Chapter 2

Lenses

A **lens** is a transparent material (like glass or plastic) that bends light rays to form an image.

It has two curved surfaces, or at least one of them must be curved.

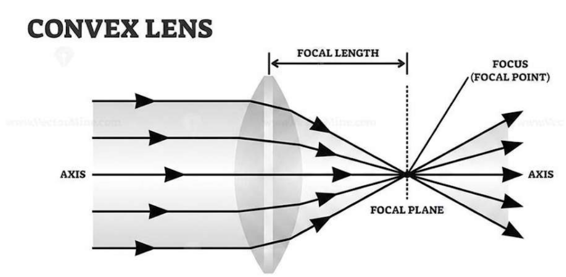
Each refracting surface is part of a sphere.

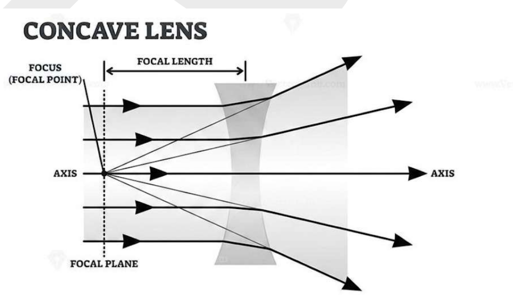
Lenses are used in:

- Glasses (spectacles)
- Cameras
- Microscopes
- Telescopes
- Projectors

Types of Lenses

- Convex Lens (Converging Lens): Thicker in the middle than at the edges. It brings light rays together (converges them). Example: Magnifying glass.
- Concave Lens (Diverging Lens): Thinner in the middle and thicker at the edges. It spreads out light rays (diverges them). Example: Used in spectacles for people with myopia (short-sightedness).





Terms Related to Lenses

- Optic Centre (O): The midpoint of a lens is the optic centre.
- Centres of Curvature: Each refracting surface of a lens is part of a sphere. The centres of such spheres are the centres of curvature.
- Optic Axis: The imaginary line passing through the centres of curvature and the optic centre of a lens.
- Aperture: The area of the lens through which light passes. In optical instruments such as cameras and microscopes, the aperture can be varied by using the stop.

Principal Focus

Convex Lens:

- Light rays near and parallel to the optic axis incident on a convex lens, after refraction converge at a point on the optic axis on the other side of the lens.
- This point is the principal focus (F).
- It is considered real because light rays actually pass through it.

Concave Lens:

- Light rays near and parallel to the optic axis incident on a concave lens, after refraction appear to diverge from a point on the optic axis on the same side of the lens.
- This point is the principal focus (F).

Focal Length (f): The distance from the optic centre of the lens to the principal focus.

Image Formation by Lenses

An image is formed when light rays coming from an object are reflected or refracted and either actually meet or appear to meet at a point.

A ray of light coming from a point on an object and passing through any point of the lens follows the laws of refraction.

If a screen is placed at the point of convergence of the refracted rays, the image is formed there.

Types of Images

Real Image

- Formed when light rays actually meet after reflection or refraction.
- Can be projected on a screen.
- Always inverted.
- Examples: Image formed on a cinema screen, captured on a camera.

Virtual Image

- Formed when light rays appear to meet but do not actually meet.

- Cannot be projected on a screen.
- Always upright (erect).
- Example: Image seen in a plane mirror.

Ray Diagram Rules for a Convex Lens

Ray Description (Incident Ray)	Path After Refraction
A ray of light from a point which is parallel to the optic axis	Passes through the principal focus on the other side.
A ray of light passing through the optic centre	Passes through the lens undeviated.
A ray of light passing through the focus on the same side of the object	Emerges parallel to the principal axis after refraction.

