane mirror. As we are not calculating any value here, so sign conventions are irrelevant.

Teachers may ask students to continue this exercise, with (incident) rays drawn along say PS and PN. Draw the corresponding reflected rays so that each ray obeys $i = r$. It would be seen that all reflected rays appear to originate from P'. The point P' is therefore, the point that can be regarded as the source of all the reflected rays. Different incident rays can be drawn with different colors for the sake of convenience.

Suppose the observer is at positions T and Y. Would she/he be able to see the object P or its image P'? Explain your answer

Activity: 9.1.3 Multiple images formed by a combination of plane mirrors

When two plane mirrors are inclined at an angle θ (in degree) with respect to each other, they form a number (n) of images of a given point object. This number, n is given by $n = \left(\frac{360}{\theta}\right) - 1$. Thus, if we take two mirrors, with an angle of 90° (60°) between them, they should form 3 (5) images. Verify the number of images by drawing ray diagrams in each case.

What happens if $\theta = 0^\circ$? The number, n as per the formula given above, then tends to *infinity*. Let students check this limiting case result, by drawing ray diagrams, *or* by locating a practical setup in which they actually see tending to an infinite number of images.

9.1.3 Spherical mirrors

Spherical mirrors are polished curved spherical surfaces which reflect light.

They are of two types: a) convex mirrors and b) concave mirrors

The centre of the sphere of which the mirror is a part is called the centre of curvature and the radius of the sphere is called the radius of curvature of the spherical mirror.

Sign convention

To derive the relevant formulae for reflection by spherical mirrors, we need to adopt a sign convention for measuring distances. Refer to Fig 9.1.2.

In this module, we shall follow the cartesian sign convention. According to this convention, all ray diagrams must be drawn with light rays propagating from left to right. All distances are measured from a reference point which is taken as the pole of the (spherical) mirror. Distances measured in the same direction, as that of propagation of the incident light, are taken as positive and those measured in the direction opposite to the incident direction are taken as negative.

Heights, measured upwards, and normal to the principal axis (x-axis), of the mirror, are taken as positive. All heights measured downwards are taken as negative. With this sign convention, we can use a single formula for spherical mirrors, to handle all cases pertaining to different positions of the object with respect to the spherical (convex as well as concave) mirror.

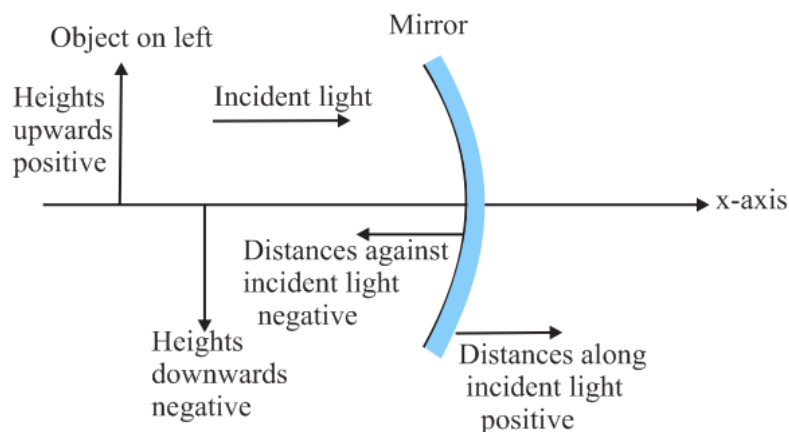


Fig. 9.1.2 *Cartesian sign convention*

9.1.4 Reflection at a spherical surface

Convex mirror

Consider a convex surface. We may take a circle of appropriate radius, a part of this circle can act as a convex mirror as shown. The concave surface which is spherical has the same radius as that of the circle with its centre at the point C. Since C is the centre, any line joining C to any point, N, on the mirror, will be the normal to the spherical mirror at the point N. Take a ray (No.1), starting from the point object, O, to be incident on the convex mirror. Draw the reflected ray as per the law $\angle r = \angle i$. Take another ray (no. 2) directed towards the centre of curvature, C, and reflected back by the mirror. This ray is incident normally and will retrace its path backward after reflection. Both these rays appear to come from the point O'. You may take other incident rays (like ray 3) from O and verify that, after reflection, they all appear to come from O'. Thus O' is the image of the point object O, due to the given convex mirror.

