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.

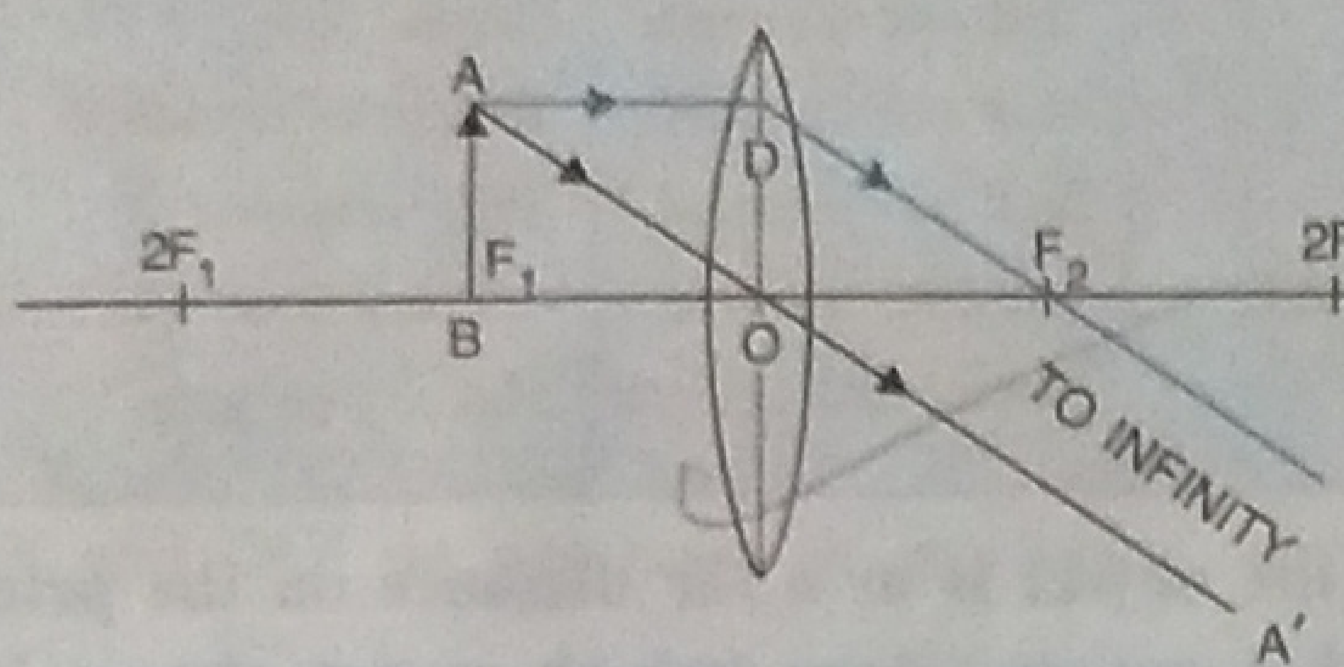

Fig. 5.35 Image formation by a convex lens for the object at F_1

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.