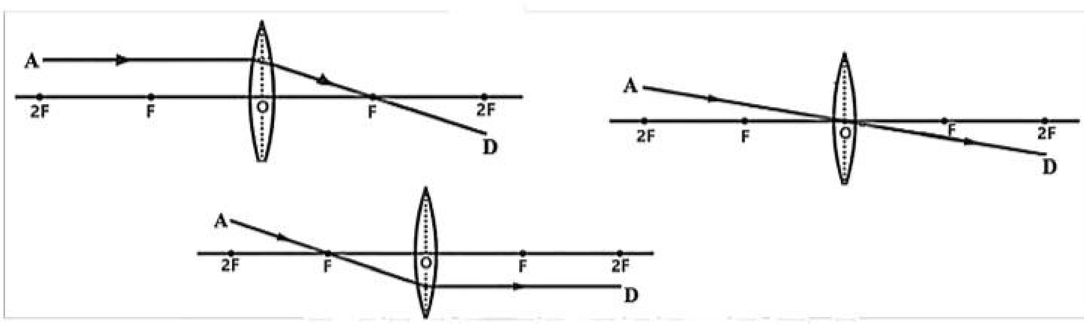


Image Positions for Convex Lenses

1. Object Beyond 2F

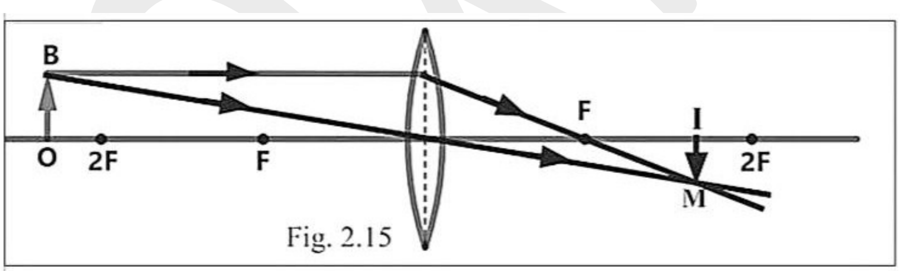
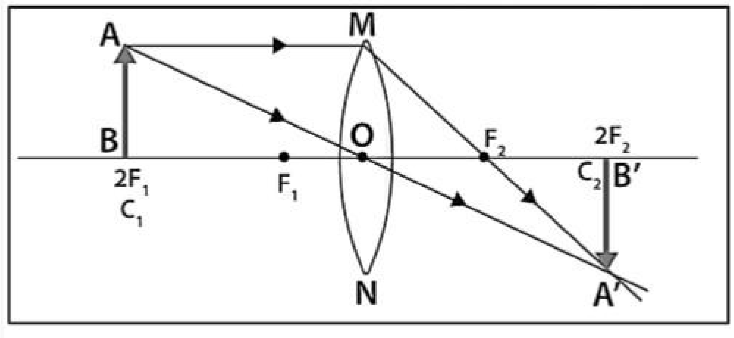


Fig. 2.15

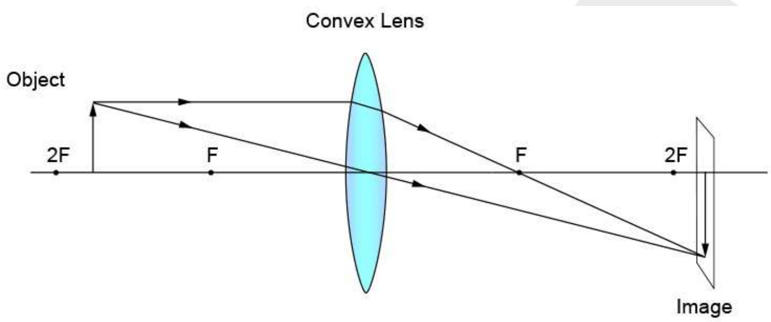
- Image Position: Between F and 2F (opposite side)
- Image Size: Diminished (smaller than object)
- Image Nature: Real and inverted

