Activity 10.13

- Take a concave lens. Place it on a lens stand.
- Place a burning candle on one side of the lens.
- Look through the lens from the other side and observe the image. Try to get the image on a screen, if possible. If not, observe the image directly through the lens.
- Note down the nature, relative size and approximate position of the image.
- Move the ca[redacted]
of the imag[redacted]
candle is pl[redacted]

The summar[redacted]

Table 10.5 Natu[redacted]ave lens for various posi[redacted]

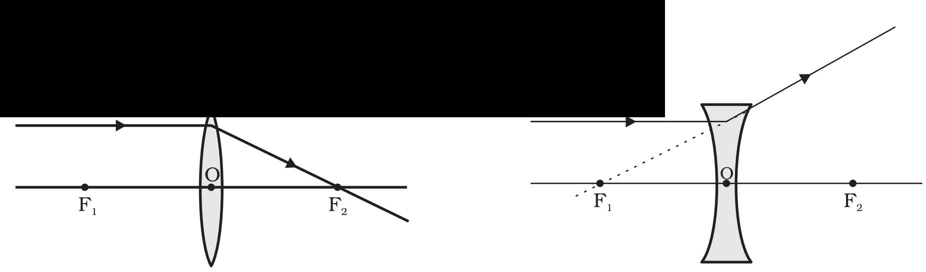
Position of th[redacted] object	[redacted]	Nature of the image
At infinity	[redacted]	[redacted]tual and erect
Between infin[redacted] optical centre[redacted] of the lens	[redacted]	[redacted]tual and erect

What conclu[redacted] will always give a[redacted] position of the ob[redacted]

10.3.5 Image[redacted]

We can represen[redacted] diagrams will als[redacted] of the image form[redacted] of spherical mirr[redacted]

(i) A ray of li[redacted] refraction[redacted] on the oth[redacted] a concave[redacted] the ray ap[redacted] to diverge from the principal focus located on the same side of the lens, as shown in Fig. 10.13 (b).



(a) (b)

Figure 10.13

2019-20

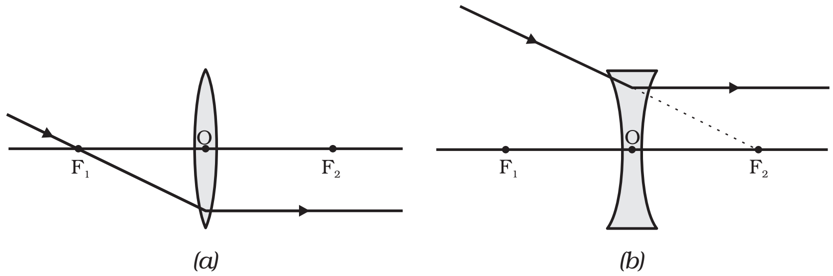


Figure 10.14

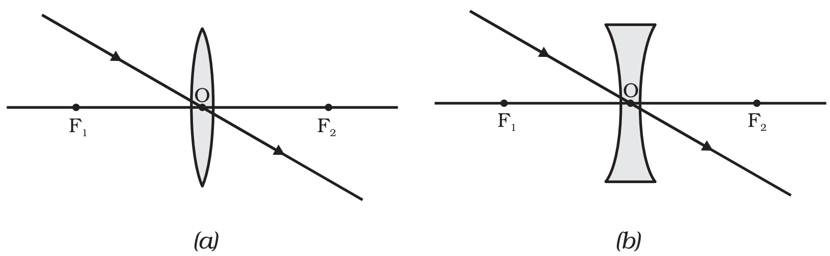
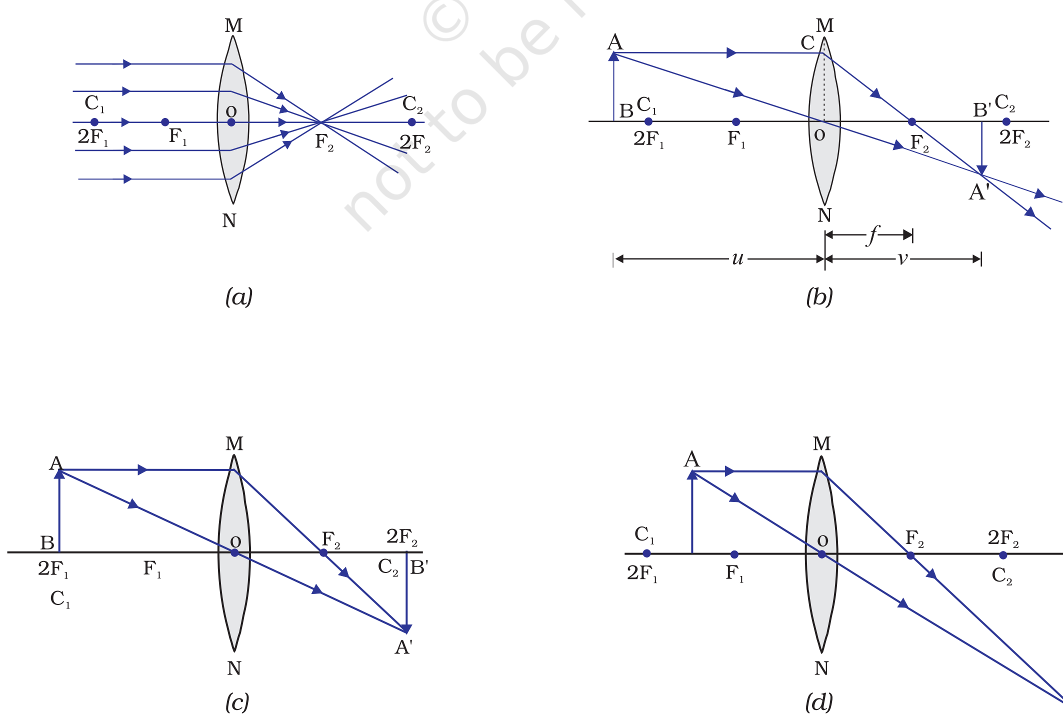


