1. LIGHT

Light is a form of energy which produces the sensation of vision in us.

1.1 NATURE OF LIGHT

The study of light is called optics and is classified in the following ways :

- Optics
  - Geometrical optics (Ray optics)
  - Physical Optics
    - Wave Optics
    - Quantum Optics

1.2 PARTICLE THEORY OF LIGHT

According to the particle theory of light, light is composed of particles which travel in a straight line at a very high speed. The elementary particle that defines light is known as photon.

The phenomenon of reflection and refraction of light and casting of shadow of objects by light can only be explained by particle theory of light.

1.3 WAVE THEORY OF LIGHT

According to wave theory, light consists of electromagnetic waves. The light waves travel with a very high speed of 3×10^8 m/s in vacuum.

The wavelength of visible light waves lies between 4×10^{-7} m to 8×10^{-7} m.

The phenomenon of diffraction (bending of light around the corners of tiny objects) interference and polarization of light can only be explained if the light is considered to be of wave nature.

1.4 MODERN QUANTUM THEORY OF LIGHT

Quantum theory of light reconciles the particle properties of light and its wave properties.

According to this theory light has a dual nature: light exhibits the properties of both wave and particle. Light is emitted or absorbed as a particle and light propagates as a wave.

2. SOME IMPORTANT TERMS RELATED WITH LIGHT

2.1 ELECTROMAGNETIC WAVES

The waves which do not require a material medium for their propagation are known as electromagnetic waves. e.g. all light waves are electromagnetic waves.

2.2 SOURCE OF LIGHT

A source of light is an object, from which light is given out. The source of light are of two kinds:

(i) Luminous source of light: A luminous source of light is that which emits light itself. For example : The sun, the stars, etc.

(ii) Non Luminous source of Light : The source of light which does not emit light itself is called a non-luminous source of light.
For example, planets, moon, building, trees etc.

2.3 MEDIUM

A medium is a substance through which light propagates or tries to do so.

(i) Transparent : The medium which allows most of the light to pass through it is called a transparent medium. For example : air, water, glass etc.

(ii) Translucent : The medium which allows only a part of the light to pass through it is called a translucent medium. For example : paper, ground glass etc.

(iii) Opaque: The medium which does not allow any light to pass through it is called opaque medium. For example : wood, bricks, metals etc.

2.4 RAY

A ray of light is the straight line path along which light travels. It is represented by an arrow head, on a straight line ($\xrightarrow[\text{(Ray)}]{\qquad}$). The direction of arrow gives the direction of propagation of light.

2.5. BEAM OF LIGHT

A group of parallel rays is called a **beam** of light. It is also called a pencil of light.

A pencil of light may be of three types.

(i) Convergent pencil
(ii) Divergent Pencil
(iii) Parallel Pencil

Convergent Pencil

A convergent Pencil is that in which rays of light propogates to meet at a particular point say O as shown in the figure 1.

The diameter of the pencil goes on decreasing as the rays proceed forward.

Convergent pencil is also known as convergent beam of light. In the convergent pencil, as the beam of light progresses the rays converge to a point.

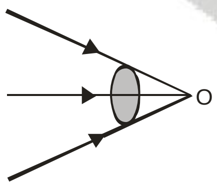
Divergent Pencil

A divergent pencil is that in which rays of light come out of a point source such that the diameter of the pencil goes on increasing as the rays proceed forward as shown in the figure 2.

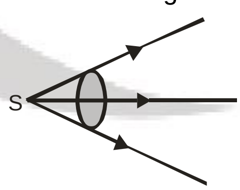
Divergent pencil is also known as divergent beam of light. In the divergent pencil, as the beam of light progresses, the rays diverge from each other.

Parallel Pencil

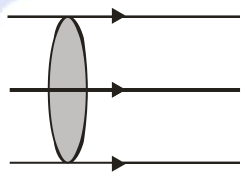
Parallel pencil is that in which all the rays move parallel to one another. The diameter of the pencil remains constant throughout as shown in the figure 3.



Convergent Pencil
Figure 1



Divergent Pencil
Figure 2



Parallel Pencil
Figure 3

3. REFLECTION OF LIGHT

The process of bouncing back of light in the same medium on striking the surface of any object is known as reflection of light.

Reflection of light is of two types:

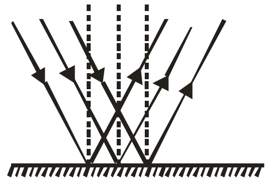
REFLECTION

- Regular / Specular
- Irregular / Diffused

3.1 REGULAR REFLECTION

When the reflecting surface is smooth and well polished, e.g. mirror, the parallel rays falling on it are reflected parallel to one another i.e. the reflected light goes in one particular direction as shown in the figure 4. Then it is known as a regular reflection.

The laws of reflection are valid only in regular reflection. It is the regular reflection that makes an object visible.

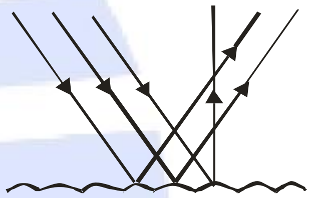


Regular Reflection
Figure 4

3.2 IRREGULAR REFLECTION

When the reflecting surface is rough, the parallel rays falling on it are reflected in different directions as shown in the figure 5. Such a reflection is known as irregular, reflection or diffused reflection or scattering of light.

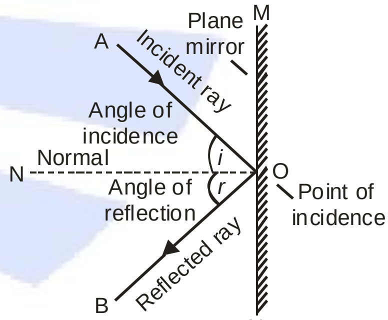
Laws of reflection are not valid in irregular reflection. In this case only the surface is visible and not the image.



Irregular Reflection
Figure 5

4. SOME IMPORTANT TERMS USED IN THE REFLECTION OF LIGHT

Let us consider the reflection of light by a plane mirror as shown in the diagram.



Reflection of light from a plane mirror
Figure 6

4.1 INCIDENT RAY

Any ray of light that strikes the reflecting surface is called the incident ray. In the figure 6. 'AO' is the incident ray.

4.2 POINT OF INCIDENCE

The point of incidence is that point at which light is incident on the reflecting surface. That is, the point at which the incident ray falls on the reflecting surface.

In the figure 6 'O' is the point of incidence.

4.3 NORMAL

The perpendicular drawn to the reflecting surface at the point of incidence is called normal. In the figure 6 'ON' is the normal.

4.4 REFLECTED RAY

The ray of light which is turned back after reflection into the same medium in which the incident light is travelling is called reflected ray.

In the figure 6. OB is the reflected ray.

4.5 ANGLE OF INCIDENCE

The angle of incidence is the angle made by the incident ray with the normal at the point of incidence. The angle between the incident ray and the normal to the surface is called angle of incidence.
In the figure 6 the angle ∠AON is the angle of incidence.

4.6 ANGLE OF REFLECTION

The angle of reflection is the angle made by the reflected ray with the normal at the point of incidence. The angle between the reflected ray and normal to the surface is called angle of reflection. In the figure 6 the angle ∠BON is the angle of reflection.

5. LAWS OF REFLECTION

There are two laws of reflection

5.1 FIRST LAW OF REFLECTION

According to the first law of reflection, the incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane which is perpendicular to the plane of the reflecting surface (as shown in the figure 7).

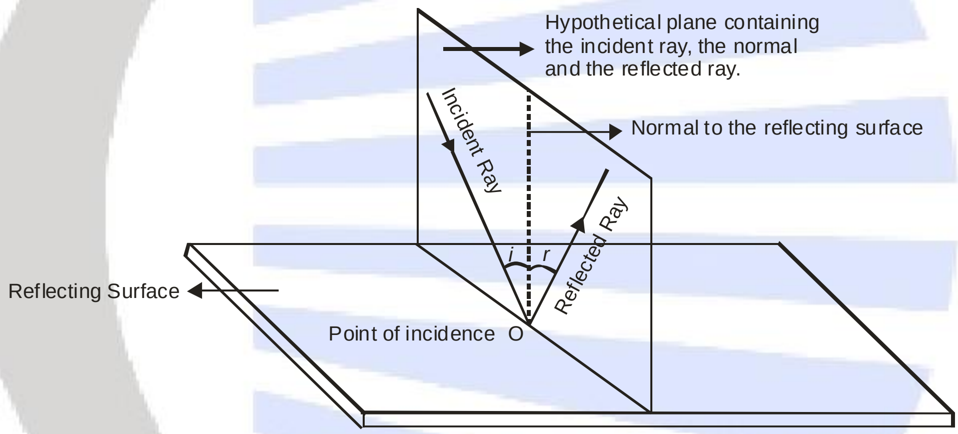


Figure 7

5.2 SECOND LAW OF REFLECTION

According to the second law of reflection, the angle of incidence is always equal to the angle of reflection for small angles.

i.e. $\angle i = \angle r$

Where $\angle i$ = angle of incidence.

$\angle r$ = angle of reflection.

The laws of reflection of light apply to all kinds of mirrors, plane mirrors as well as spherical mirrors.

6. OBJECTS

Object is a point of intersection of the incident rays.
Objects are of two types :

6.1 REAL OBJECT

If the incident rays are diverging from the point of intersection of incident rays then it is called a real object.

6.2 VIRTUAL OBJECT

If the incident rays are converging from the point of intersection of incident rays then it is called a virtual object.

7. IMAGES

Image is a point of intersection of the reflected or refracted rays.
An image is formed when the light rays coming from an object actually meet (or appear to meet) at a point after reflection or refraction.
Images are of two types

7.1 REAL IMAGE

The real image formed due to real intersection of reflected or refracted rays. Real image can be obtained on screen.
The image formed when two or more reflected or refracted rays intersect each other at a point in front of the reflecting surface (mirror) is known as a real image. It can be obtained on a screen.
e.g. the images formed on a cinema screen are real images.

7.2 VIRTUAL IMAGE

The virtual image formed due to apparent intersection of reflected or refracted light rays. Virtual image can't be obtained on screen.
The image formed when two or more reflected or refracted rays appear to intersect at a point behind the normal. It can't be obtained on a screen.
e.g. The image of our face in a plane mirror is a virtual image.

8. PLANE MIRROR

Any smooth, highly polished reflecting surface is called a mirror. A plane mirror is a highly polished plane surface.

8.1 CHARACTERISTICS OF IMAGE FORMED BY PLANE MIRRORS

Following are the important characteristics of image formed by plane mirrors.

