CHAPTER – 9

Light – Reflection and Refraction

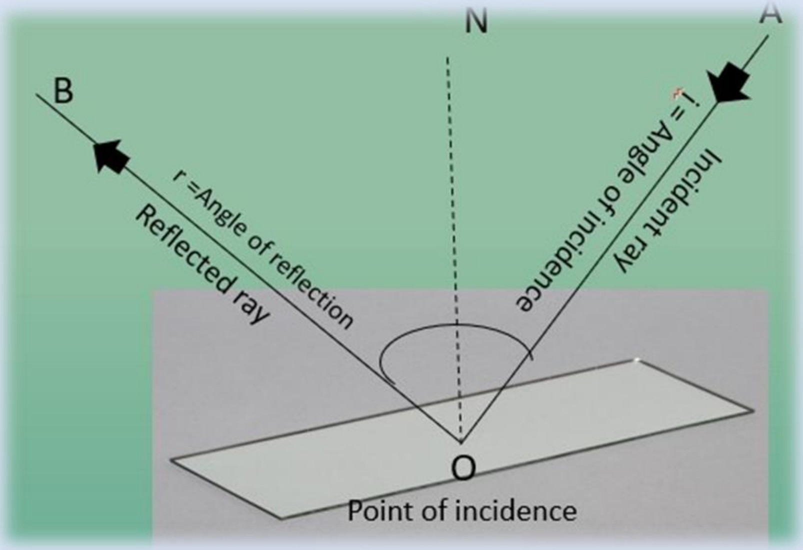
If an opaque object on the path of light becomes very small, light tends to bend around it and not walk in a straight line – an effect known as the diffraction of light. Then the straight-line treatment of optics using rays fails. The wave theory of light often becomes inadequate for treatment of the interaction of light with matter, and light often behaves somewhat like a stream of particles. According to wave theory: Light consists of electromagnetic waves which do not require a material medium for their propagation. The wavelength of visible light waves is very small. The speed of light waves is very high (being about 3 × 108 metres per second in vacuum).

REFLECTION OF LIGHT

(i) The angle of incidence is equal to the angle of reflection, and

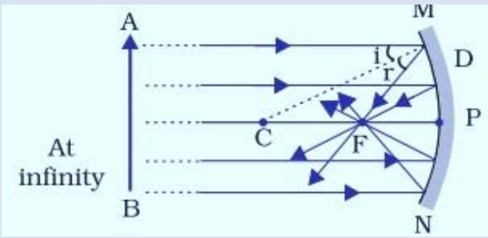
(ii) The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.

These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces.

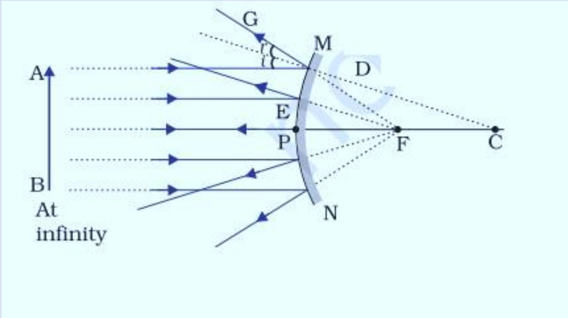


The centre of the reflecting surface of a spherical mirror is a point called the pole. It lies on the surface of the mirror. The pole is usually represented by the letter P. The reflecting surface of a spherical mirror forms a part of a sphere. This sphere has a centre. This point is called the centre of curvature of the spherical mirror. It is represented by the letter C.
centre of curvature is not a part of the mirror. It lies outside its reflecting surface. The centre of curvature of a concave mirror lies in front of it. However, it lies behind the mirror in case of a convex mirror.
The radius of the sphere of which the reflecting surface of a spherical mirror forms a part, is called the radius of curvature of the mirror. It is represented by the letter R.

A number of rays parallel to the principal axis are falling on a concave mirror. Observe the reflected rays. They are all meeting/intersecting at a point on the principal axis of the mirror. This point is called the principal focus of the concave mirror.



