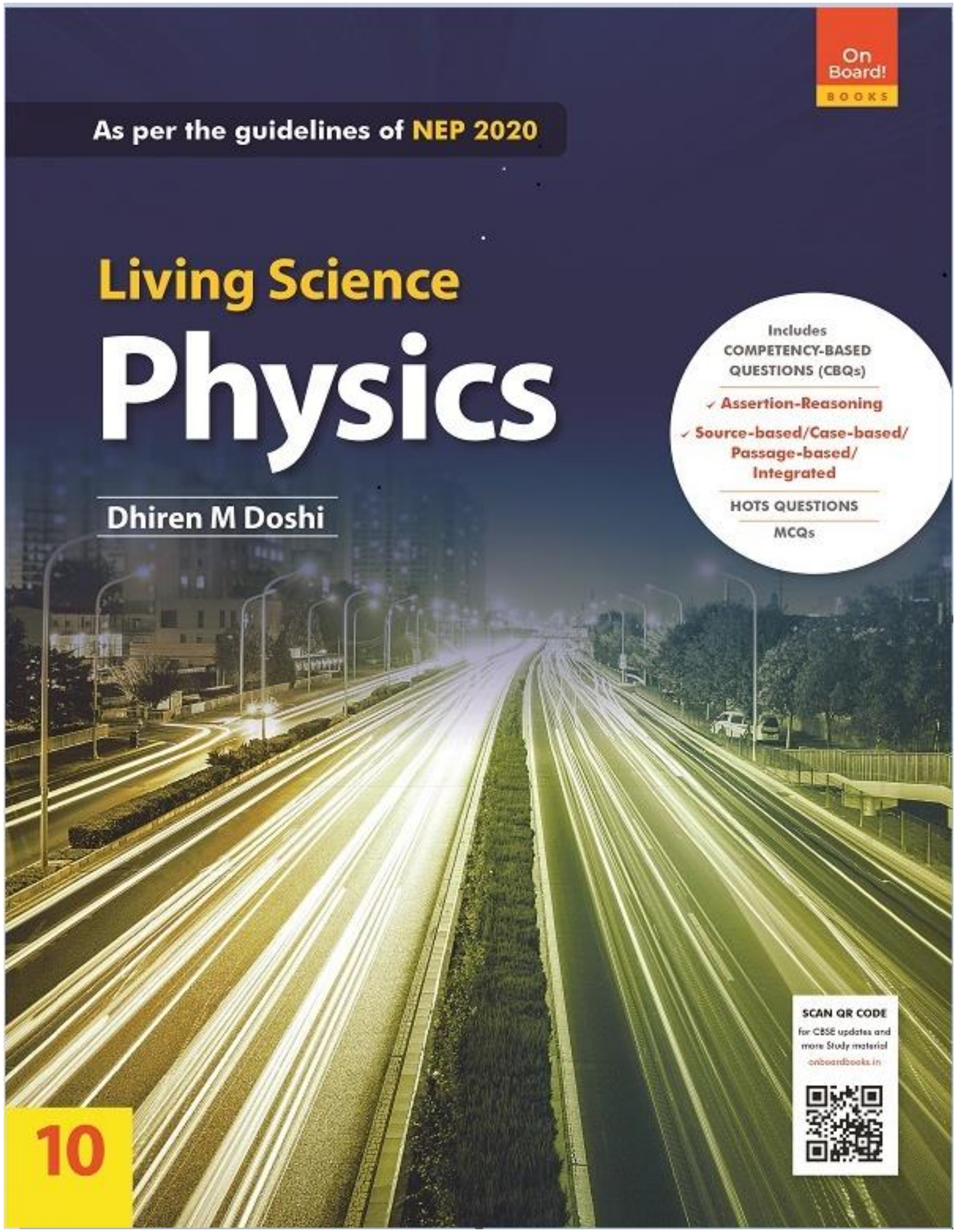
On Board!
BOOKS



CBSE Living Science Physics

Class 10

Chapter 5: REFRACTION OF LIGHT

Learning Objectives

❖ Optically rarer medium and optically denser medium

❖ Cause of refraction

Laws of Refraction of Light

❖ Refractive index of the medium

❖ Absolute refractive index

Refractive index and speed of light in a medium

❖ Principle of reversibility of light

Refraction through lenses

❖ Types of lenses: Concave and convex lenses

❖ Technical terms related to lenses

Image formation by convex and concave lenses

❖ New cartesian sign convention

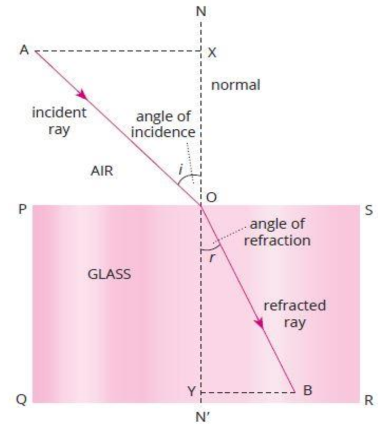
Lens formula

❖ Magnification produced by lenses

Power of a Lens

Refraction of Light

The change in direction of light when it passes obliquely from one transparent medium to another at the boundary separating the two media is called refraction of light.



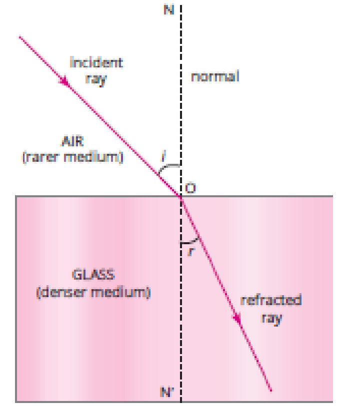
Refraction of light when it passes from air into glass

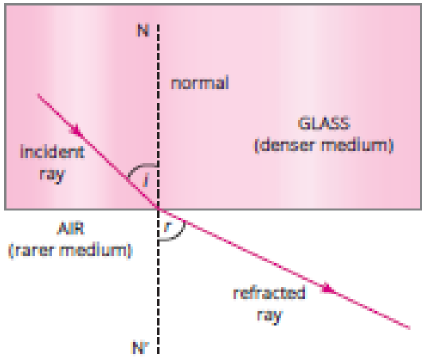
Optically rarer medium and optically denser medium

A medium in which the speed of light is more is known as an optically rarer medium. A medium in which the speed of light is less is known as an optically denser medium.

Cause of refraction

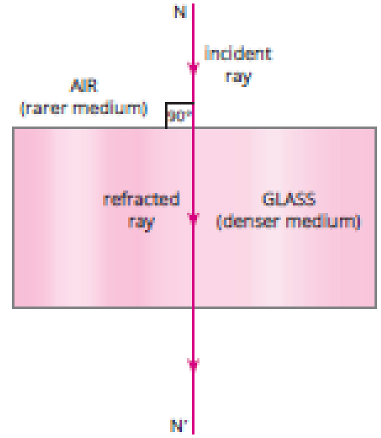
1. When a ray of light travels from a rarer medium to a denser medium, it bends towards the normal (at the point of incidence).





2. When a ray of light travels from a denser medium to a rarer medium, it bends away from the normal (at the point of incidence).