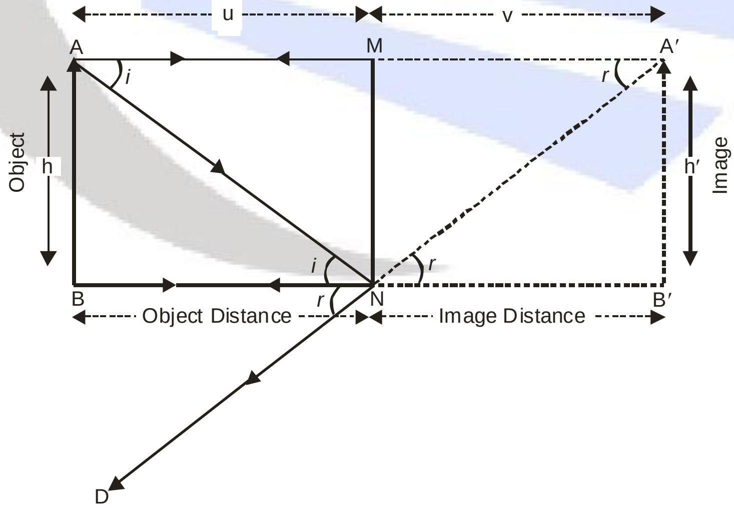


Image formation by a plane mirror
Figure 8

1. The image formed in a plane mirror is always virtual. Such an image cannot be taken on a screen. (figure 8)
2. The image formed in a plane mirror is always erect. It is the same side up as the object. (figure 8)
3. The image in a plane mirror is of the same size as the object. (figure 8)
4. The image formed by a plane mirror is at the same distance behind the mirror as the object is in front of the mirror i.e. image distance is always equal to the object distance in a plane mirror. (figure 8)
5. The image formed in a plane mirror is laterally inverted i.e. the left side of the object becomes the right side of the image and vice-versa as shown in the figure 9.

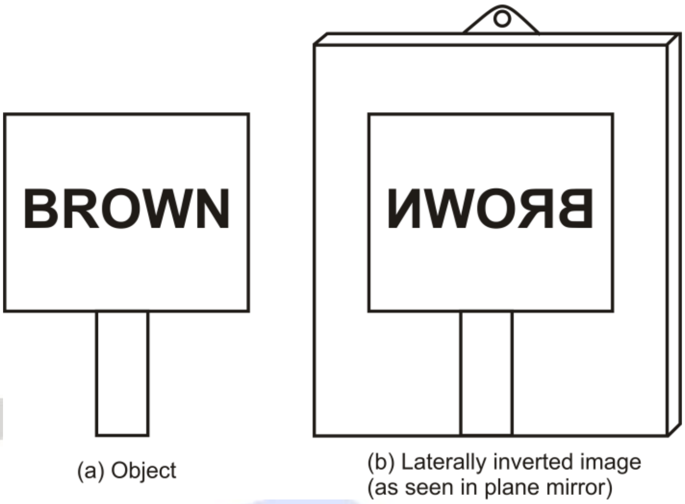


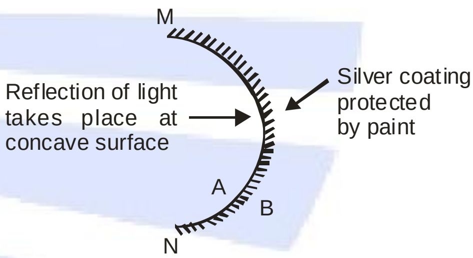
Figure 9
Diagram to show lateral inversion

9. SPHERICAL MIRRORS

A mirror whose reflecting surface is a part of a hollow sphere of glass is known as a spherical mirror. Spherical mirrors are of two types :

9.1 CONCAVE MIRROR

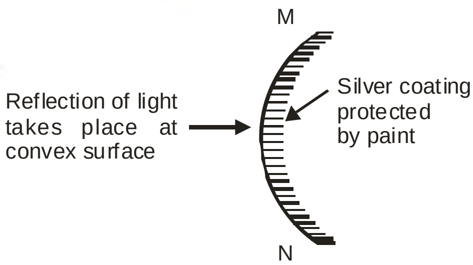
A concave mirror is that spherical mirror in which the reflecting surface is towards the centre of the sphere (i.e. inside the mirror) of which the mirror is a part. i.e. the reflection of light takes place at the concave surface (or bent-in-surface). As a concave mirror converges the parallel beam of light falling on it, therefore, it is also called a converging mirror. [figure 10 (a)]



Concave mirror
Figure 10(a)

9.2 CONVEX MIRROR

A convex mirror is that spherical mirror in which the reflecting surface is away from the centre of the sphere (i.e. bulging out) of which mirror is a part i.e. reflection of light occurs at convex surface or the bulging out surface. As a convex mirror diverges the parallel beam of light falling on it, therefore it is also called a diverging mirror. [figure 10 (b)]



Convex mirror
Figure 10(b)

10. SOME IMPORTANT TERMS RELATED TO SPHERICAL MIRRORS

The important terms related to spherical mirrors are –

10.1 CENTRE OF CURVATURE (*C*)

The centre of curvature of a spherical mirror is the centre of the imaginary hollow sphere of glass, of which the spherical mirror is a part. The centre of curvature is usually denoted by the letter C. The centre of curvature of a concave mirror is in front of it and the centre of curvature of convex mirror is behind it as shown in the figure 11 (a, b).

10.2 RADIUS OF CURVATURE (*R*)

The radius of curvature of a spherical mirror is the radius of the imaginary hollow sphere of glass, of which the spherical mirror is a part. The radius of curvature is usually denoted by the letter 'R'.
In figure 11 (a) the distance *PC* is the radius of curvature of a concave mirror and in figure (b) the distance PC is the radius of curvature of a convex mirror.

10.3 POLE (*P*)

The centre of the reflecting surface of a spherical mirror is called its pole. It is usually denoted by the letter 'P' in each concave and convex mirror. The pole of a spherical mirror lies on the surface of the mirror as shown in figure 11 (a, b).

10.4 PRINCIPAL AXIS

The principal axis of a spherical mirror is the straight line passing through the centre of curvature C and pole P of a spherical mirror, produced on both sides.
In the figure 11 (a, b) x x′ is the principal axis of a concave and convex mirror.

10.5 APERTURE

The portion of a mirror from which the reflection of light actually takes place is called the aperture of the mirror. It is also called linear aperture of the mirror. The aperture of a spherical mirror is denoted by the diameter of its reflecting surface. In the figure 11 (a, b) MN represent the aperture of concave and convex mirror.

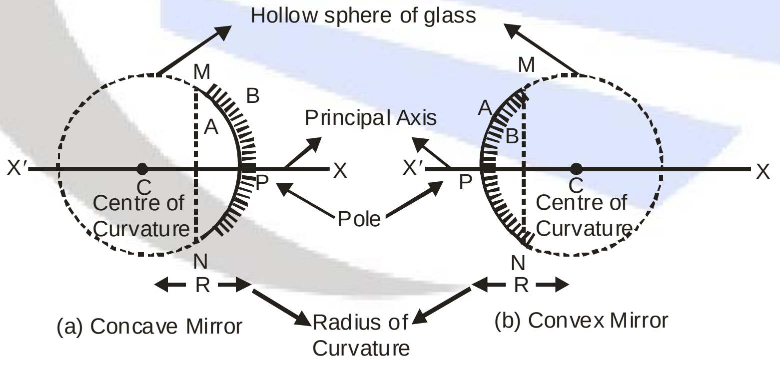


Figure 11

10.6 PRINCIPAL FOCUS OF A CONCAVE MIRROR

The principal focus of a concave mirror is a point on the principal axis of the mirror, at which all the incident rays parallel to the principal axis, and close to it, actually meet (converge) after reflection from the mirror.

A concave mirror always have a real focus. It always lies in front of the concave mirror and is denoted by the letter 'F'. as shown in the figure 12.

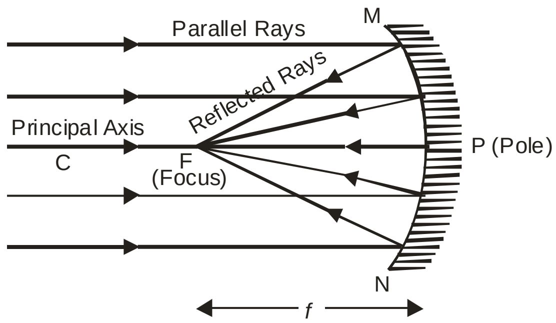


Figure 12

10.7 FOCAL LENGTH OF A CONCAVE MIRROR

Focal length of a concave mirror is the distance between the principal focus 'F' and the pole 'P' of the mirror. It is represented by the letter '*f*'. In the figure 12, PF = *f* = focal length of the concave mirror.

10.8 PRINCIPAL FOCUS OF A CONVEX MIRROR

The principal focus of a convex mirror is a point on the principal axis of the mirror, at which all the incident rays parallel to the principal axis and close to it, appears to diverge, after reflection from the mirror.

A convex mirror has a virtual focus. It always lies behind the convex mirror and is denoted by the letter 'F' as shown in the figure 13.

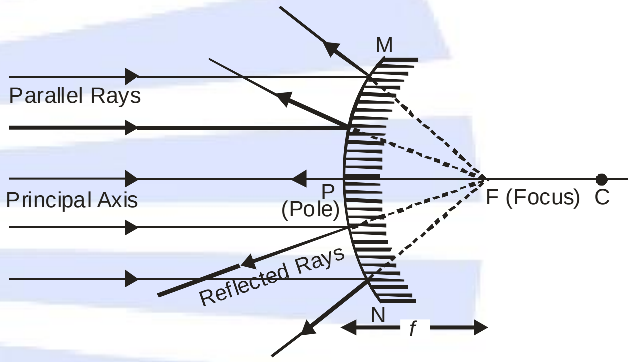


Figure 13

10.9 FOCAL LENGTH OF A CONVEX MIRROR

Focal length of a convex mirror is the distance between the principal focus (F) and the pole 'P' of the mirror. It is represented by the letter '*f*'

In the figure 13, PF = f = focal length of the convex mirror.

10.10 RELATION BETWEEN RADIUS OF CURVATURE AND FOCAL LENGTH OF A SPHERICAL MIRROR

For spherical mirror having small aperture, the principal focus 'F' lies exactly at the mid point of the pole P and the centre of curvature C as shown in the figure 12 & 13. Therefore the focal length of a spherical mirror (concave or convex) is equal to half of its radius of curvature.

i.e.

$$\boxed{f = \frac{R}{2} \Rightarrow R = 2f}$$

10.11 RULES FOR TRACING IMAGES FORMED BY CONCAVE MIRRORS

When an object is placed in front of a concave mirror, its image is formed by reflection in the mirror. To trace this image the four rays of light are commonly used, out of which we take any two rays of light (starting from the object) whose paths, after reflection from the mirror, are known to us and easy to draw. We may call them (the four rays) as rules for tracing images in concave mirrors. These are as follows :

(i) The incident ray of light which is parallel to the principal axis of a concave mirror, actually passes through the principal focus of the mirror after reflection from the mirror as shown in the figure 14.

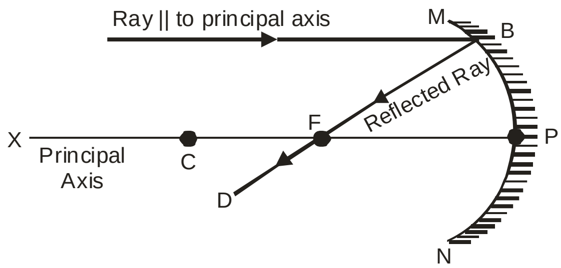


Figure 14

(ii) The incident ray of light passing through the centre of curvature at a concave mirror is reflected back along the same path i.e. such a ray follows the same path after the reflection, but in the opposite direction as shown in the figure 15.