2. Object at 2F



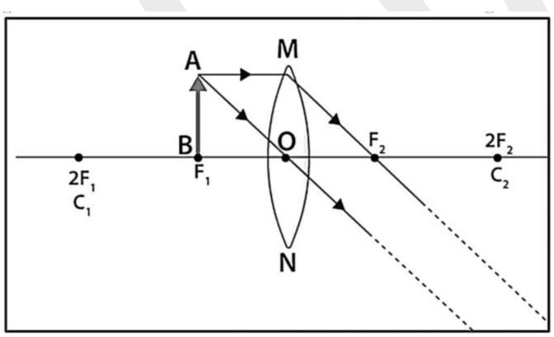
- Image Position: At 2F (opposite side)
- Image Size: Same size as the object
- Image Nature: Real and inverted

3. Object Between F and 2F



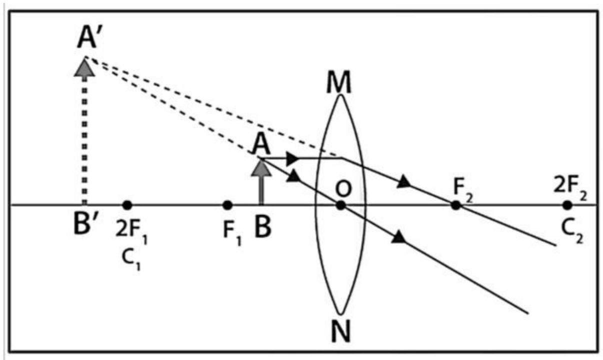
- Image Position: Beyond 2F (opposite side)
- Image Size: Enlarged (magnified)
- Image Nature: Real and inverted

4. Object at F



- Image Position: At infinity (rays emerge parallel)
- Image Size: Highly enlarged
- Image Nature: Real and inverted

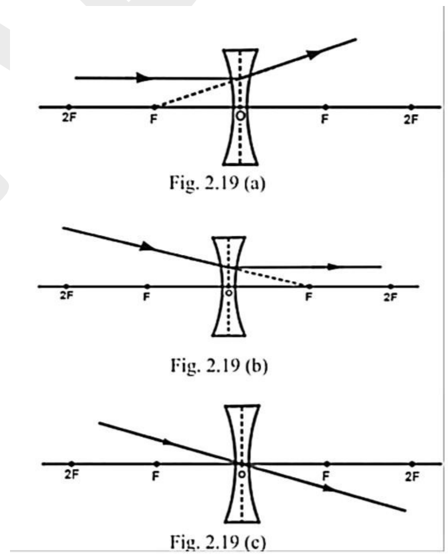
5. Object between F and the Lens (Optic Centre)



- Image Position: On the same side of the lens as the object
- Image Size: Enlarged (magnified)
- Image Nature: Virtual and erect

Image Formation by a Concave Lens

Ray Description (Incident Ray)	Path After Refraction
Parallel to the optic axis	Appear to diverge from the principal focus on the same side.
Directed towards the principal focus on the other side	Emerges parallel to the principal axis.
Passing through the optic centre	Passes through undeviated.



Object anywhere between infinity and optic centre

- Position: On the same side of the object, between F and O
- Characteristics: Virtual, Erect, Diminished (Smaller)

Lens Equation & Sign Convention

The lens equation relates the object distance (u), the image distance (v), and the focal length (f) of the lens:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{OR} \quad f = \frac{u \times v}{u - v}$$

Cartesian Sign Convention

- All distances should be measured from the optic centre of the lens.

- Distances measured in the same direction as the incident ray should be considered positive and those in the opposite direction should be considered negative.
- Distances measured above the optic axis should be considered positive and those below should be considered negative.
- The pole (for mirrors) or optical center (for lenses) is taken as the origin.
- Distances measured to the right of the origin (along the direction ofincident light) are positive.
- Distances measured to the left of the origin (against the direction of light) are negative.
- Heights above the principal axis are positive.
- Heights below the principal axis are negative.

