Light – Reflection and Refraction

- We see objects because they reflect light that falls on them. This reflected light enters our eyes, allowing us to see.
- In a dark room, there is no light to reflect, so we can't see anything.

Reflection of Light:

- **Laws of Reflection:**
  - The angle of incidence (angle at which light hits a surface) equals the angle of reflection (angle at which light bounces off).
  - The incident ray (incoming light), the normal (line perpendicular to the surface), and the reflected ray all lie in the same plane.
- **Plane Mirrors:**
  - Create virtual (appear behind the mirror) and erect (upright) images.
  - Image size is equal to the object size.
  - Image is the same distance behind the mirror as the object is in front.
  - Image is laterally inverted (left and right are flipped).

Spherical Mirrors:

- **Types:**
  - **Concave Mirror:** Curves inward.

(a) Concave mirror

  - **Convex Mirror:** Curves outward.

(b) Convex mirror

- **Key Terms:**
  - **Pole (P):** Center of the mirror's surface.
  - **Center of Curvature (C):** Center of the sphere that the mirror is a part of.
  - **Radius of Curvature (R):** Distance from the pole to the center of curvature.
  - **Principal Axis:** Line passing through the pole and center of curvature.
  - **Principal Focus (F):** Point where parallel rays of light converge after reflection (concave) or appear to diverge from (convex).

- **Focal Length (f):** Distance between the pole and the principal focus.
- **Aperture:** Diameter of the mirror's reflecting surface.

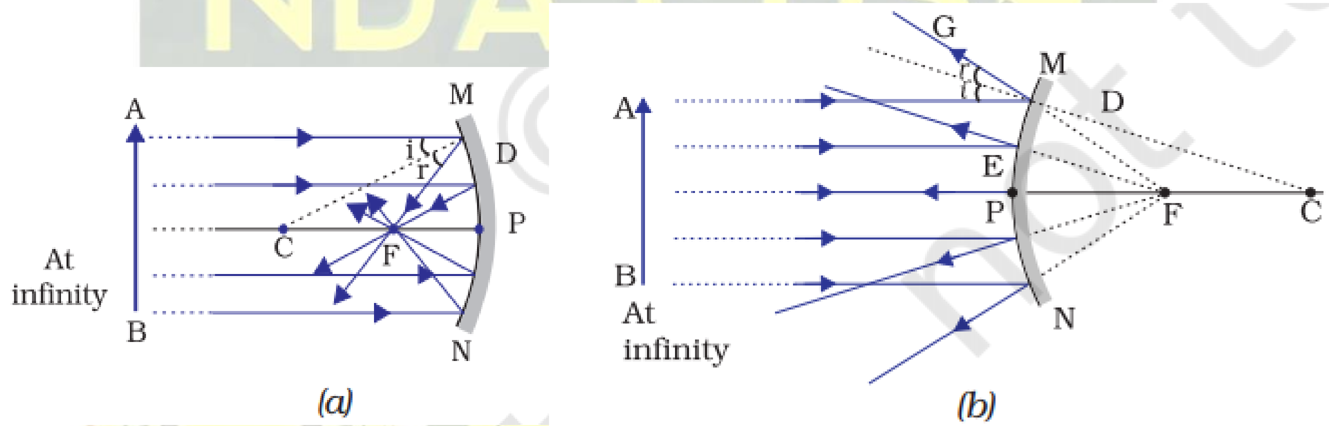
- **Relationship between R and f:** R = 2f (for small apertures)

Image Formation by Spherical Mirrors:

- The nature, position, and size of the image depend on the object's position relative to the pole (P), principal focus (F), and center of curvature (C).
- Images can be real (formed in front of the mirror) or virtual, magnified, reduced, or the same size as the object.

Light Travels in Straight Lines:

- Everyday observations like shadow formation suggest that light travels in straight lines, called rays.



