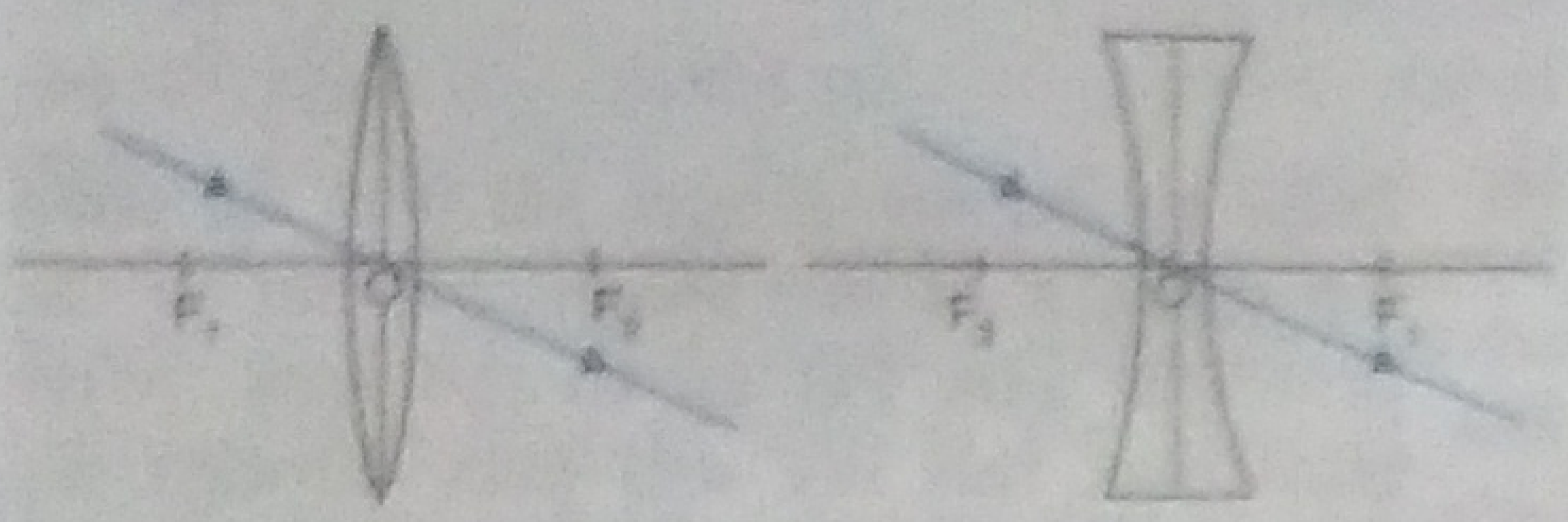
(B) FORMATION OF IMAGE BY A LENS

5.5 PRINCIPAL (OR CONSTRUCTION) RAYS FOR RAY DIAGRAMS

The position, size and nature of the image of an object formed by a lens, can be determined by drawing a ray diagram. For this, we need to consider at least *two* rays starting from a point on the object. The rays chosen are those for which the path after refraction from the lens is known to us.

Generally we use the following *three* principal rays for the construction of the ray diagrams.

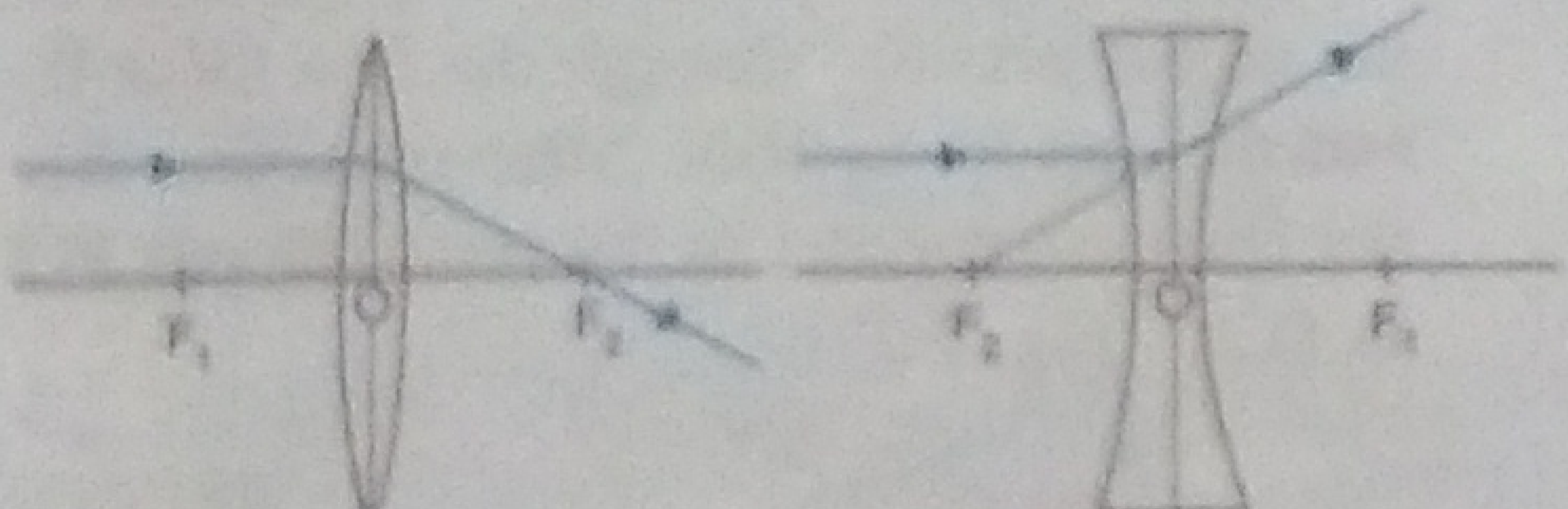
(1) *A ray of light incident at the optical centre O of the lens passes undeviated through the lens* as shown in Fig. 5.19 (a) and (b) respectively for the convex and concave lens.