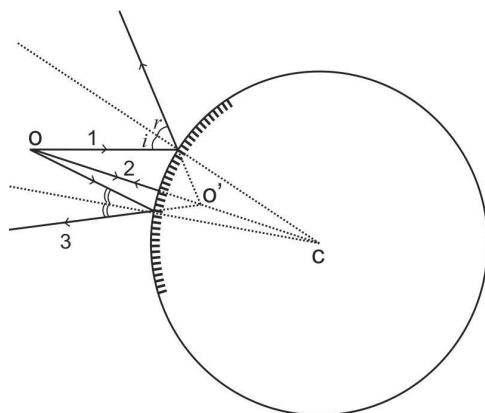


Fig.9.1.3. Image of a point object O in front of a convex mirror

Concave Mirror

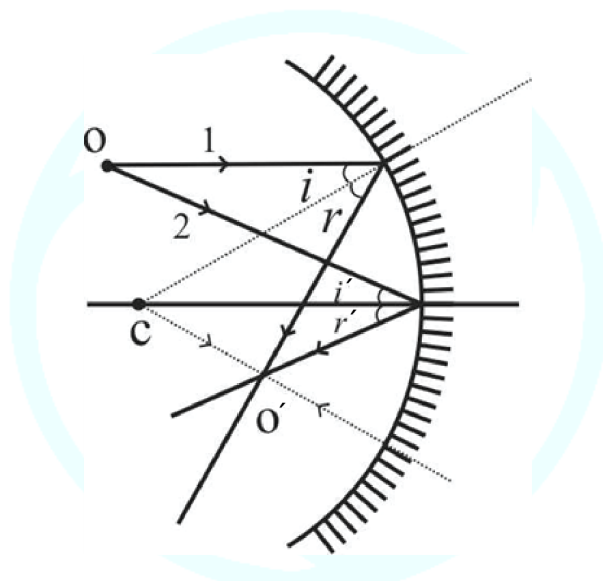


Fig. 9.1.4 Image of a point object O in front of a concave mirror.

Consider a concave surface. We may take a circle of appropriate radius, a part of this circle can act as a concave mirror as shown. The concave surface, which is spherical, has the same radius as that of the circle with its centre at the point C . Since C is the centre, any line joining C to any point, N , on the mirror, will be the normal to the spherical mirror at the point N . Take a ray, (no.1), starting from the point object, O , to be incident on the concave mirror. Draw the reflected ray as per the law $\angle r = \angle i$. Take another ray (no. 2) and show its reflection by the mirror. Both these rays meet at the point O' . Thus O' is the image of the point object O , due to the given concave mirror.

Activity: 9.1.4

Take an extended object (say AB) in front of a convex mirror. Draw a ray diagram to locate the images A' B' of points A and B. Join A' to B'. Now you can see the shape of the image of an extended object AB, as formed by a given convex mirror.

9.1.5 Focal length, mirror equation, and magnification of images by spherical mirrors

The distance from the centre of curvature to any point on the surface of the mirror is the radius of curvature of the mirror.

At this stage, we introduce the concept of paraxial rays. A paraxial ray is a ray that establishes an extremely small angle (θ) towards the principal axis as well as remains close to it throughout the entire system.

When paraxial rays parallel to the principal axis get reflected from the concave mirror, then after reflection, they converge to a point on the principal axis (Fig. 9.1.5). This point is known as the focus of the mirror.

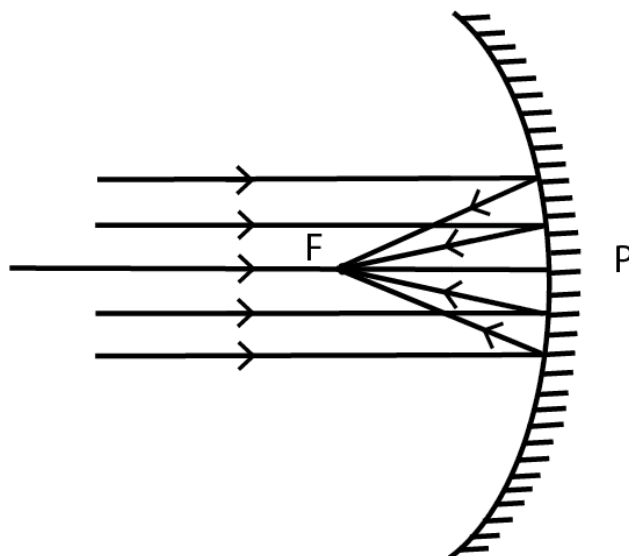


Fig.9.1.5 *F is the focus of the mirror, P is the pole.*

The distance PF = The focal length

Focal length of spherical mirrors is given by $f = \frac{R}{2}$ where R = radius of curvature of spherical mirror.