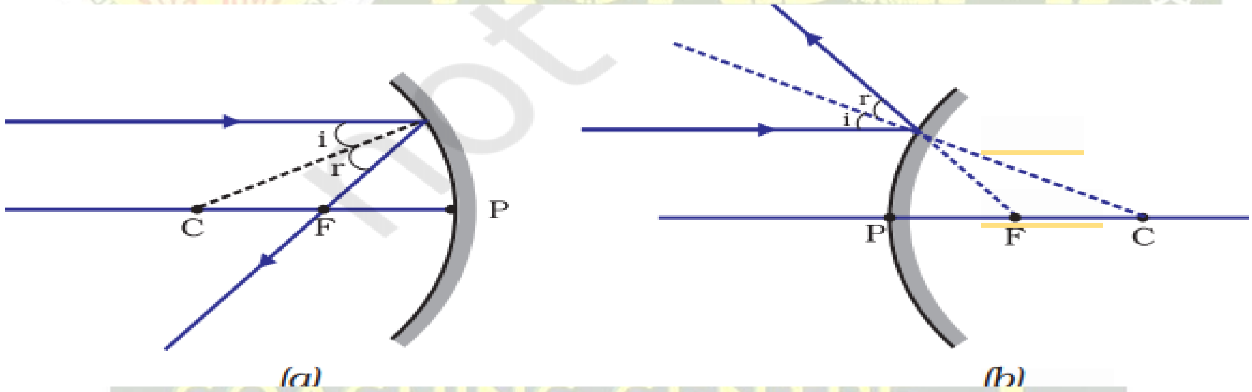
(a) Concave mirror **(b) Convex mirror**

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At the focus F	Highly diminished, point-sized	Real and inverted
Beyond C	Between F and C	Diminished	Real and inverted
At C	At C	Same size	Real and inverted
Between C and F	Beyond C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between P and F	Behind the mirror	Enlarged	Virtual and erect

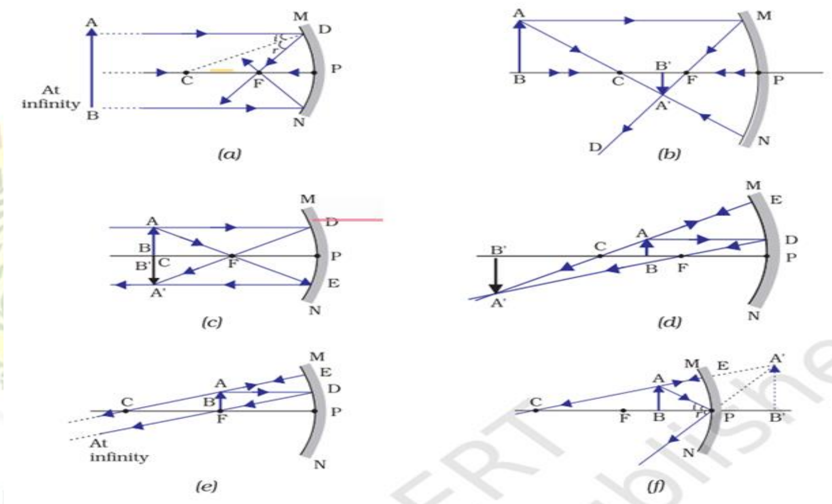
Image Formation by Spherical Mirrors: Ray Diagrams

- **Understanding Ray Diagrams:**
  - Ray diagrams help us visualize how images are formed by spherical mirrors.
  - Each point on an object acts as a source of light, emitting countless rays.

- To simplify the diagram, we use only two special rays to locate the image.
- **Important Rays for Locating Images:**
  1. **Parallel Ray:**
     - A ray parallel to the principal axis:
       - After reflection, passes through the principal focus (concave mirror).
       - After reflection, appears to diverge from the principal focus (convex mirror).



  2. **Focal Ray:**
     - A ray passing through the principal focus (concave) or directed towards it (convex):
       - After reflection, emerges parallel to the principal axis.
  3. **Center of Curvature Ray:**
     - A ray passing through the center of curvature:
       - After reflection, is reflected back along the same path (acts as a normal to the mirror surface).
  4. **Oblique Ray:**
     - A ray incident obliquely to the principal axis at the pole (P):
       - Is reflected obliquely, following the laws of reflection (angle of incidence = angle of reflection).
- **Image Formation by Concave Mirrors:**
  - The position, size, and nature of the image formed by a concave mirror depend on the object's location relative to the mirror.

