Chapter

5 Refraction Through A Lens

SYLLABUS

Lenses (converging and diverging) including characteristics of the images formed (using ray diagrams only), magnifying glass, location of images using ray diagrams and thereby determining magnification.

Scope of syllabus : Types of lenses (converging and diverging), convex and concave action of a lens as a set of prism, technical terms : centre of curvature, radius of curvature, principal axis, foci, focal plane and focal length, detailed study of refraction of light in spherical lenses through ray diagrams, formation of images – principal rays or construction rays, location of images from ray diagrams for various positions of a small linear object on the principal axis, characteristics of images, sign convention and direct numerical problems using the lens formula are included (derivation of formula not required). **Scale drawing or graphical representation of ray diagrams not required.**

Power of a lens (concave and convex), simple direct numicrical problems. Magnifiying glass or simple microscope, location of image and magnification from ray diagram only (formula and numerical problems *not* included). Applications of lenses.

(A) LENS AND REFRACTION OF LIGHT THROUGH A LENS

5.1 LENS

We are all familiar with the use of lenses in spectacles. We define a lens as follows :

A lens is a transparent refracting medium bounded by either two spherical surfaces or one surface spherical and other surface plane.

Note : A plane surface can be treated as a spherical surface of infinite radius of curvature.

Kind of lenses : Lenses are of *two* kind :

(1) *convex* or *converging lens,* and

(2) *concave* or *diverging lens.*

(1) *Convex* or *converging lens*

A convex lens is thick in its middle and thin at the periphery. In other words, a lens which bulges out in the middle, is the convex lens. A light beam converges on passing through such a lens, so it is also called the converging lens.

A convex lens may be of the following *three* kinds :

(i) bi-convex or double-convex or equi-convex,

(ii) plano-convex, and

(iii) concavo-convex.

Fig. 5.1 shows the shape of the different kind of convex lenses.

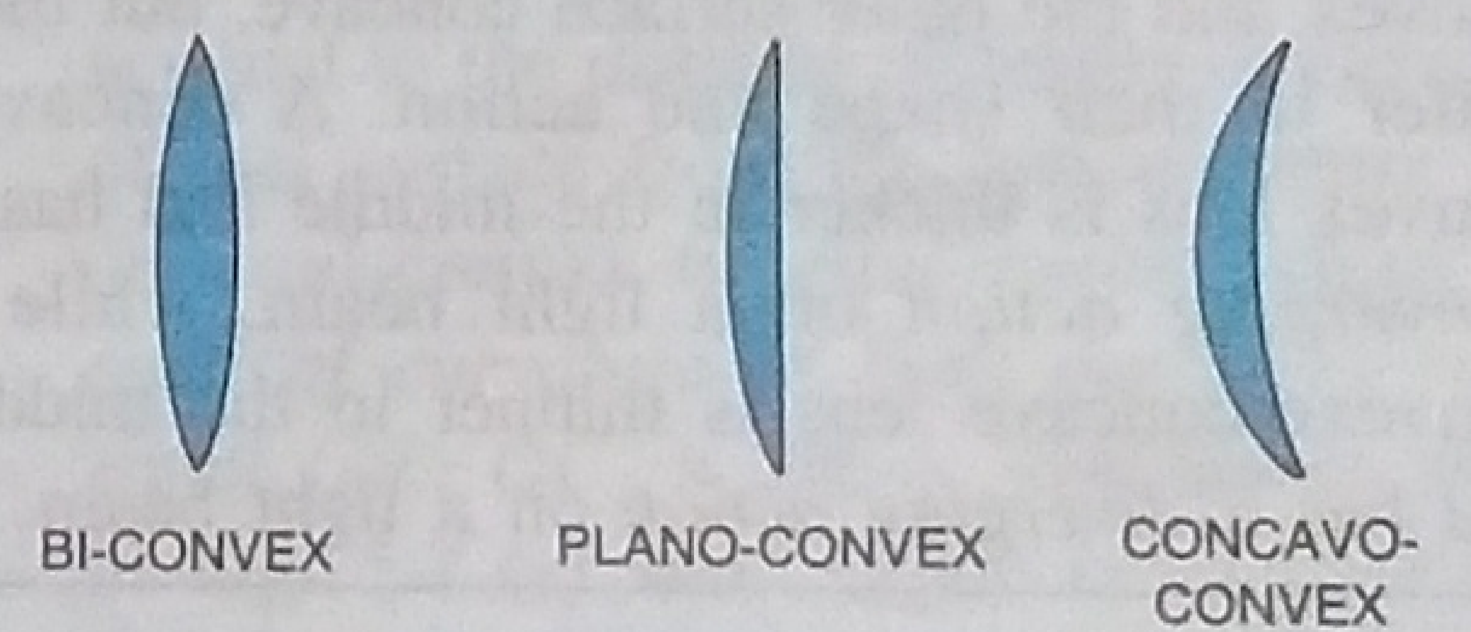


Fig. 5.1 Convex lenses

A biconvex lens has both its surfaces convex, a plano-convex lens has one surface plane and the other surface convex, while a concavo-convex lens has one surface convex and the other surface concave such that it is thicker in the middle as compared to its periphery.

(2) *Concave or diverging lens*

A concave lens is thick at its periphery and thin in the middle. In other words, a lens which is bent inwards in the middle, is the concave lens. Such a lens diverges the light rays incident on it, so it is also called the diverging lens.

A concave lens may be of the following *three* kinds :

(i) bi-concave or double-concave or equi-concave,

(ii) plano-concave, and

(iii) convexo-concave.

Fig. 5.2 shows the shape of different kind of concave lenses.