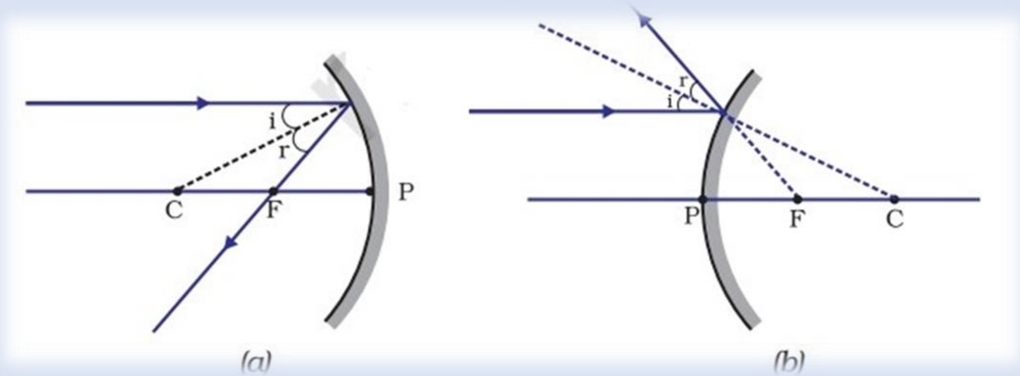
The reflected rays appear to come from a point on the principal axis. This point is called the principal focus of the convex mirror. The principal focus is represented by the letter F. The distance between the pole and the principal focus of a spherical mirror is called the focal length. It is represented by the letter f.



Is there a relationship between the radius of curvature R, and focal length f, of a spherical mirror? For spherical mirrors of small apertures, the radius of curvature is found to be equal to twice the focal length. We put this as R = 2f. This implies that the principal focus of a spherical mirror lies midway between the pole and centre of curvature.

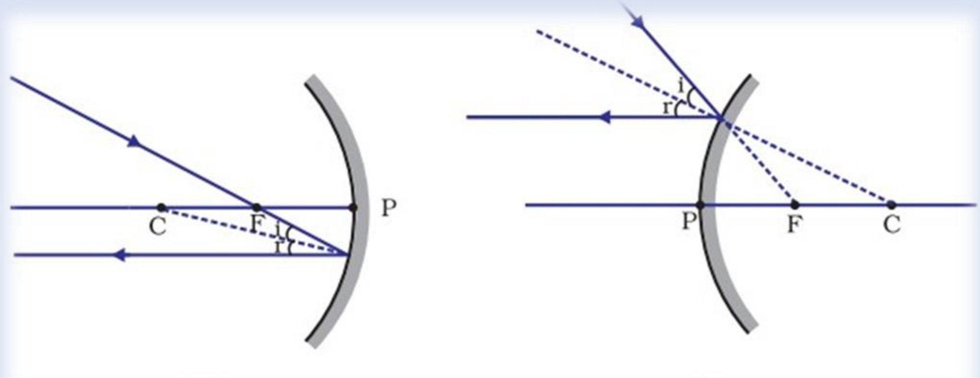
Image Formation by Spherical Mirrors

A ray parallel to the principal axis, after reflection, will pass through the principal focus in case of a concave mirror or appear to diverge from the principal focus in case of a convex mirror



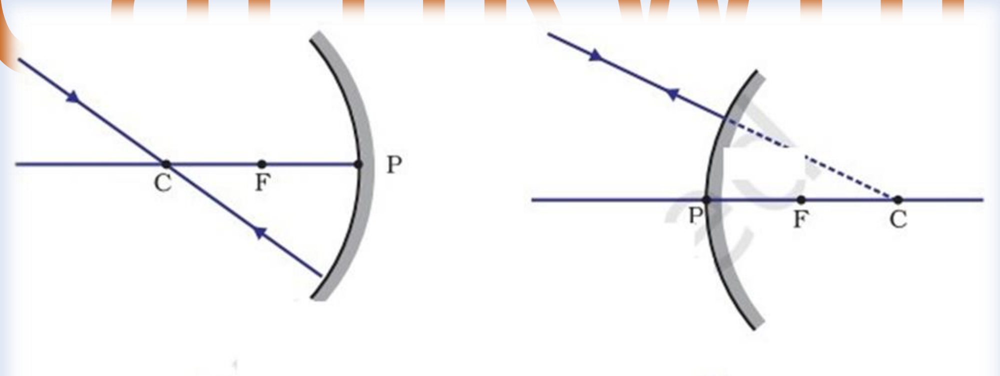
A ray passing through the principal focus of a concave mirror or a ray which is directed towards the principal

focus of a convex mirror, after reflection, will emerge parallel to the principal axis.