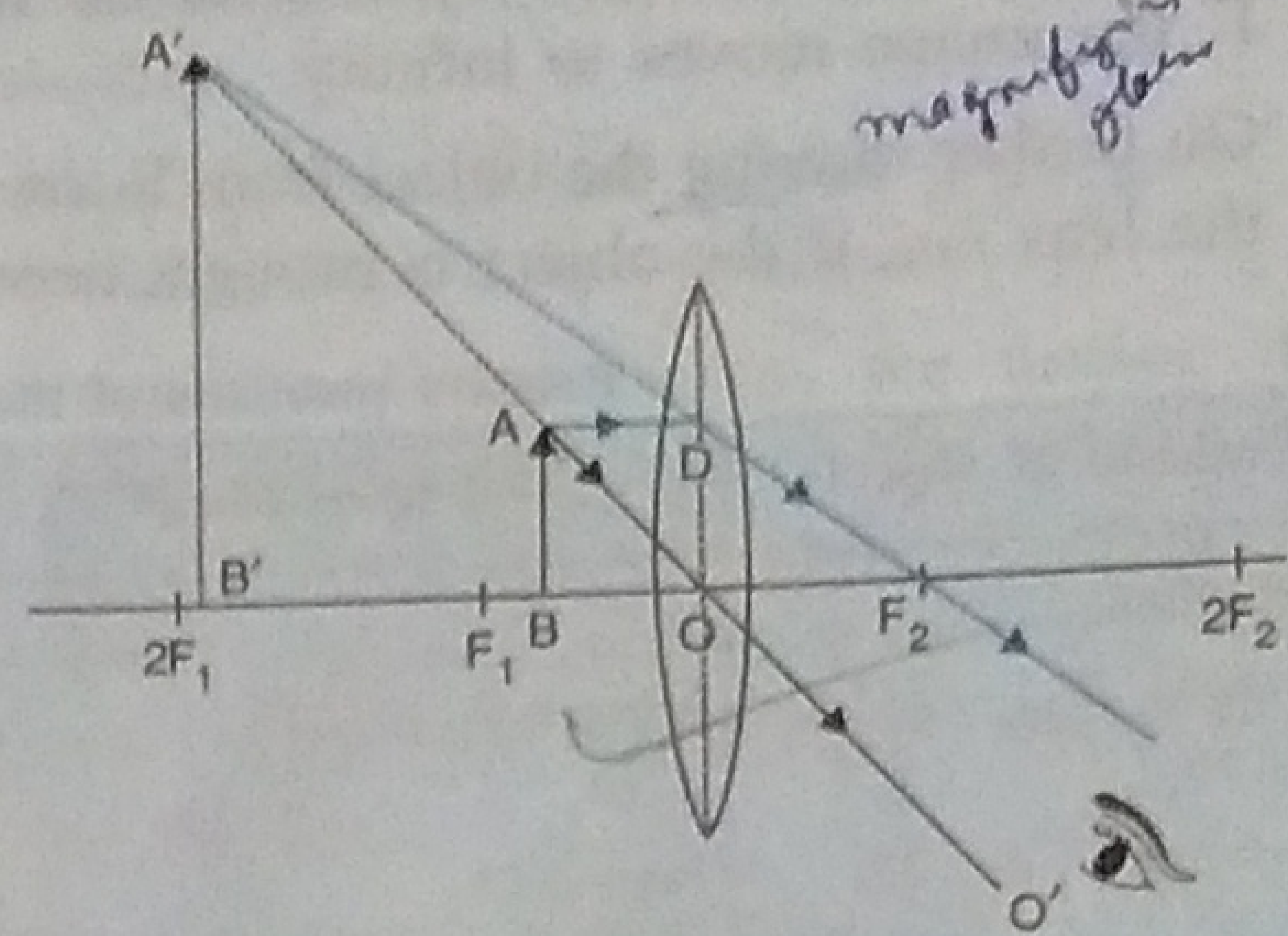

Fig. 5.36 Image formation by a convex lens for the object between the optical centre and the focus

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.

(3) As object comes at the position 2F, the image is real, inverted and of the same size. It is obtained at the position 2F on the other side of the lens.

(4) On further moving the object from 2F towards its focus F, the image will remain real and inverted, but it becomes magnified and is formed away from 2F on the other side of the lens. When object comes at focus F, the image moves to infinity.

(5) On further moving the object from F towards the lens *i.e.*, if the object is brought between the focus and the lens, the image becomes magnified, erect, and virtual on the side of the object. It is formed behind the object.

Note : The above observations will be same if the lens is moved towards the object instead of moving the object towards the lens.

The table below gives the position, size, nature of the image formed by a convex lens and its application corresponding to the different positions of the object.

Relative positions of the object and image in a convex lens

Position of object	Position of image	Size of image	Nature of image	Application
1. At infinity	at F_2	highly diminished	real and inverted	Burning glass
2. Beyond $2F_1$	between F_2 and $2F_2$	diminished	real and inverted	Camera lens
3. At $2F_1$	at $2F_2$	same size	real and inverted	Terrestrial telescope
4. Between F_1 and $2F_1$	beyond $2F_2$	magnified	real and inverted	Slide projector
5. At F_1	at infinity	highly magnified	real and inverted	Collimator of spectrometer
6. Between the lens and F_1	on same side, behind the object	magnified	virtual and upright	Magnifying glass

5.8 CHARACTERISTICS AND LOCATION OF IMAGES FOR A CONCAVE LENS

Let us now determine the position and characteristics of the image formed by a concave lens by ray diagrams for the different positions of the object.