Figure 10.15

(ii) A ray of light passing through a principal focus, after refraction from a convex lens, will emerge parallel to the principal axis. This is shown in Fig. 10.14 (a). A ray of light appearing to meet at the principal focus of a concave lens, after refraction, will emerge parallel to the principal axis. This is shown in Fig.10.14 (b).

(iii) A ray of light passing through the optical centre of a lens will emerge without any deviation. This is illustrated in Fig.10.15(a) and Fig.10.15 (b).

The ray diagrams for the image formation in a convex lens for a few positions of the object are shown in Fig. 10.16. The ray diagrams representing the image formation in a concave lens for various positions of the object are shown in Fig. 10.17.



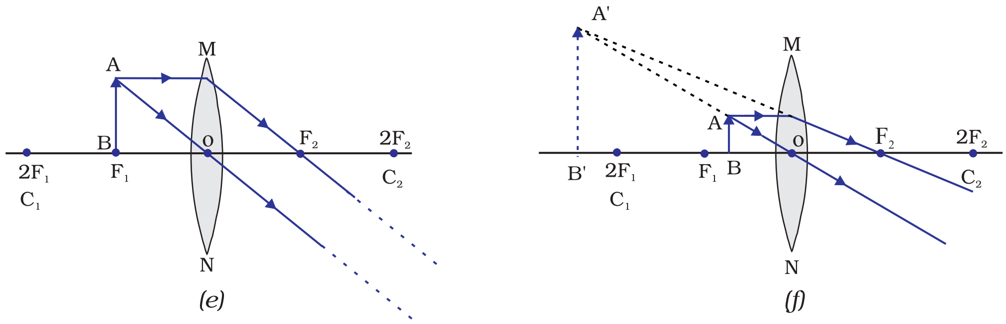


Figure 10.16 *The position, size and the nature of the image formed by a convex lens for various positions of the object*

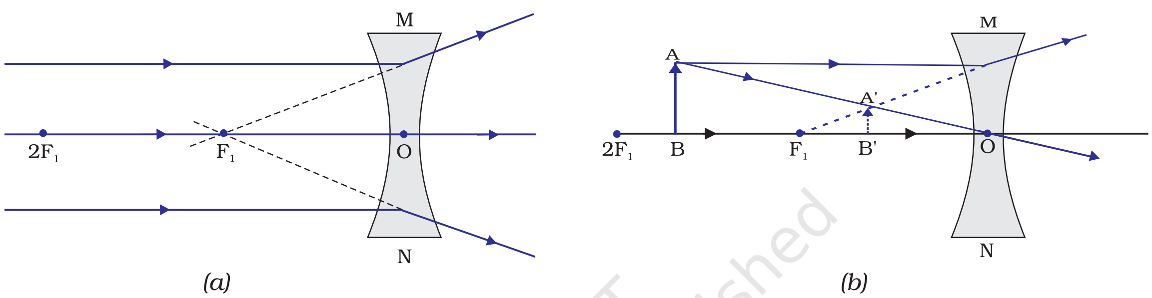


Figure 10.17 *Nature, position and relative size of the image formed by a concave lens*

10.3.6 Sign Convention for Spherical Lenses

For lenses, we follow sign convention, similar to the one used for spherical mirrors. We apply the rules for signs of distances, except that all measurements are taken from the optical centre of the lens. According to the convention, the focal length of a convex lens is positive and that of a concave lens is negative. You must take care to apply appropriate signs for the values of u, v, f, object height h and image height h'.