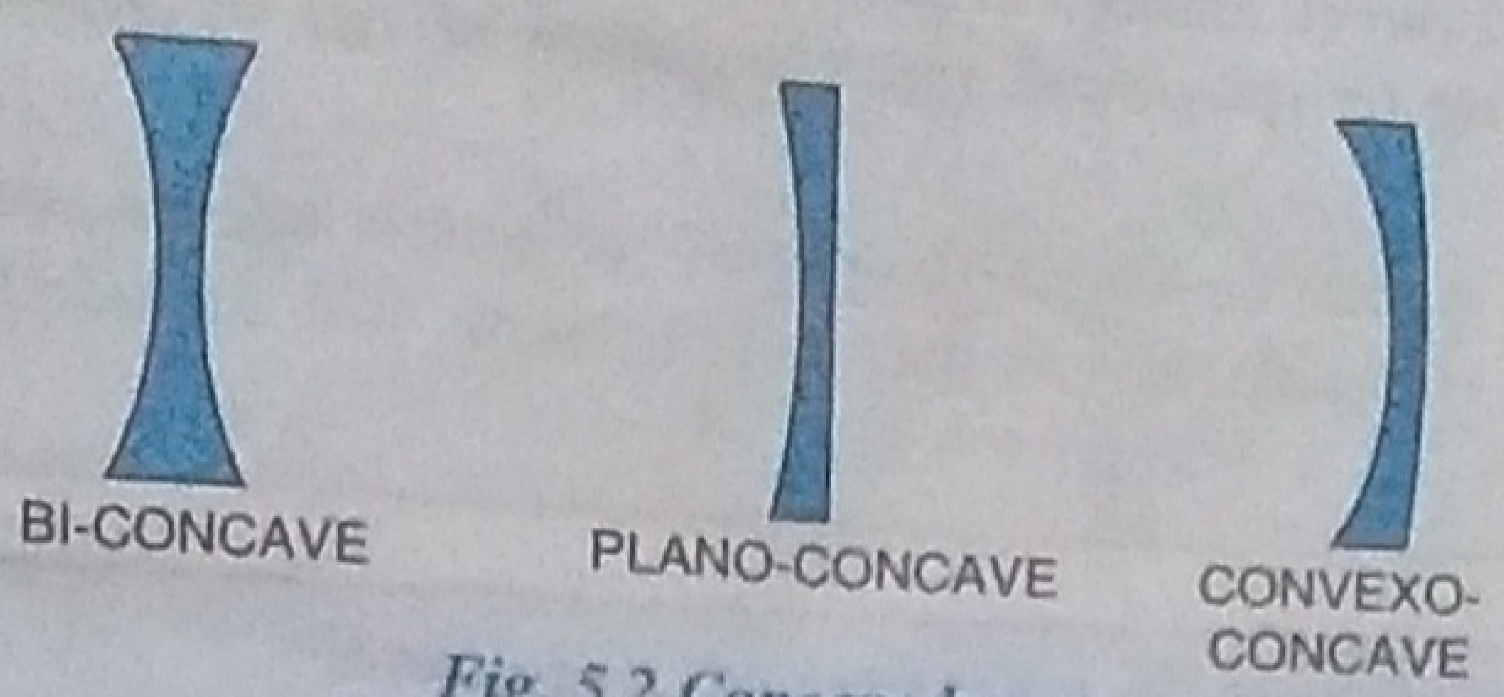


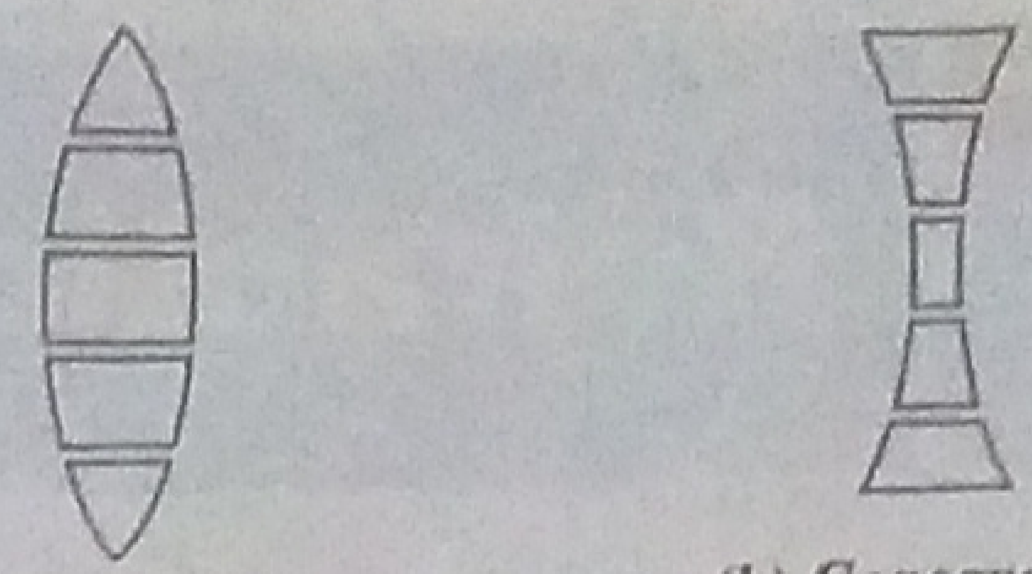
Fig. 5.2 Concave lenses

A bi-concave lens has both its surfaces concave, a plano-concave lens has one of its surface plane and the other surface concave, while a convexo-concave lens has one surface concave and the other surface convex such that it is thinner in the middle as compared to its periphery.

> *Note* : Both the concavo-convex and the convexo-concave lenses have one surface convex and the other surface concave, but they differ in their shape and action. A concavo-convex lens is thicker in the middle and has a *converging action* on a light beam, while a convexo-concave lens is thinner in the middle and has a *diverging action* on a light beam.

5.2 ACTION OF A LENS AS A SET OF PRISMS

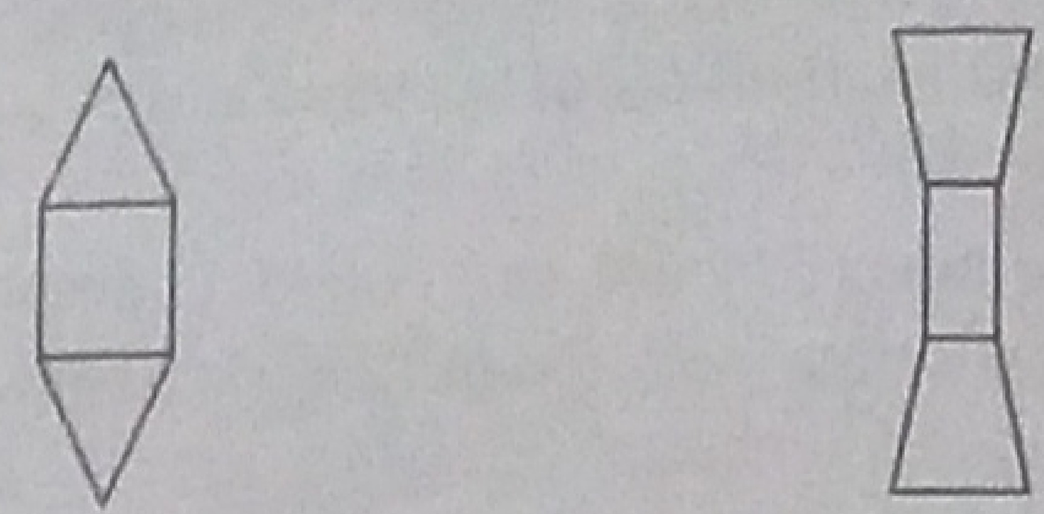
We have read the refraction of light through a prism. The refraction of light through a lens can be understood in a simple way by considering a lens as being made up of a set of prisms as shown in Fig. 5.3.