Case (i) : When the object is at infinity

The light rays from an object at infinity are parallel to each other and in Fig. 5.37 they are incident parallel to the principal axis of the concave lens, so after refraction from the concave lens, they appear to diverge from the second focus F_2. Thus a *virtual*, *erect* and *diminished* image is formed at the second focus on the side of the object in front of the concave lens.

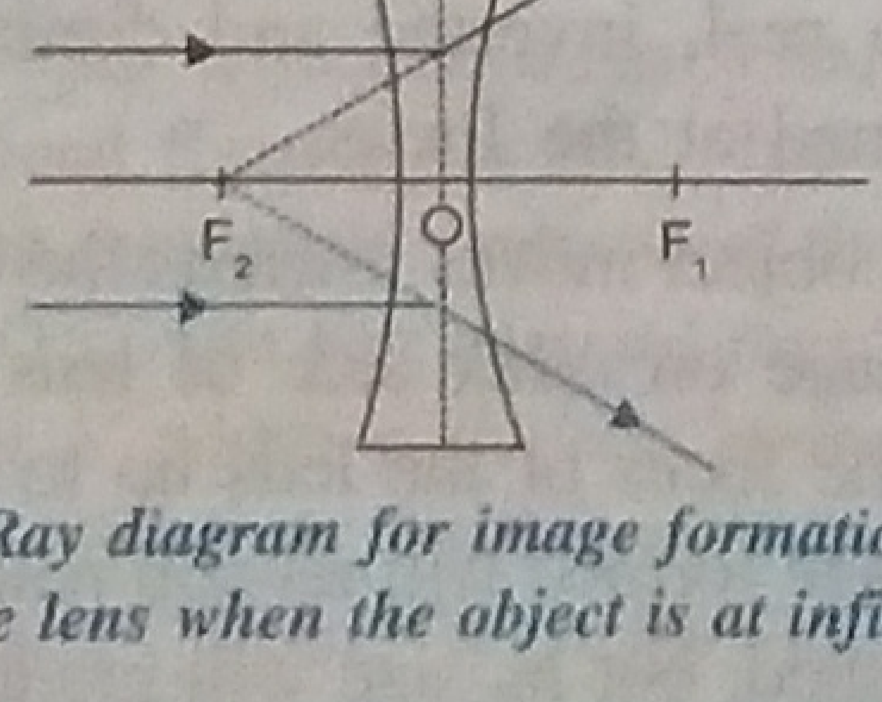

Fig. 5.37 Ray diagram for image formation by a concave lens when the object is at infinity

If the object is at a far distance on the principal axis of a concave lens (which is not shown in the diagram) : From the top point A of the object, rays reaching the lens will be parallel to each other and they will be obliquely incident on the lens. The ray PD incident towards the first focus F_1 of the lens, after refraction from the lens, becomes parallel to the principal axis as DD′. The other ray QO from the same point A of object, incident at the optical centre O of the lens, passes undeviated through the lens as OO′. The two refracted rays DD′ and OO′ do not meet each other, but when produced backwards, they meet at a point A′ which is the *virtual* image of the point A of the object. Similarly, for the bottom point B of the object lying on the principal axis, the virtual image is