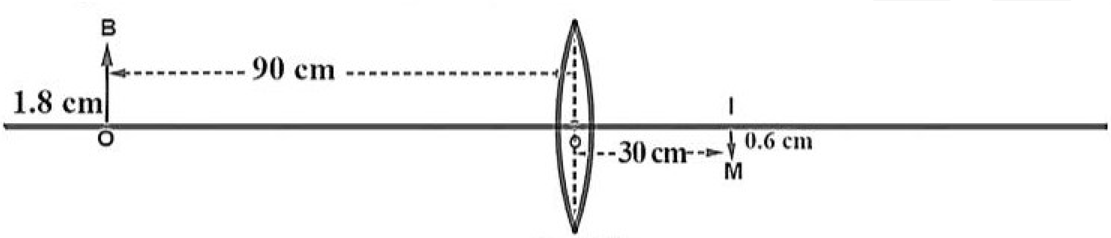


Fig 2.23

Distance to the object, u = -90 cm
Distance to the image, v = +30 cm

F = $\frac{-90cm\times +30\ cm}{-90cm\times +30\ cm}$ = $\frac{-2700cm^2}{-120cm}$ = +22.5 cm

Magnification

Magnification is the ratio of the height of the image to the height of the object. It has no unit.

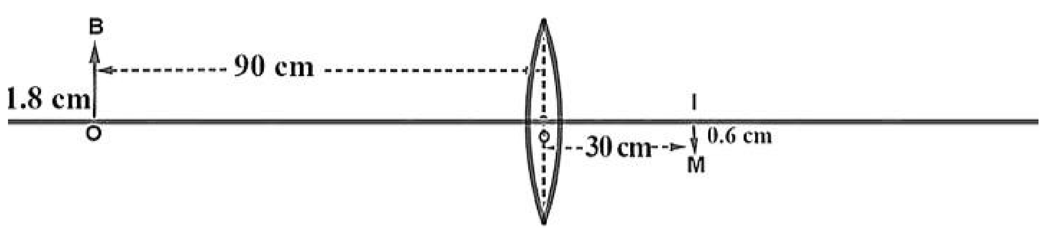
$$\textbf{Magnification (m)} = \frac{\textit{Height of the image}}{\textit{Hight of the object}} = \frac{hi}{ho}$$

$$\textbf{Magnification (m)} = \frac{\textit{Distance of the image}}{\textit{Distance of the object}} = \frac{v}{u}$$

If magnification is positive, the image is erect (virtual). If magnification is negative, the image is inverted (real).

Example Problems

Example Problem 1



$$m = \frac{h_i}{h_o} \quad \text{or} \quad m = \frac{v}{u}$$

$u = -90$ cm $h_o = +1.8$ cm $v = +30$ cm $h_i = -0.6$ cm

$$m = \frac{h_i}{h_o} = \frac{-0.6}{+1.8} = -\frac{1}{3}$$

$$m = \frac{v}{u} = \frac{+30}{-90} = -\frac{1}{3}$$

Since magnification is less than one (in magnitude), the image is smaller than the object. The negative sign indicates it is inverted.

Example Problem 2

An object of height 2 cm is placed at a distance of 12 cm from a convex lens of focal length 6 cm. Calculate magnification and image characteristics.Focal length of the convex lens is 6 cm.

a) Draw a ray diagram based on the given measurements and write down the characteristics of the image.

b)Calculate the magnification by measuring the height of the image

Given: u = -12 cm, f = +6 cm, ho = +2 cm

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{6} + \left(-\frac{1}{12}\right) = \frac{1}{12} \; => \; v = +12\,cm$$

$$m = \frac{v}{u} = \frac{12}{-12} = -1 \qquad \text{hi = m × ho = -1 × 2 = -2 cm}$$

Characteristics: Real, inverted, same size as object, formed at 12 cm on the other side.

Example Problem 3

A concave lens has a focal length of 20 cm. An object of height 2 cm is placed at a distance 30 cm from the lens. Calculate image distance and magnification.

a) Calculate the distance from the lens to the image.

b) How much will the magnification be? What are the characteristics of the image?