(a) (b)

A ray passing through the centre of curvature of a concave mirror or directed in the direction of the centre of curvature of a convex mirror, after reflection, is reflected back along the same path. The light rays come back along the same path because the incident rays fall on the mirror along the normal to the reflecting surface.



(a) (b)

A ray incident obliquely to the principal axis, towards a point P (pole of the mirror), on the concave mirror or a convex mirror, is reflected obliquely. The incident and reflected rays follow the laws of reflection at the point of incidence (point P), making equal angles with the principal axis.

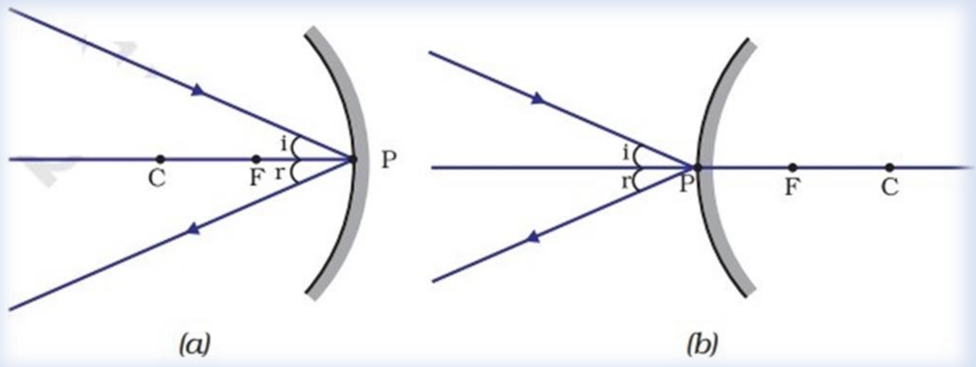
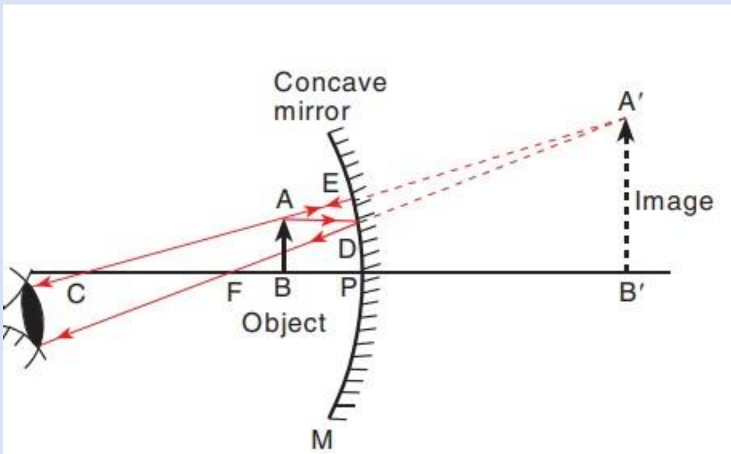


Image formation by Concave Mirror & Convex Mirror

Image formation by Concave Mirror

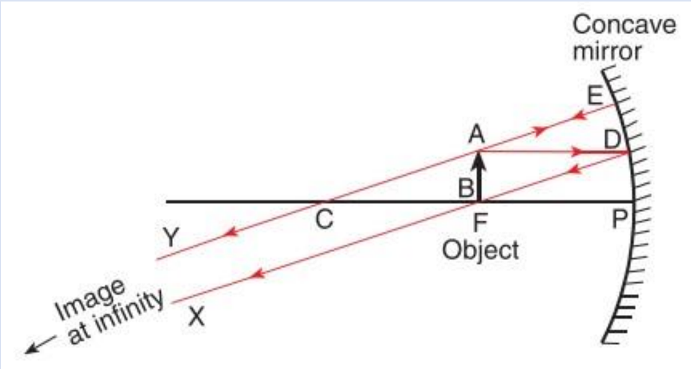
Image formed by a concave mirror when the object is placed between pole and focus of the mirror (Object between P and F).