3. If the incident ray falls normally (or perpendicularly) on the surface of a glass slab, then there is no bending of the ray of light and it goes straight.



Laws of Refraction of Light

The refraction of light in going from one medium to another takes place according to two laws which are known as the **laws of refraction of light**.

(a) **First Law of Refraction of Light:** The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.

(b) Second Law of Refraction of Light: The ratio of sine of angle of incidence to the sine of angle of refraction is a constant for the light of a given colour and for a given pair of media. This is also known as Snell's law of refraction. (This is true for angle $0^\circ < i < 90^\circ$)

If *i* is the angle of incidence and r is the angle of refraction, then according to **Snell's law of refraction of light**,

$$\frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}} = \text{constant}$$

or, $\sin i / \sin r = \text{constant}$

This constant value is called the **refractive index** of the second medium with respect to the first medium.

Refractive Index of the Medium

Let us consider a ray of light travelling from medium 1 to medium 2. Then, from Snell's law, we have

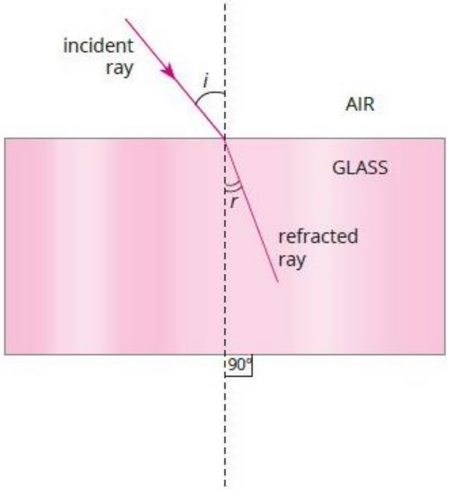
$$\sin i / \sin r = \text{constant}$$

This 'constant' is called the refractive index of medium 2 with respect to medium 1. Refractive index of a medium is denoted by the letter n or μ (μ is a Greek letter pronounced as 'mew'). Snell's law can be expressed as:

$$\sin i / \sin r = {}^{1}n_{2}$$

Since the refractive index is a ratio of two similar quantities (the sines of angles), it has no units. It is a pure number.