Mirror equation gives a relationship between object distance (u), image distance (v) and focal length (f) of a spherical mirror. It is given by $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$. While using the mirror equation the sign conventions must be taken into consideration.

Magnification produced by a spherical mirror is $m = \frac{h'}{h}$ where h is the size of the object and h' is the size of the image. Using mirror equation $m = -\frac{v}{u}$

Example 9.1.1 A 4.5 cm long needle is placed normal to the principal axis of a convex mirror of focal length 15 cm. The lower end of the needle lies on the principal axis and is at a distance of 12 cm from the pole, P, of the mirror. Find the location of the image and its magnification. Describe what happens as the needle is moved farther away from the mirror.

Solution Applying proper sign convention, we have $u = -12$, $f = +15$. So, we have the mirror equation as

$$\frac{1}{v} + \frac{1}{-12} = \frac{1}{15}$$

$$\text{or } \frac{1}{v} = \frac{1}{12} + \frac{1}{15} = \frac{9}{60} = \frac{3}{20}$$

$$v = \frac{20}{3} = 6.7$$

So, the image appears to be formed at a distance of 6.7 cm, from the pole of the mirror, towards its right.

Magnification $\frac{-v}{u} = \frac{-\frac{20}{3}}{-12} = \frac{20}{36} = \frac{5}{9}$, i.e., the size of the image is $\frac{5}{9} \times 4.5 = 2.5$ cm. As $u \rightarrow \infty$; $v \rightarrow f$, (but never beyond).

Example 9.1.2: A small candle, 2.5 cm in size is placed 27.0 cm, in front of a concave mirror of radius of curvature 36.0 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

Solution Applying the sign convention, we have,

$$u = -27, f = -\frac{36}{2} = -18$$

$$\therefore \frac{1}{v} + \frac{1}{-27} = \frac{1}{-18}$$

$$\text{or, } \frac{1}{v} = \frac{1}{-18} + \frac{1}{27} = \frac{-3-2}{54} = -\frac{1}{54}$$

$\therefore v = -54.0$ cm. (According to Cartesian convention the negative sign here indicates that the image is formed in front of the mirror.) The screen should therefore be placed at a distance of 54.0 cm from the mirror. The image is real, inverted and magnified. The size of the image is 5.0 cm. As $u \rightarrow f$, $v \rightarrow \infty$; For $u < f$, the image formed is virtual. (Draw the ray diagram for an object distance of 12 cm (say) and verify that the image appears to be formed behind the mirror, i.e., it is a virtual image.)

Activity 9.1.5

- i) For a spherical mirror, we have $f = R/2$, i.e. the focal point is midway between the pole of the mirror and its centre of curvature. You may take any two parallel rays (two laser beams). At their respective points of incidence, draw normal to the mirror (all radii are normal to a sphere). Construct the reflected rays and observe where they meet, or appear to meet. This point will be seen to lie in the focal plane. If this point lies on the principal axis, it is the focal point. Try to establish $f = R/2$, using your ray diagram, or otherwise. Do you find any difference between your observation and this accepted result?
- (ii) You may construct the image of an extended (linear) object (say a pin) kept normal to the principal axis of a spherical mirror, at different positions: say
 - (a) $u \rightarrow \infty$ (b) $u > 2f$ (c) $u = 2f$ (d) $f < u < 2f$ (e) $u = f$ (f) $u < f$
 (Here u = distance of object from the pole of the mirrors, f = magnitude of the focal length of the mirror)



Q.9.1.1 Consider a point object O in front of a concave mirror at distance equal to $2f$ where f is focal length and at height h above the principle axis (Fig.9.1.6) .Where will its image be?

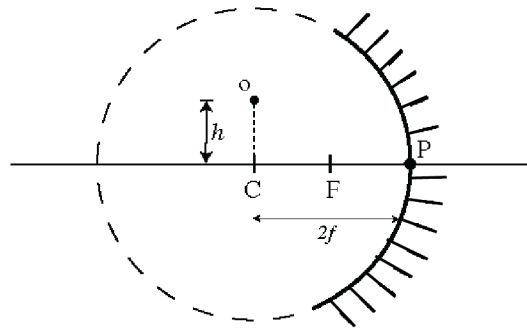


Fig.9.1.6

Q.9.1.2 An object kept in front of a convex mirror has its image formed at the point between the pole of the mirror and focal point. Where should a plane mirror be kept so that the image formed by the plane mirror coincides with the image formed by the convex mirror (Fig.9.1.7) ?