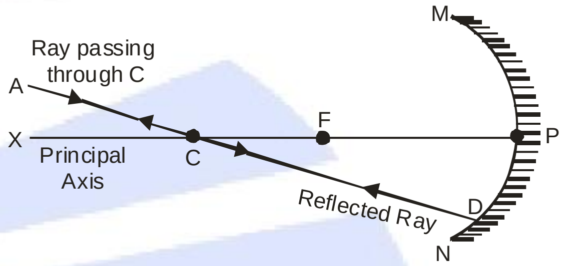


Figure 15

(iii) Incident ray of light passing through the focus of a concave mirror becomes parallel to the principal axis of the mirror after reflection as shown in the figure 16.

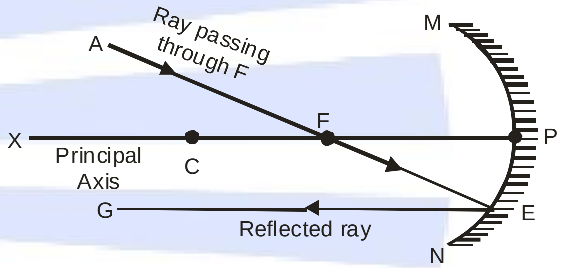


Figure 16

(iv) Incident ray of light which is incident (obliquely) at the pole P of the concave mirror is reflected back making the same angle with the principal axis of the concave mirror as shown in the figure 17.

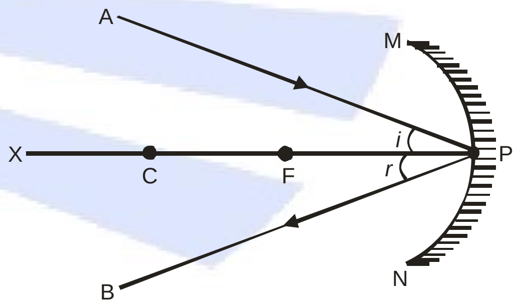


Figure 17

10.12 FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONCAVE MIRROR IN DIFFERENT POSITIONS OF THE OBJECT

The type of image formed by a concave mirror primarily depends on the position of the object in front of the mirror. When an object is moved closer to the mirror, starting from infinity, the following six cases arise :

(i) When the object is at infinity

When the object is at infinity, the rays of light starting from the object on travelling such a large distance are assumed to become parallel to each other while falling on the mirror. These parallel rays of light may fall on the mirror in the following two ways.

All the rays become parallel to the principal axis of the mirror as shown in the figure 18.
All the rays falling obliquely to the principal axis as shown in the figure 19.

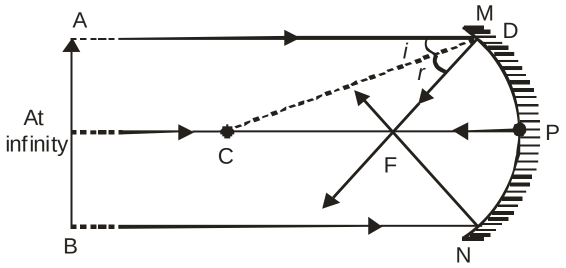


Figure 18

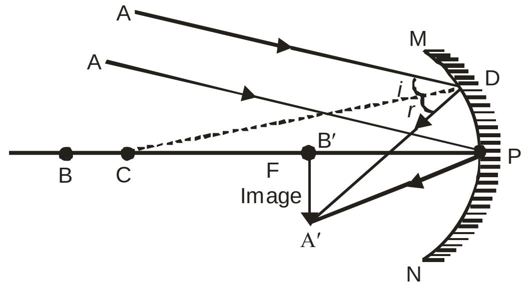


Figure 19

In the above two cases image is formed at the focus of the mirror. Therefore we can say that when the object is at infinity. The image is

(a) formed at the focus 'F' of the mirror.
(b) real and inverted
(c) highly diminished, point sized.

(ii) When the object is beyond the centre of curvature 'C' of concave mirror

When the object is placed beyond the centre of curvature 'C' of the concave mirror (figure 20). The image is

(a) formed between the Focus 'F' and the centre of curvature 'C' of the concave mirror.
(b) real and inverted
(c) smaller in size i.e. diminished

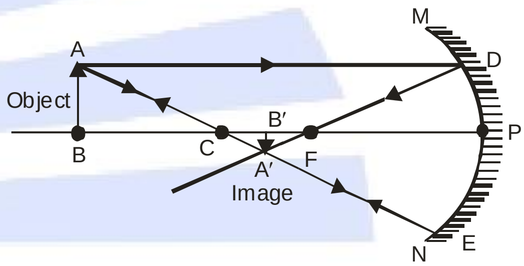


Figure 20

(iii) When the object is at the centre of curvature of concave mirror

When the object is placed at the centre of curvature of concave mirror (figure 21). The image is

(a) formed at the centre of curvature 'C' of the concave mirror.
(b) real and inverted.
(c) of the same size as that of the object.

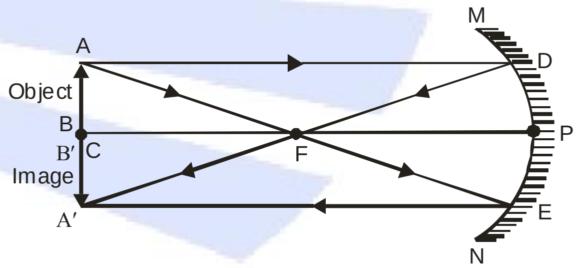
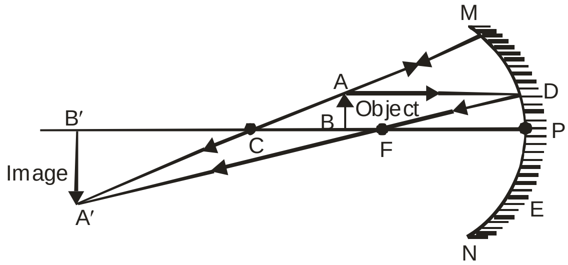


Figure 21

(iv) When the object is placed between the centre of curvature 'C' and Focus 'F' of concave mirror

When the object is placed between the centre of curvature 'C' and Focus 'F' of concave mirror as shown in figure 22. The image is

(a) formed beyond centre of curvature 'C' of concave mirror
(b) real and inverted.



(c) enlarged, i.e. Larger in size than the object.

Figure 22

(v) When the object is at the Focus 'F' of a concave mirror

When the object is placed at the focus 'F' of a concave mirror as shown in the figure 23. The image is
(a) formed at infinity.
(b) real and inverted.
(c) highly enlarged, magnified.

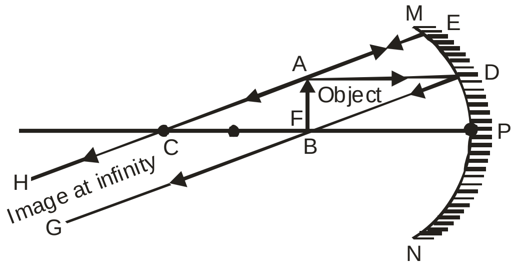


Figure 23

(vi) When the object is placed between Focus 'F' and pole 'P' of the concave mirror

When the object is placed between the Focus 'F' and Pole 'P' of the concave mirror as shown in the figure 24. The image is
(a) formed behind the mirror.
(b) virtual and erect.
(c) enlarged, larger than the size of the object.

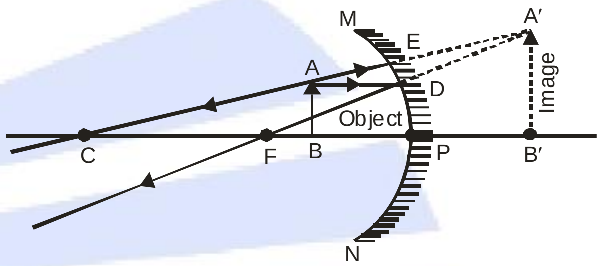


Figure 24

Image formation by a concave mirror for different positions of the object:

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

10.13 USES OF CONCAVE MIRRORS

Some of the practical uses of concave mirrors are :

(i) Concave mirrors are used as reflectors in torches, search lights and head lights of motor vehicles etc. to get powerful and parallel beams of light.
(ii) Concave mirrors are used as shaving mirrors to see a larger image of the face.
(iii) Concave mirrors are used by dentists to see the larger images of the teeth of patients.
(iv) Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces.

10.14 METHOD TO FIND OUT THE APPROXIMATE FOCAL LENGTH OF A CONCAVE MIRROR

To find out the approximate focal length of a concave mirror, focus a distant object (at infinity) on a screen by using a concave mirror whose focal length is to be determined. The sharp image of this object will be formed at the focus of the concave mirror. The distance of the image so formed from the concave mirror is equal to the focal length of concave mirror. Measure this distance with the help of a scale. It will give us the approximate focal length of the concave mirror.

10.15 RULES FOR TRACING IMAGES FORMED BY CONVEX MIRRORS

When an object is placed in front of a convex mirror, its image is formed by reflection in the mirror. To trace this image the four rays of light are commonly used, out of which we take any two rays of light (starting from the object) whose paths, after reflection from the mirror, are known to us and easy to draw. We may call them (the four rays) as rules for tracing images in convex mirrors. These are as follows :

(i) The incident ray of light parallel to the principal axis of a convex mirror, appears to be coming from its focus 'F' after reflection from the mirror as shown in the figure 25.

In the figure the incident ray AB which is parallel to the principal axis, after reflection from the convex mirror follows the path BD. This reflected ray BD appears to come from the Focus 'F' behind the convex mirror.

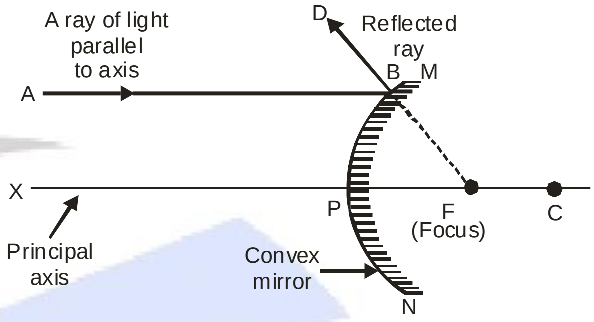


Figure 25

(ii) The incident ray of light which appears to pass through the centre of curvature 'C' of a convex mirror is reflected back along the same path, as shown in the figure 26.

In the figure the incident ray AD appears to pass through the centre of curvature 'C' behind the convex mirror, after reflection follows the same path DA.

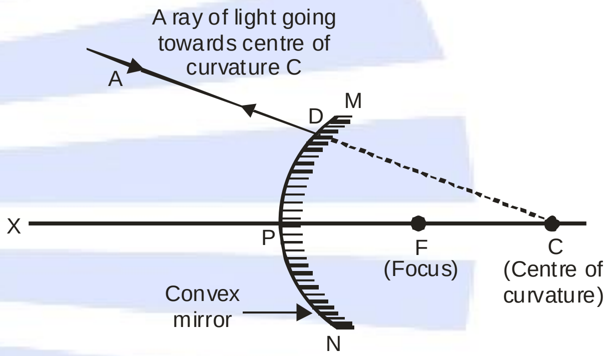


Figure 26

(iii) The incident ray of light which appears to pass through the focus 'F' of a convex mirror becomes parallel to the principal axis after reflection as shown in the figure 27.

