$\sin^{-1}(0.9) = \frac{D_m}{2} + 30^\circ$

$64.16^\circ = \frac{D_m}{2} + 30^\circ$

$\frac{D_m}{2} = 64.16^\circ - 30^\circ = 34.16^\circ$

$\therefore D_m = 34.16^\circ \times 2 = 68.32^\circ$

$\simeq 68^\circ$

$i = \left(\frac{D_m + A}{2}\right)$

$= \frac{68^\circ + 60^\circ}{2} = \frac{128^\circ}{2}$

$= 64^\circ$

Deviation is defined as the change in direction of a ray of light when it passes through a glass prism, owing to the inclination of two faces.

Worked example 31.10

An object is placed directly below a glass block of thickness 3.0cm. Calculate the lateral displacement of the object if the refractive index of the glass is 1.5.

Solution

$t = 3,\ n = 1.5 = \frac{3}{2},\ d = ?$

$D = t\left(1 - \frac{1}{n}\right)$

$= 3\ \ 1 - \frac{1}{1.5} = 3\,[1 - \tfrac{2}{3}]$

$= 3 \times \tfrac{1}{3} = 1m$

Worked example 31.11

An object pin is placed inside a beaker and water is poured into the beaker to a depth of 6.0cm. Calculate the displacement of the pin if the refractive index of water is $\frac{4}{3}$

Solution: $n = \frac{\text{real depth}}{\text{apparent depth}}$

$\therefore \frac{4}{3} = \frac{6}{\text{apparent depth}}$

apparent depth $= 6 \times \frac{3}{4} = 4.5cm$

$\therefore$ displacement (lateral) = real depth - apparent depth

$= 6 - 4.5 \quad = 1.5cm$

Revision exercise

1(a). Explain: (i) how refraction occurs on a plane surface. (ii) The factors which determine its refractive index.

2. State Snell's law of refraction and explain an experiment to show the existence of the law.

3. Explain the refraction through a given equilateral triangle prism and show with an experiment that the refractive index of the glass is

$$\mu = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

4. Give account of an experiment of refraction on liquid and water. What is (i) apparent depth (ii) real depth?

5. The refractive index of glass and water with respect to air are $\frac{3}{2}$ and $4/3$ respectively. What is the refractive index of glass to water.

6. Find the real depth of a substance in water, if the refractive index of the water is $4/3$ and the apparent depth is 15m.

7. Show that when a ray is refracted through a dense medium to a denser medium, the refractive index changes.

8. Name five applications of total internal reflection.

9. (i)What is meant by total internal reflection and critical angle?

(ii) Give two factors affecting total internal reflection

10. Find the refractive index of a prism, when a light ray is incidented on the prism of angle 45° and if the refracting angle of the prism is 60°

11. Find the thickness of a prism of refractive index of 1.5, if the prism displacement of the object is 1.3m.

12(a)(i) State the laws of refraction of light.

(ii) Describe an experiment to determine the refractive index *n* of the material of an equilateral triangle glass prism using the minimum deviation method.

(b) A rectangular glass prism of thickness 12cm is placed on a mark on a piece of paper resting on a horizontal bench. (i) Draw a ray diagram to show

32. REFRACTION THROUGH LENSES

32.1 Refraction

Refraction can simply be defined as the transmission (change) in speed of rays of light from one medium to another. In the process of transmission, the velocity of transmission, the wavelength, the density of transmission and the direction of transmission change as refraction occurs. Only frequency of the transmission remains the same.

Lenses are a transparent medium which could be glass, plastic and nylon which are bounded by non-coated spherical surface or curved surfaces.

Types of lenses

There are many types of lenses and each type possesses different characteristics:

(i) Concave lens (diverging lens)

(ii) Convex lens (converging lens)

32. 2 Classification of Lenses

Every lens is classified according to shape or form.

Concave lenses (Diverging lenses): They are biconcave, plano concave and diverging meniscus. Rays that pass through diverging lenses are diffused or spread out. This is because they are thinner at the middle than at the edge.