Relationship between Refractive Index and Speed of Light in a Medium



The refractive index of glass (medium 2) with respect to air (medium 1) is given by the ratio of the speed of light in air (medium 1) and the speed of light in glass (medium 2).

$${}^{air}n_{glass} = {}^{1}n_{2} = \text{Speed of light in air / Speed of light in glass}$$
$$= v1/ v2$$

The refractive index of air (medium 1) with respect to glass (medium 2) is given by the ratio of speed of light in glass (medium 2) and the speed of light in air (medium 1).

$$n_{12} = \frac{\text{Speed of light in glass (medium 2)}}{\text{Speed of light in air (medium 1)}} = \frac{v_2}{v_1}$$

Absolute Refractive Index

If the incident ray is travelling through vacuum or air and is then refracted in a medium, then the value of the refractive index is called the absolute refractive index of that medium. It can also be just termed as the refractive index of that medium. It is written as *n*.

***n* = Speed of light in vacuum /Speed of light in medium = c/v**

The speed of light in vacuum is almost same as in the air. Therefore, for determining the refractive index, we can consider air as it were vacuum.

The refractive index of a medium is also defined as the ratio of the speed of light in air and the speed of light in that medium.

The refractive index depends on the nature of material of the medium and on the wavelength of light used.

Refractive Index and Speed of Light in a Medium

The refractive index of a medium is related to the speed of light in that medium through the following relationship:

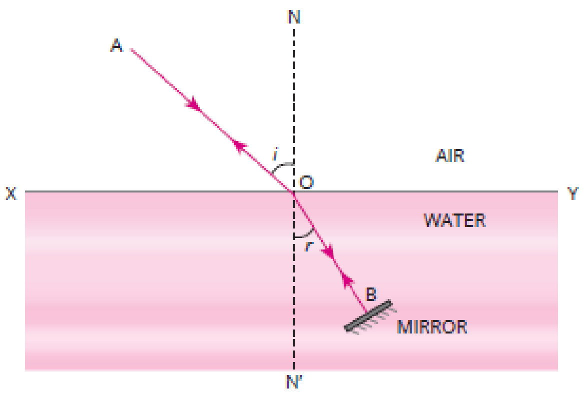
Refractive index of a medium,

n = Speed of light in vacuum (c) / Speed of light in the medium (v)

The speed of light (c) in vacuum is fixed and hence the speed of light in any medium decreases with increase in the refractive index and vice versa.

Principle of Reversibility of Light

If a reflected or refracted ray is reversed in direction, it will retrace its original path. This implies that the refractive index of medium 1 with respect to medium 2 is equal to the reciprocal of the refractive index of medium 2 with respect to medium 1.



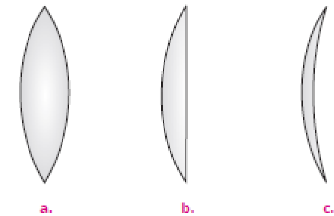
Refraction Through Lenses

A lens is a piece of transparent, optical material bounded by two refracting surfaces that are usually spherical, or one surface spherical and the other plane. Thus, a lens is bound by at least one spherical surface.

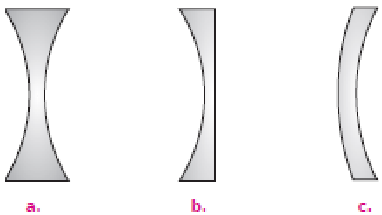
Types of Lenses

Convex or Converging Lens

A convex lens is thicker in the middle and thinner at the edges. It can be of three types – biconvex, plano-convex and concavo-convex.