In the figure the incident ray AE appears to pass through the Focus 'F' behind the mirror, after reflection follows the path EG. This reflected ray EG is parallel to the principal axis of the convex mirror.

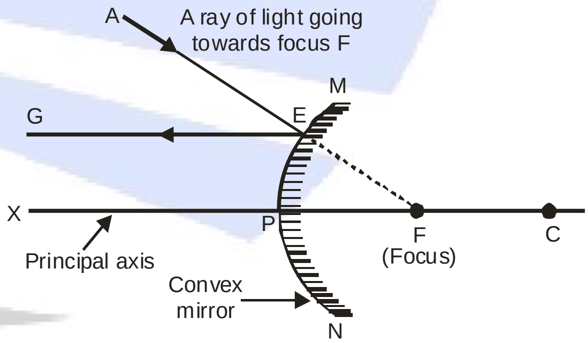


Figure 27

(iv) The incident ray of light which is falling obliquely at some angle towards the pole 'p' of a convex mirror is reflected back making the same angle with the principal axis, as shown in the figure 28.

In the figure the incident ray AP which is falling on the pole 'P' of the convex mirror making some angle of incidence with the normal, after reflection follows the path PH, thereby making an angle of reflection '*r*' with the normal such that the angle of incidence '*i*' is equal to the angle of reflection *r* i.e. $\angle i = \angle r$.

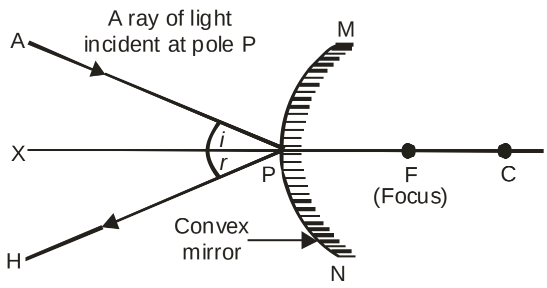


Figure 28

10.16 FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONVEX MIRROR IN DIFFERENT POSITIONS OF THE OBJECT

The type of image formed by a convex mirror primarily depends upon the position of the object in front of the mirror. When an object is moved closer to the mirror, starting from infinity, the following two cases arise :

(i) When the object is at infinity

When the object is at infinity, the rays of light starting from the object on travelling such a large distance are assumed to become parallel to each other while falling on the mirror. These parallel rays of light may fall on the mirror in the following two ways–

(a) All the incident rays become parallel to the principal axis of the convex mirror as shown in the figure 29.

(b) All the incident rays falling obliquely to the principal axis, as shown in the figure 30.

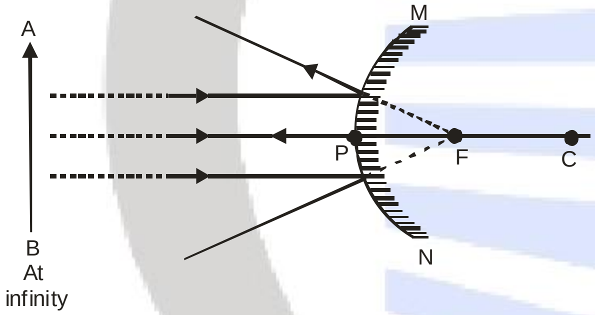


Figure 29

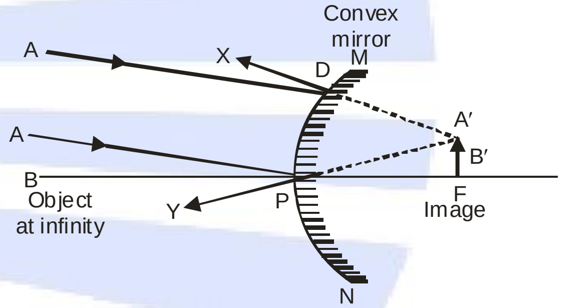


Figure 30

In the above two cases image is formed at the Focus 'F' of the convex mirror, behind the mirror. Therefore we can say that when the object is at infinity, the image is formed

(a) At the Focus 'F' behind the mirror.

(b) Virtual and erect.

(c) Highly diminished, point sized (much smaller than the object).

(ii) When the object is at finite distance from the convex mirror. i.e. between infinity and the pole P of the convex mirror :

When the object is at finite distance i.e. anywhere between infinity and the pole 'P' of the convex mirror (figure 31). The image is formed

(a) Between the pole 'P' and Focus 'F' behind the convex mirror.

(b) Virtual and erect.

(c) Diminished, smaller than the object.

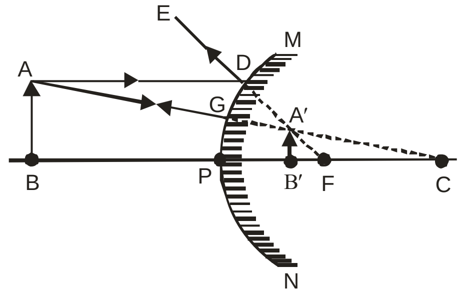


Figure 31

Image formation by a convex mirror for different positions of the object:

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

10.17 USES OF CONVEX MIRROR

Some of the practical uses of convex mirrors are :

(i) A convex mirror is used as a reflector in street lamps. As a result, light from the lamp diverges over a large area.

(ii) Convex mirrors are used as rear-view mirrors in automobiles (like cars, trucks and buses) to see the objects (traffic) at the rear side.

The convex mirror is preferred as a rear view mirror because

(a) A convex mirror always produces an erect image of the objects.

(b) The size of the image formed by a convex mirror is highly diminished or much smaller than the object, due to which it covers a wide field of view, which enables the driver to view much larger area of the traffic behind him than would be possible with a plane mirror.

10.18 METHOD TO DISTINGUISH BETWEEN A PLANE MIRROR, A CONCAVE MIRROR AND A CONVEX MIRROR WITHOUT TOUCHING THEM

To distinguish between a plane mirror, a concave mirror and a convex mirror, without touching them, we simply look at the image of our face in the three mirrors, turn by turn.

All of them will produce an image of our face but of different types.

A plane mirror will produce virtual and erect image of the same size as our face and we will look our normal self.

A concave mirror will produce a virtual, erect and magnified image of our face i.e. our face will look much bigger.

A convex mirror will produce a virtual, erect but diminished image of our face i.e. our face will look much smaller.

11. SIGN CONVENTION FOR REFLECTION BY SPHERICAL MIRRORS

The new Cartesian sign convention is used for measuring the various distances in the ray-diagrams of spherical mirrors.

According to the new Cartesian sign convention (figure 32) :

(i) The pole 'P' of the mirror is taken as the origin and the principal axis of the mirror is taken as the x-axis of the coordinate system.

(ii) The object is always placed to the left of the mirror i.e. the light (incident rays) from the object falls on the mirror from the left hand side.
(iii) All the distances parallel to the principal axis of the spherical mirrors are measured from the pole 'P' of the mirror.
(iv) All the distances measured to the right of the origin (along +ve x-axis) are taken as positive.
(v) All the distances measured to the left of the origin (along –ve x-axis) are taken as negative.
(vi) The distances (heights) measured upwards (i.e. above the x-axis) and perpendicular to the principal axis of the mirror are taken as positive
(vii) the distances (heights) measured downwards (i.e. below the x-axis) and perpendicular to the principal axis of the mirror are taken as negative.

The following fig. 32 illustrates all the points of the new cartesian sign convention stated above.

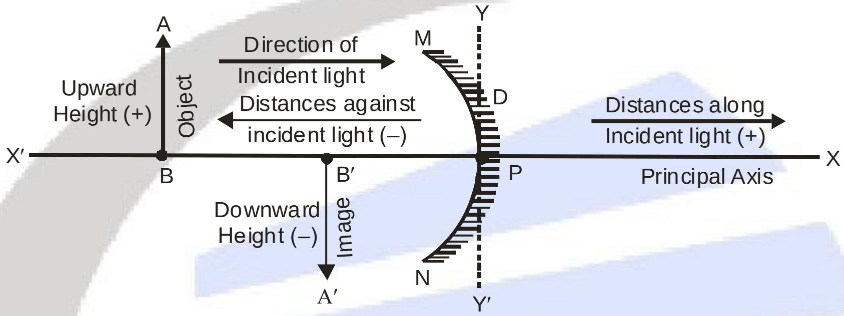


Figure 32

12. MIRROR FORMULA

Let us first know about the terms used in the mirror formula of spherical mirrors.

(i) Object distance (*u*) : The distance of the object from the pole 'P' of the spherical mirror is called the object distance. It is denoted by the letter '*u*'

(ii) Image Distance (*v*) : The distance of the image from the pole 'P' of the spherical mirror is called the image distance. It is denoted by the letter 'v'.

(iii) Focal length (*f*) : The distance of the principal focus (F) from the pole (P) of the spherical mirror is called the focal length. It is denoted by the letter '*f* '.

The relationship between the image distance (v), object distance (*u*) and focal length (*f*) of a spherical mirror is known as the mirror formula. The Mirror formula can be written as :

$$\frac{1}{\text{Image distance}} + \frac{1}{\text{object distance}} = \frac{1}{\text{focal length}}$$

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

where the symbols have their usual meaning.

13. LINEAR MAGNIFICATION PRODUCED BY MIRRORS

The linear magnification produced by a spherical mirror (concave or convex) is defined as the ratio of the height of the image (*h*′) to the height of the object (*h*). It is a pure ratio and has no units. It is denoted by the letter '*m*' and is given by

$$\text{linear magnification}\,(m) = \frac{\text{height of the image (h}')}{\text{height of the object (h)}}$$

or $$\boxed{m = \frac{h'}{h}}$$

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

Linear Magnification, $m = -\frac{v}{u}$

$\Rightarrow$ Linear magnification, $$\boxed{m = \frac{h'}{h} = -\frac{v}{u}}$$

This shows that the linear magnification produced by a mirror is also equal to the ratio of the image distance (*v*) to the object distance (*u*) with a minus sign.

13.1 IN CASE OF CONCAVE MIRROR

(i) For real and inverted image: According to the New Cartesian Sign Convention, for the real and inverted images formed by a concave mirror,
object height (h) is always +ve
image height (*h*′) is always –ve

$\therefore$ Linear magnification, $m = \frac{h'}{h}$

$m = \frac{-ve}{+ve}$ or $m = -ve$.

(ii) For virtual and Erect image : According to the new Cartesian sign convention, for the virtual and erect images formed by a concave mirror,
object height (*h*) is always +ve
image height (*h*′) is always +ve.

$\therefore$ Linear magnification, $m = \frac{h'}{h}$

$m = \frac{+ve}{+ve}$ or $m = +ve$.

13.2 In case of convex mirror

A convex mirror always forms a virtual and erect image.