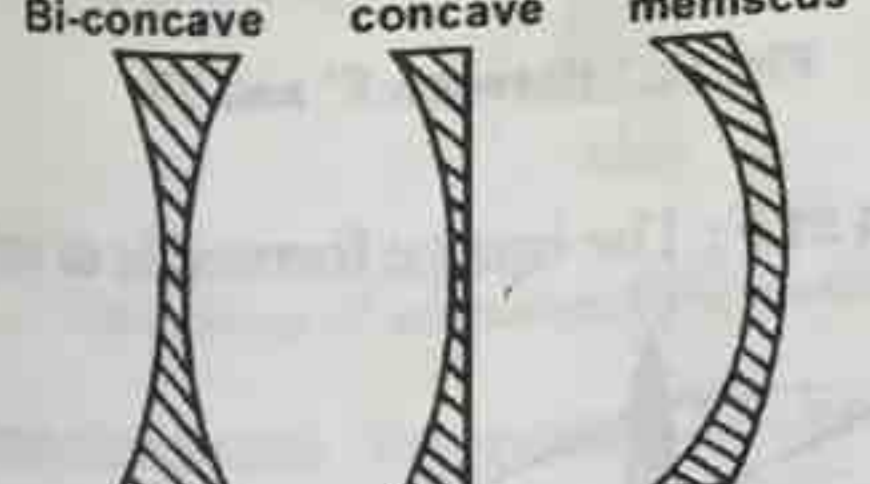

Fig. 32.1 Concave lenses (Diverging lenses)

Concave lens has its centre thinner than the edge. This enables parallel rays of light to diverge after refraction. These are the characteristics:

1. They produce virtual images, meaning that they do not possess the focus.
2. Concave lenses are independent of the distance of the object. Thus images produced are always virtual, diminished and erect (upright).

Convex lenses (converging lenses): They are convex, planoconvex and converging meniscus. Rays that pass through converging lenses come together at the point of the focus. This is because they are thicker at the middle than at the edge.

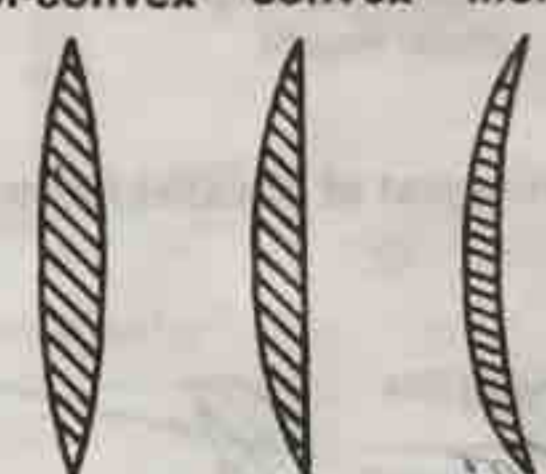

Fig. 32.2 Convex lenses (converging lenses)

Convex lenses have their centre thicker than the edge. This enables them to cause parallel rays of light to converge at a point. The characteristics of convex lenses are:

1. They possess a true focus, giving rise to the formation of real images.
2. They can form images which can be magnified, erect or inverted.
3. Images produced on convex lenses are dependent on the distance of the object.

32.3 Terms Used in Refraction through Lenses

1. Principal focus of a converging lens: This is the point at which rays closer and parallel to the principal axis come together or converge after refraction.

2. Optical centre (c): This is the point on the lens through which rays of light pass.

3. Principal focus of a diverging lens: This is the point at which rays closer and parallel to the principal axis spread out or diverge after refraction.