a. Biconvex **b.** Plano-convex **c.** Concavo-convex

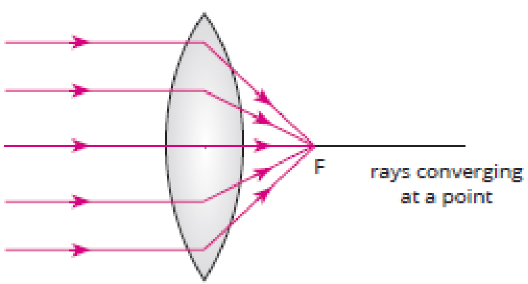


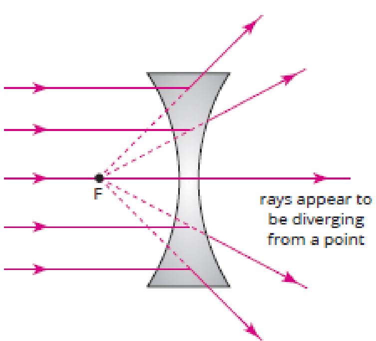
a. Biconcave **b.** Plano-concave **c.** Convexo-concave

Concave or Diverging Lens

A concave lens is thinner in the middle and thicker at the edges. It can also be of three types – biconcave, plano-concave and convexo-concave.

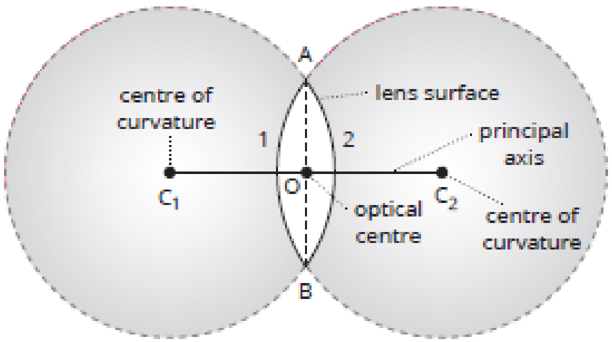
The convex lens converges parallel beam of light at a point. Therefore, a convex lens is also called a converging lens.



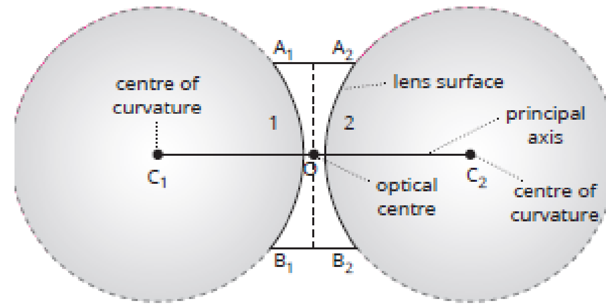


The concave lens diverges parallel beam of light and the diverged rays appear as if they are coming from a point. Therefore, a concave lens is also called a diverging lens.

Terms Related to Lenses



Convex lens



Concave lens

❖ **Centre of Curvature:** The centre of curvature of a lens is defined as the centre of the spherical surface from which the lens has been cut.

❖ **Aperture:** The maximum portion of the spherical surfaces from which refraction takes place is called the aperture of the lens.

❖ **Radius of Curvature:** The radius of the sphere of which the lens surface is a part is called the radius of curvature of the lens.

❖ **Principal Axis of a Lens:** An imaginary straight line passing through the two centres of curvature of a lens is called the principal axis of a lens.

❖ **Optical Centre:** The geometrical centre of the lens is called its optical centre. The principal axis and the line joining the lens aperture intersect at the optical centre.

❖ **Focus (or Principal Focus):** A point on the principal axis of a lens at which parallel rays of light after passing through the lens converge (in case of convex lens) or appear to diverge (in case of concave lens) after passing through the lens is called the focus (or principal focus).

❖ **Focal Length:** The distance between the optical centre and the principal focus of a lens is called its focal length.

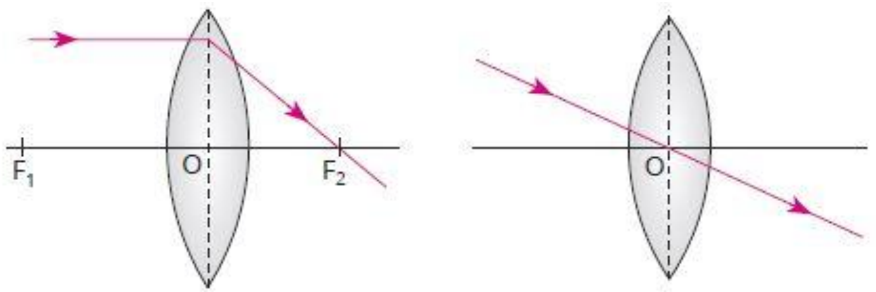
❖ **Focal Plane:** An imaginary plane passing through the focus of a lens and perpendicular to the principal axis is called its focal plane.