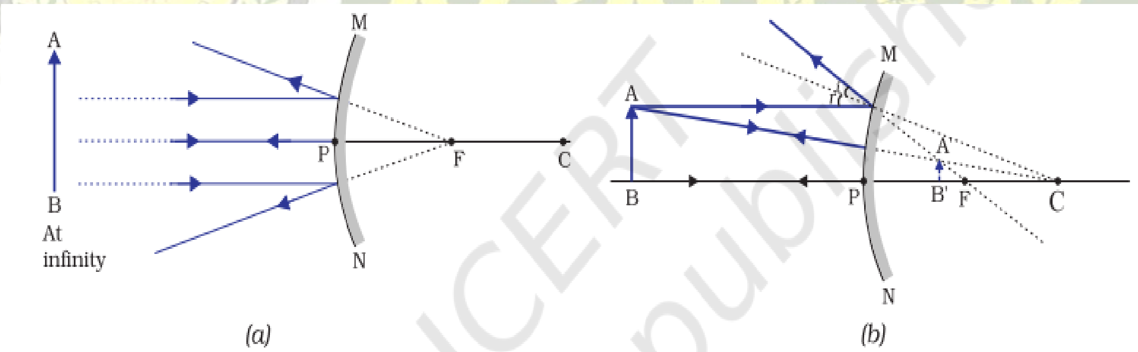


Ray diagrams for the image formation by a concave mirror

- **Uses of Concave Mirrors:**
  - Torches, searchlights, vehicle headlights (for parallel beams of light).
  - Shaving mirrors (magnified image).
  - Dentist's mirrors (magnified image of teeth).

    Solar furnaces (concentrating sunlight to produce heat).

- **Image Formation by Convex Mirrors:**
  - Convex mirrors always form virtual, erect, and diminished images.
  - Refer to Figure 9.8 in your textbook for ray diagrams.



Formation of image by a convex mirror

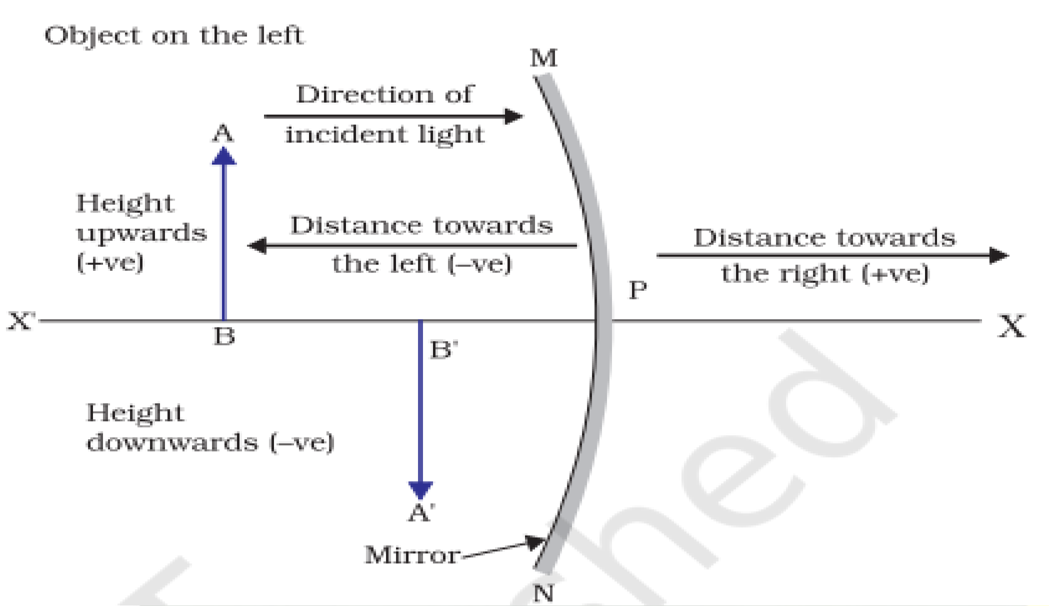
- **Uses of Convex Mirrors:**
  - Rear-view mirrors in vehicles (wide field of view, erect image).
  - Security mirrors in shops (wide field of view).

Nature, position and relative size of the image formed by a convex mirror

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At the focus F, behind the mirror	Highly diminished, point-sized	Virtual and erect
Between infinity and the pole P of the mirror	Between P and F, behind the mirror	Diminished	Virtual and erect

Sign Convention for Reflection by Spherical Mirrors (New Cartesian Sign Convention)

- **Reference Point:** The pole (P) of the mirror is the origin of the coordinate system.
- **Principal Axis:** The principal axis of the mirror is the x-axis (X'X).
- **Object Location:** The object is always placed to the left of the mirror.
- **Measuring Distances:**
    - **Along the Principal Axis:**
        - Distances measured to the right of the pole (along +x-axis) are positive.
        - Distances measured to the left of the pole (along -x-axis) are negative.
    - **Perpendicular to the Principal Axis:**
        - Distances measured above the principal axis (along +y-axis) are positive.
        - Distances measured below the principal axis (along -y-axis) are negative.
- **Purpose:** These sign conventions help us use the mirror formula and solve numerical problems related to spherical mirrors.