4. Principal axis of a lens: This is a line joining the curvature to its surface.

5. Focal length: This is the distance between the optical centre and the principal focus.

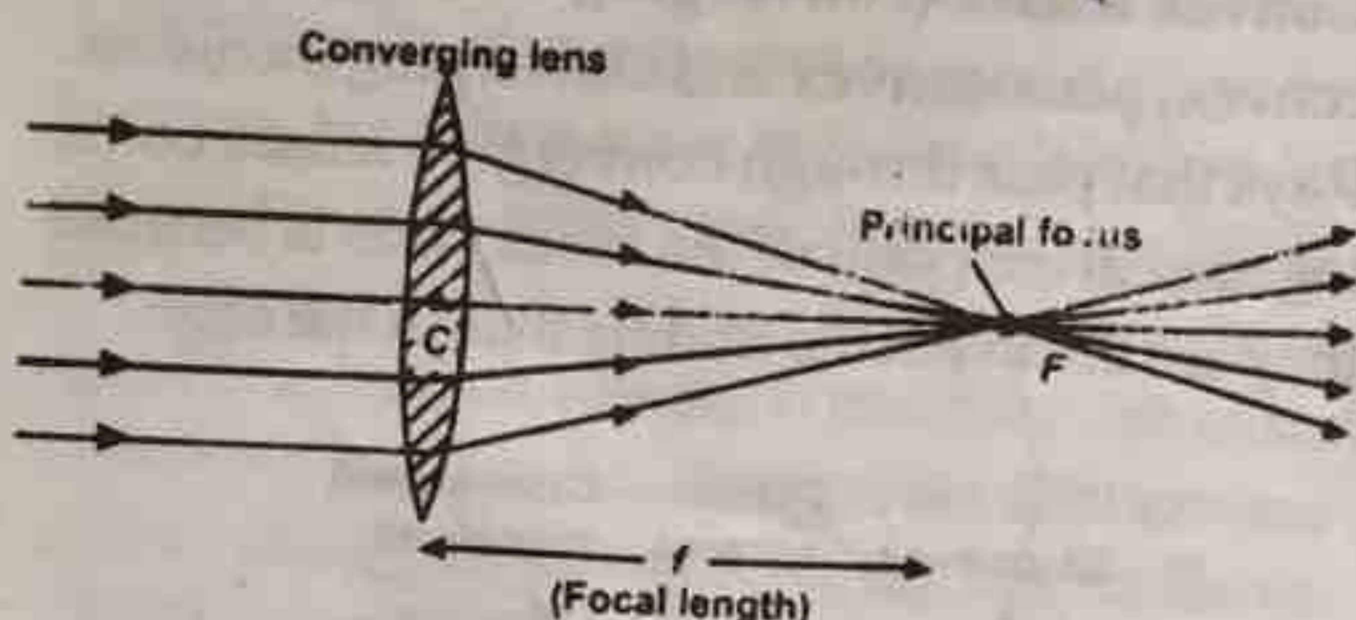

Fig. 32.3 Convergent of parallel beams

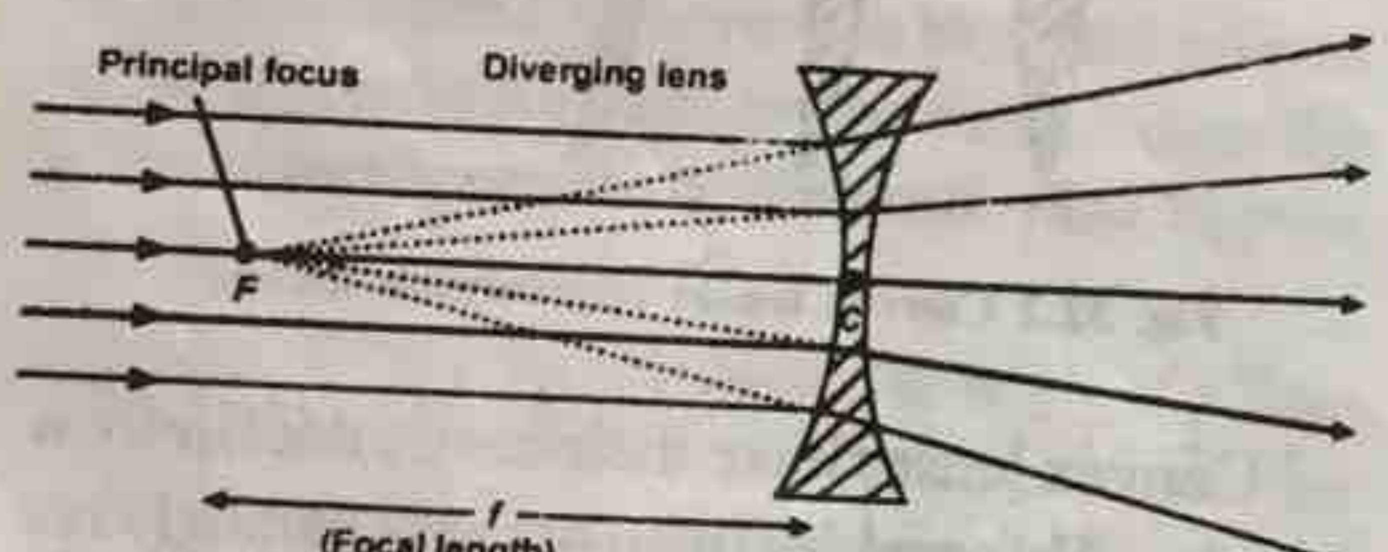

Fig. 32.4 Divergent of parallel beams

32.4 Shapes (Formations) of Lens Rays

Three classes of rays are used to obtain the position and nature of images formed by lenses. These are:

(i) Rays parallel to the principal axis and close to it, which pass through the principal focus after refraction

(ii) Rays through the principal focus which emerge parallel to the principal axis after refraction

(iii) Rays through the optical centre which pass through the lens undeviated, i.e. their direction is unchanged.