(a) Convex lens (b) Concave lens

Fig. 5.19 A ray through the opticenter passes undeviated

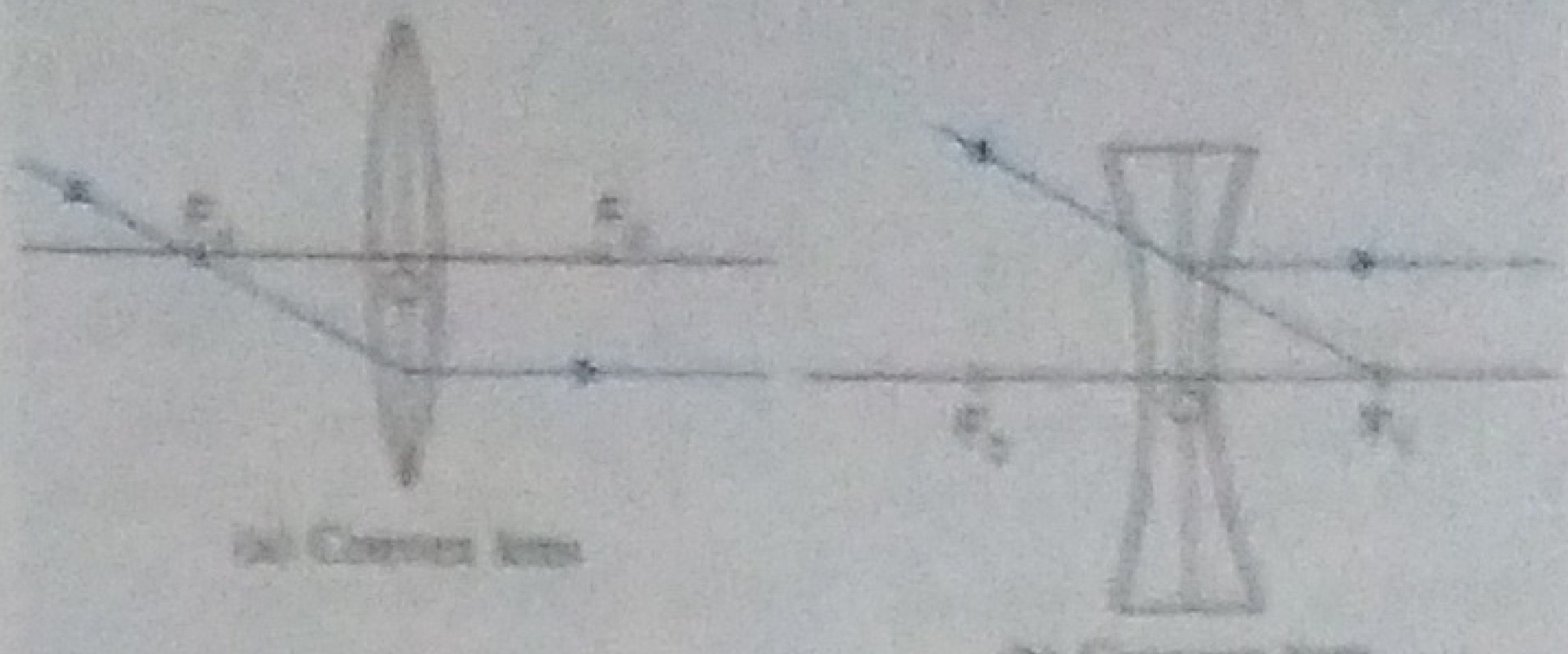
(2) *A ray of light incident parallel to the principal axis of the lens, after refraction passes through the second focus* F_2 *(in a convex lens)* or *appears to come from the second focus* F_2 *(in a concave lens)* as shown in Fig. 5.20 (a) and (b) respectively.



(a) Convex lens (b) Concave lens

Fig. 5.20 A ray incident parallel to principal axis either passes or appears to pass through the second focus

(3) *A ray of light passing through the first focus* F_1 *(in a convex lens)* or *directed towards the first focus* F_1 *(in a concave lens), emerges parallel to the principal axis after refraction* as shown in Fig. 5.21(a) and (b) respectively.



(a) Convex lens

(b) Concave lens

Fig. 5.21 A ray either incident from or directed towards first focus becomes parallel to the principal axis

From a point of the object, although an infinite number of rays travel in all possible directions, but we choose only *two* convenient rays out of the above mentioned three rays from that point on the object. The point where the rays meet (or appear to meet) after refraction from the lens is the image of that point of the object. The image is obtained in a similar manner for each point of the object and all these image points together then form the full image of the object.

Kind of images : The images can be of *two* kind : (1) *real*, and (2) *virtual*.

(1) ***Real image*** : If the rays from a point of object after refraction through the lens *actually meet* at a point, the image is *real*. If a screen is placed at this point, the image is obtained on it (*i.e., a real image can be obtained on a screen*). It is inverted with respect to the object.

(2) ***Virtual image*** : If the rays from a point of object after refraction through the lens do not actually meet at a point, but they appear to diverge from a point, the image is *virtual*. A screen placed at this point will not show any image on it (*i.e., a virtual image cannot be obtained on a screen*). However, the eye kept between the diverging rays is able to see this image because the eye lens being convex, converges the diverging rays to form the image on the retina of eye. The virtual image is erect (or upright) with respect to the object.

Distinction between a real and a virtual image

Real image	Virtual image
1. A real image is formed due to actual intersection of the rays refracted by the lens.	1. A virtual image is formed when the rays refracted by the lens appear to meet if they are produced backwards.
2. A real image can be obtained on a screen.	2. A virtual image can not be obtained on a screen.
3. A real image is inverted with respect to the object.	3. A virtual image is erect with respect to the object.
Example: The image of a distant object formed by a convex lens.	*Example:* The image of an object formed by a concave lens.

5.6 CONSTRUCTION OF RAY DIAGRAM FOR A LENS

A ray diagram to determine the position and the characteristics of the image formed by a *convex lens* is drawn following the steps given below.

(1) Draw a line PQ across the paper. Name it as *principal axis*. Choose a point O on the principal axis as the *optical centre* (Fig. 5.22). Draw the *convex lens* and its principal section by a vertical line passing through O. For a thin lens, we shall show the light rays to bend at this line, instead of bending them at the two surfaces of lens.

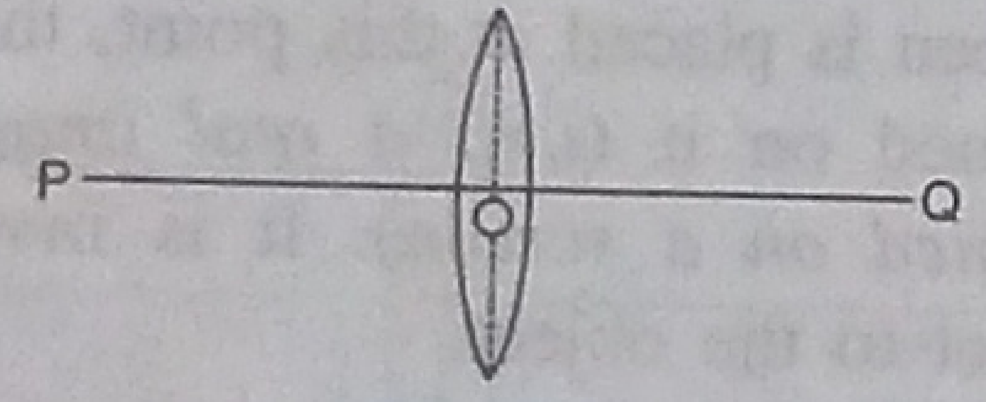


Fig. 5.22

(2) Choose a proper scale and mark *two principal foci* F_1 and F_2 on the principal axis PQ (Fig. 5.23). F_1 is on the left of O, while F_2 is on the right of O at an equal distance *i.e.*, $OF_1 = OF_2$, since there is air on both sides of the lens.

