Refraction & Reflection Light

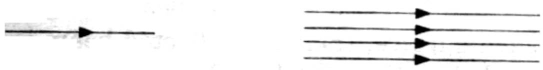
Physics - X CBSE

Reflection of Light

BEAUTY OF REFLECTION AND REFRACTION OF LIGHT

Light is a from of invisible energy which produces the sensation of sight. We can see the objects in the presence of light, although light itself is invisible. Same object like the sun, a burning candle, an electric bulb etc. emit light. The objects which emit light are known as sources of light or luminous objects. When light emitted by a source of light falls on an object like a chair or a table or a book some of the incident light is returned back or reflected by the object enters our eyes. Hence, the object seen by us. Thus, light enables us to see the object which do not emit their own light (known as non – luminous object). Any object which reflects the light falling on it is visible to us. On the other hand, if an object neither emits light nor reflects the light falling on it, then that object is not visible to us. For example we are not able to see anything in a dark room.

When sun light falls on a solid object like a building, a stone or a black board etc. a shadow is formed behind the solid object (or an opaque object). This shows that light travels in a straight line. Light traveling in a straight line is represented by rays of light. A ray of light is a path followed by light energy in a transparent medium. A ray of light is represented by a straight line having the sign of an arrow on it in the direction of propagation of light. a group of parallel rays of light emitted by the source of light is called beam of light.



Using the ray picture of light, we shall discuss the phenomena like reflection of light, refraction of light (i.e., bending of light when it goes from one medium to another medium) and the formation of images by spherical mirrors and lens. ATION

When light is treated in terms of rays of light, then it is known as ray optics. Ray optics is valid only if the size of the opaque object in the path of light is much bigger than t he wavelength of light. However, ray picture of light is invalide if the size of the opaque object in the path of light is very small as compared to the wavelength of light. In such cases, the light bends around the corners of the opaque object. The phenomenon of bending light around the corners of the opaque objects is known as diffraction of light.

Diffraction of light can be explained by considering light as a wave. However, the details of diffraction of light is beyond the scope of the book. Later on it was observed that light behaves as particles, when interacts with matter. Finally, it was established that light has dual nature. i.e., it behave as a wave as well stream of particles.

REFLECTION OF LIGHT

If light falling on a surface bounces back to the same medium then this return of light is called reflection of light. The reflection of light from a surface is similar to the bouncing back of a rubber ball after striking a wall.

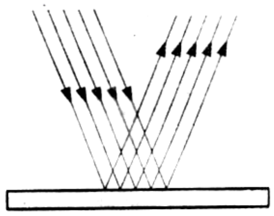
Definition. The process of returning (or bouncing back) the light to the same medium after striking a surface is called reflection of light.

A surface which reflects the light is known as a reflector. The polished metal surfaces are good reflectors. However, silver metal is the best reflector. Even water surfaces, waxed surfaces and glazed tiles act as good reflectors. The most commonly used reflector is a looking glass or a plane mirror.

ADDITIONAL INFORMATION

Reflectance : the ratio of the amount light reflected form a surface to the amount of light falling on the surface is called reflectance.

$$\text{i.e,} \qquad \text{Reflectance} = \frac{\text{Amount of light reflected from a surface}}{\text{Amount of light falling on the surface}}$$



Reflectance of a surface is expressed as a percentage

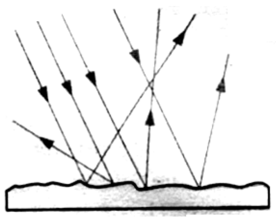
Reflectance of few surfaces

Surface made up of	Reflectance
Silver	95 %
Coal	4 %

TYPES OF REFLECTION

Regular reflection. When a parallel beam of light falls on a smooth and highly polished surface, then the reflected beam is also parallel and directed in fixed directed. Such reflection of light is called regular reflection. This type of reflection of light.

The glare of regular reflected light beam is dazzling. Search lights and automobile head lights are the example of regular reflection light.

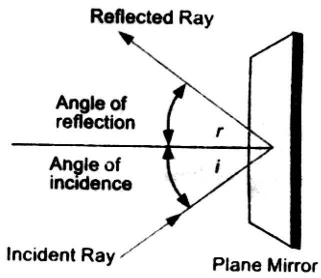


Diffused reflection. When a parallel beam of light falls on a rough surface, then the reflected light is not parallel but spreads over a wide area, such reflection of light is called irregular or diffused reflection. This type of reflection of light.

Light reflected from the wooden table, newspaper etc. is the example of diffused reflection of light.

(i) We can read a newspaper or the page of a book due to the diffused reflection of light from it.

(ii) We cannot see the object if light falling on it suffers regular reflection. This is because the glare of regular reflected flight beam is dazzling and our eyes close down automatically when this beam falls on our eyes.



RELECTION

The reflection of light from a surface obeys certain laws called laws of reflection. They are :

(i) Incident angle is equal to the reflected angle, i.e., $\angle i = \angle r$.

(ii) Incident ray, reflected ray and normal to the reflecting surface lie in the same plane.