Image formation by convex lenses

When an object is placed in front of a lens, light rays from the object fall on it and get refracted. The refracted rays produce an image at a point where they intersect or appear to intersect each other.

Rules for Obtaining Images Formed in Convex Lenses

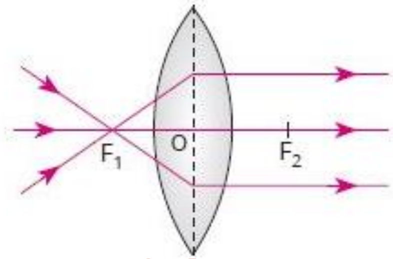
Some important rules for obtaining images formed by convex lenses are as follows:



1. A ray of light parallel to the principal axis, after passing through the lens, converges at the focus .

2. A ray of light passing through the optical centre of the lens, emerges without any deviation after refraction.

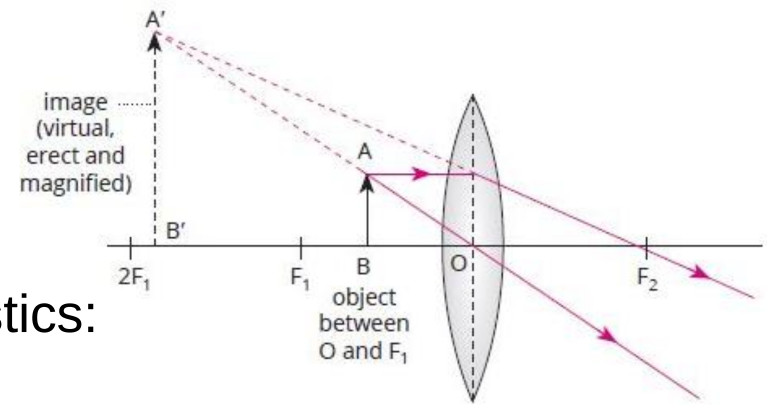
3. A ray of light passing through the first focal point of a convex lens, is refracted parallel to the principal axis.



Formation of Images by a Convex Lens for Different Positions of the Object

The object AB is placed at different positions. The image A′B′ is formed at that point where at least two rays of light meet or appear to meet.

Case I: When the object is placed between the optical centre and the principal focus (object between O and F_1)



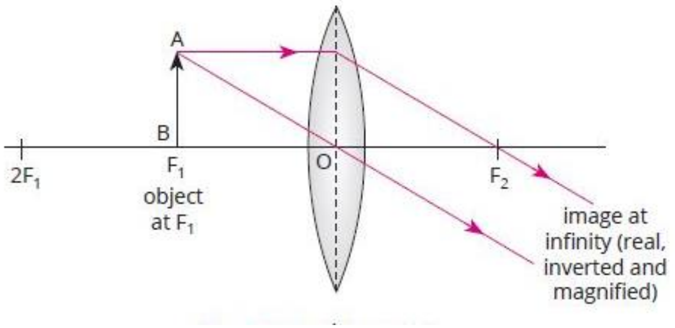
The image formed has the following characteristics:

- The image is virtual.
- The image is erect.
- The image is enlarged (or magnified).
- The image is formed on the same side of the lens, behind the object

Applications: When the object is placed between the optical centre of the convex lens and the principal focus, an erect and magnified image is formed. It is used as a magnifying glass

Case II: When the object is placed at the focus of a convex lens (object at F_1)

The image formed has the following characteristics:

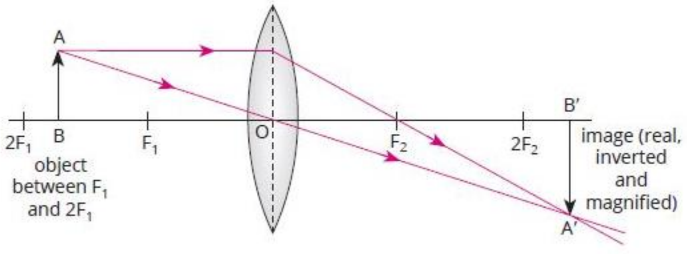


❖ The image is real.
❖ The image is inverted.
❖ The image is highly enlarged (or magnified).
❖ The image is formed at infinity, on the other side of the lens.