When an object is placed between the pole (P) and focus (F) of a concave mirror, the image formed is : (i) behind the mirror, (ii) virtual and erect, and (iii) larger than the object (or magnified)

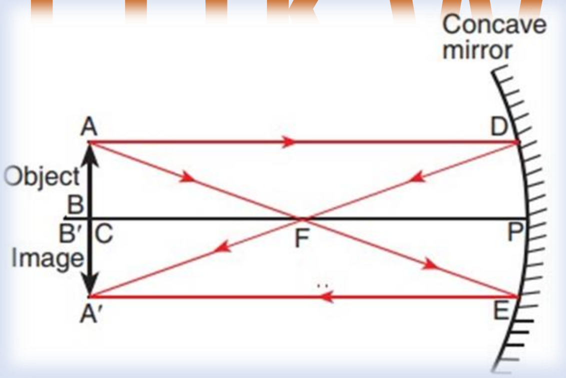


When the object is placed at the focus of a concave mirror (Object at F). When an object is placed at the focus of a concave mirror, the image formed is : (i) at infinity, (ii) real

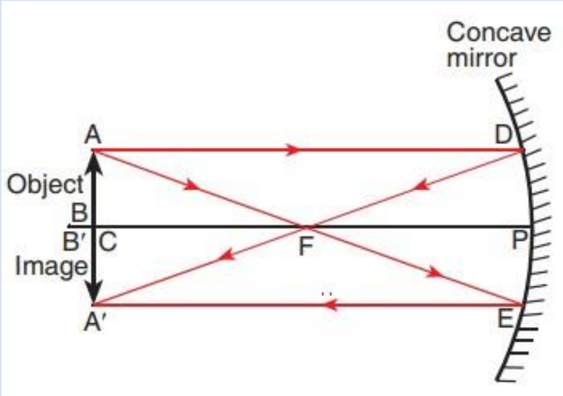
and inverted, and (iii) highly magnified (or highly enlarged).



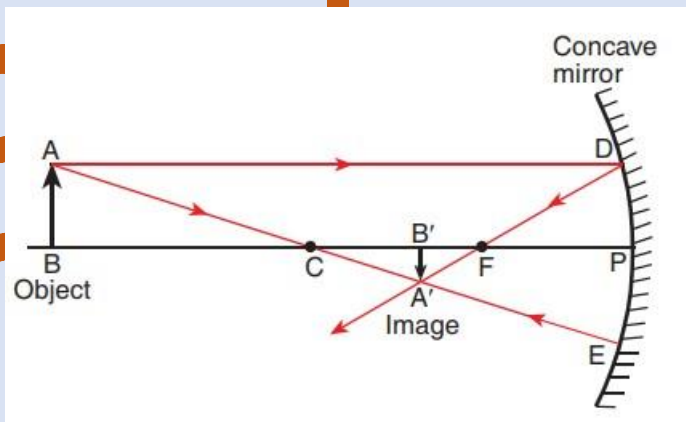
When the object is placed between focus and centre of curvature (Object between F and C). When an object is placed between the focus (F) and centre of curvature (C) of a concave mirror, the image formed is : (i) beyond the centre of curvature, (ii) real and inverted, and (iii) larger than the object (or magnified).



When the object is placed at the centre of curvature of a concave mirror (Object at C). When an object is placed at the centre of curvature (C) of a concave mirror, the image formed is : (i) at the centre of curvature (C), (ii) real and inverted, and (iii) same size as the object.

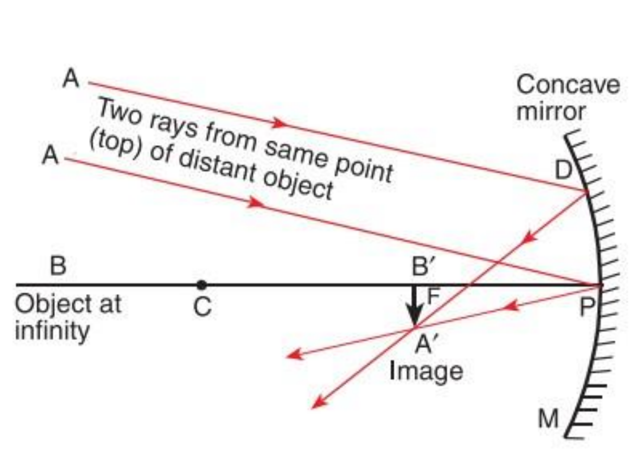


When the object is beyond the centre of curvature of the concave mirror (Object beyond C). When an object is placed beyond the centre of curvature (C) of a concave mirror, the image formed is : (i) between the focus and centre of curvature, (ii) real and inverted, and (iii) smaller than the object (or diminished).