1. A ray of light striking the surface normally retraces its path.

Explanation. When a ay light strike a surface normally then angle of incidence is zero i.e. $\angle i = 0$. According to the law of reflection, $\angle r = \angle i = 0$ i.e., the reflected ray is also perpendicular to the surface. Thus, an incident ray normal to the surface (i.e. perpendicular to the surface) retraces its path.

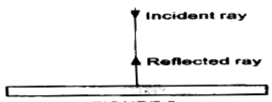
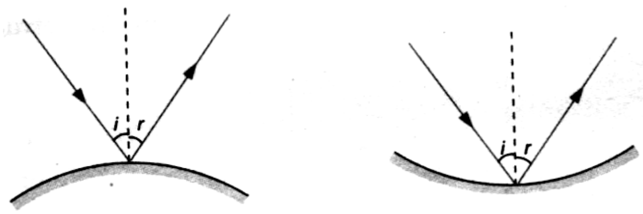


FIGURE 5

2. Laws of reflected are obeyed when light is reflected from the spherical or curved surface.



IMAGE

When we stand in front of a looking mirror, we see our face. The picture of our face in the mirror is known as the image of our face. Image are of two types :

(i) Real image and (ii) Virtual image.

(i) Real Image. When a beam of light from an object actually meets at a point after reflection, then the image of the object formed at that point is known as real image.

A real image can be obtained on a screen.

(ii) Virtual image. When a beam of light from an object does not meet at a point but appears to diverge from it, then the image of the object at that point is known as virtual image.

A virtual image can not be obtained on a screen.

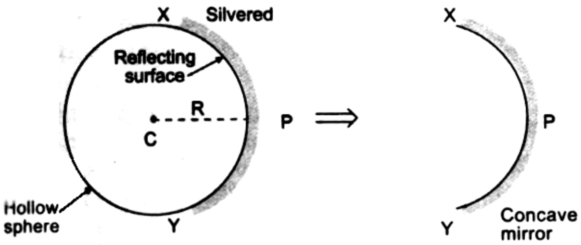
Difference between Real and Virtual Image

S. No.	Real Image`	Virtual Image
1.	When rays of light after reflection meet at a point, real image formed.	When rays of light after reflection do not meet at a point but appears to meet at a point, virtual image is formed
2.	Real image can be obtained on a screen	Virtual image cannot be obtained on a screen.
3.	Real image is formed in front of a mirror.	Virtual image is formed behind the mirror.
4.	Real image is always inverted	Virtual image is always erect (i.e., upright).

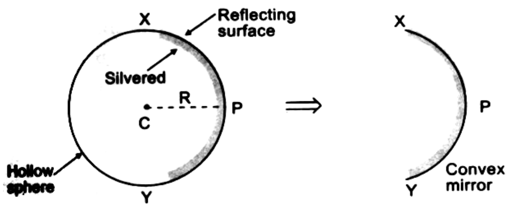
A spherical mirror is the reflecting part of a spherical surface. Type of spherical mirrors. There are two of spherical mirrors.

(i) Concave mirror and (ii) Convex mirror.

(i) **Concave mirror.** Concave mirror is the part of a hollow sphere whose outer surface (i.e., bulging surface) whose outer surface (i.e. bulging surface) is silvered and the inner surface (i.e. depressed surface) acts as reflecting surface.

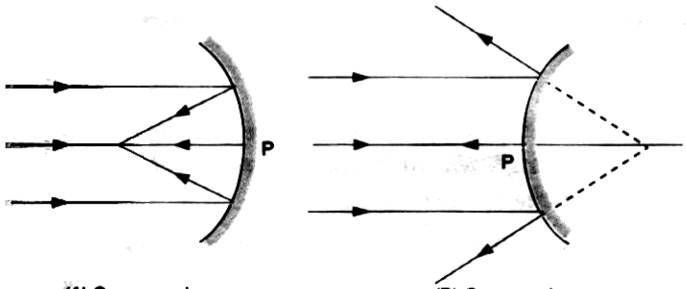


(ii) **Convex mirror.** Convex mirror is the part of a hollow sphere whose outer surface (i.e., bulging surface) acts as reflecting surface and the inner surface (i.e., depressed surface) is silvered.



Convergence of light. If a parallel beam of light after reflection meets at a point, then the process is known as convergence of light. The reflected beam is known as convergent beam of light. Convergence of light by a concave mirror. Since concave mirror converges a parallel beam of light, so concave mirror is also known as convergent mirror.

Divergence of light. If a parallel beam of light after reflection diverges (i.e., spreads out) and appears to come from a point, then the process is known as divergence of light. The reflected beam is known as divergent beam of light. Divergence of light by a convex mirror is shown in figure 9(B). Since convex mirror diverges a parallel beam of light, so convex mirror is also known as divergent mirror.