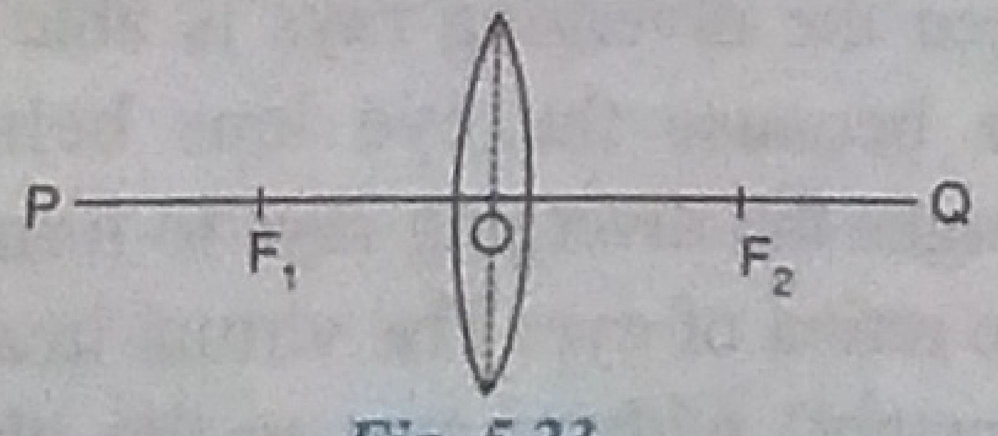


Fig. 5.23

(3) Draw a straight line AB on the principal axis to represent the vertical *linear object*, of given height at the given position according to the scale choosen (Fig. 5.24).

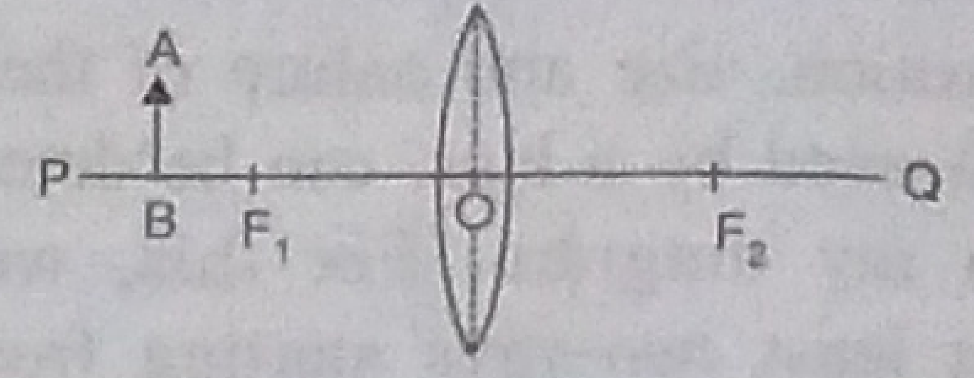


Fig. 5.24

(4) Draw *one ray of light* AO from the top point A of the object, passing straight through the optical centre O of the lens without any deviation (Fig. 5.25).

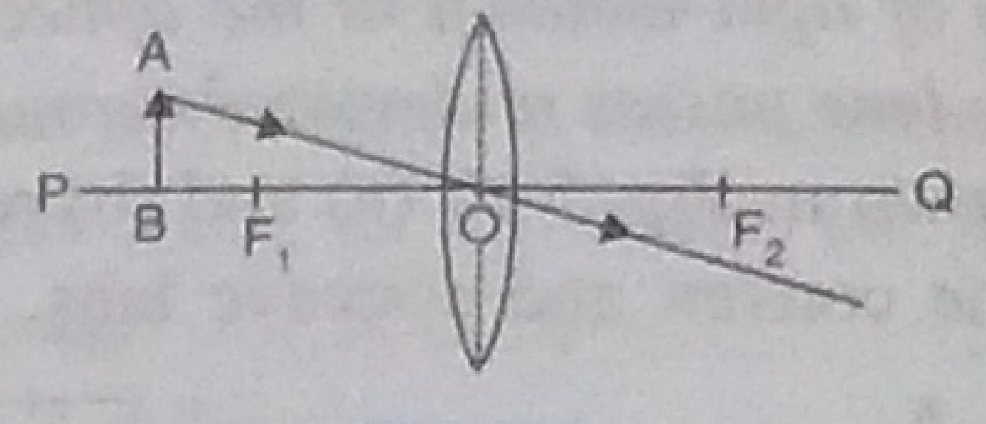


Fig. 5.25

(5) Draw *second ray* of light AD from the same top point A of the object, parallel to the principal axis PQ up to the lens. After refraction, this ray will pass through the focus F_2 as DA′ (Fig. 5.26).

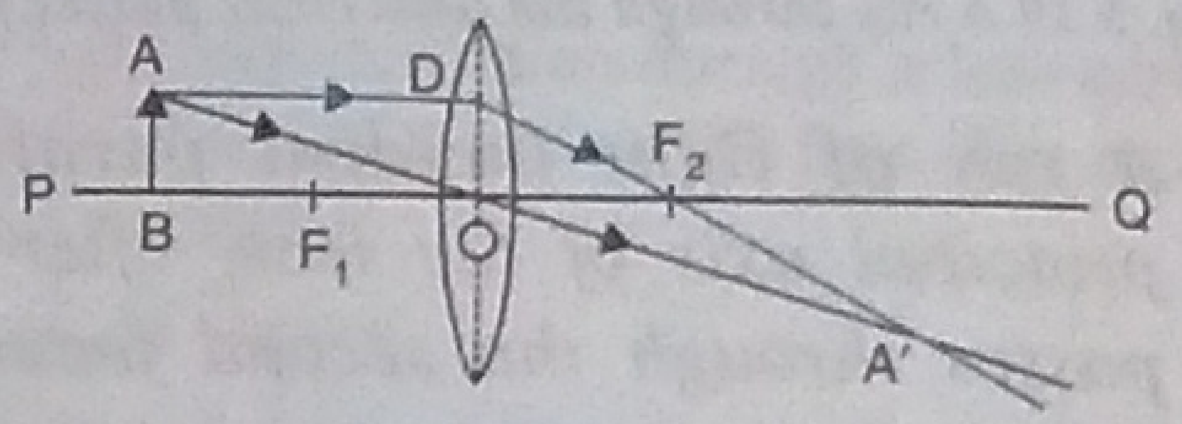


Fig. 5.26

For the *second* ray, the other choice can be to draw a ray AD′ from the top point A of the object passing through the first focus F_1 and then up to the lens. After refraction, this ray becomes parallel to the principal axis PQ as D′A′ (Fig. 5.27).