When the Object is at Infinity.

When an object is at infinity from a concave mirror, the image formed is : (i) at the focus (F), (ii) real and inverted, and (iii) much smaller than the object (or highly diminished).



Uses of concave mirrors

Concave mirrors are commonly used in torches, search-lights, and vehicles headlights to get powerful parallel beams of light.

They are often used as shaving mirrors to see a larger image of the face. The dentists use concave mirrors to see large images of the teeth of patients.

Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces.

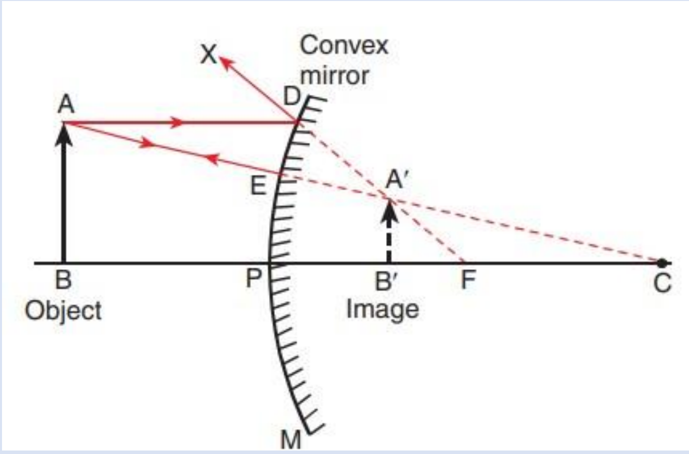
Image formation by a Convex Mirror

When an object is placed anywhere between pole (P) and infinity in front of a convex mirror, the image formed is :

(i) behind the mirror between pole (P) and focus (F),

(ii) virtual and erect, and

(iii) diminished (smaller than the object).



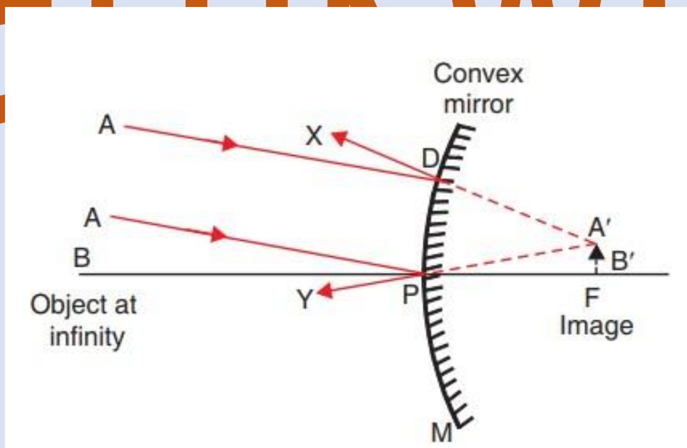
When the Object is at Infinity

When an object is at infinity from a convex mirror, the image formed is :

(i) behind the mirror at focus (F),

(ii) virtual and erect, and

(iii) highly diminished (much smaller than the object).



<u>Sign Convention for Reflection by Spherical Mirrors</u>

While dealing with the reflection of light by spherical mirrors, we shall follow a set of sign conventions called the New Cartesian Sign Convention. In this convention, the pole (P) of the mirror is taken as the origin. The principal axis of the mirror is taken as the x-axis (X'X) of the coordinate system.

(i) The object is always placed to the left of the mirror. This implies that the light from the object falls on the mirror from the left-hand side.

(ii) All distances parallel to the principal axis are measured from the pole of the mirror.

(iii) All the distances measured to the right of the origin (along + x-axis) are taken as positive while those measured to the left of the origin (along – x-axis) are taken as negative.

(iv) Distances measured perpendicular to and above the principal axis (along + y-axis) are taken as positive.

(iv) Distances measured perpendicular to and below the principal axis (along –y-axis) are taken as negative.