Applications: It is used in making searchlights and spotlights in theatres.

Case III: When the object is placed between F_1 and F_2

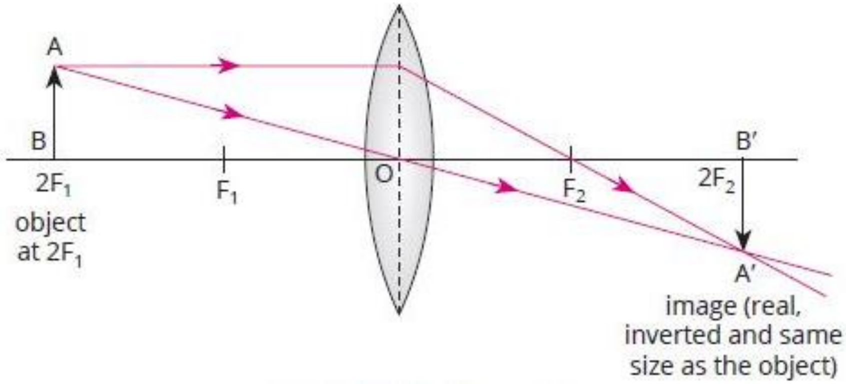
The image formed has the following characteristics



❖ The image is real. ❖ The image is inverted.
❖ The image is enlarged (or magnified).
❖ The image is formed beyond $2F_2$ on the other side of the lens.

Applications: This type of image formation is used in film and slide projectors, where enlarged image of a small slide is formed on the screen.

Case IV: When the object is at $2F_1$

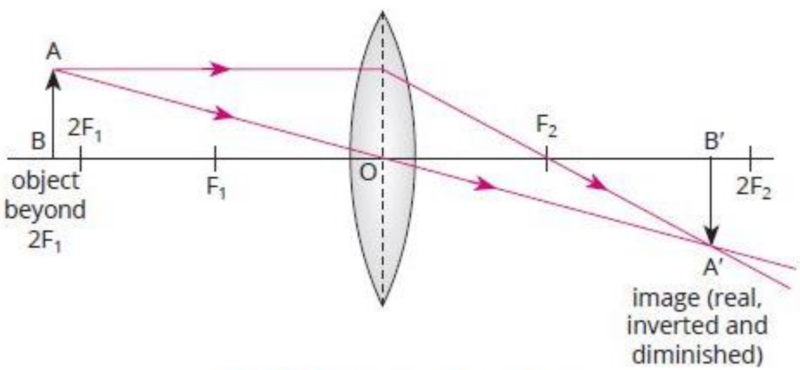


The image formed has the following characteristics:

- ❖ The image is real.
- ❖ The image is inverted.
- ❖ The image is same size as the object.
- ❖ The image is formed at $2F_2$ on the other side of the lens.

Applications: This type of image formation is used in terrestrial telescopes.

Case V: When the object is beyond $2F_1$

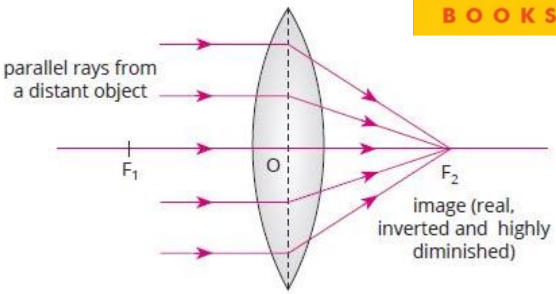


The image formed has the following characteristics:

- ❖ The image is real.
- ❖ The image is inverted.
- ❖ The image is diminished.
- ❖ The image is formed between F_2 and $2F_2$ on the other side of the lens .

Applications: This type of image formation is used in photographic camera.

Case VI: When the object is at infinity (such that the rays coming from it are parallel to the principal axis of the convex lens)

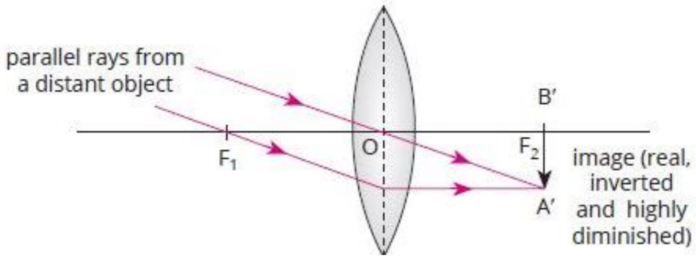


The image formed has the following characteristics:

❖ The image is real and inverted.
❖ The image is diminished to a point.
❖ The image is formed at F_2, on the other side of the lens .