(a) Convex lens *(b) Concave lens*

Fig. 5.3 A lens being made up of a set of prisms

To make it further simple, the prisms in the central portion of the lens, shown in Fig. 5.3, may be treated as a rectangular slab. Then the lens can be considered as being made up of a rectangular slab at the centre and one prism on either side of it as shown in Fig. 5.4.



(a) Convex lens *(b) Concave lens*

Fig. 5.4 A lens being made up of a rectangular slab at the centre and one prism on either side of it

A convex lens in its upper part has a prism with its base downwards and in its lower part has a prism with its base upwards as shown in Fig. 5.4(a). On the other hand, a concave lens in its upper part has a prism with its base upwards and in its lower part has a prism with its base downwards as shown in Fig. 5.4(b).

Convergent action of a convex lens

Let us consider the refraction of parallel rays of light A, B and C incident on the prisms respectively in the upper, central and lower parts of the convex lens. We know that a ray of light incident on a prism, on refraction through it, always bends towards the base of the prism. Therefore the prism in the upper part of convex lens bends the incident ray A downwards, while the prism in the lower part of convex lens bends the incident ray C upwards (Fig. 5.5). The central part which is a parallel sided glass slab passes the ray B normally incident on it, undeviated. Thus the set of prisms forming a convex lens *converges* the parallel rays to a point F. Therefore *a convex lens has a converging action on the incident light rays.*

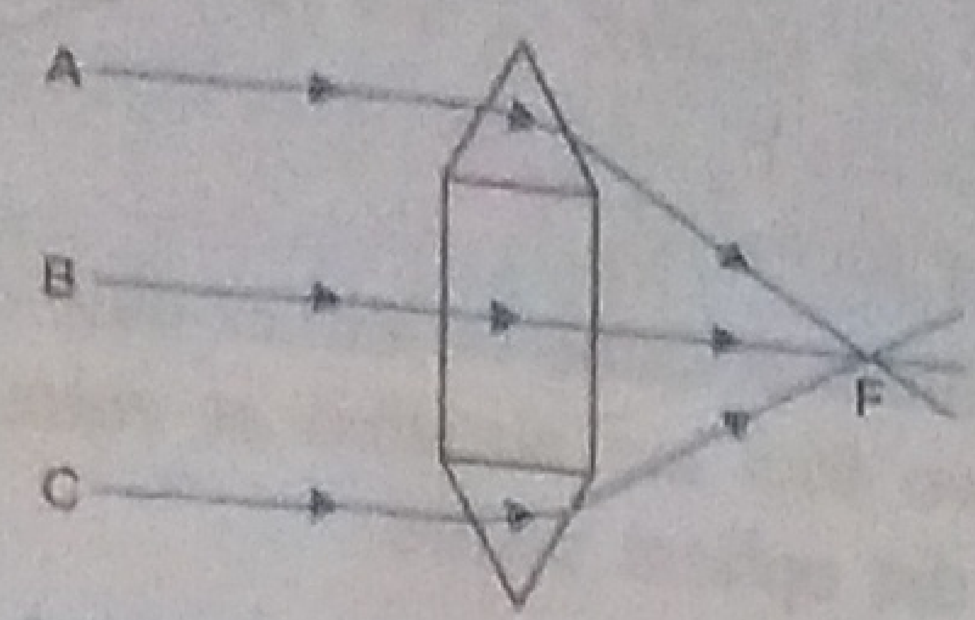


Fig. 5.5 Convergent action of a convex lens

Divergent action of a concave lens

In Fig. 5.6, the prism in the upper part of the concave lens bends the incident ray A upwards *i.e.*, towards its base, while the prism in the lower part of the concave lens bends the incident ray C downwards *i.e.*, towards its base. The central part, which is a parallel sided glass slab, passes the normally incident ray B undeviated. Thus, the set of prisms forming a concave lens *diverges* the parallel rays as if they are coming from a common point F situated on the side of rays incident on the lens. Therefore, *a concave lens has a diverging action on the incident light rays.*