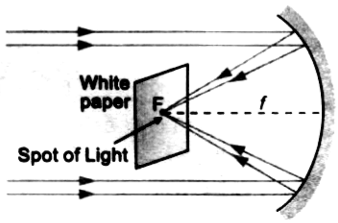


(A) Concave mirror *(B) Convex mirror*

1. Centre of curvature. The centre of a hollow sphere of which the spherical mirror forms a part is called centre of curvature. It is denoted by C.

2. Radius of curvature. The radius of a hollow sphere of which the spherical mirror forms a part is called radius of curvature. It is denoted by R.

3. Pole. The mid point of a spherical mirror is called its pole. It is denoted by P.

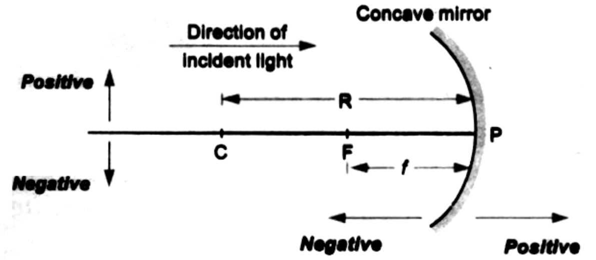


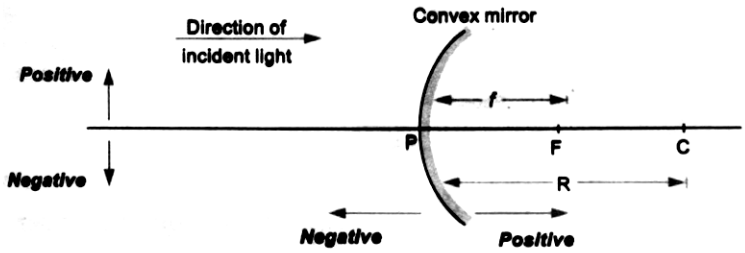
4. Aperture. The part of a spherical mirror exposed to the incident light is called the aperture of the spherical mirror. In other words, diameter of a spherical mirror is known as its aperture. The apertures of a concave mirror are represented and a convex mirror are represented by XY.

5. Principal axis. A line joining the centre of curvature (C) and pole (P) of a spherical mirror and extended on either side is called principal axis.

6. Principal focus. A point on the principal axis of a spherical mirror where the rays of light parallel to the principal axis meet of appear to meet after reflection from the spherical mirror is called principal focus. It is denoted by F.

In case of a concave mirror, the rays of light parallel to the principal axis after reflection actually meet (or diverge from) the principal axis at F. So, principal focus of a convex mirror is virtual.





7. Focal plane. A plane normal or perpendicular to the principal axis and passing through the principal focus (F) of a spherical mirror is called focal plane spherical mirror.

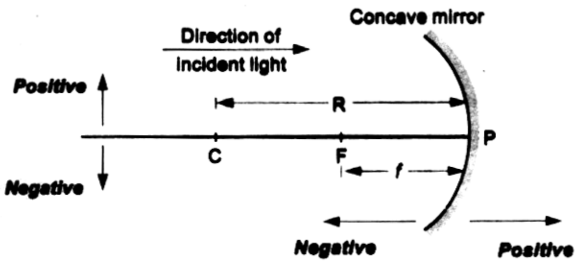
8. Focal length. The distance between the pole (P) and principal focus (F) of a spherical mirror is called is focal length of the mirror. It is denoted by f. Focal length of a mirror is given by f= PF.

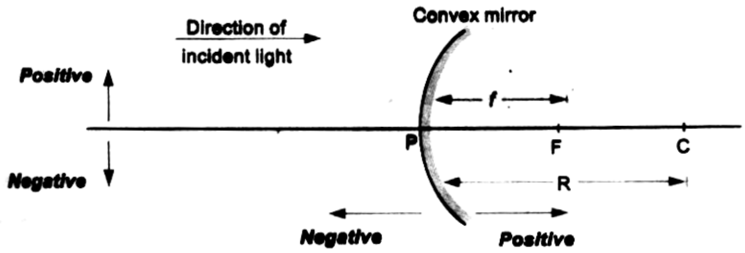
1.08. Sign Conventions For Reflection By Spherical Mirrors

While studying the reflection of light by spherical mirrors and formation of image by spherical mirrors, we use some sign conventions as given below :

1. All distances are measured from the pole of a spherical mirror.
2. Distance measured in the direction of incident light are taken as positive, while distances measured in a direction opposite to the direction of the incident light are taken as negative.
3. The upward distances perpendicular to the principal axis are taken as positive, while the downward distances perpendicular to the principal axis are taken as negative.

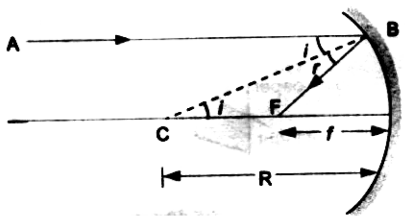
For convenience, object is assumed to be placed on the left side of a mirror. Hence, the distance of an object form the pole of a spherical mirror is taken as negative.





IMPORTANT INFORMATION

Focal length and radius of curvature of a concave mirror are taken as negative.



Focal length and radius of curvature of a convex mirror are taken as positive.