Nature of images formed by lenses

1. Objects beyond 2F^1: The features of the images formed are: (i) formed between F and 2F (ii) real (iii) inverted (iv) smaller than the object.

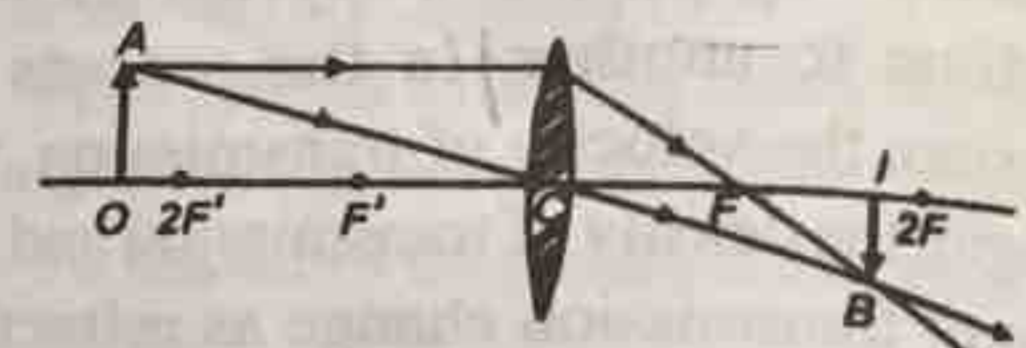

Fig. 32.5 Objects beyond 2F

2. Object at 2F^1: The feature of the images formed are: (i) at 2F (ii) real (iii) inverted (iv) same size as object.

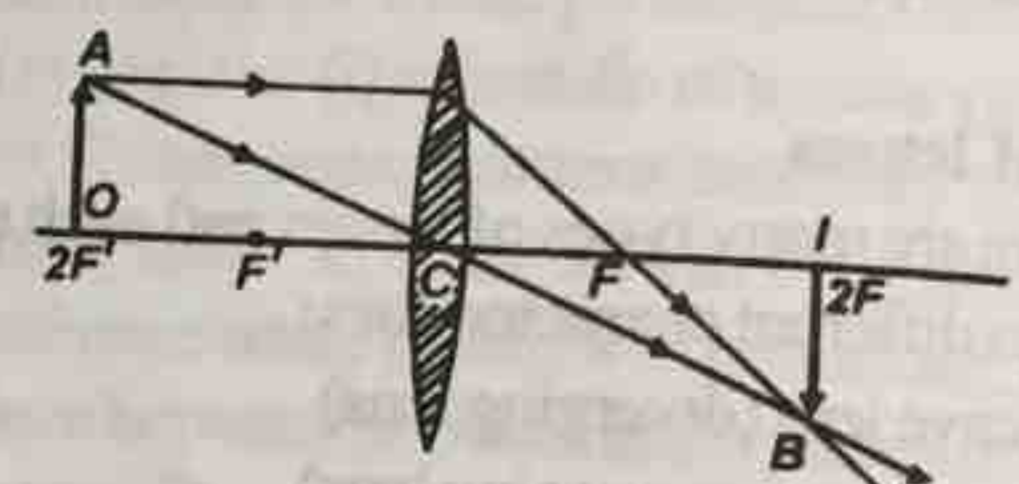

Fig. 32.6 Object at 2F

3. Between F^1 and 2F: The features of the images formed are: (i) beyond 2F (ii) real (iii) inverted (iv) larger than the object.