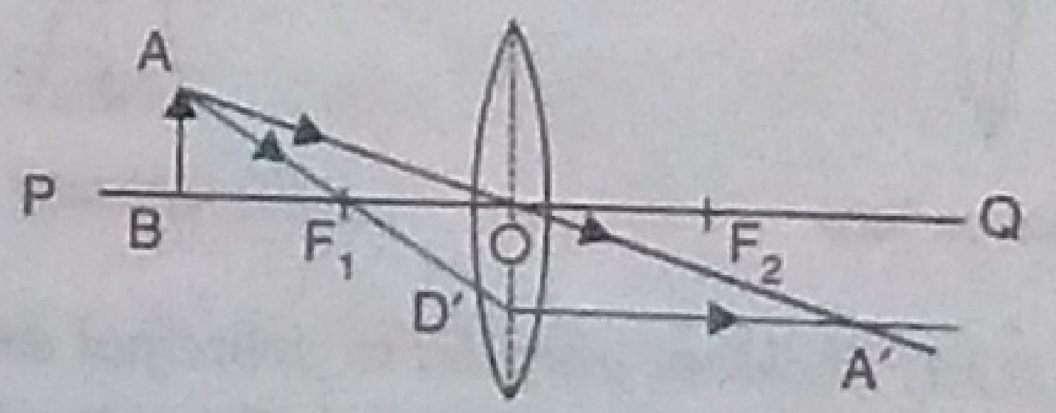


Fig. 5.27

(6) The point A′ where the *two* refracted rays meet (or appear to meet) is the image of the

point A of the object. By drawing a perpendicular A′B′ from A′ on the line PQ, we get the image A′B′ of the object AB (Fig. 5.28).

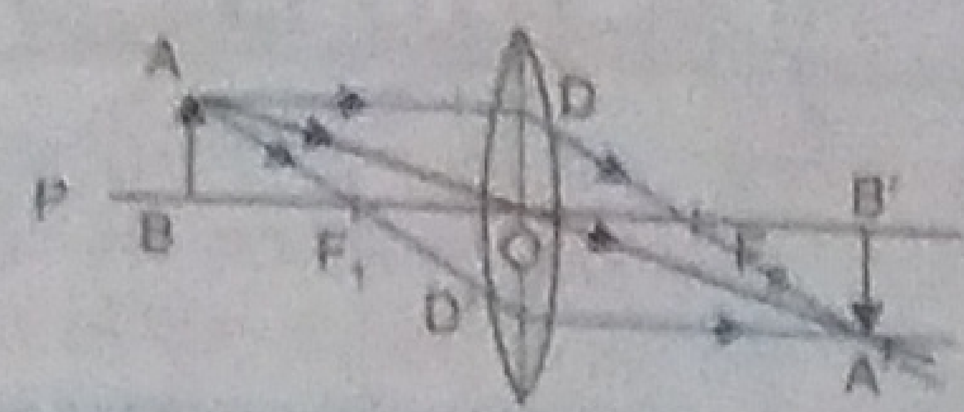


Fig. 5.28 Three construction rays in a convex lens

(7) Measure the height A′B′ and the distance OB′ of the image and then convert it on the chosen scale to get the actual height or size of the image and position of the image.

The same procedure is adopted to draw the ray diagram for a *concave lens*. In a concave lens, the focus F_1 is on the right of optical centre O and the focus F_2 is on its left. In Fig. 5.29, the ray of light AO incident at the optical centre passes undeviated as AOX, the ray of light AD incident parallel to the principal axis will appear to diverge as DY from F_2 after refraction and the ray AD′ appearing to meet at the focus F_1 will become parallel to the principal axis as D′Z after refraction. The refracted rays when produced backwards, meet at A′. Thus A′ is the virtual image of the point A of object. For the object AB, the virtual image is A′B′.

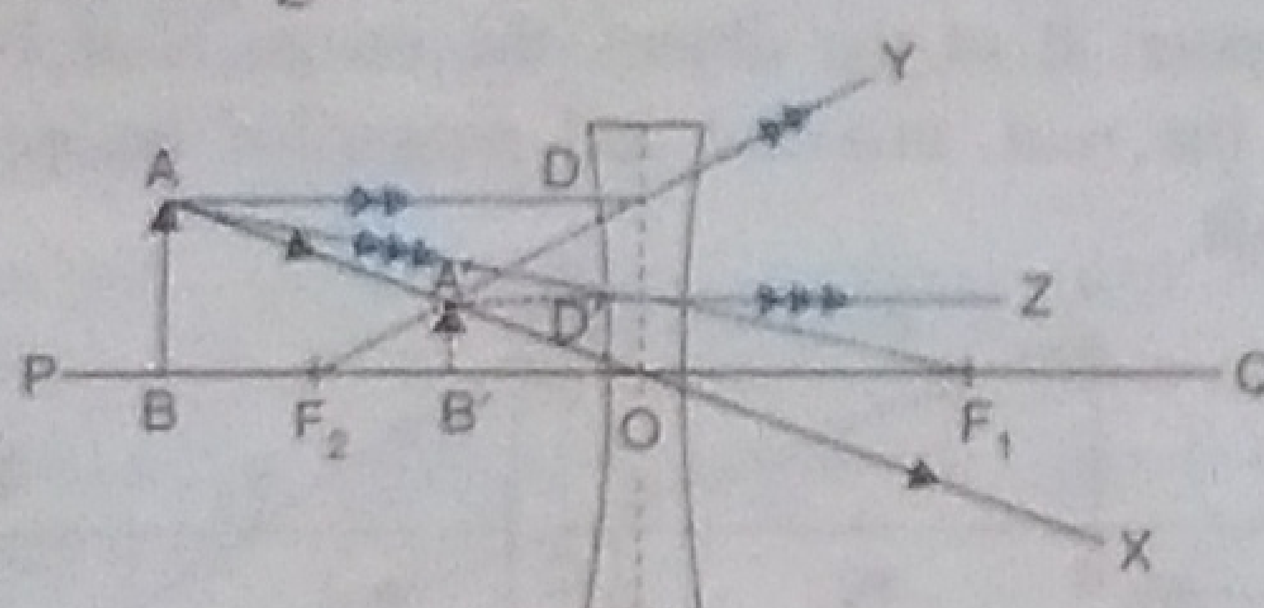


Fig. 5.29 Three construction rays in a concave lens.

5.7 CHARACTERISTICS AND LOCATION OF IMAGES FOR A CONVEX LENS

Now we shall consider the ray diagrams for formation of images by a convex lens (focal length = f) for different positions of the object. Let u denotes the distance of object from the lens.

Case (i) : When the object is at infinity (*i.e.*, $u = \infty$)

In Fig. 5.30, the rays coming from an object at infinity, are parallel to each other and they are incident on the convex lens parallel to the principal axis of the lens, which after refraction pass through the second focus F_2 of the lens. Thus a *real, inverted* and *diminished (almost to a point)* image is formed at the second focus on the other side of the lens.