Consider a concave mirror of small aperture. Let AB be the incident ray parallel to the principal axis which falls on the which falls on the concave mirror at point B. CB is normal to the concave mirror at B. After reflection the ray passes through the principal focus F on the principal axis.

According to law of reflection

$\angle ABC = \angle FBC$ $\quad$ $(i.e., \angle i = \angle r)$

But $\angle ABC = \angle BCF$ $\quad$ (alternate angle)

$\therefore$ $\angle FBC = \angle BCF$

Hence $BF = FC$ $\quad$ (sides of isosceles BCF)

Since point B is very close to P as the aperture of the concave mirror is small, so instead of B, we can write P i.e., BF = PF

Therefore, eqn (1) becomes

$PF = FC$

or $PF = PC - PF$ $\quad$ $(\because FC = PC - PF)$

or $2PF = PC$

$f = \dfrac{R}{2}$ is also true for both the concave mirror and convex mirror.

According to sign conventions, $PF = -f$ (focal length of concave mirror)

and $PC = -R$ (radius of curvature of concave mirror)

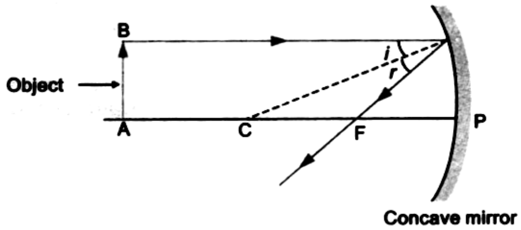
Hence eqn. (2) becomes

$$-2f = -R \text{ or } f = \frac{R}{2}$$

Thus, focal length of a concave mirror is equal to half of its radius of curvature.

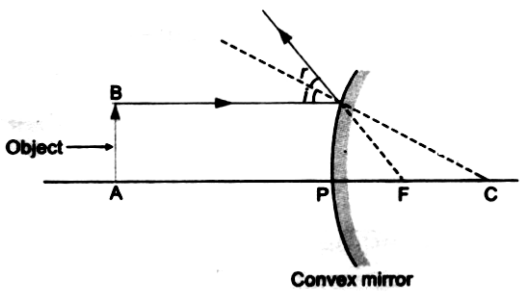
Radius of currvature of a plane mirror $= \infty$ (infinite)

Focal length of a plane mirror $= \infty$



REPRESENTATION OF IMAGES FORMED BY SPHERICAL MIRRORS USING RAY DIAGRAMS (RULES FOR OBTAINING IMAGES FORMED BY SPHERICAL MIRRORS)

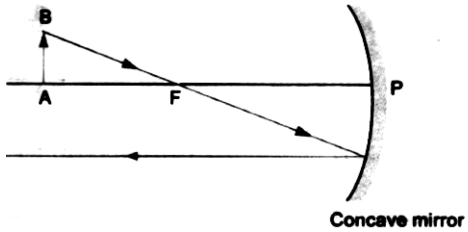
To find the position and nature of the image formed by a spherical mirror (concave or convex), we make a ray diagram. In



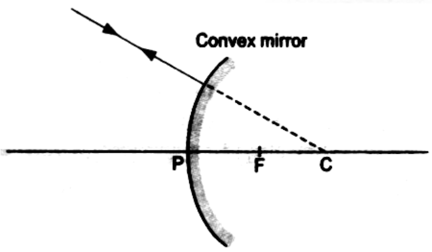
fact, large number of rays of light from an object falls on the reflecting surface of the mirror because each point on an object acts as a source of light. These rays are then reflected by the mirror and intersect or appear to intersect to form the image of the object. But for our convenience, we consider only the two rays out of the following four rays while making a ray diagram for locating the image of an object.

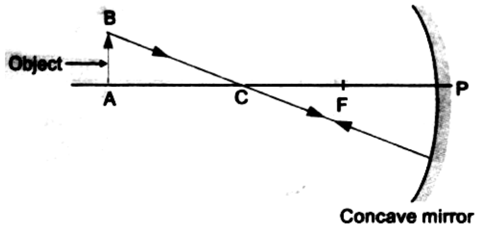
1. Incident ray parallel to the principal axis. Any incident ray parallel to the principal axis passes or appears to pass through the principal focus (F) of a spherical mirror after reflection.

2. Incident ray passing through the focus of a spherical mirror.
Any incident ray passing through the focus of a spherical mirror travels parallel to the principal axis after reflection.

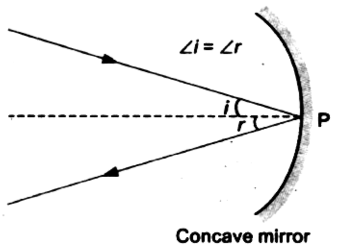


3. Incident ray passing through the centre of curvature of a spherical mirror. Any incident ray passing through the centre of curvature (C) of a spherical mirror retraces its path after reflection.
When a ray passes through the centre of curvature and falls on the mirror, then $\angle i = 0.$ According to the law of reflection, $\angle i = \angle r,$ so $\angle r$ must be zero. Hence, it retraces its path after reflection.