Mirror Formula and Magnification

In a spherical mirror, the distance of the object from its pole is called the object distance (u). The distance of the image from the pole of the mirror is called the image distance (v) , the distance of the principal focus from the pole is called the focal length (f). There is a relationship between these three quantities given by the mirror formula which is expressed as

$$1/v + 1/u = 1/f$$

Magnification produced by a spherical mirror gives the relative extent to which the image of an object is magnified with respect to the object size. It is expressed

as the ratio of the height of the image to the height of the object. It is usually represented by the letter m. If h is the height of the object and h′ is the height of the image, then the magnification m produced by a spherical mirror is given by

$$m = \frac{\text{Height of the image h2}}{\text{Height of the objecth1}}$$

The magnification m is also related to the object distance (u) and image distance (v). It can be expressed as:

$$\text{Magnification (m)} = \frac{h2}{h1} \text{ or } -\frac{v}{u}$$

REFRACTION OF LIGHT

The change in direction of light when it passes from one medium to another obliquely, is called refraction of light. In other words, the bending of light when it goes from one medium to another obliquely is called refraction of light.

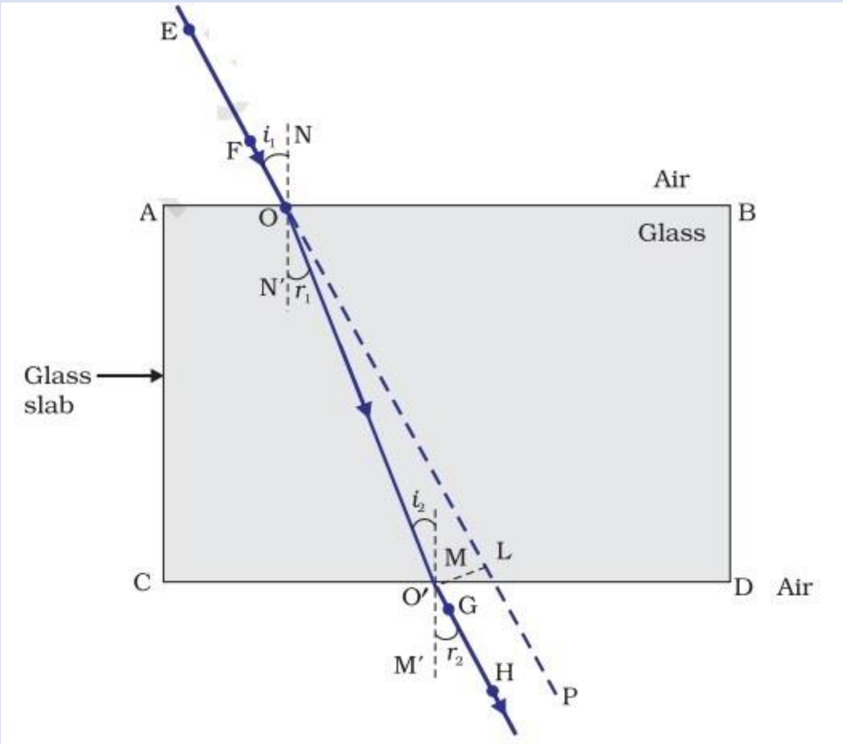
Refraction through a Rectangular Glass Slab

Refraction is due to change in the speed of light as it enters from one transparent medium to another. Experiments show that refraction of light occurs according to certain laws.

The following are the laws of refraction of light. (i) The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane. (ii) 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 the given pair of media. This law is also known as Snell's law of refraction. If i is the angle of incidence and r is the angle of refraction, then,

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

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



The Refractive Index

The refractive index can be linked to an important physical quantity, the relative speed of propagation of light in different media. It turns out that light propagates with different speeds in different media. Light travels fastest in vacuum with speed of $3\times10^{8}\ \mathrm{ms}^{-1}$.