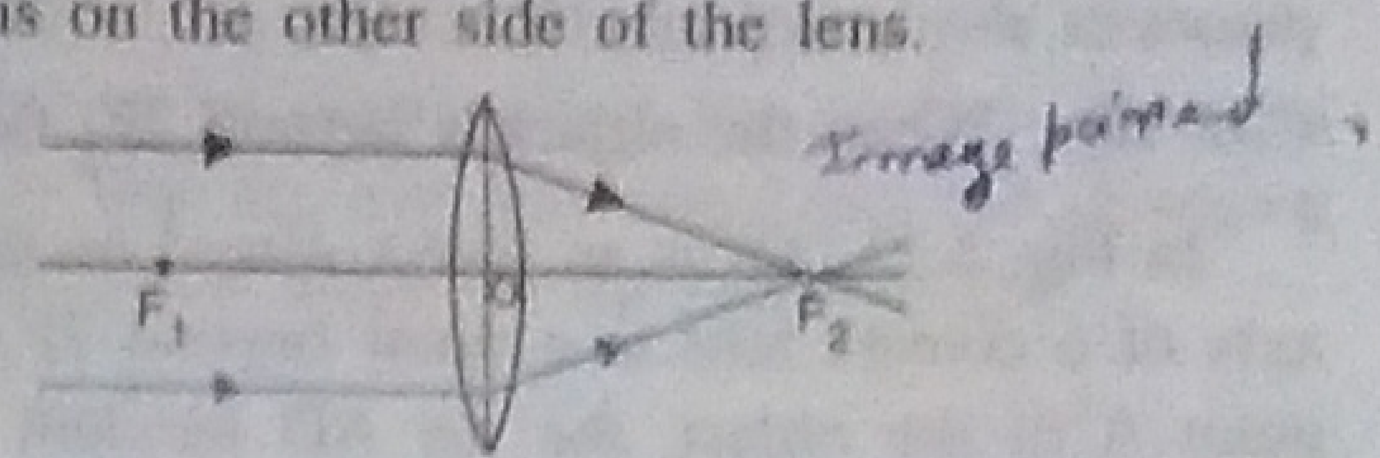


Fig. 5.30 Image formation by a convex lens for an object at infinity

If the object AB is at a far distance ($u >> f$) : The light rays reaching the lens from a point of the object will be parallel to each other, but will be incident obliquely on the lens. In Fig. 5.31, the object AB is not shown. The rays from the top point A of the object are obliquely incident on the convex lens. The incident ray passing through the optical centre O travels undeviated through the lens, as OA′. Another ray from the same point A of the object, incident on the lens through the first focus F_1, after refraction becomes parallel to the principal axis as DA′. The two refracted rays OA′ and DA′ meet at a point A′. Thus A′ is the *real image* of the object point A which will lie in the focal plane of the lens passing through the second focus F_2. Similarly, for the bottom point B of the object lying on the principal axis, the image will be B′ at F_2. Thus B′A′ is the *real, inverted* and *highly diminished* image of the object AB formed in the second focal plane.

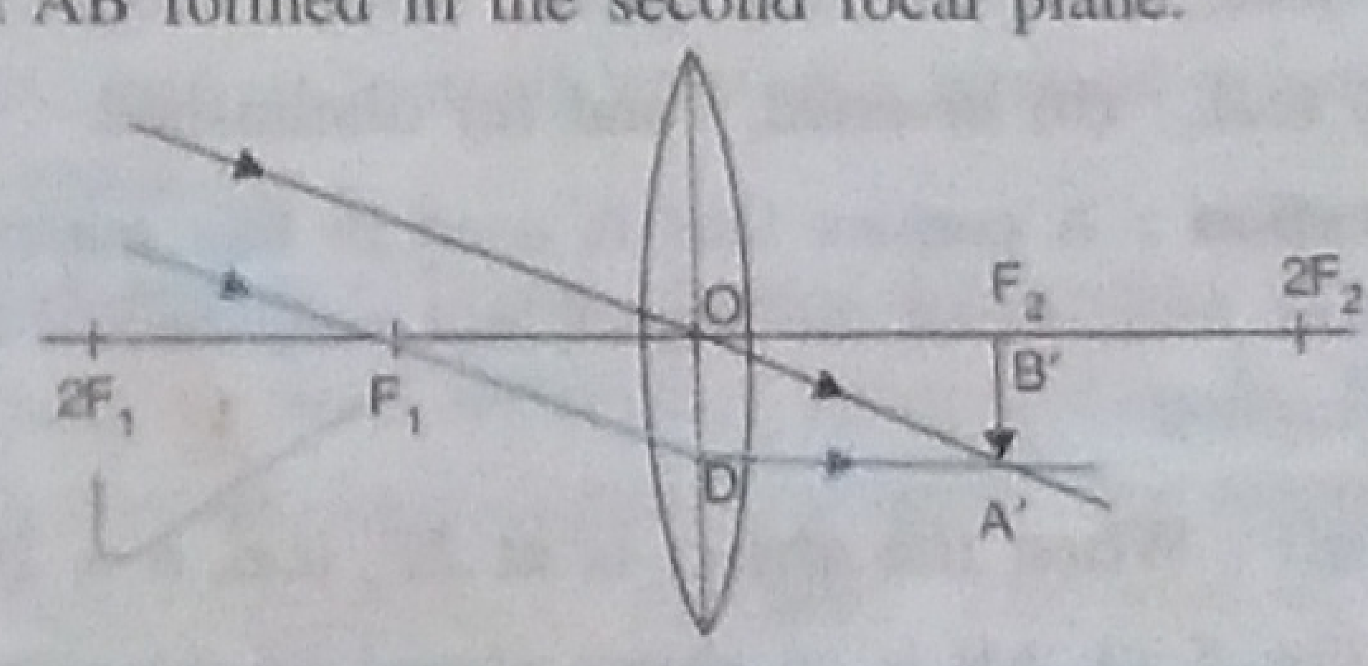


Fig. 5.31 Image formation by a convex lens for a very distant object

Characteristics and location of the image formed

The image is at the *focus* (or in the focal plane) on the other side of the lens. It is

(a) real, (b) inverted, and (c) highly diminished.

Application : In this manner, a convex lens is used either as a *burning glass* (Fig. 5.30) or a *camera lens* (Fig. 5.31). To use the convex lens as a burning glass, the rays of light from sun (at infinity) are brought to seen on a piece of paper kept in the second focal plane of the lens. Due to sufficient heat of sun rays, the paper burns. In a camera, the object lies very far from the lens and the image is formed at the camera film which is placed at the second focus (or lies in the second focal plane) of the lens.

Case (ii) : When the object is beyond $2F_1$ (*i.e.*, $u > 2f$)

In Fig. 5.32, AB is an object placed on the principal axis of a convex lens at a point beyond $2F_1$. From the point A of the object, the ray AD incident parallel to the principal axis, after refraction through the lens, passes through the second focus F_2 as DA′. The other ray AO incident at the optical centre O of the lens travels undeviated as OA′. The two refracted rays DA′ and OA′ meet at a point A′. Thus A′ is the *real image* of the point A of the object. Similarly B′ is the image of the point B of the object. Thus A′B′ is the *real*, *inverted* and *diminished* image of the object AB.