4. Incident ray traveling obliquely to the principal axis is reflected obliquely after striking a spherical mirror at its pole.



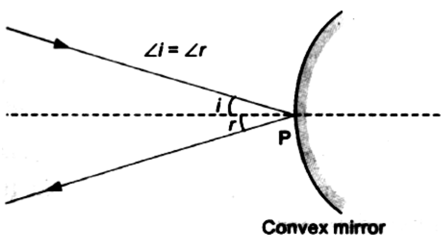
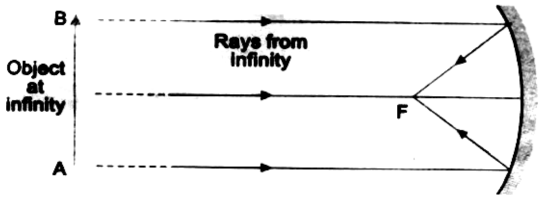


IMAGE FORMATION BY A CONCAVE MIRROR

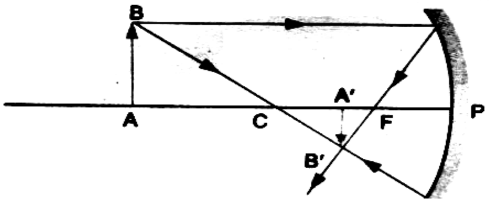
The position and nature of images formed by a concave mirror depend upon the position of the object placed in front of the concave mirror. Let us discuss the formation of image by a concave mirror when the object is at different positions.



1. When object is at infinity

Consider an object AB lying at infinity. The rays of light from infinity travel parallel to the principal axis. According to Rule 1, these each rays of light after reflection from a concave mirror intersect each other at the principal focus F of the concave mirror.

Thus, a point image of the object is formed at the principal focus of the concave mirror. Hence, the image formed is highly diminished. As the rays of light actually intersect each other at a point, so the image formed is real. A real image is inverted.

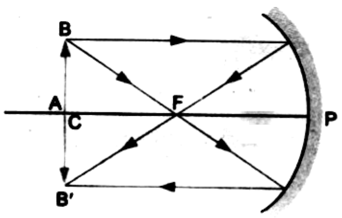


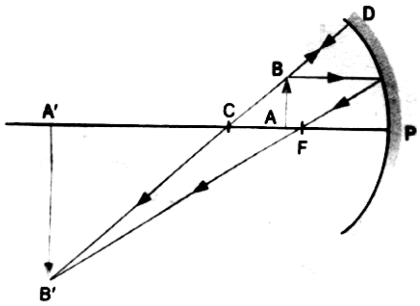
2. When object is beyond the centre of curvature of a concave mirror

Consider an object AB placed beyond the centre of curvature C of a concave mirror. A ray of light from point B of the object travels parallel to the principal axis. According to Rule 1. this ray after reflecting from the concave mirror passes through the principal focus of the mirror. Another ray of light starting from point B of the object passes through the centre of curvature C of the mirror and after reflecting from the concave mirror retraces its path (Rule 3). This reflecting ray intersects the first reflecting ray at point B'. Thus, the image A'B' is formed in between C and F.

The size of the image A'B' is less than the size of the object AB. Therefore, a diminished image A'B' is formed. This image is real and inverted.

3. When object is at the centre of curvature of a concave mirror





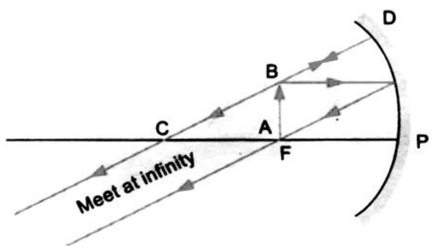
Consider an object AB placed at the centre of curvature C of a concave mirror. A ray of light from point B of the object travels parallel to the principal axis of the concave mirror. According to Rule 1, this ray of light after reflecting from the mirror passes through the focus of the mirror. Another ray of light from point B after passing through the focus F strikes the mirror. According to Rule 2, this ray of light after reflection travels parallel to the principal axis and intersect the first reflected ray at point B'. So the image A'B' is formed at the centre of curvature of the mirror.

The size of the image AV is same as that of the size of the object. The image is real and inverted.

4. When object is between the centre of curvature and the principal focus of a concave mirror

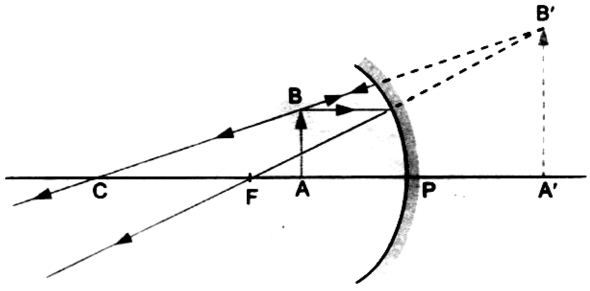
Consider an object AB placed between the centre of curvature C and the principal focus F of a concave mirror. A ray of light from point B of the object travels parallel to the principal axis (Rule 1). After reflecting from the mirror, this ray passes through the principal focus P of the mirror. Another ray of light from point B falls perpendicular to the surface of the mirror at point D. According to Rule 3, this ray of light retraces its path and after passing through the centre of curvature of the mirror, it intersects the first reflected ray at point B' as shown in figure 22. Thus, the image A'B' is formed beyond the centre of curvature of the mirror.