(i) For virtual and erect image : According to the New Cartesian Sign Convention, for the virtual and erect images formed by a convex mirror,
Object height (*h*) is always +ve
Image height (*h*′) is always +ve

$\therefore$ Linear magnification, $m = \frac{h'}{h}$

or $m = \frac{+ve}{+ve}$

or $\mathrm{m} = +\mathrm{ve}$.

13.3 FOR SPHERICAL MIRRORS IF THE

(i) Linear magnification, $m > 1$
the image is enlarged i.e. greater than the object

(ii) Linear magnification, $m = 1$
the image is of the same size as the object.

(iii) Linear magnification, $m < 1$
The image is diminished i.e. the image is smaller than the object.

14. SOME IMPORTANT CONCLUSIONS

On the basis of the New Cartesian Sign Convention discussed above, we can draw the following conclusions for the spherical mirrors (concave as well as convex mirrors).

14.1 IN THE CASE OF CONCAVE MIRROR

(i) For real and inverted image (figure 33)

Focal length	(f)	=	–ve
Radius of curvature	(R)	=	–ve
Object distance	(u)	=	–ve
Object height	(h)	=	+ve
Image distance	(v)	=	–ve
Image height	(h')	=	–ve
Magnification	(m)	=	–ve

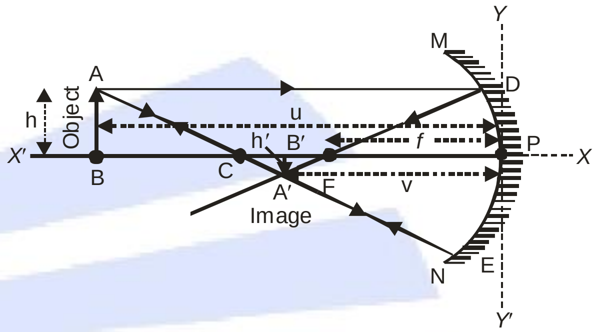


Figure 33

(ii) For virtual and erect image (figure 34)

focal length	(f)	= –ve
Radius of curvature	(R)	= –ve
Object distance	(u)	= –ve
Object height	(h)	= +ve
Image distance	(v)	= +ve
Image height	(h')	= +ve
Magnification	(m)	= +ve

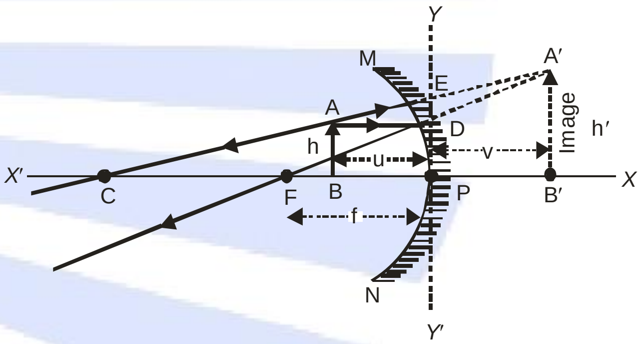


Figure 34

14.2 IN CASE OF CONVEX MIRROR

A convex mirror always form virtual and erect image.

Therefore for virtual and erect image :

Focal length	(f)	=	+ve
Radius of curvature	(R)	=	+ve
Object distance	(u)	=	–ve
Object height	(h)	=	+ve
Image distance	(v)	=	+ve
Image height	(b')	=	+ve
Magnification	(m)	=	+ve

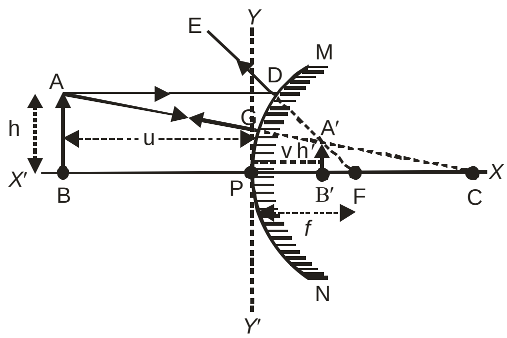


Figure 35

15. REFRACTION OF LIGHT

The phenomenon of bending of light from its original path on passing from one medium to another is known as refraction. The refraction occurs right at the bounding (interface) of the two media.

15.1 CAUSE OF REFRACTION

The refraction of light is due to the change in the speed of light on going from one medium to another. The light travels with different speeds in different media. Therefore when light goes from one medium to another, its speed changes. This change in speed of light on going from one medium to another causes the refraction of light.

Explanation: Let us take an example to describe the refraction. Consider a rectangular glass slab PQRS as shown in the figure 36.

Here we have two media; air which is an optically rarer medium as compared to glass. The incident ray of light AO travelling in air is incident on the glass slab at point O. This incident ray 'AO' of light bends at point 'O' on the interface of air and glass and goes along the direction OB inside the glass slab. This OB is known as the refracted ray.

As light travels faster in air than in glass, so as the light ray AO enters from air into glass at point O, its speed decreases and it bends towards normal ON' as shown in the figure 36. Angle AON is called the angle of incidence '*i*' and angle N′OB is the angle of refraction '*r*'.

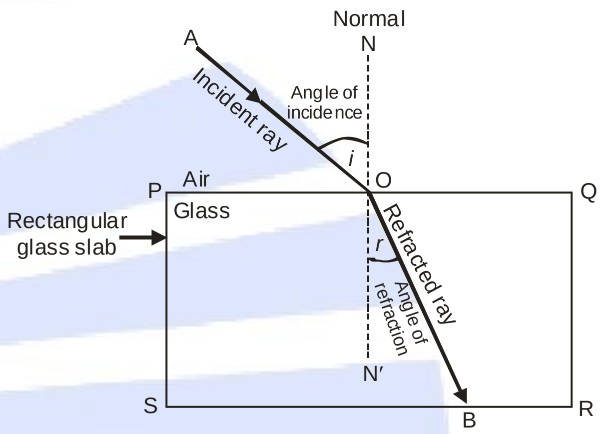
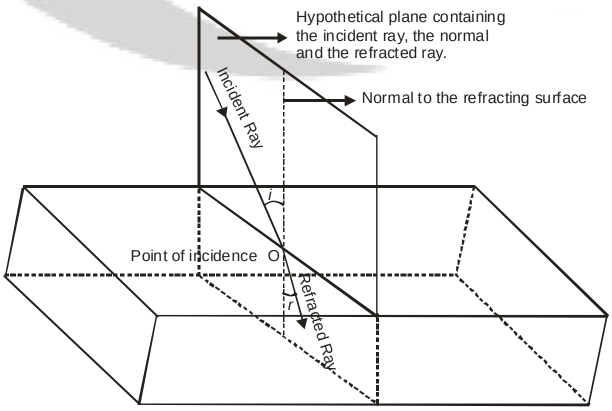


Figure 36

15.2 LAWS OF REFRACTION

Refraction of light occurs according to certain laws, known as laws of refraction. The following are the two laws of refraction:

(i) According to the first law of refraction of light. "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) According to the second law of refraction. "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 (wavelength) and for the given pair of media." **This law is also known as Snell's law of refraction.**

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

where i = angle of incidence

r = angle of refraction

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

15.3 THE REFRACTIVE INDEX OR ABSOLUTE REFRACTIVE INDEX

The absolute refractive index or simply called refractive index of any medium is defined as the ratio of speed of light in air (or vacuum) to the speed of light in any medium. It is usually represented by the symbol 'n_m'

i.e. $$\text{Absolute Refractive Index of a medium} = \frac{\text{speed of light in air (or vacuum)}}{\text{Speed of light in medium}}$$

or $$\boxed{n_m = \frac{c}{v}}$$

Where n_m Absolute refractive index of a medium.

c speed of light in air or vacuum

v Speed of light in medium.

The refractive index is a ratio of two velocities, it has no units. It is a pure number.

For example: The absolute refractive index of water is given by

$$\text{Absolute refractive index of water} = \frac{\text{Speed of light in air (or vacuum)}}{\text{Speed of light in water}}$$

$$= \frac{3 \times 10^8 \, m/s}{2.25 \times 10^8 \, m/s} = \mathbf{1.33}$$

15.4 RELATIVE REFRACTIVE INDEX

When light is passing from one medium (other than vacuum or air) to another medium, then the value of refractive index is called relative refractive index.

The relative refractive index of medium 2 with respect to medium 1 (other than air or vacuum) is the ratio of speed of light in medium 1 to the speed of light in medium 2. This is usually represented by the symbol 'n_{21}' or 'n_2 written as:

$$\begin{array}{l}\text{Relative refractive index of medium 2} \\ \text{with respect to medium 1}\end{array} = \frac{\text{Speed of light in medium 1(other than vacuum or air)}}{\text{Speed of light in medium 2}}$$

or $$\boxed{n_{21} = \frac{v_1}{v_2}} \quad \ldots(1)$$

Where n_{21} Relative refractive index of medium 2 with respect to medium 1.

v_1 Speed of light in medium 1.

v_2 Speed of light in medium 2.

Similarly, the relative refractive index of medium 1 with respect to medium 2 is represented as n_{12} and is given by

$$n_{12} = \frac{\text{Speed of light in medium 2}}{\text{Speed of light in medium 1}}$$

or $$\boxed{n_{12} = \frac{v_2}{v_1}} \qquad \ldots(2)$$

From (1) and (2)

$$\boxed{n_{21} = \frac{1}{n_{12}}}$$

This implies that, the refractive index for light going from medium 1 to medium 2 is equal to the reciprocal of the refractive index for light going from medium 2 to medium 1.

The value of the Refractive index of any medium depends only on the nature of material of the medium and the colour (or wavelength) of light.

The absolute refractive index of some material media are as follows :

Table : 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

16. OPTICALLY DENSER MEDIUM AND RARER MEDIUM

In the comparison of two media, the medium, or substance having higher refractive index or in which the speed of light is less, is called an optically denser medium. On the other hand, a medium (or substance) having lower refractive index or in which the speed of light is higher is called an optically rarer medium.

For example, between the two media glass and water, glass having higher refractive index is an optically denser medium than water which has lower refractive index and hence is an optically rarer medium.

16.1 OPTICAL DENSITY

Optical density of a substance is different from its mass density. A medium (substance) may have higher optical density than another medium (substance) but its mass density may be less. For example oils (kerosene, mustard etc.) having higher refractive index has a higher optical density than water which has a lower refractive index, but the mass density of oils (Kerosene, mustard etc.) is less than that of water. That is why the oils generally float on the water surface.

16.2 THE DIRECTION OF BENDING OF LIGHT

The two rules which give the direction of bending of a ray of light when it goes from one medium to another are as follows :

(i) When a ray of light goes from a rarer medium to a denser medium, it bends towards the normal at the interface of two media as shown in the figure 37.

(ii) When a ray of light goes from a denser medium to a rarer medium, it bends away from the normal at the interface of two media as shown in the figure 38.