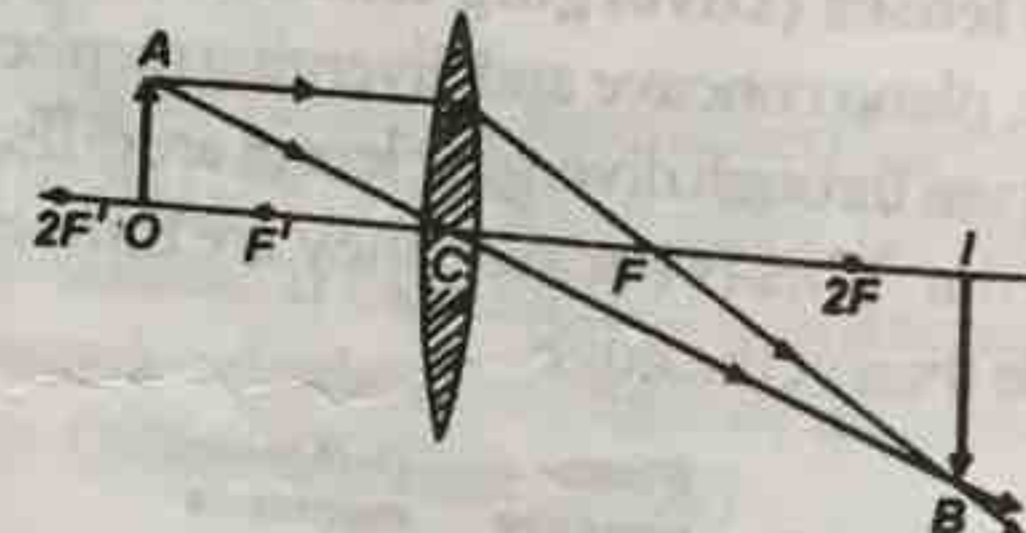

Fig. 32.7 Between F' and 2F

4. Object at F: The image formed is at infinity

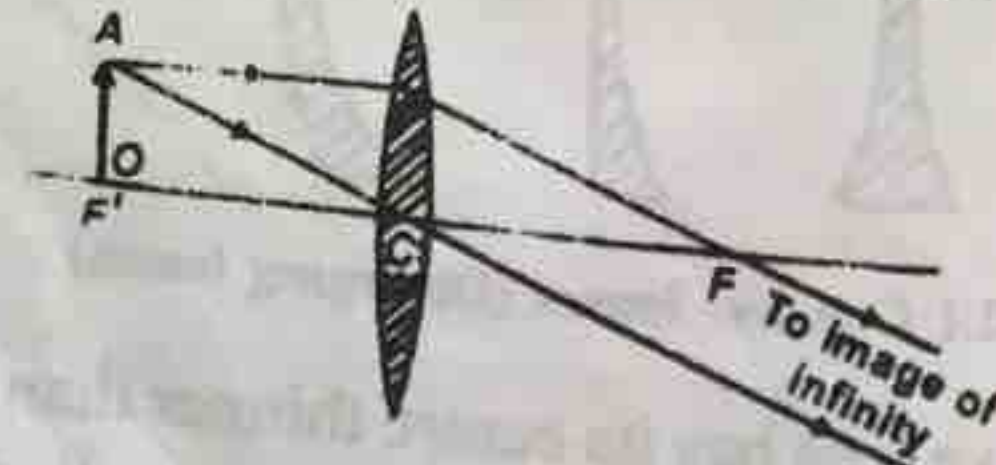

Fig. 32.8 Object at F

5. **Object between lens and F exhibit these features:** (i) behind the object (ii) virtual (iii) erect or upright (iv) larger than the object.

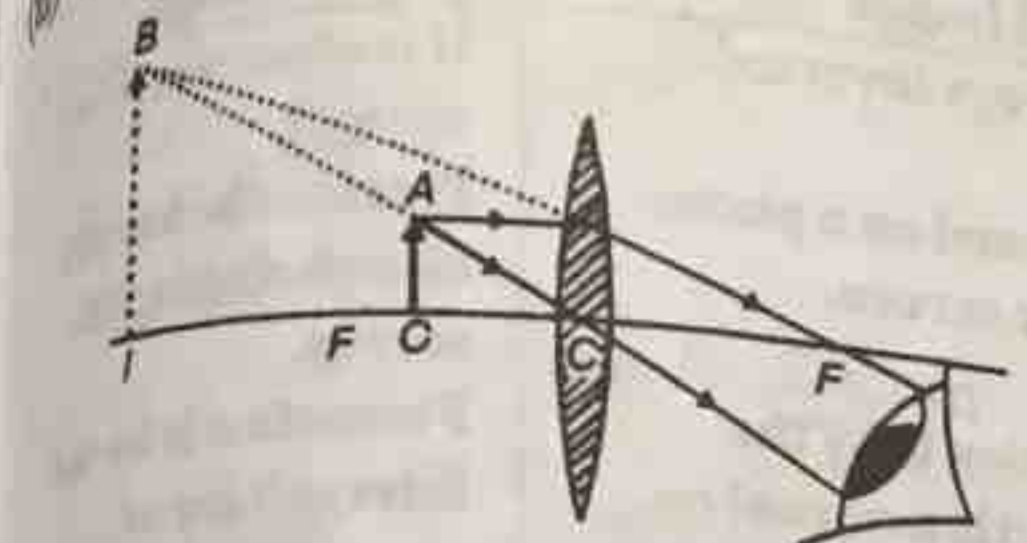

Fig. 32.9 Object between lens and F

6. **Object at infinity exhibits these features** (i) At F (ii) real (iii) inverted (iv) smaller than the object.