The size of the image A'B' is greater than the size of the object AB. Hence, magnified or enlarged image A'B' is formed. This image is real and inverted.



5. When object is at the focus of a concave mirror

Consider an object AB placed at the principal focus of a concave mirror. The rays of light from the object travel parallel to each other after reflecting from the mirror. These parallel reflected rays intersect each other at infinity. So the real and inverted image is formed at infinity. The size of the image is much greater than the size of the object. Thus, highly magnified image is obtained.



6. When object is between the pole and principal focus of the concave mirror

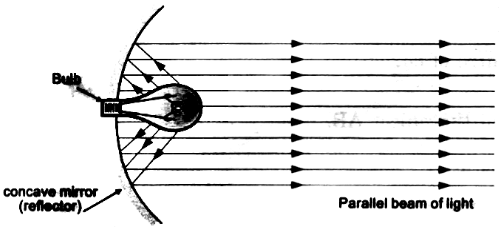
Consider an object AB, placed between the pole and the principal focus of the concave mirror. The rays of light from the object after reflection from the concave mirror appears to meet at point B' behind the mirror. Therefore, a virtual and erect image A'B' is formed behind the mirror. The size of the image is greater than the size of the object, so the virtual image formed is magnified.

As the object moves towards a concave mirror, the size of the image of the object increases.

The position of the object, the position of the image, nature of the image and the relative size of the image formed by a concave mirror are given in table 1.

Image formation by a concave mirror

S. No.	Position of object	Position of Image	Nature of Image	Relative size of Image
1.	Infinity	At principal focus (F).	Real and inverted.	Highly diminished
2.	Between F and 2F (or beyond C)	Between focus (F) and centre of curvature (C).	Real and inverted.	Diminished
3.	Centre of curvature (C)	Centre of curvature (C).	Real and inverted.	Same size as that of an object
4.	Between centre of curvature (C) and focus (F)	Between F and 2F or beyond C.	Real and inverted.	Magnified
5.	At the focus (F)	At infinity.	Real and inverted.	Highly magnified
6.	Between pole (P) and focus (F)	Behind the concave mirror.	Real and inverted.	Magnified

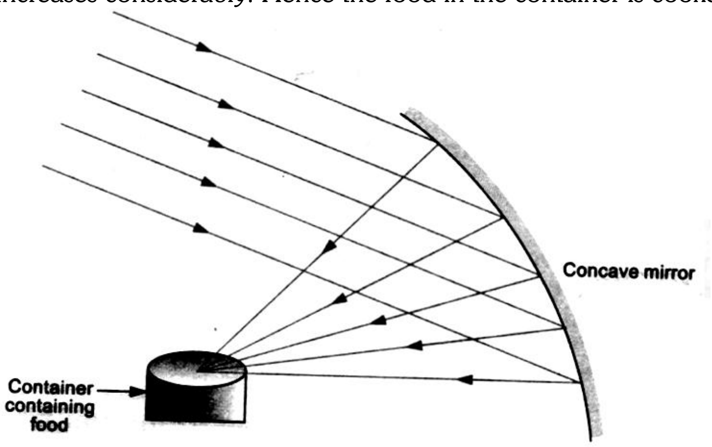


USES OF A CONCAVE MIRROR

(i) Reflector. Concave mirrors are used in motor head lights, search lights and torches etc. to produce an intense parallel beam of light. A bulb is placed at the focus of a concave mirror. The beam of light from the bulb after reflection from the concave mirror goes as a parallel beam.

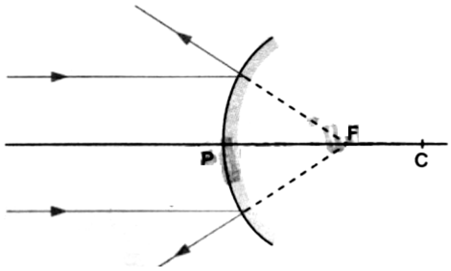
(ii) Shaving and make up mirror. When an object is placed close to a concave mirror (i.e., between the parallel beam of light pole and focus of the concave mirror), an erect and enlarged (large in size) image is formed. Because of this fact, concave mirror is used by men to see their enlarged faces while shaving. Similarly, a lady can see her face better with the help of a concave mirror while doing mate up.

(iii) In solar cookers When a parallel beam of sun light falls on a concave mirror, this beam is brought to the focus of the concave mirror. As a result of this, the temperature of an object (say a container containing un—cooked food) placed at this focus increases considerably. Hence the food in the container is cooked.