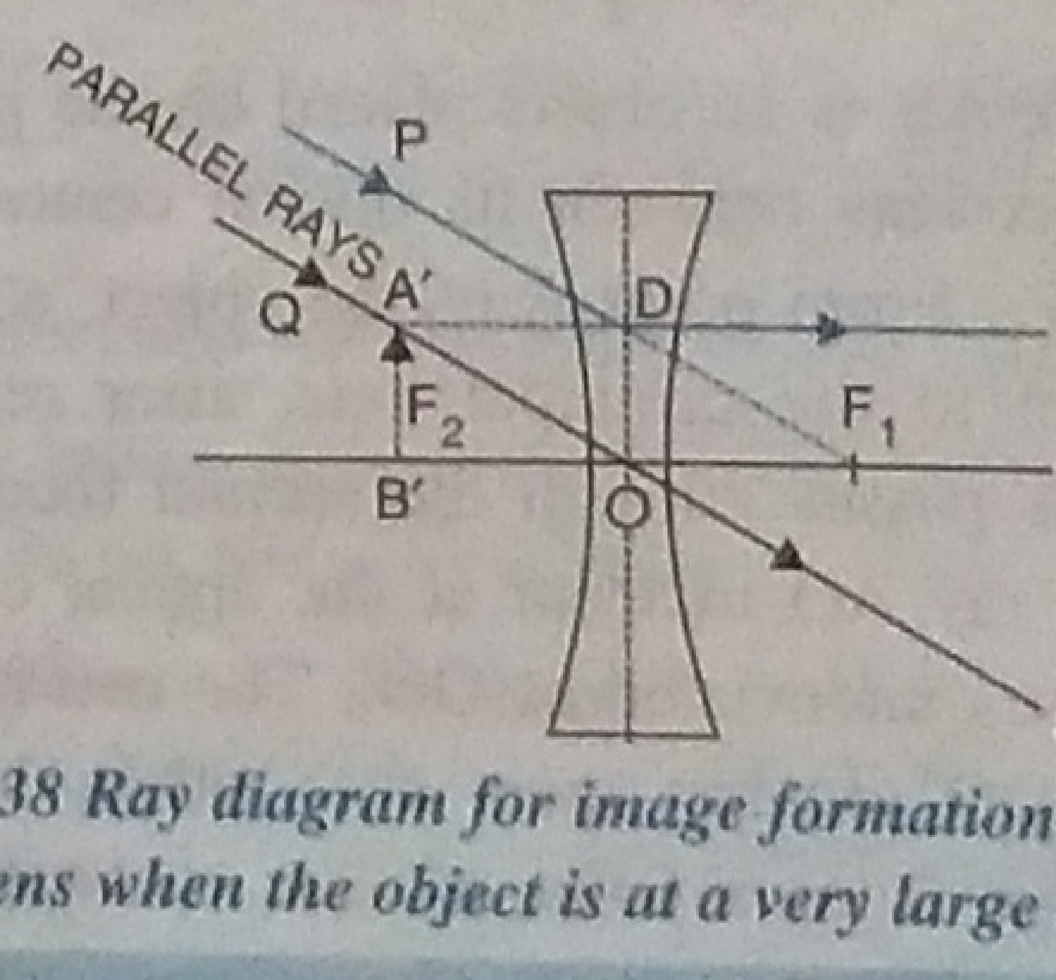

Fig. 5.38 Ray diagram for image formation by a concave lens when the object is at a very large distance

formed at B′ at the second focus F_2 of the lens. Thus A′B′ is the *virtual, erect* (or upright) and *highly diminished* image of the object AB which is formed in front of the lens in the focal plane at second focus F_2 of the lens.

Characteristics and location of the image

The image is at the second focus F_2 (or in the focal plane at F_2) on the side of the object. It is

(a) *virtual*, (b) *erect, and* (c) *highly diminished.*

Application : A concave lens is used in *Galilean telescope* in this manner.

Case (ii) : When the object is at any finite distance from the concave lens

Let AB be an object placed at a point on the principal axis at any finite distance, in front of a concave lens (Fig. 5.39). Two rays AD and AO from the point A of the object, after refraction through the lens, diverge from each other. The ray AD incident parallel to the principal axis is refracted as DD′ so as to appear to come from the second focus F_2. The ray AO, incident towards the optical centre O, passes undeviated after refraction as OO′. The two refracted rays DD′ and OO′ do not meet at any point. But the