Let v1 be the speed of light in medium 1 and v2 be the speed of light in medium 2. The refractive index of medium 2 with respect to medium 1 is given by the ratio of the speed of light in medium 1 and the speed of light in

medium 2. This is usually represented by the symbol n21. This can be expressed in an equation form as

$$n21 = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}} = \frac{v_1}{v_2}$$

By the same argument, the refractive index of medium 1 with respect to medium 2 is represented as n12.It is given by

$$n12 = \frac{\text{Speed of light in medium 2}}{\text{speed of light in medium 1}} = \frac{v_2}{v_1}$$

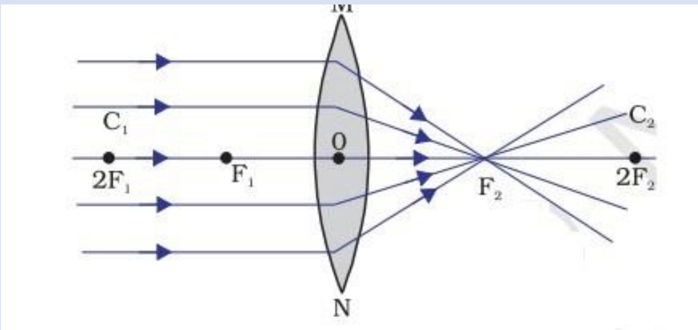
If medium 1 is vacuum or air, then the refractive index of medium 2 is considered with respect to vacuum. This is called the absolute refractive index of the medium. It is simply represented as n2 . If c is the speed of light in air and v is the speed of light in the medium, then, the refractive index of the medium n_m is given by

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

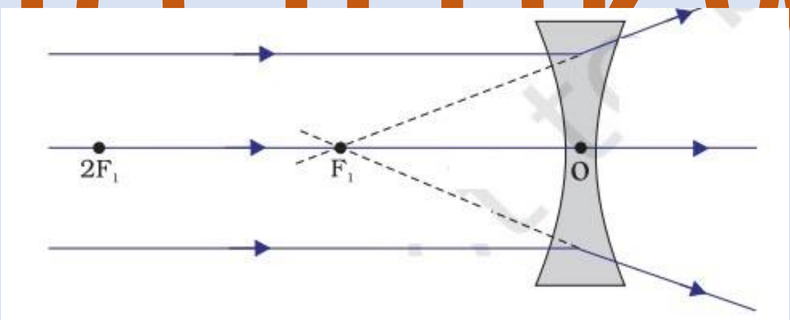
Refraction by Spherical Lenses

A lens, either a convex lens or a concave lens, has two spherical surfaces. Each of these surfaces forms a part of a sphere. The centres of these spheres are called centres of curvature of the lens. The centre of curvature of a lens is usually represented by the letter C. Since there are two centres of curvature, we may represent them as C1 and C2. An imaginary straight line passing through the two centres of curvature of a lens is called its principal axis. The central point of a lens is its optical centre. It is

usually represented by the letter O. A ray of light through the optical center of a lens passes without suffering any deviation. The effective diameter of the circular outline of a spherical lens is called its aperture.



Several rays of light parallel to the principal axis are falling on a convex lens. These rays, after refraction from the lens, are converging to a point on the principal axis. This point on the principal axis is called the principal focus of the lens.



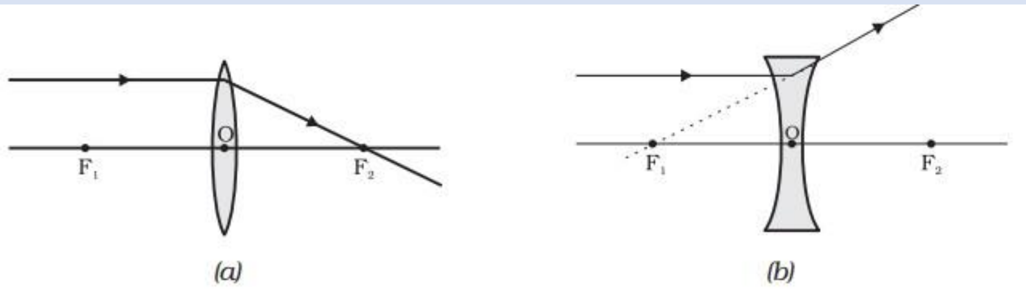
Several rays of light parallel to the principal axis are falling on a concave lens. These rays, after refraction from the lens, are appearing to diverge from a point on the principal axis. This point on the principal axis is called the principal focus of the concave lens.

pass parallel rays from the opposite surface of the lens, you get another principal focus on the opposite side. Letter F is usually used to represent principal focus. However, a lens has two principal foci. They are represented by F1 and F2. The distance of the principal focus from the optical centre of a lens is called its focal length.