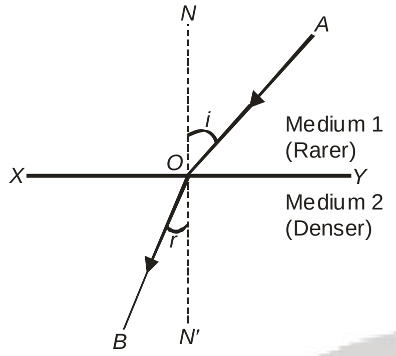


Figure 37

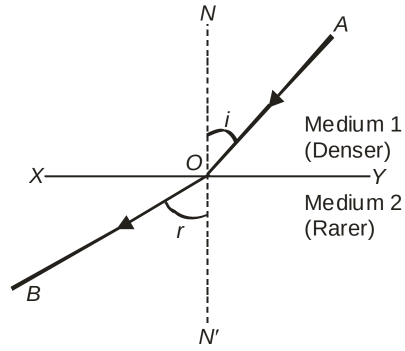


Figure 38

16.3 REFRACTION THROUGH A RECTANGULAR GLASS SLAB

Consider a rectangular glass slab PQRS as shown in the figure 39.

Here we have two media ; Air which is an optically rarer medium and glass which is an optically denser medium as compared to air.

The incident ray of light AO travelling in air (rarer medium) is incident on the glass slab (Denser medium) at point O on the interface of air and glass. On entering the glass slab as it is going from rarer medium to denser medium, it gets refracted and bends towards the normal ON′ following the path OB.

A second refraction takes place when the refracted ray of light OB, travelling in glass emerges into air at point B. Since the ray of light OB, goes from denser medium 'glass' into the rarer medium 'air', it bends away from the normal BN′, and follows the direction BC as emergent ray.

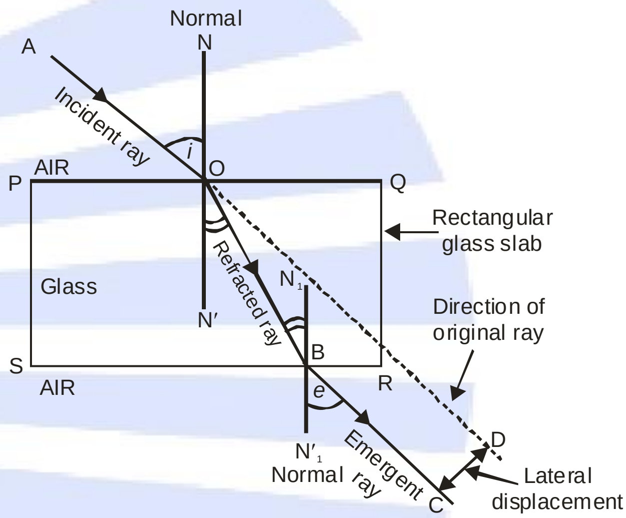


Figure 39

This emergent ray BC is parallel to the direction of the incident rays AO. This is because the extent of bending of the ray of light at the opposite parallel faces. PQ (air-glass interface) and SR (glass-air interface) of the rectangular glass slab is equal and opposite. However the emergent ray is shifted or displaced slightly sideward from the original path of the incident ray by a perpendicular distance CD which is known as the **lateral displacement**. Lateral displacement depends upon the thickness of glass slab.

16.4 EFFECT OF REFRACTION OF LIGHT

Some important effects of the refraction of light which can be easily observed in our day to day life are as follows :

(i) An object placed under water appears to be raised.

(ii) When a thick glass slab is placed over some printed matter, the letters appear raised when viewed from the top.

(iii) A pool of water appears to be less deep than it actually is.
(iv) A lemon kept in water in a glass tumbler appears to be bigger than its actual size, when viewed from the sides.
(v) Twinkling of stars.
(vi) A stick held obliquely and partly immersed in water appears to be bent at the water surface.

17. SPHERICAL LENSES

A transparent material bounded by two surfaces, of which one or both the surfaces are spherical is known as a lens.

The lens which is bounded by one spherical surface, the other surface would be plane.

Spherical lenses are of two types

(i) Double Convex Lens or Convex lens or Converging lens : A lens having two spherical surfaces, bulging outwards is called a double convex lens or simply a convex lens. It is thicker at the middle but thin at the edges. A convex lens converges light rays hence it is also known as converging lens.

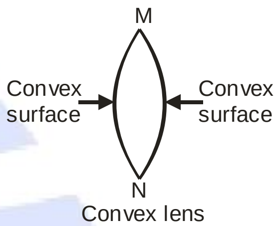


Figure 40

(ii) Double concave lens or concave lens or diverging lens: A lens having two spherical surfaces, curved inwards is called a double concave lens or simply a concave lens. It is thicker at the edges but thinner in the middle.
A concave lens diverges light rays, hence it is also known as diverging lens.

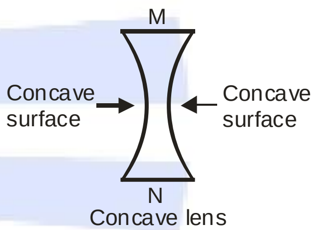


Figure 41

18. SOME IMPORTANT TERMS ASSOCIATED WITH SPHERICAL LENSES

18.1 OPTICAL CENTRE

The centre point of a lens is known as its optical centre. It is usually represented by the letter O. A ray of light passing through the optical centre at a lens goes undeviated.

18.2 APERTURE

The effective diameter of the circular outline at a spherical lens is called its aperture. In the figure 42 (a, b) 'AB' is the diameter of the circular outline of the lens which represents aperture of the lens or we can say that aperture is the actual refracting surface of the lens.

18.3 CENTRE OF CURVATURE

A lens, either a convex lens or 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 C_1 and C_2.

18.4 PRINCIPAL AXIS

An imaginary straight line passing through the two centres of curvature of a lens is called its principal axis.

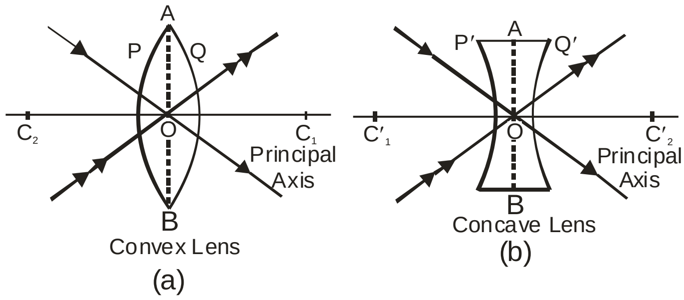


Figure 42

19. PRINCIPAL FOCUS AND FOCAL LENGTH OF A CONVEX LENS

19.1 PRINCIPAL FOCUS

Principal focus of a convex lens is a point on its principal axis to which light rays parallel to the principal axis converge after refraction by the lens. It is usually represented by the letter 'F'. However a convex lens has two spherical surfaces and hence it has two principal foci or two focal points which are usually denoted by the letters 'F_1' and 'F_2' and are known as the first principal focus (F_1) and the second principal focus (F_2). The two foci of a lens are at equal distances from the optical centre, one on either side of the lens.

Since all the light rays actually pass through the focus (or foci) of a convex lens, therefore, a convex lens has real focus (or foci).

(i) First Principal Focus (F_1) : The first principal focus (F_1) of a convex lens is the position of a point object on the principal axis of the lens, for which the image is formed at infinity. It is usually denoted by the letter 'F_1' as shown in the figure 43 (a)

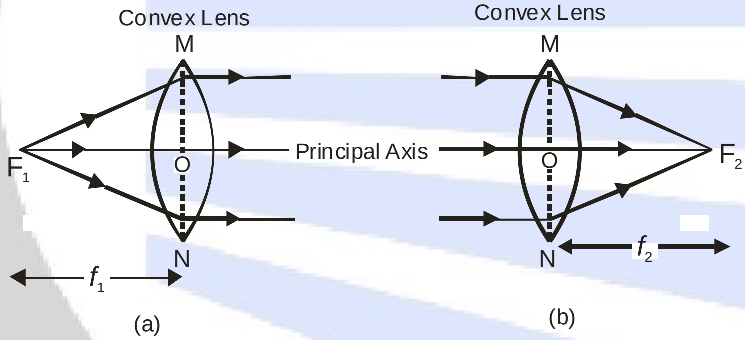


Figure 43

(ii) Second Principal Focus (F_2) : The second principal focus (F_2) of a convex lens is the position of an image point on the principal axis of the lens, for which the object is situated at infinity. It is usually denoted by the letter 'F_2' as shown in the figure 43 (b).

19.2 FOCAL LENGTH

The distance of the principal Focus (F_1 or F_2) from the optical centre 'O' of a lens is called its focal length. It is usually denoted by letter 'f'. Since a convex lens has two principal foci, so it has two focal lengths, known as first focal length (f_1) and the second focal length (f_2).

(i) First Focal length : The distance of the first principal focus of the lens from the optical centre 'O' of the lens is called first focal length of convex lens. It is represented by 'f_1'. i.e. $OF_1 = f_1$ (figure 43 a).

(ii) Second Focal length : The distance of second principal focus of the lens from the optical centre 'O' of the lens is called second focal length of convex lens. It is represented by 'f_2' i.e. $OF_2 = f_2$ (figure 43 b).

In a Convex lens $\boxed{f_1 = f_2}$

20. PRINCIPAL FOCUS AND FOCAL LENGTH OF A CONCAVE LENS

20.1 PRINCIPAL FOCUS

The principal focus of a concave lens is a point on its principal axis from which light rays parallel to the principal axis, appear to diverge after refraction by the lens. It is usually represented by the letter 'F'. However a concave lens has two spherical surfaces and hence it has two principal foci or two focal points which are usually denoted by the letters 'F_1' and 'F_2' and are known as the first principal focus (F_1) and the second principal focus 'F_2'. The two foci of a lens are at equal distances from the optical centre, one an either side of the lens.

Since the light rays do not actually pass through the focus (or foci) of a concave lens, therefore, a concave lens has a virtual focus.

(i) First Principal Focus (F_1) : The first principal focus (F_1) of a concave lens is the virtual position of a point object on the principal axis of the lens, for which the image formed by the concave lens is at infinity. It is usually denoted by the letter 'F_1' as shown in the figure 44 (a)

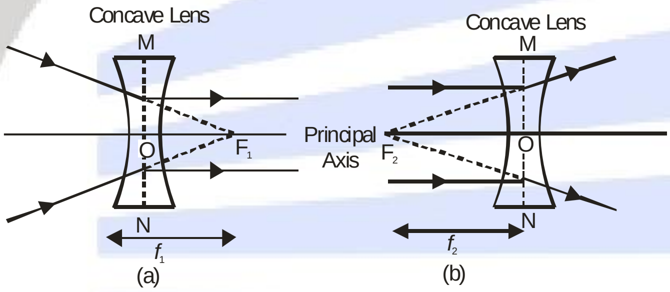


Figure 44

(ii) Second Principal Focus (F_2) : The second principal focus (F_2) of a concave lens is the position of image point on the principal axis of the lens, when the object is situated at infinity. It is generally denoted by the letter (F_2) as shown in the figure 44 (b).

20.2 FOCAL LENGTH

The distance of the principal focus (F_1 or F_2) from the optical centre 'O' of a lens is called its focal length. It is usually denoted by the letter 'f'. Since a concave lens has two principal foci, so it has two focal lengths, known as : first focal length (f_1) and second focal length (f_2).

(i) First Focal Length (f_1) : The distance of first principal focus (F_1) of the lens from optical centre 'O' of the lens is called first focal length of concave lens. It is represented by 'F_1'. i.e. $OF_1 = f_1$. [see figure 44 (a)].