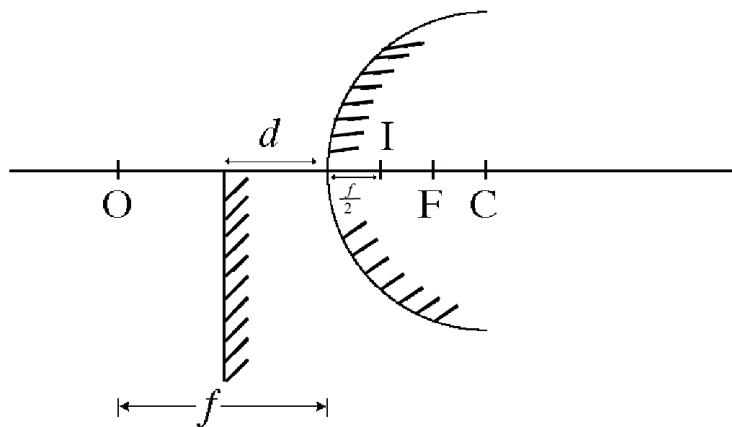


Fig.9.1.7



Answers

A.9.1.1 Since the object is at a distance $2f$, the image will be at the same distance from the mirror which means the image distance will also be $2f$.

If object O was at the pin tip, the image of the pin will be inverted at C (Fig.9.1.8). The magnification

$$m = \frac{v}{u} = -1$$

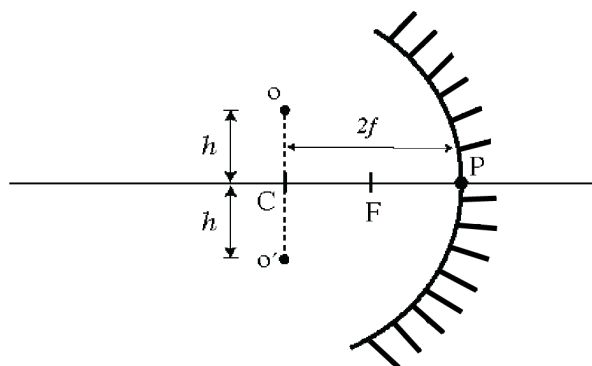


Fig.9.1.8

The image of O will be at the same distance h but on the other side of the principal axis.

A.9.1.2 Let the focal length of convex mirror be f . Therefore image due to convex mirror will be at distance $\frac{f}{2}$ inside the mirror.

$$\text{For convex mirror } v = \frac{f}{2} \Rightarrow \frac{1}{u} = \frac{1}{f} - \frac{1}{v} = -\frac{1}{f} \Rightarrow u = -f$$

$$\therefore \text{distance between object and image} = f + \frac{f}{2} = \frac{3f}{2}$$

$$\therefore \text{mirror should be at a distance } \frac{\frac{3f}{2}}{2} = \frac{3f}{4}$$

From the image

$$\text{This means } d = \frac{3f}{4} - \frac{f}{2} = \frac{f}{4}$$

9.1.6 Summary

- A ray of light reflected from the surface of the mirror follows the laws of reflection. The incident ray, the reflected ray and the normal to the surface of separation lie on the same plane, and

$$\text{Angle of reflection } (r) = \text{Angle of incidence } (i)$$

- The image formed by a plane mirror is behind the plane mirror at a distance equal to the object distance in front of the mirror. The line joining the image and the object is perpendicular to the surface of the mirror.
- Multiple images are formed by a combination of plane mirrors the number being equal to

$$n = \left(\frac{360}{\theta} \right) - 1$$

where θ is the angle between the two mirrors measured in degrees.

- Cartesian sign convention requires us to fix the principal axis and the pole of the spherical mirror and then all distances measured above the principal axis and in the direction of the incident light are positive while all distances below the principal axis and opposite to the direction of the incident light are negative.
- Reflection at a spherical surface can be understood by drawing ray diagrams and applying the laws of reflection. The images thus formed (ray diagrams) by a convex/concave mirror can be real or virtual depending on whether they can be obtained on a screen or not.
- For spherical mirrors, $f = \frac{R}{2}$

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

$$m = \frac{h'}{h} = -\frac{v}{u}$$

Where u = object distance, v = image distance and f = focal length.

h = size of object and h' = size of image.

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