Applications: This type of image formation is used in a burning glass.

Case VII: When the object is at infinity (such that the rays coming from it are not parallel to the principal axis of the convex lens)



The image formed has the following characteristics:

❖ The image is real and inverted.
❖ The image is highly diminished.
❖ The image is formed on the focal plane on the other side of the lens .

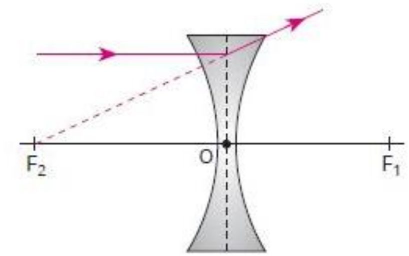
Applications: This type of image formation is used for the objective lens in a telescope.

Refer to Table 5.4 P-195 for the position, nature and relative size of the image formed by a convex lens for various positions of the object

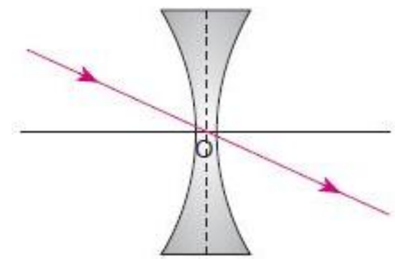
Images Formed by Concave Lenses

Rules for Obtaining Images Formed by Concave Lenses

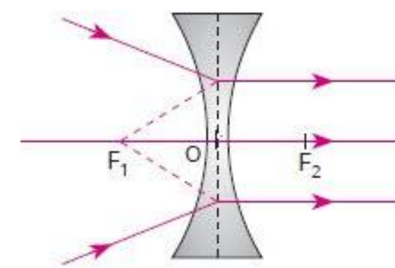
1. A ray of light parallel to the principal axis, after passing through the concave lens, appears to diverge from the focus located on the same side of the lens.



2. A ray of light passing through the optical centre of the concave lens, emerges without any deviation after refraction.

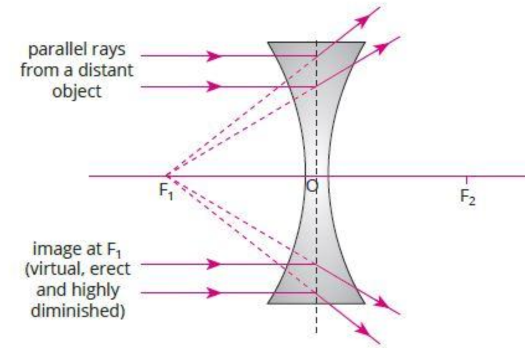


3. A ray of light appearing to meet at the second focal point of a concave lens is refracted parallel to the principal axis .



Formation of Images by a Concave Lens for Different Positions of the Object

Case I: When the object is located at infinity (such that the rays coming from it are parallel to the principal axis)



The image formed has the following characteristics:

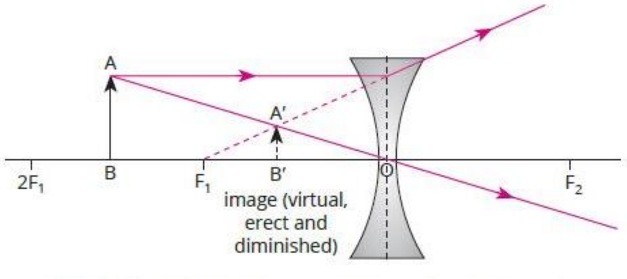
❖ The image is virtual and erect.

❖ The image is highly diminished to a point size.

❖ The image is formed at F_1 , on the same side of the lens as the object .

Applications: This type of image formation is used in Galilean telescopes.

Case II: When the object is anywhere between the optical centre (O) and infinity



The image formed has the following characteristics:

❖ The image is virtual and erect.

❖ The image is diminished.

❖ The image is formed between the optical centre and principal focus on the same side of the lens.

Applications: This type of image formation is mainly used in spectacles for the correction of myopia or short-sightedness.