(ii) Second Focal Length (F_2) : The distance of second principal focus (F_2) of the lens from the optical centre 'O' of the lens is called second focal length of concave lens. It is represented by 'f_2'. i.e. $OF_2 = f_2$ [see figure 44 (b)].

20.3 RULES FOR TRACING IMAGES FORMED BY A CONVEX LENS

When an object is placed in front of a convex lens, its image is formed at a point where at least two refracted light rays meet or appear to meet. To trace the position and nature of the image formed by a convex lens, the three rays of light are commonly used, out of which we take any two rays of light (starting from the object) whose paths, after refraction from the lens are known to us and are easy to draw. We may call them (the three rays) as rules for tracing images in convex lens. These are as follows :

(i) A ray of light which is parallel to the principal axis of a convex lens, after refraction through the lens passes through its focus on other side of the lens, as shown in the figure 45.

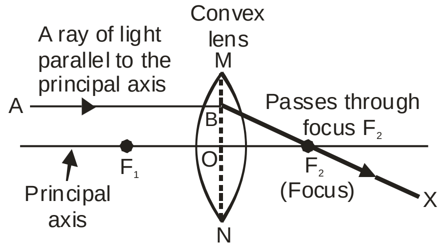


Figure 45

(ii) A ray of light passing through the optical centre 'O' of a lens goes straight (undeviated) after refraction through the lens, as shown in the figure 46.

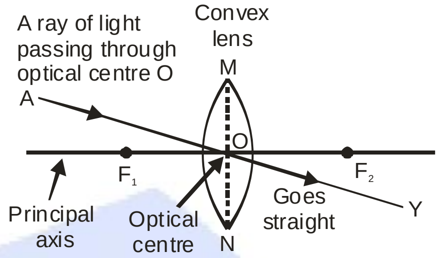


Figure 46

(iii) A ray of light passing through the focus of a convex lens becomes parallel to its principal axis after refraction through the lens as shown in the figure 47.

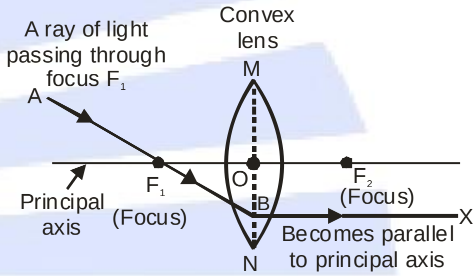


Figure 47

20.4 FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONVEX LENS IN DIFFERENT POSITIONS OF THE OBJECT

The type of image formed by a convex lens primarily depends on the position of the object in front of the lens. When an object is moved closer to the lens starting from infinity, the following six cases arise.

(i) When the object is at infinity : When the object is at infinity, the rays of light starting from the object on travelling such a large distance are assumed to become parallel to each other while falling on the lens. These parallel rays of light may fall on the lens in the following two ways:

All the rays become parallel to the principal axis of the lens as shown in the figure 48.

All the rays falling obliquely as shown in the figure 49.

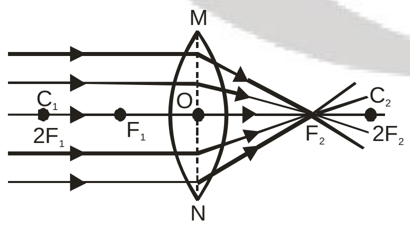


Figure 48

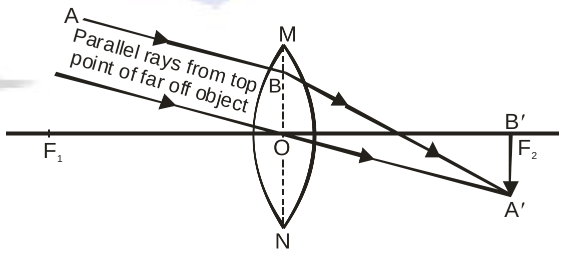


Figure 49

In the above two cases image is formed at the second principal focus (F_2) of the lens.

Therefore, we can say that when the object is at infinity, the image is

(a) formed at second focus (F_2) of the lens.

(b) real and inverted

(c) highly diminished, point sized.

(ii) When the object is placed beyond $2F_1$

When the object is placed beyond $2F_1$ of the convex lens (figure 50), the image is

(a) formed between F_2 and $2F_2$ (on other side of the lens)

(b) real and inverted

(c) smaller in size than the object i.e. diminished.

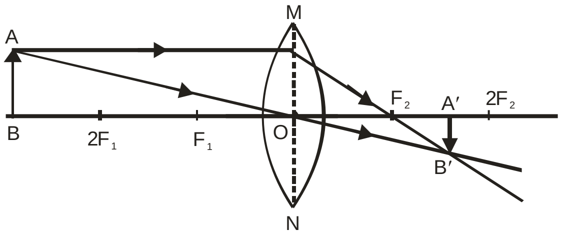


Figure 50

(iii) When the object is at $2F_1$: When the object is placed at $2F_1$ of a convex lens (figure 51), the image is

(a) formed at $2F_2$ (on the other side of the lens)

(b) real and inverted

(c) of the same size as the object.

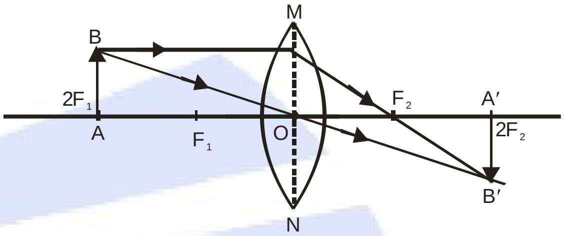


Figure 51

(iv) When the object is placed between F_1 and $2F_1$: When the object is placed between F_1 and $2F_1$ of a convex lens (figure 52), the image is formed

(a) Beyond $2F_2$ (on the other side of convex lens)

(b) Real and inverted

(c) Enlarged i.e. larger in size than the object

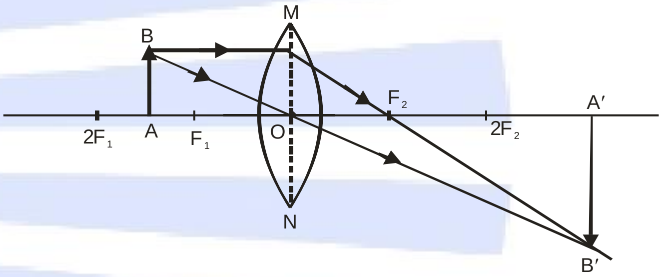


Figure 52

(v) When the object is at F_1 : When the object is at the first principal focus F_1 of a convex lens (figure 53), the image is formed

(a) At infinity (on the other side of the lens)

(b) Real and inverted

(c) Highly enlarged, magnified

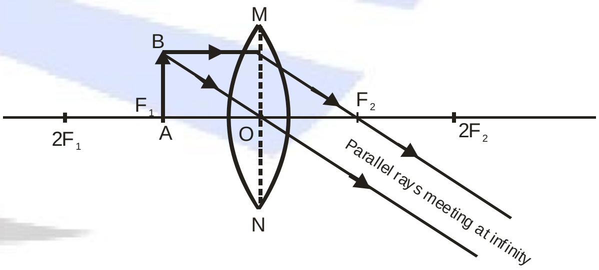


Figure 53

(vi) When the object is held between focus F_1 and optical centre O of the convex lens

When the object is placed between focus F_1 and optical centre 'O' of the convex lens (figure 54), the image is formed.

(a) Beyond F_1 (on the same side of the lens) as the object is
(b) Virtual and erect
(c) Enlarged, magnified i.e. larger in size than the object

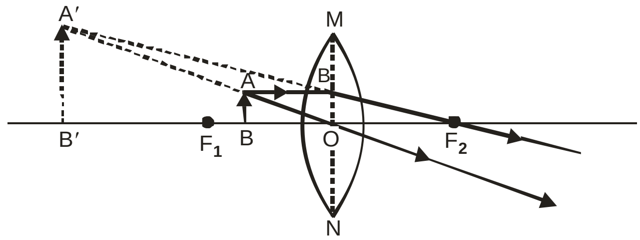


Figure 54

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

Position of the Object	Position of the image	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

20.5 HOW TO FIND OUT THE APPROXIMATE FOCAL LENGTH OF A CONVEX LENS

To find out the approximate focal length of a convex lens, focus a distant object (at infinity) on a screen by using a convex lens whose focal length is to be determined. The sharp and inverted image of this object will be formed at the focus of the convex lens. The distance of the image so formed from the convex lens is equal to the focal length of convex lens. Measure this distance with the help of a scale. It will give us the approximate focal length of the convex lens.

20.6 RULES FOR TRACING IMAGES FORMED BY CONCAVE LENS

When an object is placed in front of a concave lens, its image is formed at a point where at least two refracted light rays appear to meet. To trace the position and nature of the image formed by a concave lens, the three rays of light are commonly used, out of which, we take any two rays of light (starting from the object) whose paths, after refraction from the lens are known to us and are easy to draw. We may call them (the three rays) as rules for tracing images in concave lens. These are as follows :

(i) A ray of light which is parallel to the principal axis of a concave lens, appears to be coming from its focus after refraction through the lens as shown in the figure 55.

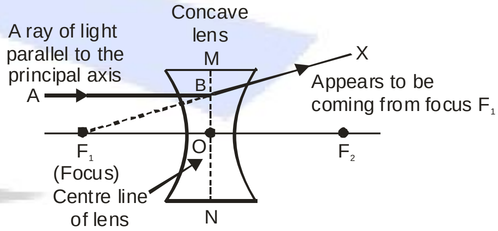


Figure 55

(ii) A ray of light passing through the optical centre 'O' of a concave lens goes straight (undeviated) after refraction through the lens as shown in the figure 56.

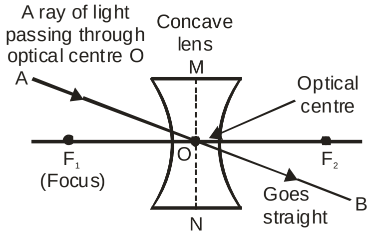


Figure 56

(iii) A ray of light appearing to pass through the focus of a concave lens, becomes parallel to its principal axis after refraction through the lens as shown in the figure 57.

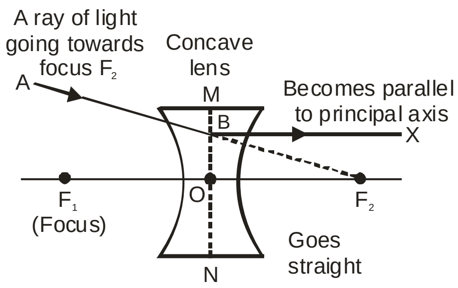


Figure 57

20.7 FORMATION OF DIFFERENT TYPES OF IMAGES BY A CONCAVE LENS IN DIFFERENT POSITION OF THE OBJECT

The type of image formed by a concave lens primarily depends upon the position of the object in front of the lens. When the object is moved closer to the lens, starting from infinity, the following two cases arise.