10.3.7 Lens Formula and Magnification

As we have a formula for spherical mirrors, we also have formula for spherical lenses. This formula gives the relationship between object-distance (u), image-distance (v) and the focal length (f). The lens formula is expressed as

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \qquad (10.8)$$

The lens formula given above is general and is valid in all situations for any spherical lens. Take proper care of the signs of different quantities, while putting numerical values for solving problems relating to lenses.

Magnification

The magnification produced by a lens, similar to that for spherical mirrors, is defined as the ratio of the height of the image and the height of the object. Magnification is represented by the letter m. If h is the height of the object and h' is the height of the image given by a lens, then the magnification produced by the lens is given by,

$$m = \frac{\text{Height of the Image}}{\text{Height of the object}} = \frac{h'}{h} \quad (10.9)$$

Magnification produced by a lens is also related to the object-distance u, and the image-distance v. This relationship is given by

$$\text{Magnification } (m) = h'/h = v/u \quad (10.10)$$

Example 10.3

A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also, find the magnification produced by the lens.

Solution

A concave lens always forms a virtual, erect image on the same side of the object.

Image-distance v = –10 cm;

Focal length f = –15 cm;

Object-distance u = ?

Since $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

or, $\frac{1}{u} = \frac{1}{v} - \frac{1}{f}$

$$\frac{1}{u} = \frac{1}{-10} - \frac{1}{(-15)} = -\frac{1}{10} + \frac{1}{15}$$

$$\frac{1}{u} = \frac{-3+2}{30} = \frac{1}{-30}$$

or, $u = -30$ cm

Thus, the object-distance is 30 cm.

Magnification $m = v/u$

$$m = \frac{-10\text{ cm}}{-30\text{ cm}} = \frac{1}{3} \simeq +0.33$$

The positive sign shows that the image is erect and virtual. The image is one-third of the size of the object.

Example 10.4

A 2.0 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 10 cm. The distance of the object from the lens is 15 cm. Find the nature, position and size of the image. Also find its magnification.

Solution

Height of the object h = + 2.0 cm;
Focal length f = + 10 cm;
object-distance u = –15 cm;
Image-distance v = ?
Height of the image h' = ?

Since $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

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

$$\frac{1}{v} = \frac{1}{(-15)} + \frac{1}{10} = -\frac{1}{15} + \frac{1}{10}$$

$$\frac{1}{v} = \frac{-2+3}{30} = \frac{1}{30}$$

or, v = + 30 cm

The positive sign of v shows that the image is formed at a distance of 30 cm on the other side of the optical centre. The image is real and inverted.

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

or, $h' = h\,(v/u)$

Height of the image, h' = (2.0) (+30/–15) = – 4.0 cm

Magnification $m = v/u$

or, $m = \frac{+30\,\text{cm}}{-15\,\text{cm}} = -2$

The negative signs of m and h' show that the image is inverted and real. It is formed below the principal axis. Thus, a real, inverted image, 4 cm tall, is formed at a distance of 30 cm on the other side of the lens. The image is two times enlarged.

10.3.8 Power of a Lens

You have already learnt that the ability of a lens to converge or diverge light rays depends on its focal length. For example, a convex lens of short focal length bends the light rays through large angles, by focussing them closer to the optical centre. Similarly, concave lens of very short focal length causes higher divergence than the one with longer focal length. The degree of convergence or divergence of light rays achieved by a lens is expressed in terms of its power. The power of a lens is defined as the reciprocal of its focal length. It is represented by the letter P. The power P of a lens of focal length f is given by

$$P = \frac{1}{f} \qquad (10.11)$$

The SI unit of power of a lens is 'dioptre'. It is denoted by the letter D. If f is expressed in metres, then, power is expressed in dioptres. Thus, 1 dioptre is the power of a lens whose focal length is 1 metre. $1D = 1m^{-1}$. You may note that the *power of a convex lens is positive and that of a concave lens is negative.*

Opticians prescribe corrective lenses indicating their powers. Let us say the lens prescribed has power equal to + 2.0 D. This means the lens prescribed is convex. The focal length of the lens is + 0.50 m. Similarly, a lens of power – 2.5 D has a focal length of – 0.40 m. The lens is concave.

More to Know!

Many optical instruments consist of a number of lenses. They are combined to increase the magnification and sharpness of the image. The net power (P) of the lenses placed in contact is given by the algebraic sum of the individual powers P_1, P_2, P_3, … as $P = P_1 + P_2 + P_3 + \ldots$

The use of powers, instead of focal lengths, for lenses is quite convenient for opticians. During eye-testing, an optician puts several different combinations of corrective lenses of known power, in contact, inside the testing spectacles' frame. The optician calculates the power of the lens required by simple algebraic addition. For example, a combination of two lenses of power + 2.0 D and + 0.25 D is equivalent to a single lens of power + 2.25 D. The simple additive property of the powers of lenses can be used to design lens systems to minimise certain defects in images produced by a single lens. Such a lens system, consisting of several lenses, in contact, is commonly used in the design of lenses of camera, microscopes and telescopes.