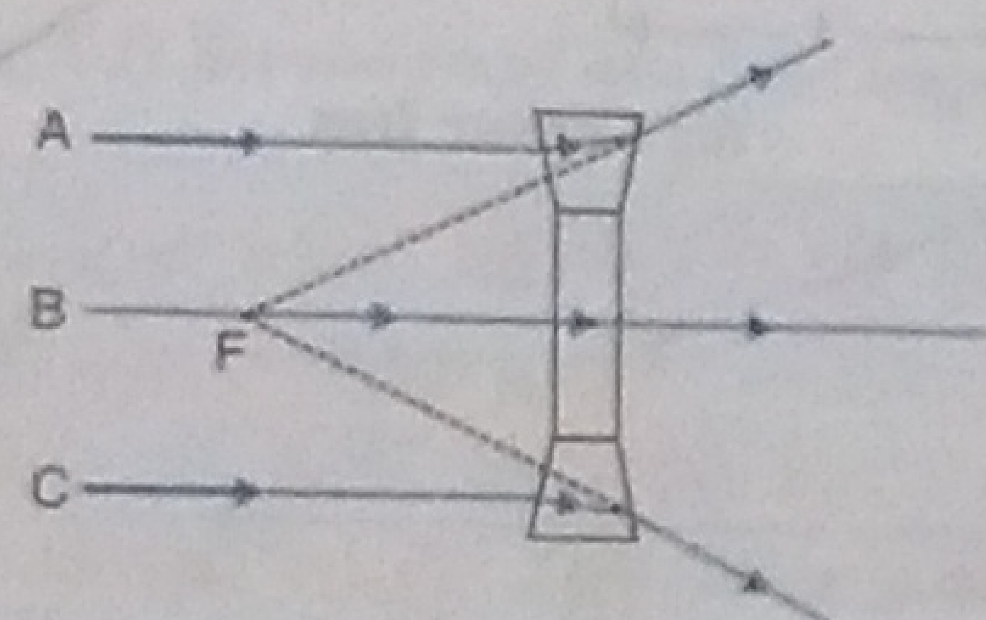
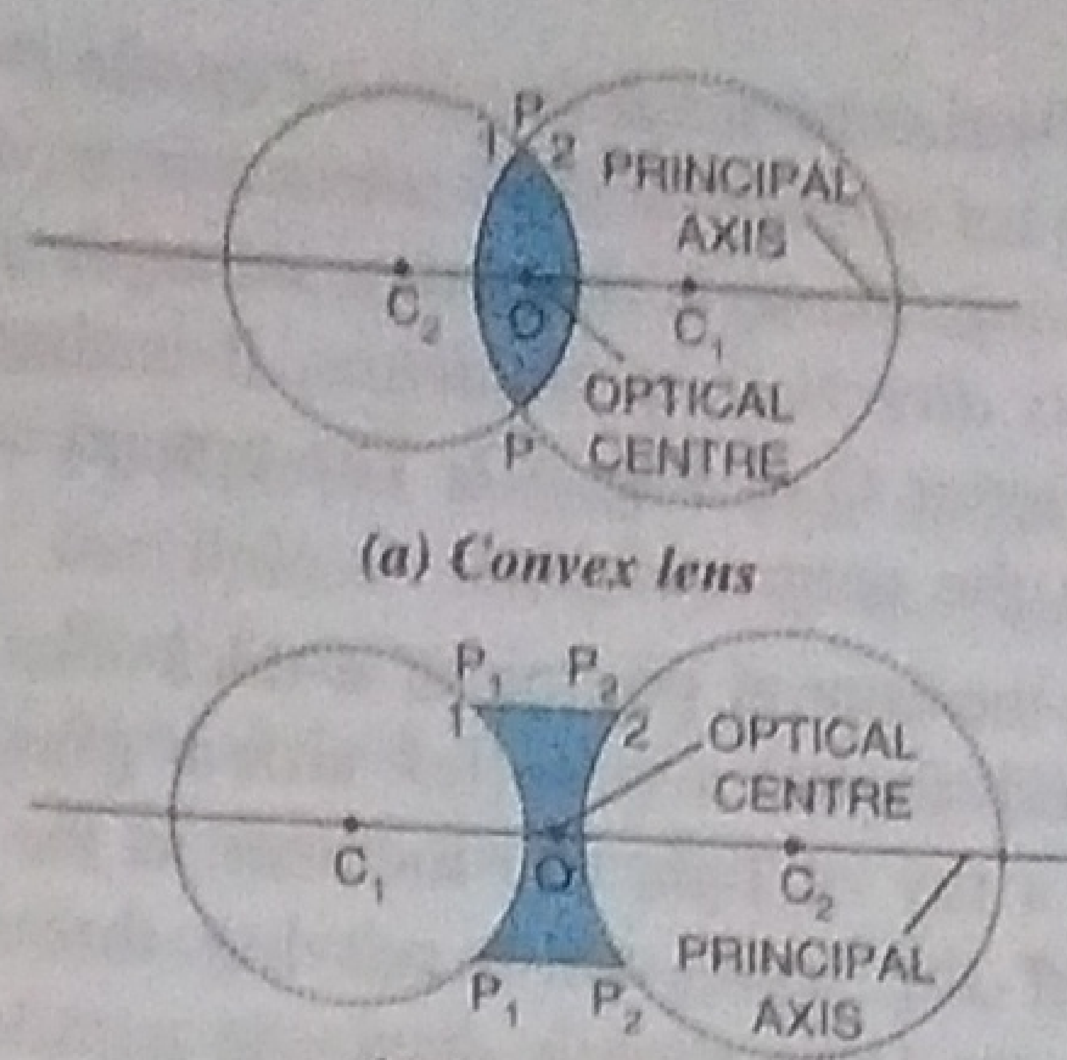


Fig. 5.6 Divergent action of a concave lens

5.3 TECHNICAL TERMS RELATED TO A LENS

(1) **Centre of curvature** : A lens has two surfaces. Each surface of the lens is a part of a sphere. *The centre of the sphere whose part is the lens surface, is called the centre of curvature of that surface of the lens.* Since a lens has two spherical surfaces, so there are two centres of curvature of a lens. In Fig. 5.7, C_1 and C_2 are respectively the centres of curvature of the two surfaces 1 and 2 of the lens.