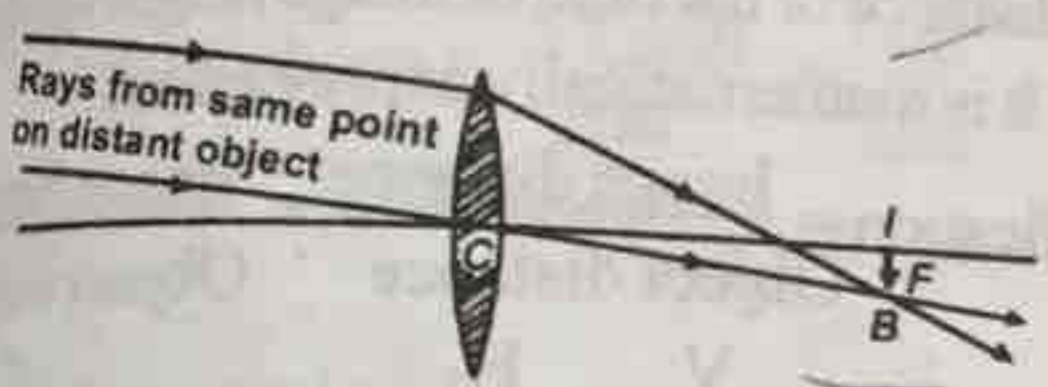

Fig. 32.10 Object at infinity

The nature of the image formed by a convex mirror is not affected by the position of the object from the mirror. Thus, the image is always: (i) virtual (ii) erect or upright (iii) diminished or smaller than the object.