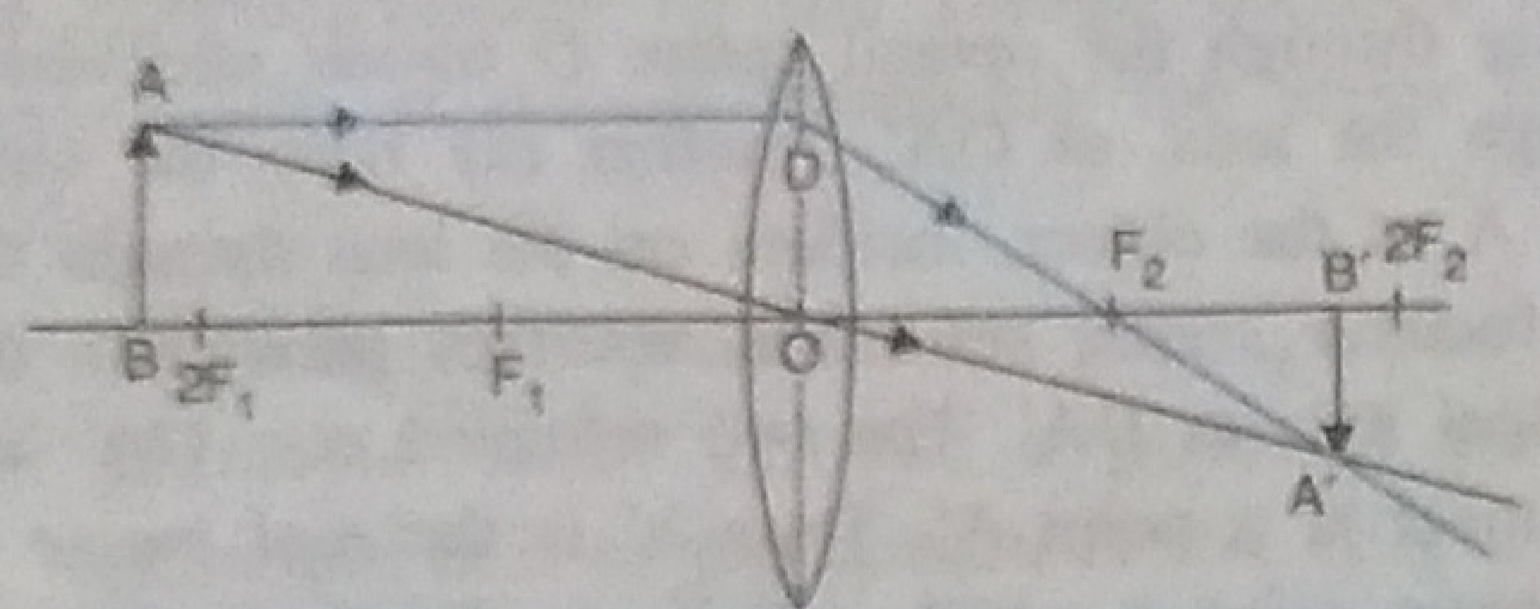


Fig. 5.32 Image formation by a convex lens for the object beyond $2F_1$

Characteristics and location of the image formed

The image is between F_2 and $2F_2$ on the other side of the lens. It is

(a) real, (b) inverted, and (c) diminished.

Application : A convex lens is used in this manner as a *camera lens*, when the object, not very far, is to be photographed.

Case (iii) : When the object is at $2F_1$ (*i.e.*, $u = 2f$)

In Fig. 5.33, AB is an object placed on the principal axis of a convex lens at a distance equal to twice the focal length of the lens *i.e.*, at $2F_1$. From the point A of the object, the ray AD incident parallel to the principal axis after refraction through the lens, passes through its second focus F_2 as DA′. The other ray AO incident through the optical centre O of the lens, travels undeviated as OA′. The two refracted rays DA′ and OA′ meet at a point A′ which is the *real image* of the point A of the object. Similarly for the point B of the object, the image is at B′. Thus A′B′ is the *real* and *inverted* image of the object AB. This image is of same size as the object.

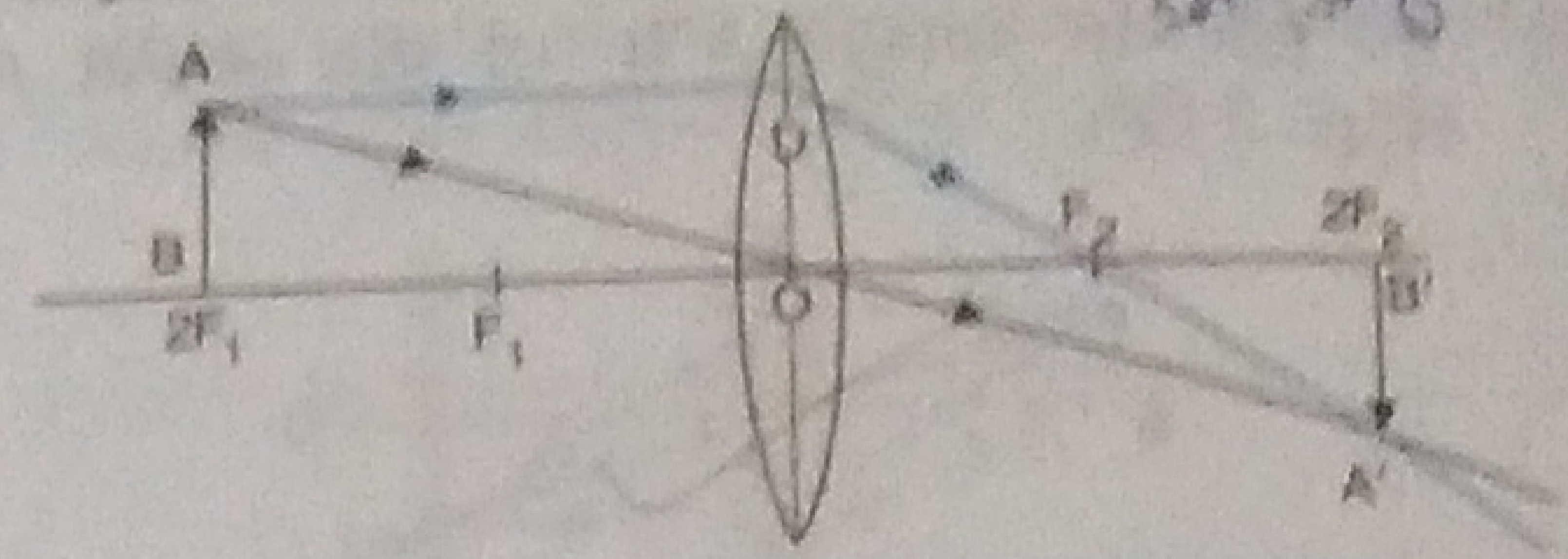


Fig. 5.33 Image formation by a convex lens for the object at $2F_1$

Characteristics and location of the image formed

The image is at $2F_2$ on the other side of the lens. It is (a) real, (b) inverted, and (c) of the same size as the object.

Application : In this manner, a convex lens is used in a *terrestrial telescope* for erecting the inverted image formed by the objective lens.

Case (iv) : When the object is between F_1 and $2F_1$ (*i.e.*, $f < u < 2f$)

In Fig. 5.34, AB is an object placed on the principal axis of a convex lens at a point between F_1 and $2F_1$. From the point A of the object, a ray AD incident parallel to the principal axis, after refraction from the lens, passes through its second focus F_2 as DA′. The other ray AO incident towards the optical centre O, passes undeviated through the lens as OA′. The two refracted rays DA′ and OA′ meet at a point A′ which is the *real image* of the point A of the object. Similarly, for the point B of the object, the image is at B′. Thus A′B′ is the *real*, *inverted* and *magnified image* of the object AB.