(a) Convex lens

(b) Concave lens

Fig. 5.7 Centre of curvature, principal axis and optical centre

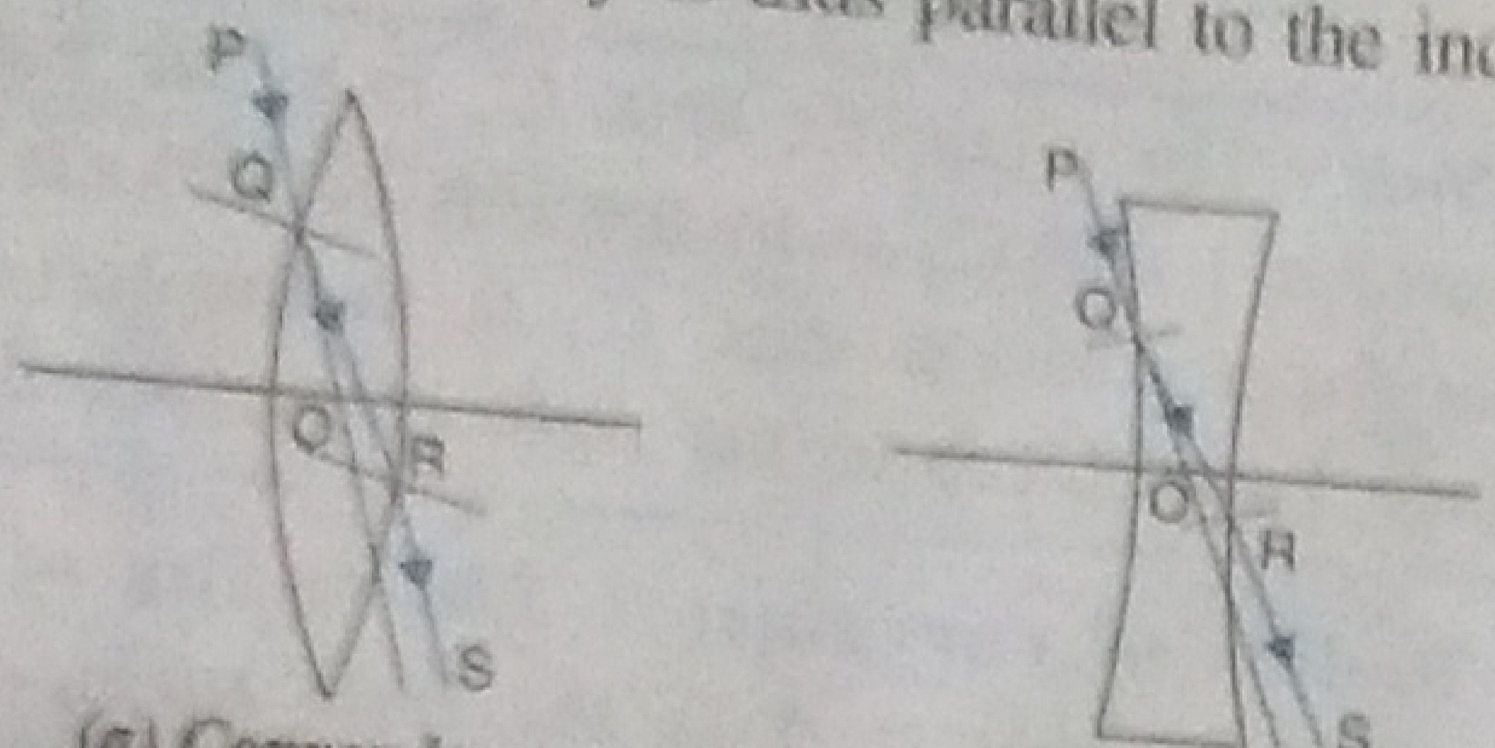
> *Note* : For a convex lens, C_1 is to the right of surface 1 and C_2 is to the left of surface 2, while for a concave lens, C_1 is to the left of surface 1 and C_2 is to the right of surface 2.

(2) **Radius of curvature** : *The radius of the sphere whose part is the lens surface, is called the radius of curvature of that surface of the lens.* In Fig. 5.7(a), PC_1 and PC_2 are the radii of curvature of the two surfaces 1 and 2 of the convex lens. If the lens is thin, then $PC_1 = OC_1$ and $PC_2 = OC_2$. Similarly in Fig. 5.7(b), P_1C_1 and P_2C_2 are the radii of curvature of the two surfaces 1 and 2 of the concave lens. If the lens is thin, then $P_1C_1 = OC_1$ and $P_2C_2 = OC_2$. The point O is called the *optical centre*. Thus for a thin lens, the radius of curvature of a surface of lens is equal to the distance of centre of curvature of that surface from the optical centre. *For an equi-convex* or *equi-concave lens, the radii of curvature of both the surfaces are equal (i.e.,* $OC_1 = OC_2$*).* The lenses shown in Fig. 5.7 (a) and (b) are not equi-convex and equi-concave since the radii of curvature of the two surfaces OC_1 and OC_2 are not equal.

(3) **Principal axis** : *It is the line joining the centres of curvature of the two surfaces of the lens.* In Fig. 5.7, the line C_1C_2 is the principal axis. It can extend on either side of the lens.

(4) **Optical centre :** *It is a point on the principal axis of the lens such that a ray of light passing through this point emerges parallel to its direction of incidence.* It is marked by the letter O in Fig. 5.7. The optical centre is thus the centre of lens.

Since the central portion of a thick lens can be considered to be a parallel sided glass slab, therefore a ray of light PQ incident at the central portion of the lens, while passing through the optical centre O, is *slightly* displaced parallel to its incident direction PQ and emerges as RS. In Fig. 5.8, the emergent ray is thus parallel to the incident ray.

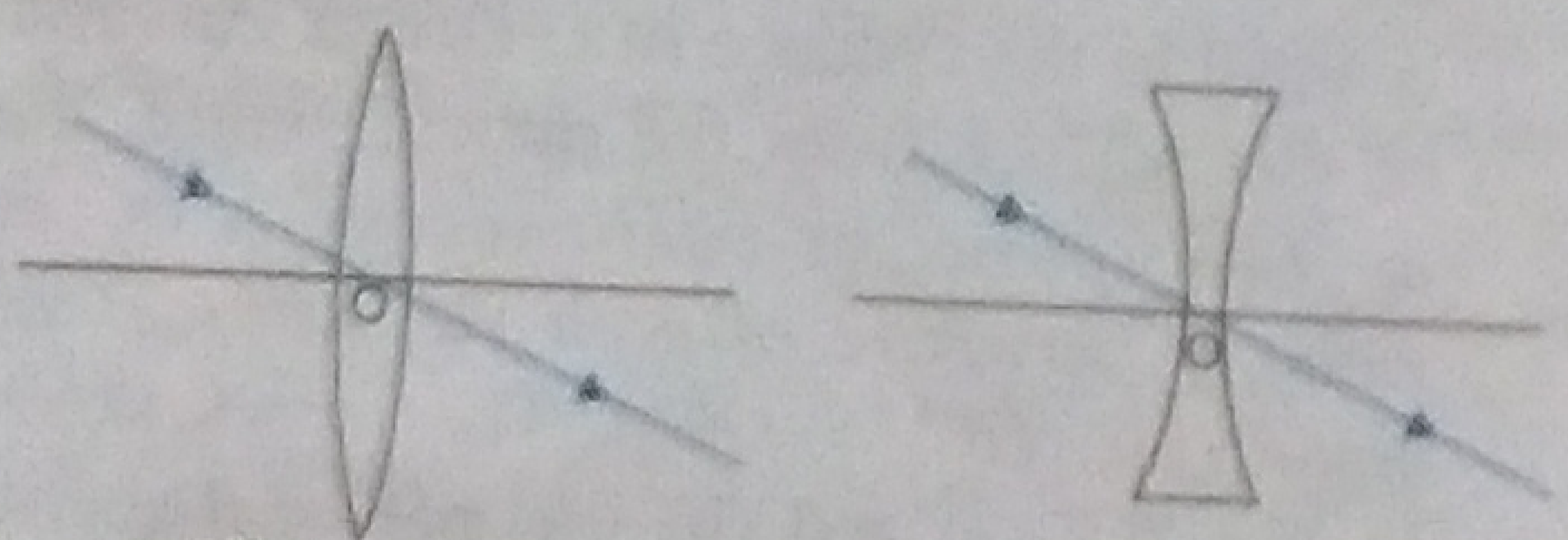


(a) Convex lens (b) Concave lens

Fig. 5.8 Optical centre (thick lens)

> *Note* : In Fig 5.8, the lateral shift of the ray has been shown quite large, but actually it is very small.