Image Formation in Lenses Using Ray Diagrams

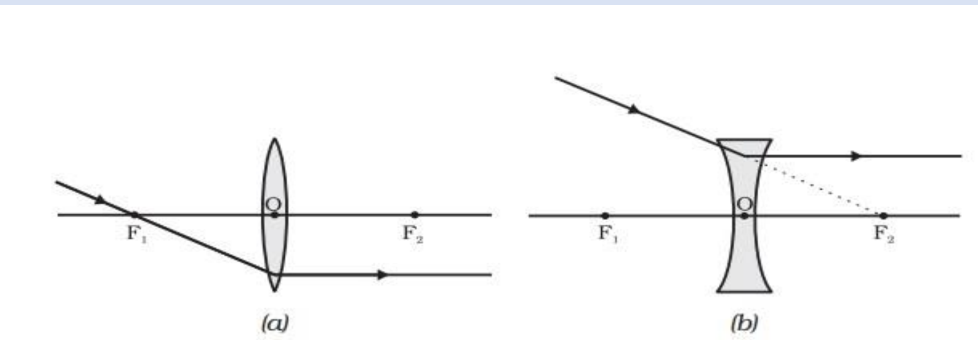
1.

A ray of light from the object, parallel to the principal axis, after refraction from a convex lens, passes through the principal focus on the other side of the lens. a concave lens, the ray appears to diverge from the principal focus located on the same side of the lens.



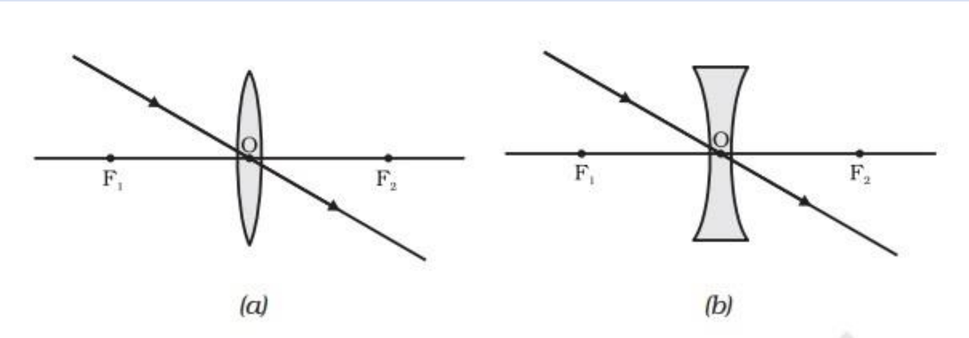
2.

A ray of light passing through a principal focus, after refraction from a convex lens, will emerge parallel to the principal axis. A ray of light appearing to meet at the principal focus of a concave lens, after refraction, will emerge parallel to the principal axis.



3.

A ray of light passing through the optical centre of a lens will emerge without any deviation.



Sign Convention for Spherical Lenses

According to the convention, the focal length of a convex lens is positive and that of a concave lens is negative. You must take care to apply appropriate signs for the values of u, v, f, object height h and image height h′.

Lens Formula and Magnification

As we have a formula for spherical mirrors, we also have formula for spherical lenses. This formula gives the relationship between object distance (u), image-distance (v) and the focal length (f). The lens formula is expressed as

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

Magnification

The magnification produced by a lens, similar to that for spherical mirrors, is defined as the ratio of the height of the image and the height of the object. Magnification is represented by the letter m. If h is the height of the object and h′ is the height of the image given by a lens, then the magnification produced by the lens is given by,

$$M = \frac{\text{Height of the Image}}{\text{Height of the object}} = \frac{h'}{h} = \frac{v}{u}$$

Magnification produced by a lens is also related to the object-distance u, and the image-distance v.

Power of a Lens

The power of a lens is defined as the reciprocal of its focal length. It is represented by the letter P. The power P of a lens of focal length f is given by

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

The SI unit of power of a lens is 'dioptre'. It is denoted by the letter D. If f is expressed in metres, then, power is expressed in dioptres. Thus, 1 dioptre is the power of a lens whose focal length is 1 metre.

$$1D = 1\mathrm{m}^{-1}$$