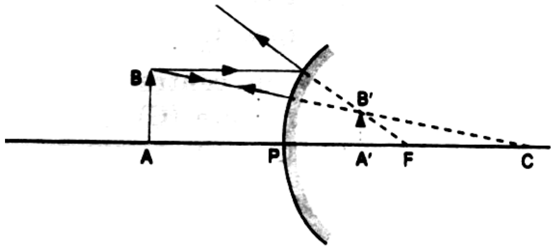
(iii) In hospital. Concave mirrors are used by dentists and ENT specialists to focus light on teeth, nose, eye and throat to examine these organs.

IMAGE FORMATION BY A CONVEX MIRROR



Convex mirror always produces a virtual image irrespective of the position of object in front of it. Let us discuss the formation of image by a convex mirror when the object lies at different positions.

1. Position of object (AB). between infinity and pole of the convex mirror. Formation of image (A'B').
Position of Image. Between pole and focus, behind the convex mirror.
Size of Image. Diminished. Nature of image. Erect and virtual.



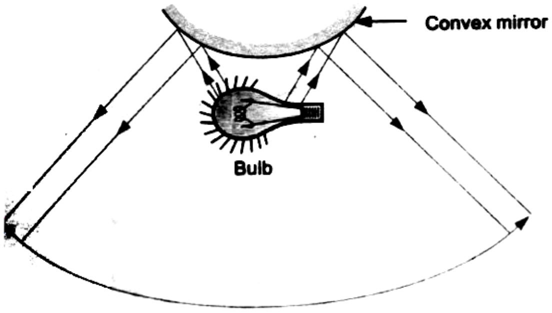
2. Position of object. At infinity.
Formation of image.
Size of image. At the focus (F) and behind the mirror.
Nature of image. Highly diminished.
Nature of image. Erect and virtual.

1. Concave mirror produces real as well as virtual image depending upon the position of the object.
2. A concave mirror produces virtual image when object lies between the pole (P) and focus (F) of the mirror.
3. A concave mirror always produces virtual and diminished image irrespective of the position of the object in front of the mirror.
4. A real image is inverted while virtual image is erect.


DRIVER'S MIRROR

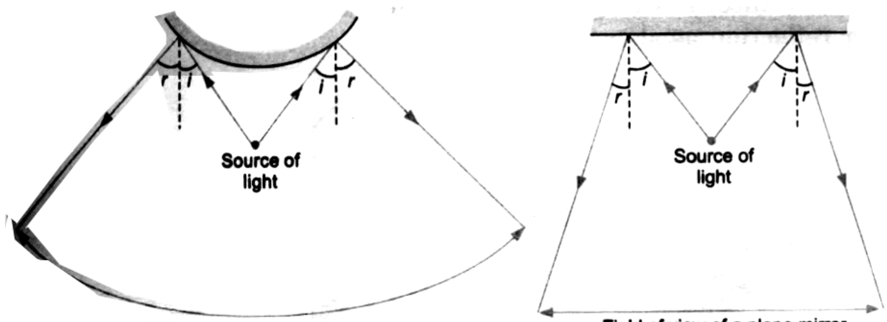
USES OF A CONVEX MIRROR

(i) Rear view or driver's mirror. Convex mirror is used as a rear view mirror because this mirror produces an erect and diminished image of an object behind the vehicle. Since the image of the object formed is small in size, so the field of view is increased. It means, the driver of a vehicle can see the traffic over large area behind his vehicle. This mirror is also known as driver's mirror
(ii) In street lights. Convex mirror is used in street lights to diverge light over a large area (Figure 29).



Area receiving light

✓ The field of view of a plane mirror is small as compared to the field of view of a convex mirror as shown is figure 30.



Field of view of a convex mirror
Field of view of a plane mirror

MIRROR FORMULA

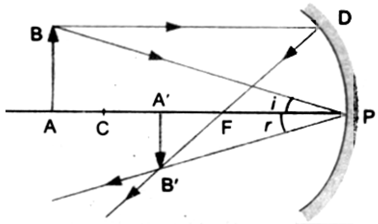
Mirror Formula
$\frac{1}{u}+\frac{1}{\upsilon}=\frac{1}{f}$s

The distance of the position of an object on the principal axis from the pole of a spherical mirror is known as object distance. It is denoted by u .
The distance of the position of the image of an object on the principal axis from the pole of a spherical mirror is known as image distance. It is denoted by υ .
The relation between u,υ and focal length (f) of a spherical mirror is known as mirror formula.0

It is given by $\frac{1}{u}+\frac{1}{\upsilon}=\frac{1}{f}$

Note : (i) Mirror formula holds good for both concave and convex mirrors.
(ii) While solving Numerical Problems, sign conventions are used when values of u, v and f substituted.

MAGNIFICATION (OR LINEAR MAGNIFICATION)



Linear Magnification produced by a mirror is defined as the ratio of the size (or height) of the image to the size (or height) of the object. It is denoted by m.
If h' = Size (or height) of the image produced by the mirror
and h = Size (or height) of the object.

Then, linear magnification, $m=\frac{h'}{h}$

Linear magnification has no unit.