Generally the lens is thin, so the lateral shift is small enough and it can be ignored. Therefore, *a ray of light directed towards the optical centre of a thin lens can be considered to pass through the lens undeviated and undisplaced* as shown in Fig. 5.9.



(a) Convex lens (b) Concave lens

Fig. 5.9 Optical centre (thin lens)

Thus,

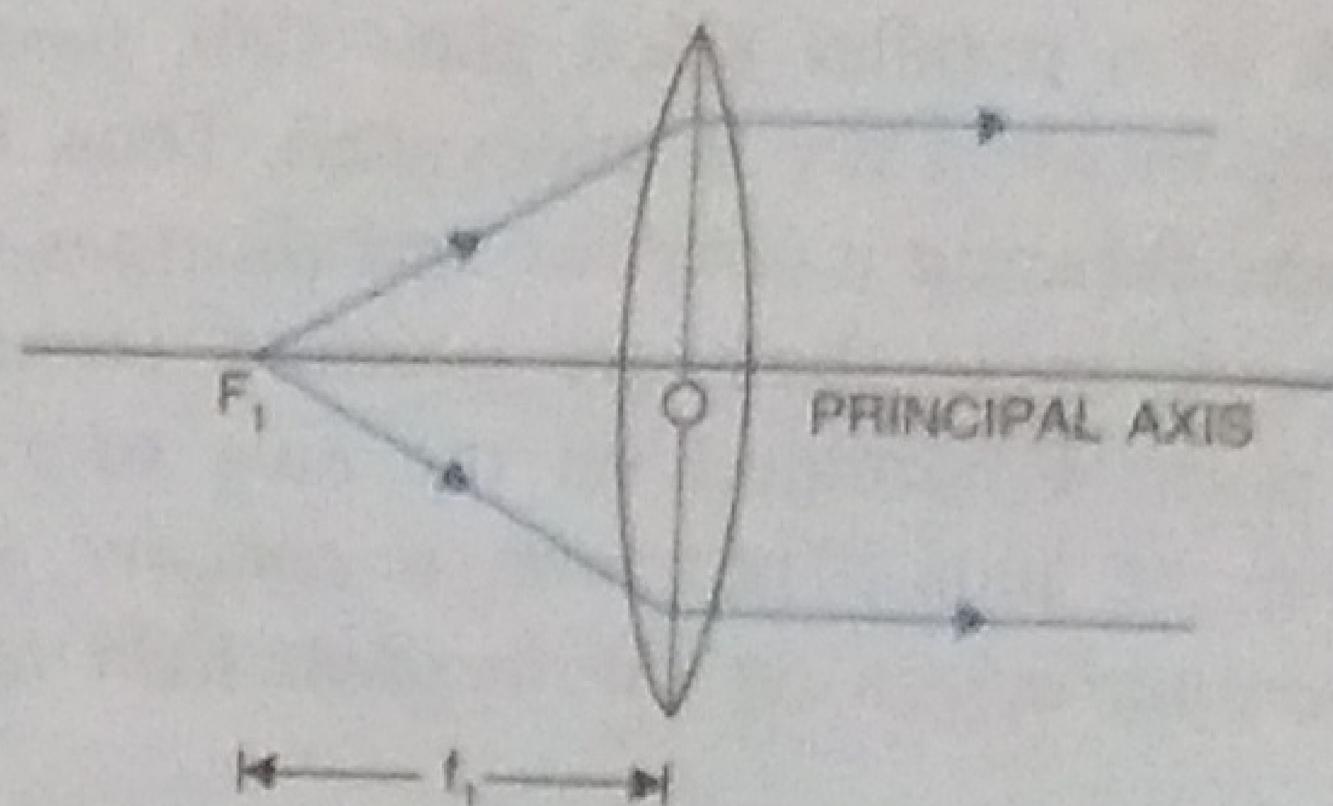
> *Optical centre of a thin lens is the point on the principal axis of lens such that a ray of light directed towards it, passes undeviated through it.*

(5) **Principal foci :** A light ray can enter a lens from either side, therefore a lens has two principal foci, one on either side of the lens. These are known as the *first focal point (or first focus)* F_1 and the *second focal point (or second focus)* F_2.