The New Cartesian Sign Convention for spherical mirrors

Mirror Formula and Magnification

- **Key Distances:**
    - **Object distance (u):** Distance of the object from the pole of the mirror.
    - **Image distance (v):** Distance of the image from the pole of the mirror.

- **Focal length (f):** Distance of the principal focus from the pole of the mirror.

- **Mirror Formula:**
    - This formula relates the object distance (u), image distance (v), and focal length (f):
    - $1/u + 1/v = 1/f$
    - **Important:** Use the New Cartesian Sign Convention when substituting values into this formula.
- **Magnification (m):**
    - **Definition:** Magnification tells us how much larger or smaller the image is compared to the object.
    - **Formula:**
        - m = height of image (h') / height of object (h)
        - $m = -v/u$
    - **Sign of Magnification:**
        - **Negative m:** Image is real and inverted.
        - **Positive m:** Image is virtual and erect.

Example : Convex Mirror

- **Problem:** A convex mirror in a car has a radius of curvature of 3.00 m. A bus is 5.00 m from the mirror. Find the position, nature, and size of the image.
- **Solution:**
    1. **Given:**
        - Radius of curvature (R) = +3.00 m
        - Object distance (u) = -5.00 m (using sign convention)
    2. **Calculate Focal Length:**
        - $f = R/2 = +3.00\text{ m} / 2 = +1.50\text{ m}$
    3. **Use Mirror Formula:**
        - $1/v + 1/(-5.00) = 1/1.50$
        - Solving for v, we get v = -1.15 m
    4. **Calculate Magnification:**
        - $m = -v/u = -(-1.15) / (-5.00) = +0.23$
    5. **Interpretation:**
        - **Position:** The image is 1.15 m behind the mirror (virtual).
        - **Nature:** The image is virtual, erect, and smaller than the object.
        - **Size:** The image is 0.23 times the size of the object.

Refraction of Light

- **What is Refraction?**
    - Refraction is the bending of light when it passes from one transparent medium to another (like from air to water).
    - This bending happens because light travels at different speeds in different mediums.
- **Everyday Examples of Refraction:**

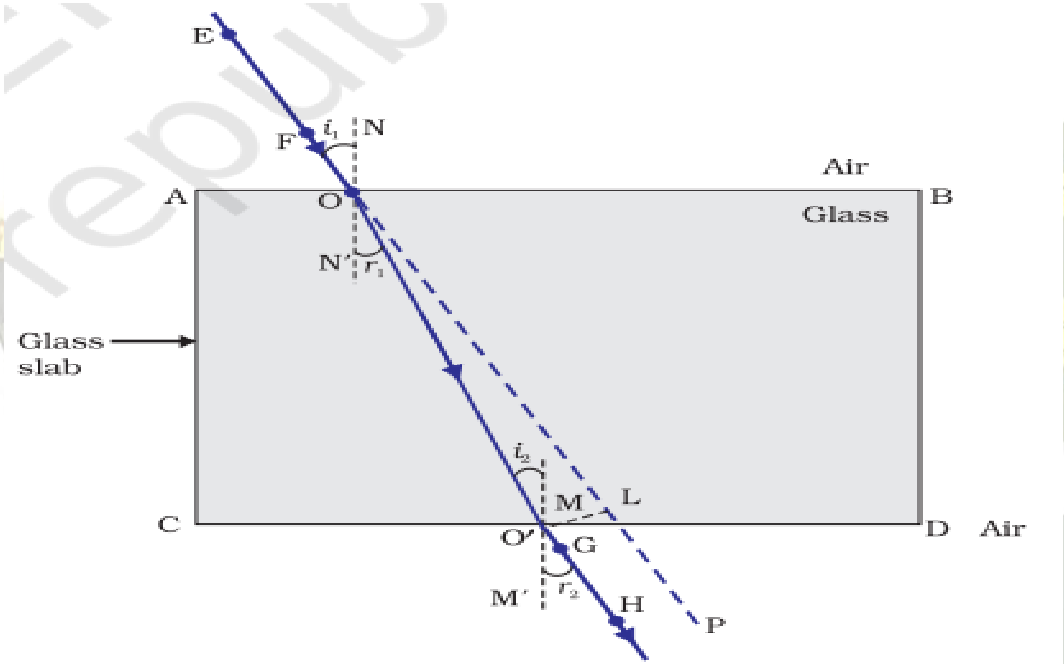
- A coin at the bottom of a bowl of water appears raised.
- A pencil partly immersed in water looks bent or displaced at the waterline.
- Letters seen through a glass slab seem raised.
- A lemon in water appears bigger than its actual size.