Given: u = -30 cm, f = -20 cm (concave lens), ho = +2 cm

$$\frac{1}{v} = \frac{1}{f} + \frac{1}{u} = \frac{1}{-20} + \frac{1}{-30} = -\left(\frac{1}{20} + \frac{1}{30}\right) = -\left(\frac{3+2}{60}\right) - \frac{5}{60} = -\frac{1}{12} \; => \; v = -12\,cm$$

$$m = \frac{v}{u} = \frac{-12}{-30} = +0.4$$

hi = m × ho = 0.4 × 2 = +0.8 cm

Characteristics: Formed 12 cm from the lens on the same side. It is virtual, erect, and smaller than the object.

Power of Lens

Power is a term related to the focal length of the lens. It is the ability to converge or diverge light rays.

Power is the reciprocal of focal length (when expressed in meters).

$$\mathbf{P = \frac{1}{\mathit{f}}}$$

(f should be in meter, multiply the given centimeter value by 0.01 meters)

- SI unit of power is Dioptre (D).
- Positive power (+) -> Converging lens (Convex lens)
- Negative power (-) -> Diverging lens (Concave lens)

Diopter (1D)

The power of a lens with a focal length of one meter is one diopter (1 D)

Power Examples

What is the power of a concave lens of focal length 25 cm ?

Focal length of concave lens = – 25 cm

Since the focal length is considered in metre while calculating the power of the lens in the SI unit,

$$f = \frac{-25}{100} \text{ m} = -0.25 \text{ m}$$

$$\text{Power } P = \frac{1}{f}$$

$$P = \frac{1}{-0.25 \text{ m}} = -4 \text{ D}$$

If the power is negative, it is identified as concave lens.

What does +2.00D refer to?

Positive sign means it is a convex (converging) lens.

$$f = \frac{100}{P} = \frac{100}{2.00} = 50\ cm = 0.5\ m$$

Optical Instruments

Compound Microscope

The main parts of a compound microscope are two convex lenses:

- Objective Lens: Placed close to the object. It has a short focal length. Forms a real, inverted, and magnified image.
- Eyepiece: The lens through which the image is observed. Its focal length is greater than the objective.

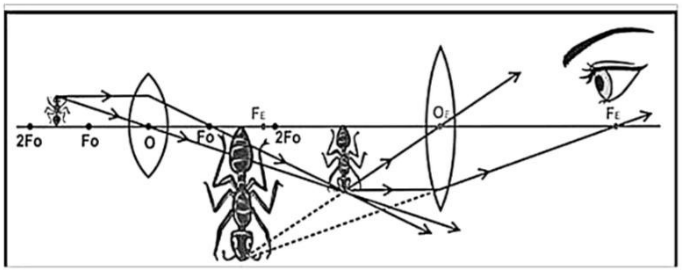


Image formation in a compound Microscope

- The object is placed between the focus and twice the focal length of the objective lens.
- The objective lens forms a real, inverted, and magnified image.
- This first image is formed beyond twice the focal length of the objective lens.
- This image then acts as the object for the eyepiece lens.
- The image falls exactly between the optical centre and the focus of the eyepiece.
- The eyepiece acts just like a simple magnifying glass.
- It forms a virtual, erect, and highly magnified final image.
- Increasing the focal length of the objective lens is not useful because it makes the image smaller.
- A smaller image means less magnification, which is why the objective lens must always have a short focal length.

Increasing the focal length of the objective lens will not be beneficial in the compound microscope. What is the reason?

If the focal length of the objective lens is longer, the size of image will be smaller.

That means the magnification will be lesser. So the objective lens should have a shorter focal length

Refracting Telescope

Telescopes are instruments used to see distant objects clearly.

- Objective Lens: Gathers parallel light rays from a distant object and focuses them to form a real, inverted, and diminished image at its focal plane.
- Eyepiece Lens: Positioned so the real image lies within its focal length. It acts as a magnifying glass.
- Final Image: Virtual, magnified, and inverted compared to the original object.