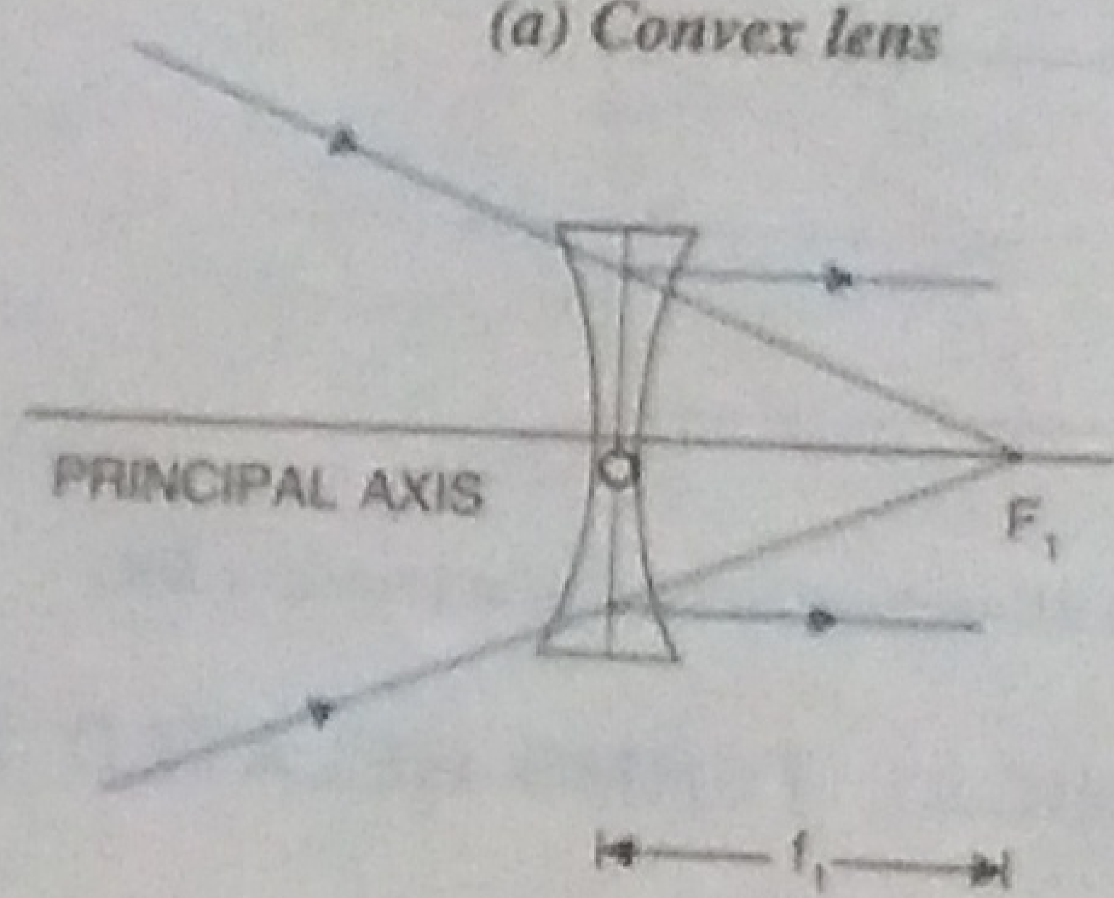
If medium is same on either side of the lens, the two foci are situated at equal distances from the optical centre.

First focal point

> *For a convex lens, the first focal point is a point F_1 on the principal axis of the lens such that the rays of light coming from it, after refraction through the lens, become parallel to the principal axis of the lens* [Fig. 5.10 (a)].



(a) Convex lens



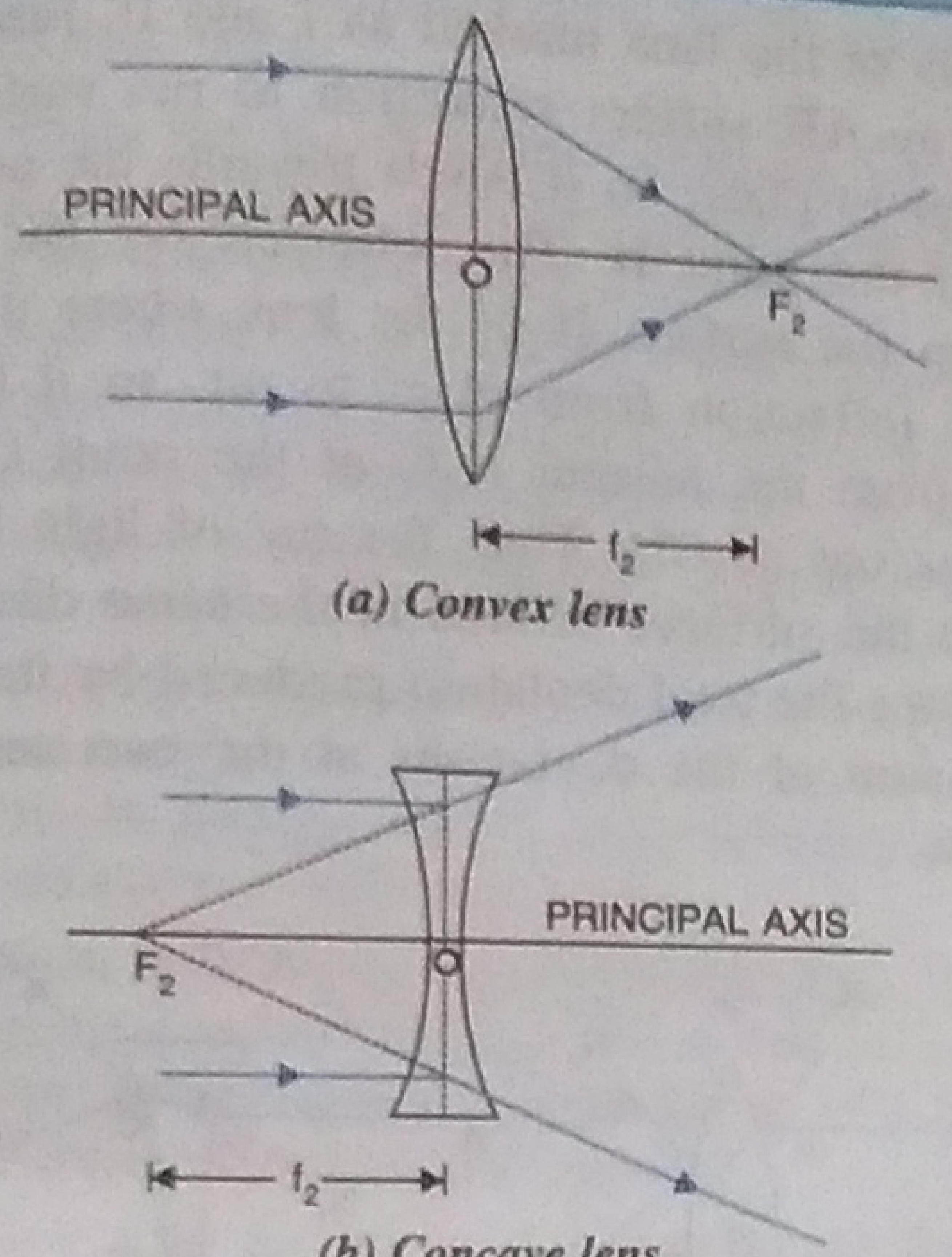
(b) Concave lens

Fig. 5.10 First focus and focal length

> *For a concave lens, first focal point is a point F_1 on the principal axis of the lens such that the incident rays of light appearing to meet at it, after refraction from the lens become parallel to the principal axis of the lens* [Fig. 5.10 (b)].