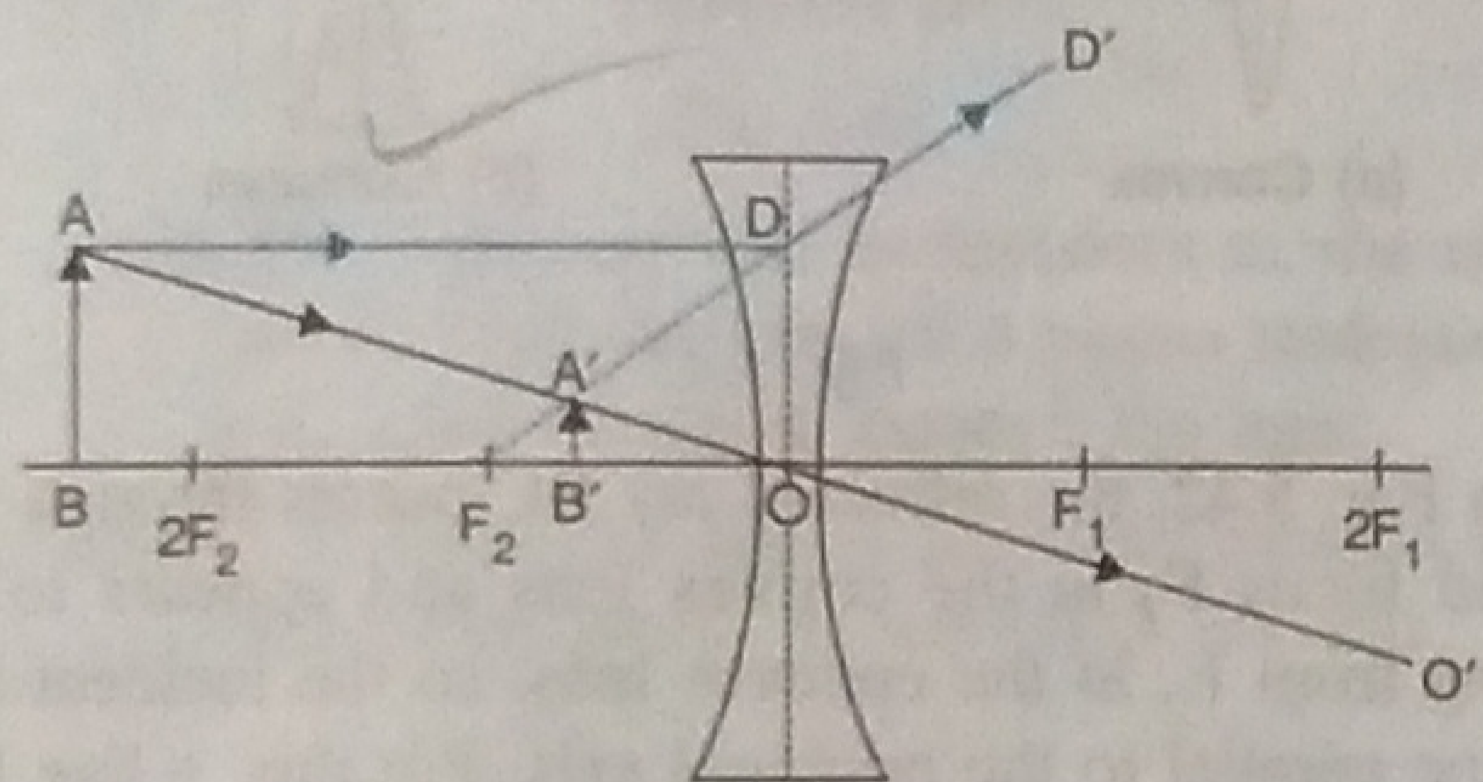

Fig. 5.39 Ray diagram for image formation by a concave lens when the object is between infinity and the lens

refracted ray DD′, on being produced backwards, meets the ray AO at a point A′ which is the *virtual* image of the point A. Similarly B′ is the virtual image of the point B. Thus A′B′ is the *virtual, erect* and *diminished image* of the object AB formed in front of the lens, between the optical centre and second focus of the lens.

Characteristics and location of the image

The image is between the lens and focus, on the side of the object. It is (a) *virtual*, (b) *erect, and* (c) *diminished.*

Application : A concave lens is used in *spectacles* for the *short-sighted persons* in this manner.

Inference : From above, we notice that irrespective of the position of the object, the image formed by a thin concave (or divergent) lens is always *virtual, upright, diminished,* and *it is situated on the side of the object between the focus and the lens.*

(1) When the object moves from a large distance towards the lens, the image shifts from the focus towards the optical centre of the lens and the size gradually increases, but it always remains smaller than the object.

(2) When the object is at a distance equal to the focal length of the lens, the image is exactly at the mid-point between the optical centre and the second focus of the lens.

The table below gives the position, size, nature of the image formed by a concave lens and its application corresponding to the different positions of the object.

Relative positions of the object and image in a concave lens

Position of the object	Position of the image	Nature of the image	Size of the image	Application
1. At infinity	At the focus, on the same side of the lens as the object.	Virtual and upright	Highly diminished	Galilean telescope
2. At any position between infinity and optical centre	Between the focus and optical centre, on the same side of the lens as the object.	Virtual and upright	Diminished	Myopic eye