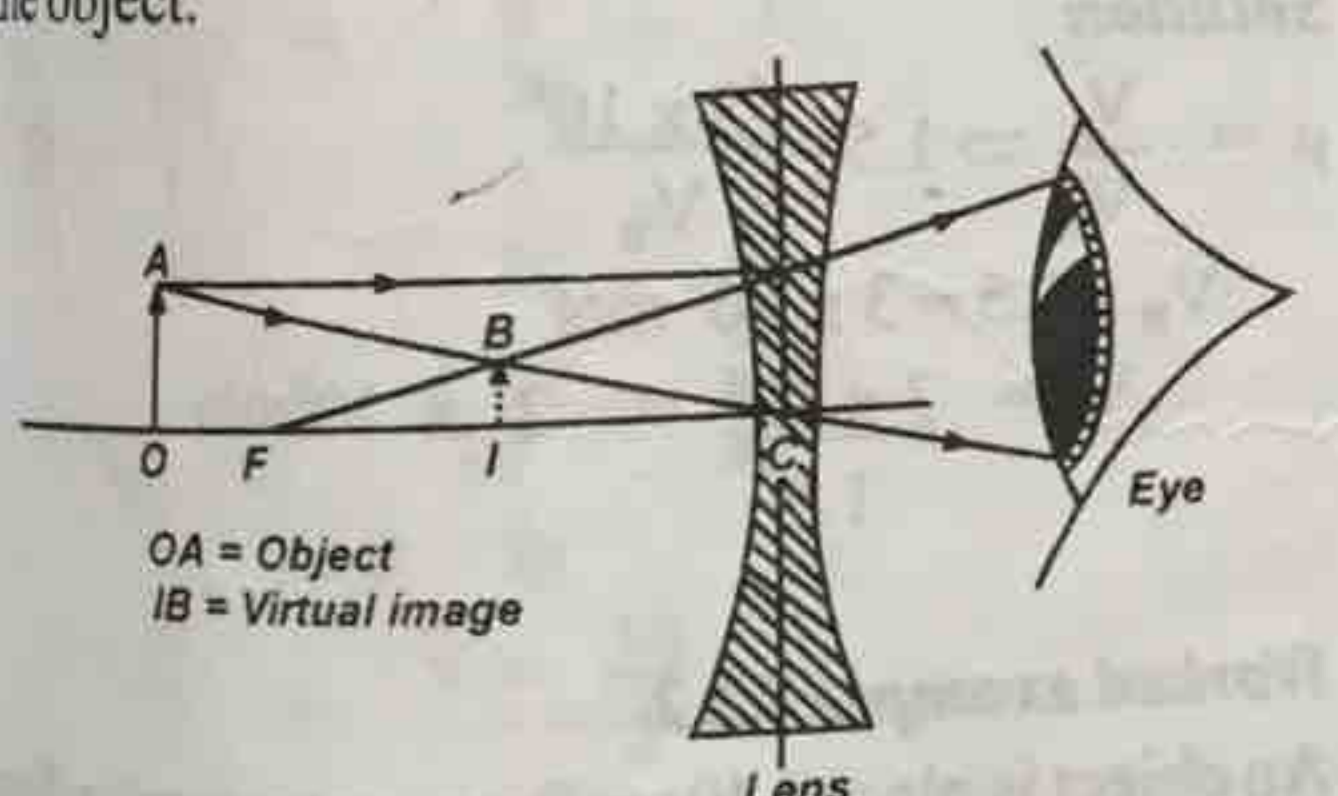

Fig. 32.11 Formation of an image by a diverging lens

32.5 Experiment to Determine Accurate Focal Length of a Convex Lens Using Office Pins

Aim: To determine the accurate focal length of a convex lens using office pins.

Apparatus: Convex lens, screen, source of light and cross wire pins.

Method: An object pin is set up in front of a lens.

The object pin is located out using the locating pin which is at the opposite end of the lens. The image pin is moved to and fro until parallax is eliminated between the point and the image point. The distance object, U, and image distance, V, are measured. The experiment is repeated for different values of object distance U. Then the focal length of the lens is obtained. The focal length is calculated using lens formula.

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

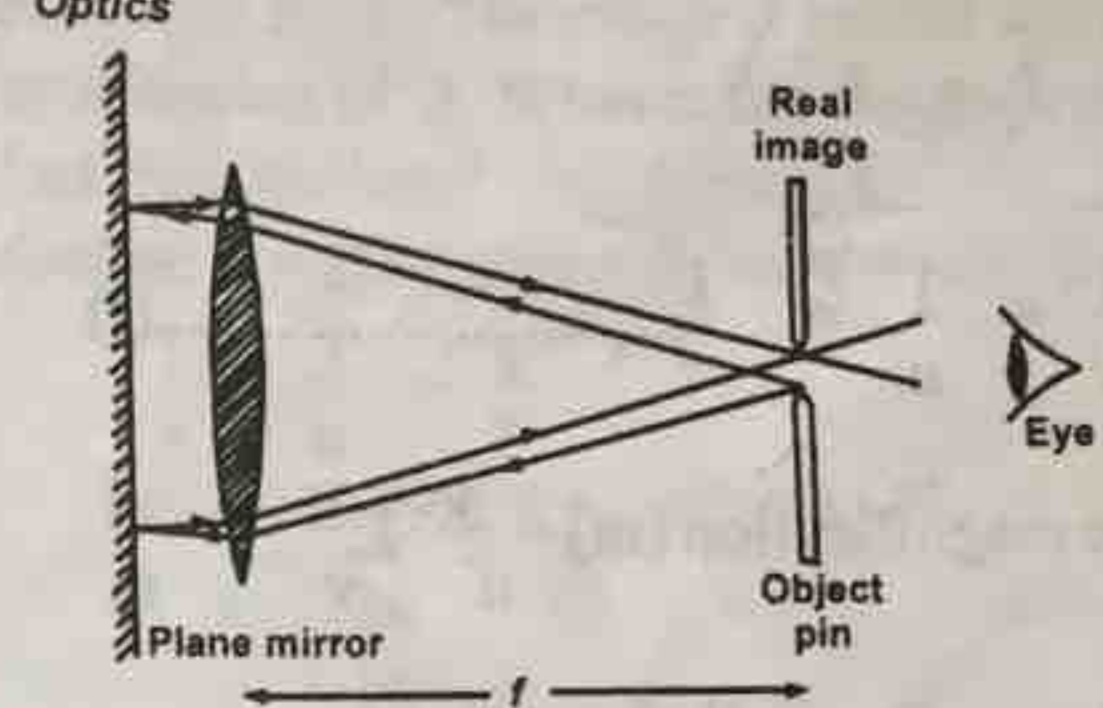

Fig. 32.12 Focal length of a converging lens by pin method

Measurement of focal length of a convex lens using illuminated source

The focal length of a convex lens using illuminated source is done by placing mirror close to lens. The screen is moved forward and backward in order to obtain a sharp image of the wire in front of the screen. The distance between the screen and lens gives the required focal length of the lens.