- **Why Does Refraction Occur?**
  - When light travels from one medium to another at an angle (obliquely), it changes direction.
  - This change in direction is caused by the change in the speed of light.
- **Factors Affecting Refraction:**
  - The amount of bending (refraction) depends on the pair of media involved.
  - For example, light bends differently when passing from air to water compared to air to kerosene.
- **Key Takeaway:**
  - Refraction shows us that light doesn't travel in the same way in all mediums. Its direction can change when it moves from one medium to another.

Refraction Through a Rectangular Glass Slab

- **Experiment:**
  - Shine a light ray through a rectangular glass slab at an angle.
  - Observe how the light bends as it enters and exits the slab.
- **Observations:**
  - **Bending Towards Normal:** When light enters the glass slab from air (rarer to denser medium), it bends *towards* the normal (an imaginary line perpendicular to the surface).
  - **Bending Away From Normal:** When light exits the glass slab into air (denser to rarer medium), it bends *away* from the normal.
  - **Emergent Ray Parallel:** The emergent ray (the ray exiting the slab) is parallel to the incident ray (the ray entering the slab). This is because the bending at the two parallel surfaces of the slab cancels out.
  - **Lateral Shift:** Even though the emergent ray is parallel to the incident ray, it is slightly shifted to the side.
- **Laws of Refraction:**
  1. **Same Plane:** The incident ray, the refracted ray, and the normal all lie in the same plane.
  2. **Snell's Law:** The ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) is a constant for a given pair of media and color of light:
  3. $\sin i / \sin r$ = constant = refractive index (n)

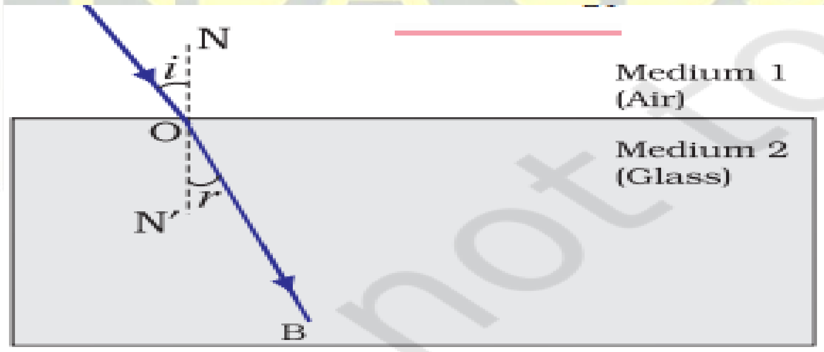
- **Refractive Index (n):**
  - This constant value in Snell's Law is called the refractive index.
  - It indicates how much the speed of light changes when it enters a new medium.
  - A higher refractive index means light travels slower in that medium.



Refraction of light through a rectangular glass slab

Refractive Index

- **What it is:**
  - Refractive index (n) measures how much light bends when it goes from one medium to another.
  - It's linked to how fast light travels in each medium.
- **Speed of Light and Refractive Index:**
  - Light travels fastest in a vacuum (3×10^8 m/s).
  - It slows down in other mediums like air, water, and glass.
  - The more light slows down in a medium, the higher its refractive index.
- **Calculating Refractive Index:**
  - When light travels from medium 1 to medium 2:
    - n_{21} (refractive index of medium 2 with respect to medium 1) = speed of light in medium 1 (v_1) / speed of light in medium 2 (v_2)
- **Absolute Refractive Index:**
  - When medium 1 is a vacuum or air, n_2 is called the absolute refractive index of medium 2.
  - n_2 = speed of light in vacuum (c) / speed of light in medium 2 (v_2)



- **Examples:**
    - The refractive index of water (n_w) is 1.33. This means light travels 1.33 times faster in air than in water.
    - The refractive index of crown glass (n_g) is 1.52.

$$n_m = \frac{\text{Speed of light in air}}{\text{Speed of light in the medium}} = \frac{c}{v}$$