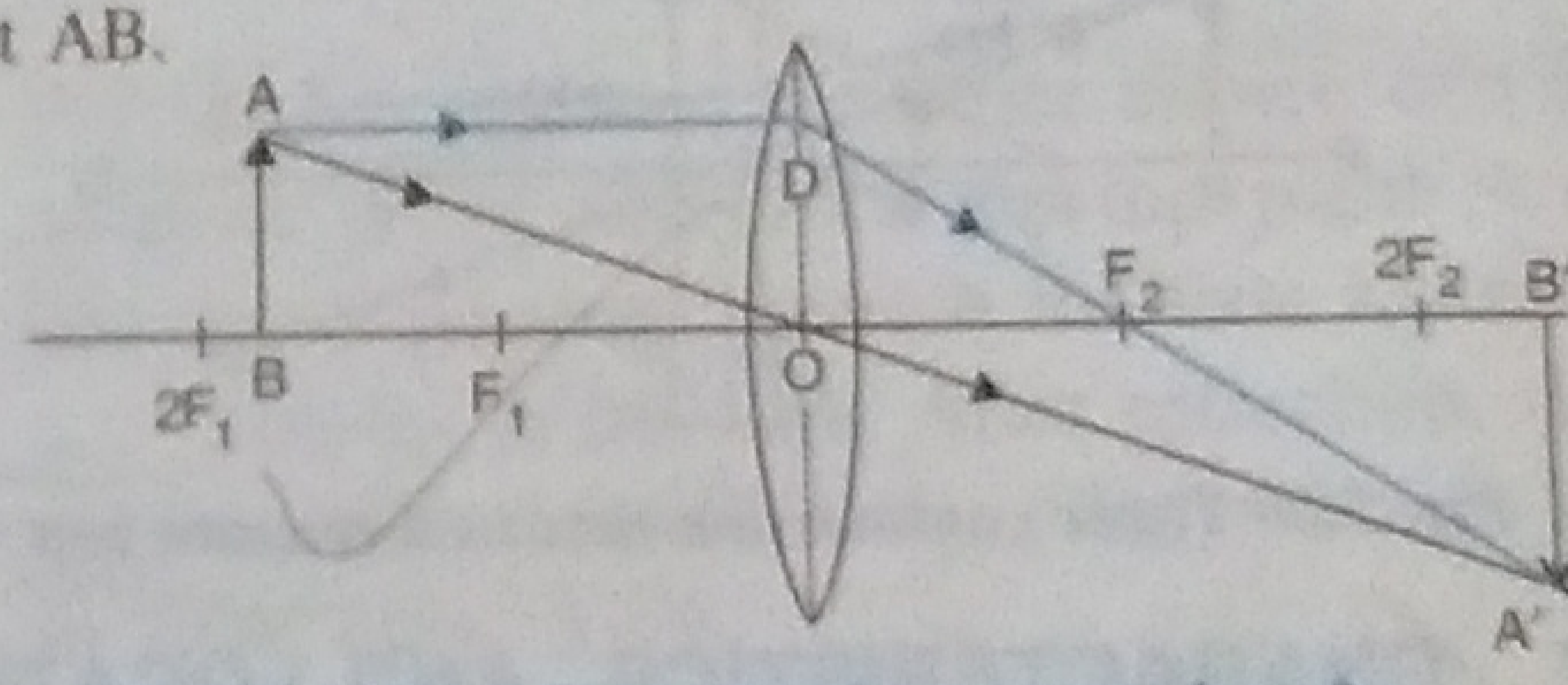


Fig. 5.34 Image formation by a convex lens for the object between F_1 and $2F_1$

Characteristics and location of the image formed

The image is beyond $2F_2$ on the other side of the lens. It is (a) real, (b) inverted, and (c) magnified.

Application : In this manner, a convex lens is used in *cinema* and *slide projectors*. Here the magnified image is obtained on a screen placed at a large distance o the other side of the lens. Care is taken to put the slide (or film i.e., illuminated object) in front of the lens just beyond its focus in inverted position so as to obtain an erect and magnified image on the screen.

Case (v) : When the object is at F_1 (*i.e.*, $u = f$)

In Fig. 5.35, AB is an object placed at the focus F_1 on the principal axis of a convex lens. From the point A of the object, a ray AD incident parallel to the principal axis, after refraction from the lens, passes through the second focus F_2 of the lens as DF_2. The other ray AO incident towards the optical centre O of the lens, passes undeviated through it as OA′. The two refracted rays DF_2 and OA′ being parallel to each other, do not converge at a point at finite distance. For point B, the image will be at B′ at infinity on the principal axis. Thus a highly enlarged image A′B′ is formed at infinity.