(i) When the object is at infinity: When the object is at infinity all the incident rays of light become parallel to the principal axis of the concave lens and appears to be coming from its focus after refraction through the lens (Figure 58). Hence the image is formed.
   (a) At focus F_1 (on the same side of the object)
   (b) Virtual and erect
   (c) Highly diminished, point sized

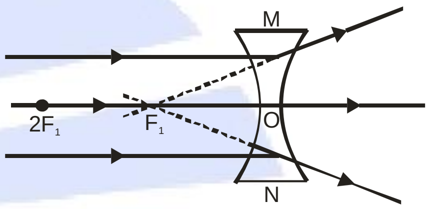


Figure 58

(ii) When the object is placed between infinity and optical centre 'O' of the concave lens: When the object is placed anywhere between the infinity and the optical centre 'O' of the concave lens (figure 59), the image is formed.
   (a) Between focus (F_1) and optical centre 'O' (on the same side of the object)
   (b) Virtual and erect
   (c) Diminished (smaller than the object).

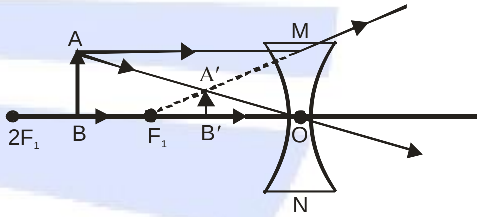


Figure 59

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

Position of the Object	Position of the image	Size of the image	Name 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

20.8 TO DISTINGUISH BETWEEN A CONVEX LENS AND A CONCAVE LENS WITHOUT TOUCHING THEM

To distinguish between a convex lens and a concave lens without touching them keep the two lenses close to the page of a book and look for image of the writing on the page through the lens. If the writing

(letters) of the book appears enlarged, the lens is convex, and if the writing (letters) appears diminished, then it is a concave lens.
This is because, when an object is within the focus of a convex lens, it produces an enlarged image, whereas a concave lens produces a diminished image for all positions of the object.

21. SIGN CONVENTION FOR REFRACTION BY SPHERICAL LENSES

The New Cartesian Sign Convention is used for measuring the various distances in the ray-diagrams of spherical lenses (convex as well as concave spherical lenses)
According to the New Cartesian Convention (figure 60).

(i) The optical centre 'O' of the lens is taken as the origin and the principal axis of the lens is taken as the x-axis of the co-ordinate system.
(ii) The object is always placed to the left of the lens i.e. the light (incident rays) from the object falls on the lens from the left hand side.
(iii) All the distances parallel to the principal axis of the spherical lenses are measured from the optical centre 'O' of the lenses.
(iv) All the distances measured to the right of the origin (along +ve x-axis) are taken as positive.
(v) All the distances measured to the left of the origin (along –ve x-axis) are taken as negative.
(vi) The distances (heights) measured upwards (i.e. above the x-axis) and perpendicular to the principal axis of the lens are taken as positive.
(vii) The distances (heights) measured downwards (i.e. below the x-axis) and perpendicular to the principal axis of the lens are taken as negative.
The following figure illustrates all the points of the New Cartesian.
Sign Convention stated above

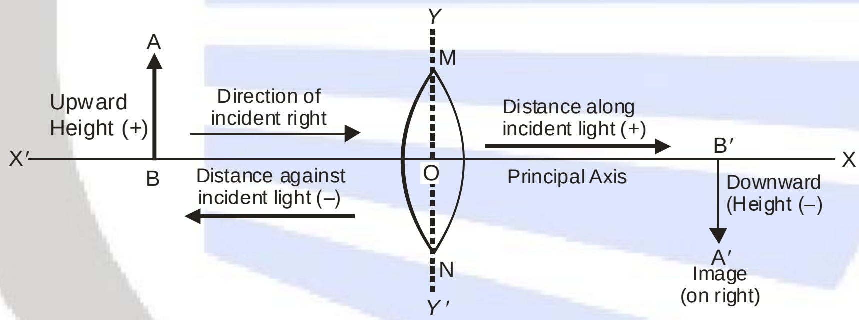


Figure 60

22. LENS FORMULA

The relationship between the image distance (*v*), object distance (*u*) and focal length (*f*) of a spherical lens is known as the lens formula. The lens formula can be written as :

$$\frac{1}{\text{Image distance}} - \frac{1}{\text{Object distance}} = \frac{1}{\text{focal length}}$$

Symbolically, $\boxed{\frac{1}{v} - \frac{1}{u} = \frac{1}{f}}$ Where the symbols have their usual meaning.

23. LINEAR MAGNIFICATION PRODUCED BY LENSES

The linear magnification produced by a spherical lens (convex or concave) is defined as the ratio of the height of the image (*h*′) to the height of the object (*h*). It is a pure ratio and has no units. It is denoted by the letter '*m*' and is given by,

$$\text{Linear magnification (m)} = \frac{\text{height of the image } (h')}{\text{height of the object } (h)}$$

or $m = \dfrac{h'}{h}$

The linear magnification (m) is also related to the object distance (u) and image distance (v).

It can be expressed as: $m = \dfrac{v}{u}$.

$\Rightarrow$ Linear magnification, $\boxed{\boldsymbol{m = \dfrac{h'}{h} = \dfrac{v}{u}}}$

This shows that linear magnification produced by a lens is also equal to the ratio of the image distance (v) to the object distance (u).

23.1 IN CASE OF A CONVEX LENS

(i) For real and inverted image : According to the New Cartesian Sign Convention, for real and inverted images formed by a convex lens,

Object height (h) is always +ve

Image height (h') is always –ve

$\therefore$ Linear magnification, $m = \dfrac{h'}{h}$

or $m = \dfrac{-ve}{+ve}$ or $m = -ve$

(ii) For virtual and erect image : According to the New Cartesian Sign Convention, for the virtual and erect images formed by a convex lens,

Object height (h) is always +ve

Image height (h') is always +ve

$\therefore$ Linear magnification, $m = \dfrac{h'}{h}$

or $m = \dfrac{+ve}{+ve}$

or $m = +ve$

23.2 IN CASE OF A CONCAVE LENS

A concave lens always form a virtual and erect image.

(i) For virtual and erect image : According to the new Cartesian sign convention, for the virtual and erect images formed by a concave lens,

Object height (h) is always +ve

Image height (h') is always +ve

$\therefore$ Linear magnification, $m = \dfrac{h'}{h}$

or $m = \dfrac{+ve}{+ve}$

or $\boldsymbol{m = +ve}$

23.3 FOR SPHERICAL LENSES

(i) If linear magnification, $m > 1$, then the image is enlarged *i.e.* bigger than the object.
(ii) If linear magnification, $m = 1$, then the image is of the same size as the object.
(iii) If linear magnification, $m < 1$ the image is diminished i.e. the image is smaller than the object.
(iv) If the magnification 'm' is +ve the image is virtual and erect. And if the magnification 'm' is –ve the image will be real and inverted.

24. SOME IMPORTANT CONCLUSIONS

On the basis of the New Cartesian Sign Convention discussed above, we can draw the following conclusions for the spherical lenses (convex as well as concave lenses).

24.1 IN CASE OF CONVEX LENS

(i) For real and inverted image

Focal length (f) = +ve
Object distance (u) = –ve
Object height (h) = +ve
Image distance (v) = +ve
Image height (h') = –ve
Magnification (m) = –ve

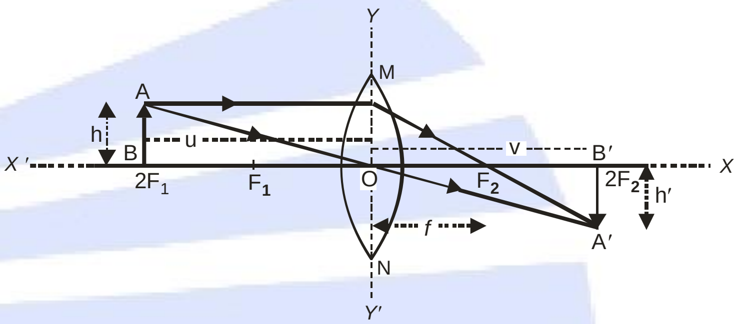


Figure 61

(ii) For virtual and erect image

Focal length (f) = +ve
Object distance (u) = –ve
Object height (h) = +ve
Image distance (v) = –ve
Image height (h') = +ve
Magnification (m) = +ve

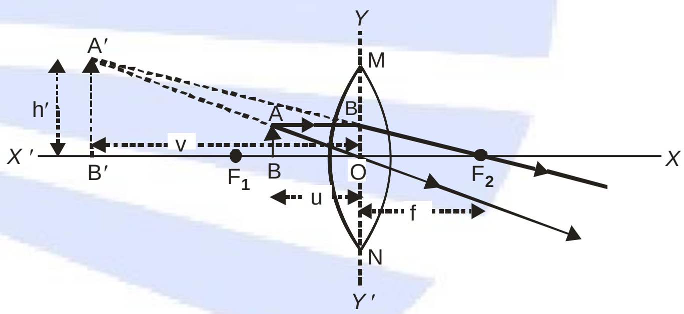


Figure 62

24.2 IN CASE OF CONCAVE LENS

Since a concave lens always form virtual and erect image therefore

For virtual and erect image

Focal length (f) = –ve
Object distance (u) = –ve
Object height (h) = +ve
Image distance (v) = –ve
Image height (h') = +ve
Magnification (m) = +ve

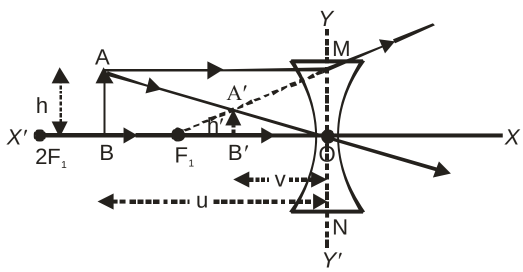


Figure 63

25. POWER OF LENS

The power of a lens is the degree of convergence or divergence of light rays achieved by a lens. The power of a lens is defined as the reciprocal of its focal length in meters. It is denoted by the letter P.

i.e. $\text{Power of a lens} = \dfrac{1}{\text{focal length of the lens (in meters)}}$

or $$\boxed{P = \frac{1}{f\ \text{(in meters)}}}$$

where P = power of a lens
and f = focal length of the lens in meters.
The S.I. unit of power is dioptre. It is denoted by the letter 'D'.
One dioptre is the power of a lens whose focal length is 1 metre.
The power of a lens is measured by an instrument called dioptre meter.
A convex lens has positive focal length so the power of a convex lens is positive.
A concave lens has a negative focal length, so the power of a concave lens is negative.

Since the power of a lens is inversely proportional to its focal length $\left(i.e.\ P = \dfrac{1}{f\,\text{(in meters)}}\right.$ therefore, a lens of short focal length has more power than a lens of long focal length (i.e. shorter the focal length, more is the power and vice-versa).

Power of a combination of lenses

It a number of lenses are placed in close contact, then the power of the combination of lenses is equal to the algebraic sum of the powers of individual lens.

i.e. $$\boxed{P = p_1 + p_2 + p_3 + \ \ldots\ldots\ldots}$$

Where P = power of combination of lenses.
p_1, p_2, p_3, ……………… = Powers of individual lens placed close to each other.