Absolute refractive index of some material media

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Canada Balsam	1.53
Ice	1.31	Rock salt	1.54
Water	1.33	Carbon disulphide	1.63
Alcohol	1.36	Dense flint glass	1.65
Kerosene	1.44	Ruby	1.71
Fused quartz	1.46	Sapphire	1.77
Turpentine oil	1.47	Diamond	2.42
Benzene	1.50		
Crown glass	1.52		

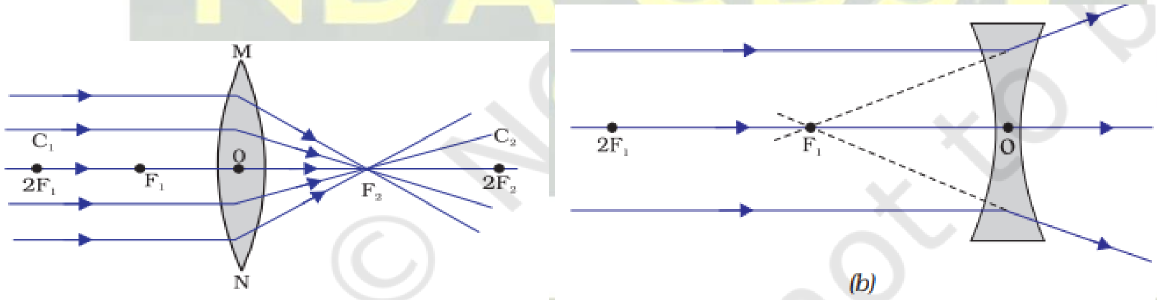
From this Table Note that an optically denser medium may not possess greater mass density. For example, kerosene having higher refractive index, is optically denser than water, although its mass density is less than water.

Lenses and Refraction

- **What is a lens?**
    - A lens is a transparent object with at least one curved surface. It bends (refracts) light rays.
- **Types of Lenses:**
    - **Convex Lens:**
        - Thicker in the middle.
        - Converges light rays (brings them together).
    - **Concave Lens:**
        - Thicker at the edges.
        - Diverges light rays (spreads them out).
- **Important Terms:**
    - **Center of Curvature (C):** Center of the sphere that the lens surface is a part of. Each lens has two centers of curvature (C_1 and C_2).
    - **Principal Axis:** Line passing through the two centers of curvature.

- **Optical Center (O):** The central point of the lens. Light passing through this point doesn't bend.
- **Aperture:** The diameter of the lens.
- **Principal Focus (F):**
  - For a convex lens, the point where parallel light rays converge after passing through the lens.
  - For a concave lens, the point where parallel light rays appear to come from after passing through the lens.
  - Each lens has two principal foci (F_1 and F_2).
- **Focal Length (f):** Distance between the optical center and the principal focus.

- **Finding the Focal Length of a Convex Lens:**
  1. Hold the lens in sunlight.
  2. Focus the sunlight onto a piece of paper.
  3. The distance between the lens and the bright spot on the paper is the focal length.



(a) Converging action of a convex lens, (b) diverging action of a concave lens

Image Formation by Lenses

Nature, position and relative size of the image formed by a convex lens for various positions of the object

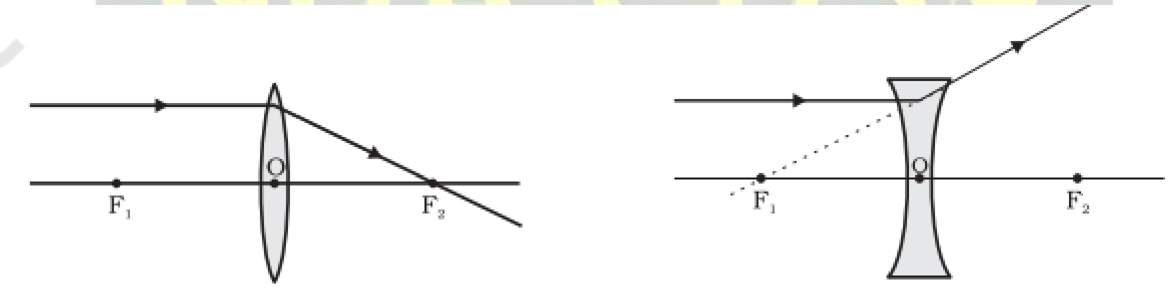
Position of the object	Position of the image	Relative size of the image	Nature of the image
At infinity	At focus F_2	Highly diminished, point-sized	Real and inverted
Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
At $2F_1$	At $2F_2$	Same size	Real and inverted
Between F_1 and $2F_1$	Beyond $2F_2$	Enlarged	Real and inverted
At focus F_1	At infinity	Infinitely large or highly enlarged	Real and inverted
Between focus F_1 and optical centre O	On the same side of the lens as the object	Enlarged	Virtual and erect