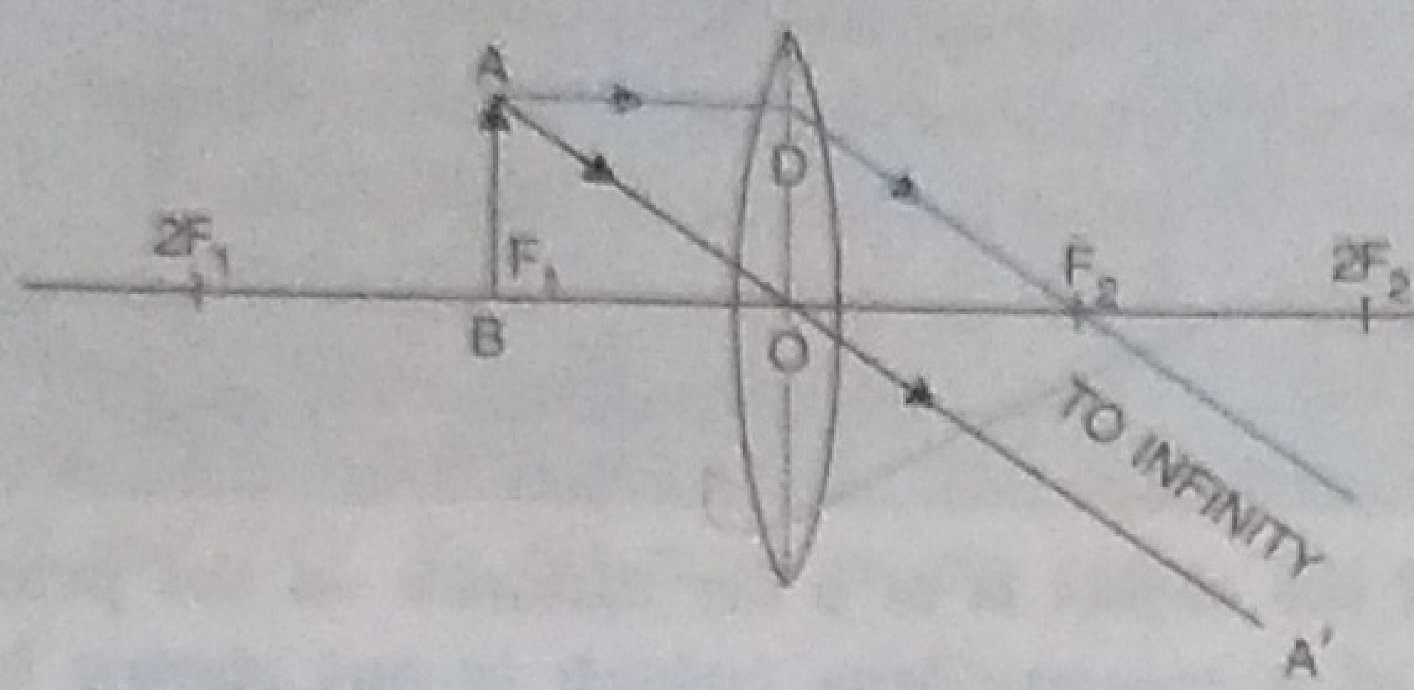


Fig. 5.35 Image formation by a convex lens for the object at F_1

Characteristics and location of the image formed

The image is at infinity *i.e.*, at a very far distance, on the other side of the lens. It is (a) real, (b) inverted, and (c) highly magnified.

Application : In this manner, a convex lens is used in the *collimator of a spectrometer* to obtain a parallel beam of light by placing the source of light at the focus of convex lens.

Case (vi) : When the object is between the lens and focus (*i.e.*, between O and F_1 or $u < f$)

In Fig. 5.36, AB is an object placed on the principal axis of a convex lens between its optical centre O and the first focus F_1. From point A of the object, a ray AD incident parallel to the principal axis, after refraction through the lens passes through the second focus F_2 as DF_2. The other ray AO incident at the optical centre O of the lens, passes undeviated as OO′. The two refracted rays DF_2 and OO′ do not meet each other, but they appear to diverge from a point A′, *i.e.*, when they are produced backwards, they meet at a point A′. Thus A′ is the *virtual image* of the point A of the object. Similarly, for point B of the object, B′ is the virtual image. Thus, A′B′ is the *virtual, erect* and *magnified image* of the object AB which is formed on the same side and behind the object. The image can be distinctly seen by the eye by keeping it at the position shown in Fig. 5.36 so that the eye lens converges the diverging rays to form a real image on the retina of eye.

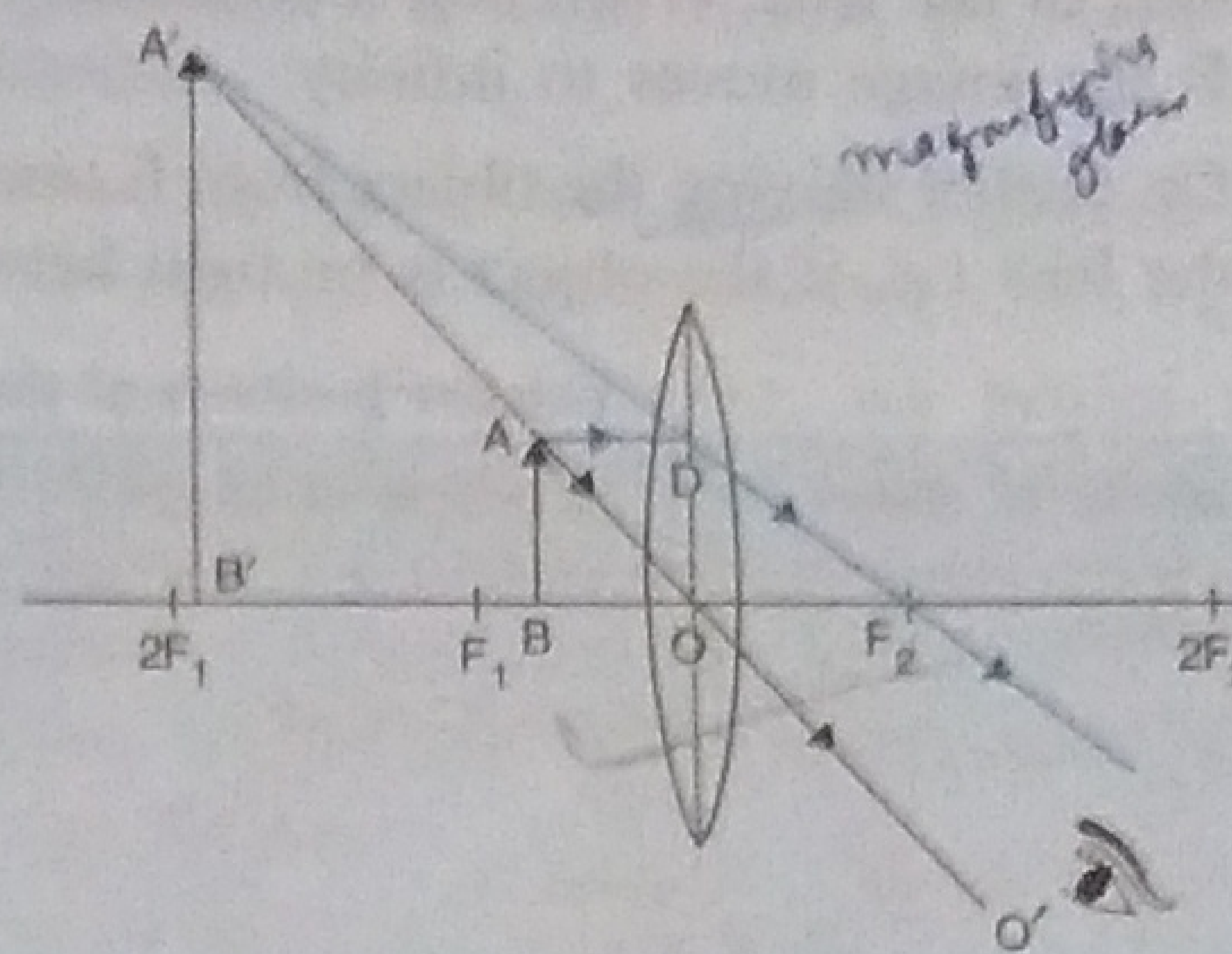


Fig. 5.36 Image formation by a convex lens for the object between the optical centre and the focus

Characteristics and location of the image formed

The image is on the same side and behind the object. It is (a) virtual, (b) erect or upright, and (c) magnified.

Application : In this manner, a convex lens is used as a *reading lens* (*i.e.*, *a magnifying glass* or *a simple microscope*) *to form* a magnified virtual image of a tiny object (such as a small letter of a book or a small part of a watch etc.).

Inference : From above, we notice that *both the real as well as virtual images can be formed by a convex lens depending upon the position of the object relative to the lens.* The size of image (magnified, diminished or same) also depends on the position of object.

(1) When object is very far off from the convex lens, a real, inverted and diminished image is formed at the focus.

(2) As the object moves towards the lens up to 2F, the image on other side of lens moves away from the focus of the lens up to 2F. However, the image formed will remain real, inverted and diminished, but its size will gradually increase.