QUESTIONS

1. Define 1 dioptre of power of a lens.
2. A convex lens forms a real and inverted image of a needle at a distance of 50 cm from it. Where is the needle placed in front of the convex lens if the image is equal to the size of the object? Also, find the power of the lens.
3. Find the power of a concave lens of focal length 2 m.

What you have learnt

- Light seems to travel in straight lines.
- Mirrors and lenses form images of objects. Images can be either real or virtual, depending on the position of the object.
- The reflecting surfaces, of all types, obey the laws of reflection. The refracting surfaces obey the laws of refraction.
- New Cartesian Sign Conventions are followed for spherical mirrors and lenses.

- Mirror formula, $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$, gives the relationship between the object-distance (u), image-distance (v), and focal length (f) of a spherical mirror.
- The focal length of a spherical mirror is equal to half its radius of curvature.
- The magnification produced by a spherical mirror is the ratio of the height of the image to the height of the object.
- A light ray travelling obliquely from a denser medium to a rarer medium bends away from the normal. A light ray bends towards the normal when it travels obliquely from a rarer to a denser medium.
- Light travels in vacuum with an enormous speed of 3×10^{8} m s^{-1}. The speed of light is different in different media.
- The refractive index of a transparent medium is the ratio of the speed of light in vacuum to that in the medium.
- In case of a rectangular glass slab, the refraction takes place at both air-glass interface and glass-air interface. The emergent ray is parallel to the direction of incident ray.
- Lens formula, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$, gives the relationship between the object-distance (u), image-distance (v), and the focal length (f) of a spherical lens.
- Power of a lens is the reciprocal of its focal length. The SI unit of power of a lens is *dioptre*.

EXERCISES

1. Which one of the following materials cannot be used to make a lens?
   (a) Water (b) Glass (c) Plastic (d) Clay
2. The image formed by a concave mirror is observed to be virtual, erect and larger than the object. Where should be the position of the object?
   (a) Between the principal focus and the centre of curvature
   (b) At the centre of curvature
   (c) Beyond the centre of curvature
   (d) Between the pole of the mirror and its principal focus.
3. Where should an object be placed in front of a convex lens to get a real image of the size of the object?
   (a) At the principal focus of the lens
   (b) At twice the focal length
   (c) At infinity
   (d) Between the optical centre of the lens and its principal focus.
4. A spherical mirror and a thin spherical lens have each a focal length of –15 cm. The mirror and the lens are likely to be
   (a) both concave.
   (b) both convex.

(c) the mirror is concave and the lens is convex.
(d) the mirror is convex, but the lens is concave.

5. No matter how far you stand from a mirror, your image appears erect. The mirror is likely to be
   (a) only plane.
   (b) only concave.
   (c) only convex.
   (d) either plane or convex.
6. Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
   (a) A convex lens of focal length 50 cm.
   (b) A concave lens of focal length 50 cm.
   (c) A convex lens of focal length 5 cm.
   (d) A concave lens of focal length 5 cm.
7. We wish to obtain an erect image of an object, using a concave mirror of focal length 15 cm. What should be the range of distance of the object from the mirror? What is the nature of the image? Is the image larger or smaller than the object? Draw a ray diagram to show the image formation in this case.
8. Name the type of mirror used in the following situations.
   (a) Headlights of a car.
   (b) Side/rear-view mirror of a vehicle.
   (c) Solar furnace.

   Support your answer with reason.
9. One-half of a convex lens is covered with a black paper. Will this lens produce a complete image of the object? Verify your answer experimentally. Explain your observations.
10. An object 5 cm in length is held 25 cm away from a converging lens of focal length 10 cm. Draw the ray diagram and find the position, size and the nature of the image formed.
11. A concave lens of focal length 15 cm forms an image 10 cm from the lens. How far is the object placed from the lens? Draw the ray diagram.
12. An object is placed at a distance of 10 cm from a convex mirror of focal length 15 cm. Find the position and nature of the image.
13. The magnification produced by a plane mirror is +1. What does this mean?
14. An object 5.0 cm in length is placed at a distance of 20 cm in front of a convex mirror of radius of curvature 30 cm. Find the position of the image, its nature and size.
15. An object of size 7.0 cm is placed at 27 cm in front of a concave mirror of focal length 18 cm. At what distance from the mirror should a screen be placed, so that a sharp focussed image can be obtained? Find the size and the nature of the image.
16. Find the focal length of a lens of power – 2.0 D. What type of lens is this?
17. A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?