Nature, position and relative size of the image formed by a concave lens for various positions of the object

Position of the object	Position of the image	Relative size of the image	Nature of the image
At infinity	At focus F_1	Highly diminished, point-sized	Virtual and erect
Between infinity and optical centre O of the lens	Between focus F_1 and optical centre O	Diminished	Virtual and erect

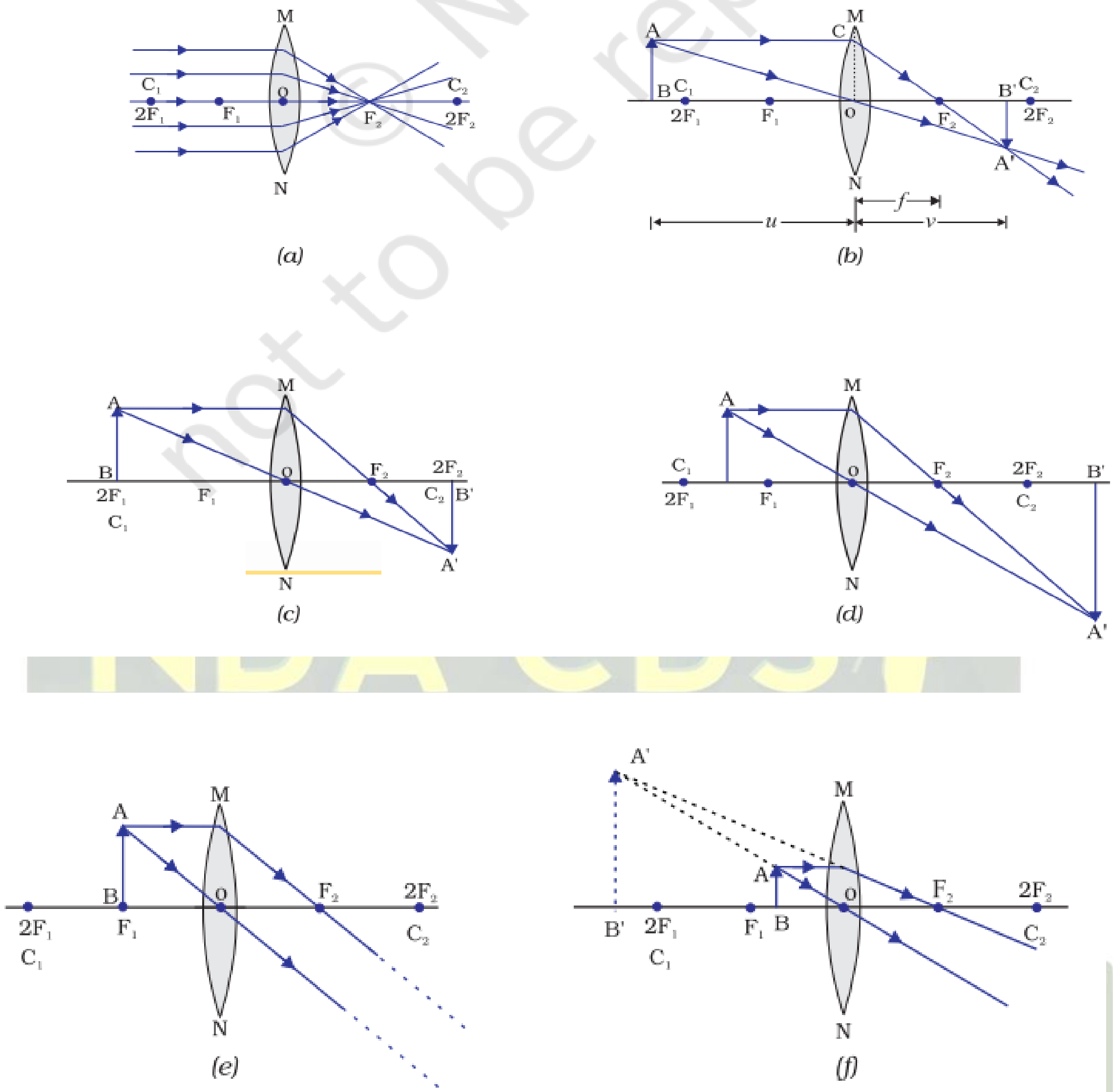
Image Formation in Lenses Using Ray Diagrams

- **Ray diagrams** help us visualize how lenses form images. We use specific rays to locate the image.