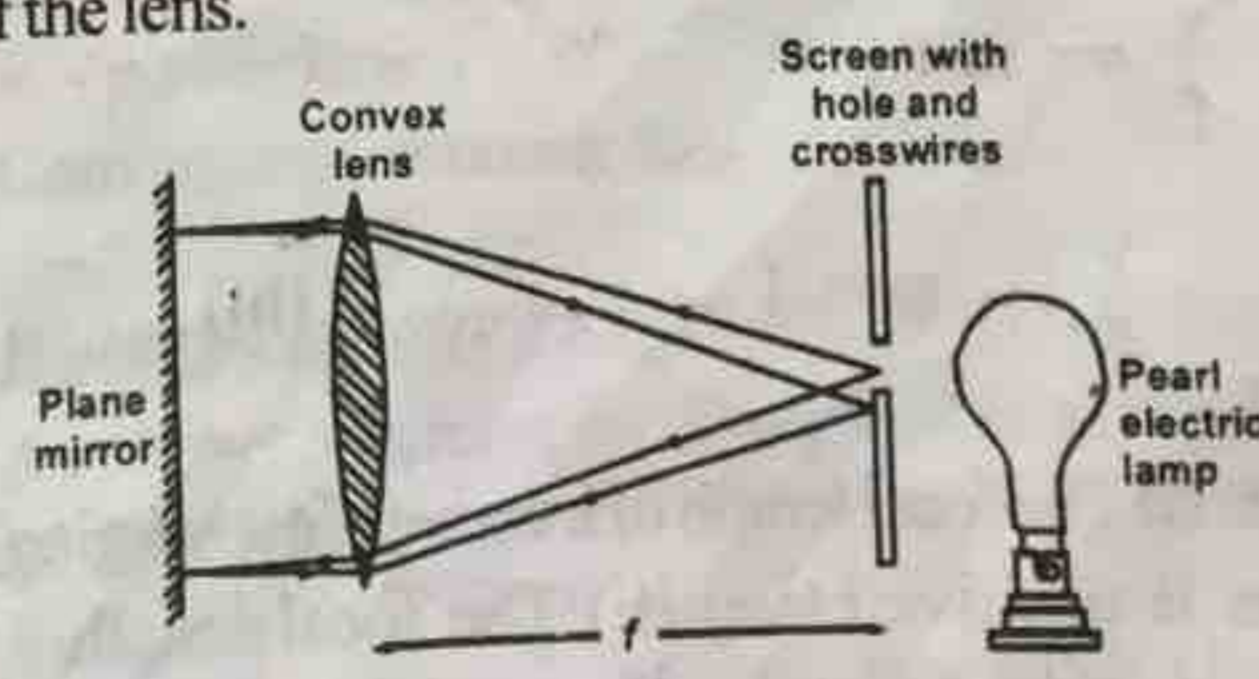

Fig. 32.13 Finding focal length of a converging lens

Measurement of focal length of a convex lens using lens formula

For lens formula, the object distance is known and the image distance at which it is formed on the screen is also known, then the focal length is calculated using,

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

32.6 Lens Formula

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

$$f = \frac{r}{2}$$

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \text{..............................(i)}$$

Since magnification (m) = $\frac{v}{u}$, $\frac{u}{v} = \frac{I}{m}$

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

multiplying equation (i) by V

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

$$\frac{u}{f} - \frac{I}{m} = 1 \text{.......................(ii)}$$

multiplying equation (i) throughout by V

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

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

$$\frac{v}{f} - m = 1 \text{ .... (iii)}$$

NB: (i) The focal length of a convex (converging) lens is positive (+ve) (ii) The focal length of concave (diverging) lens is negative (-ve).

32.7 Differences between Real and Virtual Images

Real Image	Virtual Image
1. **It is always inverted.**	**It is always erect or upright.**
2. **It is formed on a photographic screen.**	**It cannot be formed on a photographic screen.**
3. **Formation is by the intersection of real or true rays.**	**Formation is by the intersection of apparent rays.**

32.8 Magnification (Linear)

Magnification is the ratio of image distance to object distance or the ratio of image height to object height. It is mathematically expressed as:

$$\text{Magnification} = \frac{\text{Image distance}}{\text{Object distance}} = \frac{\text{Image height}}{\text{Object height}}$$

$$M = \frac{V}{u} = \frac{H_1}{H_o}$$

Worked example 32.1

The refractive index of liquid is 1.5. If the velocity of light in a vacuum is 3.0×10^8 m/s, find the velocity of light on the liquid.

Solution

$$\mu = \frac{V_A}{V_B} \Rightarrow 1.5 = \frac{3 \times 10^8}{V_B}$$

$$V_B \times 1.5 = 3 \times 10^8 \text{ m/s}$$

$$V_B = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{m/s}$$

Worked example 32.2

An object is placed 40cm from a converging lens of focal length, 25cm. If a real image which is 5cm high is formed, calculate the height of the object.

Solution

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

$$\frac{1}{40} + \frac{1}{u} = \frac{1}{25}$$