Second focal point

For a convex lens, the second focal point is a point F_2 *on the principal axis of the lens such that the rays of light incident parallel to the principal axis, after refraction from the lens, pass through it* [Fig. 5.11 (a)].



(a) *Convex lens*

(b) *Concave lens*

Fig. 5.11 Second focus and focal length

For a concave lens, second focal point is a point F_2 *on the principal axis of the lens such that the rays of light incident parallel to the principal axis, after refraction from the lens, appear to be diverging from this point* [Fig. 5.11 (b)].

(6) **Focal plane :** A plane normal to the principal axis, passing through the focus, is called the focal plane. A lens has *two* focal planes.

(i) **First focal plane :** A plane passing through the first focal point and normal to the principal axis of the lens, is called the *first focal plane.*

(ii) **Second focal plane :** A plane passing through the second focal point and normal to the principal axis of the lens, is called the *second focal plane.*

(7) **Focal length :** The distance of focus (or focal point) from the optical centre of lens, is called its focal length. A lens has *two* focal lengths.

(i) **First focal length :** *The distance from the optical centre O of the lens to its first focal point* F_1 *is called the first focal length* f_1 *of the lens.* In Fig. 5.10, it is shown as $OF_1 = f_1$.

(ii) **Second focal length :** *The distance from the optical centre O of the lens to the second focal point* F_2 *is called the second focal length* f_2 *of the lens.* In Fig. 5.11, it is shown as $OF_2 = f_2$.

Note : (1) *If the medium on both sides of a lens is same, its first and second focal lengths are equal, i.e.,* $f_1 = f_2$ (numerically).

(2) Usually, *when we say focus, we mean the second focal point. Hence the focal length of a lens implies the second focal length of the lens.*

(3) A convex lens has a *real focus* (because the parallel rays incident on a convex lens, after refraction from the lens *actually pass through this point*), while in a concave lens the *focus is virtual* (because the parallel rays incident on a concave lens, after refraction do not actually pass through this point, but they *appear to diverge* from this point).

(4) Only a beam of light incident parallel to the principal axis converges to a single point F_2 (the focus) on the principal axis after refraction through the convex lens. If the parallel beam of light is incident obliquely (*i.e.*, the rays are not parallel to the principal axis of the lens), it does not converge at the principal focus F_2, but it

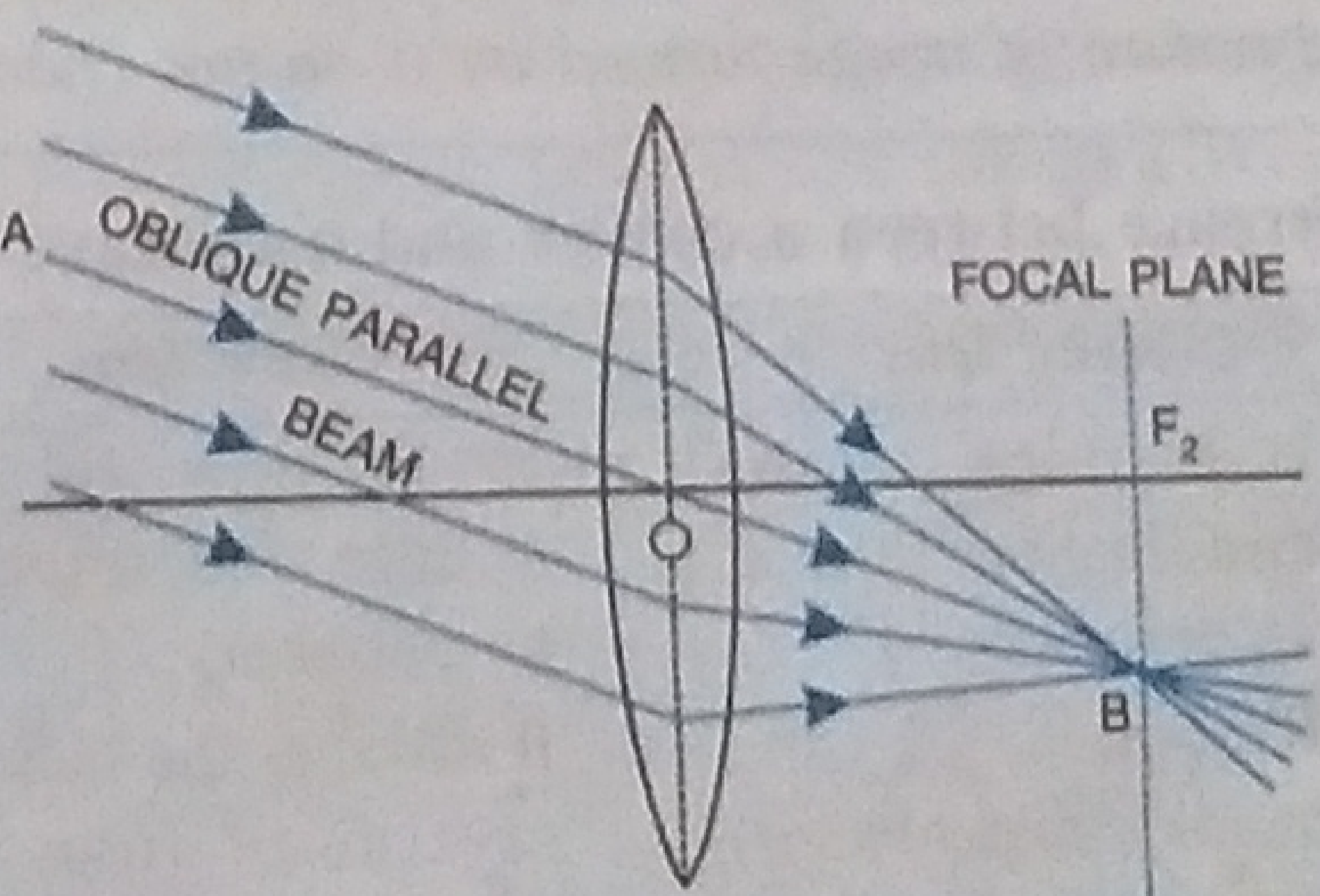


Fig. 5.12 Refraction of an oblique parallel beam by a convex lens