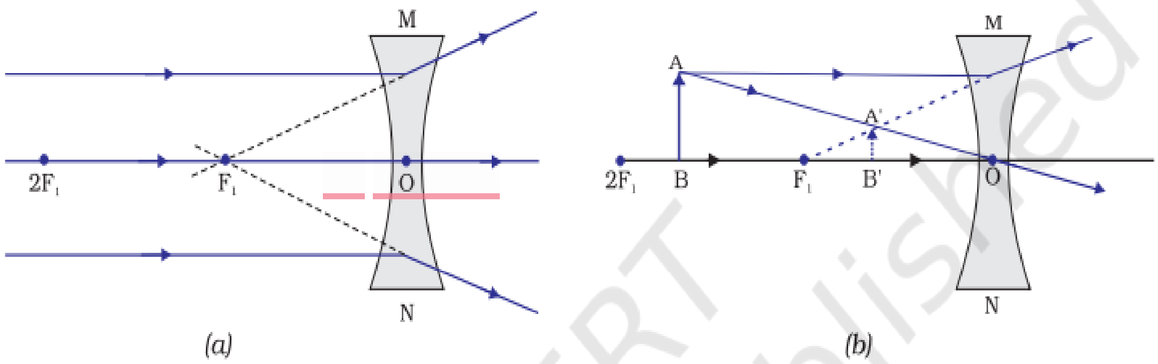


(a) (b)

- **Important Rays for Locating Images:**
  1. **Parallel Ray:**
     - **Convex Lens:** A ray parallel to the principal axis passes through the principal focus on the other side of the lens after refraction.
     - **Concave Lens:** A ray parallel to the principal axis appears to diverge from the principal focus on the same side of the lens after refraction.
  2. **Focal Ray:**
     - **Convex Lens:** A ray passing through the principal focus emerges parallel to the principal axis after refraction.
     - **Concave Lens:** A ray appearing to meet at the principal focus emerges parallel to the principal axis after refraction.
  3. **Center Ray:**
     - A ray passing through the optical center of the lens continues in a straight line without bending.
- **Image Formation:**
  - Use any two of these rays to locate the image formed by a lens.
  - The type of lens (convex or concave) and the object's position determine the image's characteristics (real/virtual, erect/inverted, magnified/diminished).



The position, size and the nature of the image formed by a convex lens for various positions of the object



Nature, position and relative size of the image formed by a concave lens

Sign Convention, Lens Formula, and Magnification

- **Sign Convention for Lenses:**

- Similar to the sign convention for mirrors, but all measurements are taken from the optical center of the lens.
- **Important:**
  - Focal length (f) of a convex lens is positive.
  - Focal length (f) of a concave lens is negative.
  - Be careful with the signs of object distance (u), image distance (v), object height (h), and image height (h').

- **Lens Formula:**
  - Relates object distance (u), image distance (v), and focal length (f):
- $1/v - 1/u = 1/f$
  - This formula works for all spherical lenses in all situations.
- **Magnification (m):**
  - **Definition:** How much larger or smaller the image is compared to the object.
  - **Formula:**
    - m = height of image (h') / height of object (h)
    - $m = v/u$

Power of a Lens

- **What is Power?**
  - The power of a lens tells us how strongly it can converge or diverge light rays.
  - A lens with a short focal length bends light rays more strongly and has more power.
- **Formula for Power (P):**
  - $P = 1/f$
  - where f is the focal length of the lens in meters.
- **Unit of Power:**
  - The SI unit of power is the **diopter (D)**.
  - 1 diopter (D) = 1 m^{-1} (1 diopter is the power of a lens with a focal length of 1 meter).
- **Sign of Power:**
  - **Convex lens:** Positive power.
  - **Concave lens:** Negative power.
- **Opticians and Lens Power:**
  - Opticians use diopters to prescribe lenses for glasses.
  - A prescription of +2.0 D means a convex lens with a focal length of +0.50 m.
  - A prescription of -2.5 D means a concave lens with a focal length of -0.40 m.

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