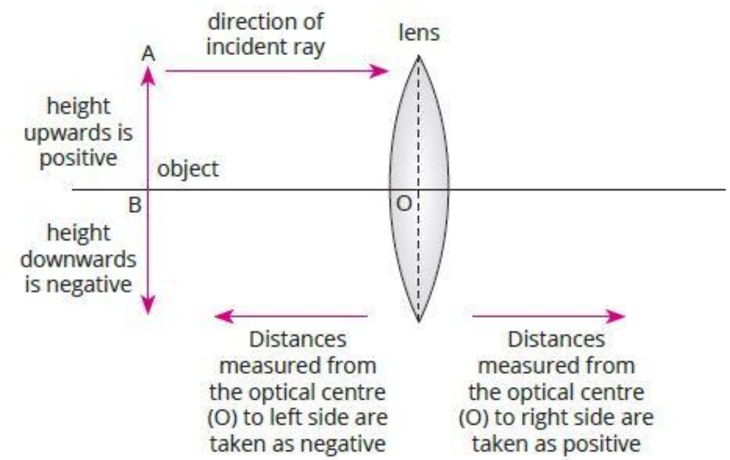
Refer to the Table 5.5; page 197 **for The position, nature and relative size of the image formed by a concave lens for various positions of the object**

New Cartesian Sign Convention

According to the convention:

❖ All distances are measured from the optical centre of the lens.

❖ The distances measured in the direction of the incident ray are taken as positive whereas the distances measured against the direction of the incident ray are taken as negative.



❖ The distances measured upwards and perpendicular to the principal axis are taken as positive whereas distances measured downwards and perpendicular to the principal axis are taken as negative.

Lens Formula

The lens formula gives the relationship between object distance (u), image distance (v) and the focal length (f). It can be written as: $\mathbf{1/f = 1/v - 1/u}$

Magnification

The magnification produced by the lens is defined as the ratio of the height of the image to that of the object. It is represented by the letter *m*. If *h* is the height of the object and *h*' is the height of the image formed by the lens, then magnification produced by the lens is given by

m = Height of the image/Height of the object = h'/h

Magnification is also defined as the ratio of the image distance (v) and the object distance (u),

m = Image distance/Object distance = v/u

Thus, we have $\boldsymbol{m = h'/h = v/u}$

Power of a Lens

The power of a lens is a measure of the degree of convergence or divergence produced by it when light falls on it. The power of a lens is defined as the reciprocal of its focal length (in metres). It is represented by letter *P*.

Power of a lens (P) = 1/ focal length of the lens (in metres)

= 1 / f (in metres)

Its SI unit is dioptre, which is denoted by the letter D.

Power of a Combination of Lenses

If a number of lenses are placed in close contact with each other, the power of the combination of these lenses is equal to the algebraic sum of the powers of the individual lenses. This additive property of the power of lenses is used by opticians, and in instruments like cameras, microscopes and telescopes.

If two lenses of powers P_1 and P_2 are placed in contact with each other, then the resultant power P is given as the algebraic sum of the individual power of the two lenses.

$$P = P_1 + P_2$$

SUMMARY

1. Refraction of light: The bending of light when it passes obliquely from one transparent medium to another is called refraction of light.

2. Medium: A transparent substance in which light travels is known as a medium. A medium in which the speed of light is more is known as an optically rarer medium. A medium in which the speed of light is less is known as an optically denser medium.

3. Bending of light: When a ray of light travels from a rarer medium to a denser medium, it bends towards the normal. When a ray of light travels from a denser medium to a rarer medium, it bends away from the normal.

4. Laws of refraction of light: a. The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane. b. The ratio of sine of angle of incidence to the sine of angle of refraction is constant for the light of a given colour and for a given pair of media.

5. Lateral displacement: The perpendicular distance between the original path of the incident ray and the emergent ray coming out of the glass slab is called lateral displacement.

6. Absolute refractive index: If the incident ray is travelling through vacuum or air and is then refracted in a medium, then the ratio sin i / sin r is called the absolute refractive index.

SUMMARY...

7. Lens: A piece of transparent, optical material bounded by two refracting surfaces which are usually spherical.

8. Convex lens: It is thicker at the middle and thinner at the edges. It is a converging lens and has a real focus.

9. Concave lens: It is thinner at the middle and thicker at the edges. It is a diverging lens and has a virtual focus.

10. Power of a lens: It is defined as the reciprocal of the focal length of a lens. Focal length is expressed in metres.

11. Dioptre: It is the SI unit of power of lens. One dioptre is the power of a lens whose focal length is one metre.