Linear magnification produced by spherical mirror (convex or concave)
$m=\frac{h'}{h}=\frac{-\upsilon}{u}$

MAGNIFICATION PRODUCED BY A CONCAVE MIRROR

Let AB be an object placed perpendicular to the principal axis in front of a concave mirror. A ray BD parallel to the principal axis passes through the focus (F) after reflection from the mirror (Figure 31). These two reflected rays intersect each other at B'. So A'B' is the real, inverted and diminished image of the object AB.

$\Delta's$ APB and A'PB' are similar.

$\therefore \frac{A'B'}{AB}=\frac{PA'}{PA}$

Applying sign conventions, we have
A'B' = - h' (Size of image)
AB = + h (Size of object)
PA' = — υ (Distance of image from the pole)
and $PA=-\upsilon$ (Distance of object from the pole)

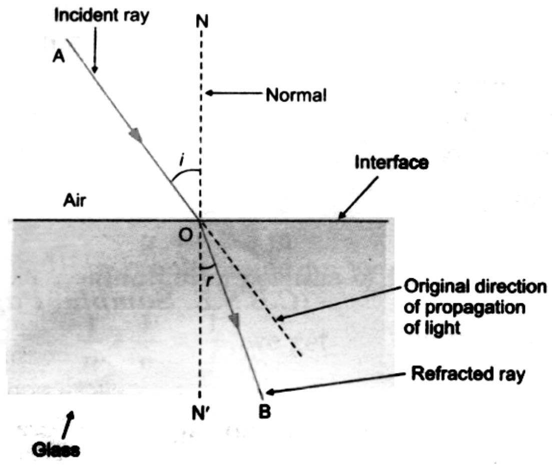
Hence eqn. (1) becomes $\frac{-h'}{h}=\frac{-\upsilon}{-u} or \frac{h'}{h}=-\frac{\upsilon}{u}$

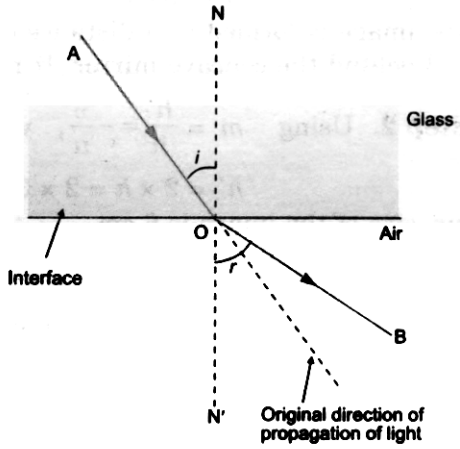
Since $\frac{h'}{h}=m$ $\therefore m=\frac{h'}{h}=-\frac{\upsilon}{u}$

- ✓ positive magnification means both the object and image are upright (i.e., erect). Since virtual image is always erect, so positive magnification indicates that the image formed by a spherical mirror is virtual.
- ✓ Negative magnification means object and image have different orientations. If object is upright (i.e., erect), then image is inverted (i.e., in the downward direction with respect to the principal axis). Since real image is always inverted, so negative magnification indicated that the image formed by spherical mirror is real.
- ✓ Linear magnification is case of plane mirror $=+1$. this is because, the size of image = size of object in plane mirror. Moreover, both object and image are erect.

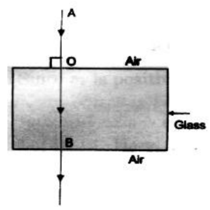
REFRACTION OF LIGHT

When light goes from air to glass, it bends towards the interface separating these two media. On the other hand, when light goes from glass to air, it bends away from the normal to the interface separating these two media. This phenomenon of bending light is known as refraction of light.





Definition. The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.



The rays AO in figure 32(a) and 32(b) are called incident rays. The rays OB in figure 32(a) and 32(b) are called refracted rays. NON' is normal to the interface separating two media.
$\angle AON$ is called incident angle $\angle i$ and $\angle BON'$ is called refracted angle $\angle r$.
The light rays do not bend at all if they fall normally or perpendicularly on a glass slab.

Cause of Refraction of light

We come across many media like air, glass, water etc. A medium is a transparent material through which light is transmitted. Every transparent medium has a property known as optical density. The optical density of a transparent medium is closely related to the speed of light in the medium. If the optical density of a transparent medium is Iow, then the speed of light in that medium is high. Such a medium is known as optically rarer medium. Thus, optically rarer medium is that medium through which light travels fast. In other words, a medium in which speed of light is more is known as optically rarer medium. On the other hand, if the optical density of a transparent medium is high, then the speed of light in that medium is low. Such a medium is known as optically denser medium. Thus, optically denser medium is that medium through which light travels slow. In other words, a medium in which speed of light is less is known as optically denser medium.

Speed of light in air is more than the speed of light in water, so air is optically rarer medium as compared to the water. In other words, water is optically denser medium as compared to air. Similarly, speed of light in water is more than the speed of light in glass, so wafer is optically rarer medium as compared to the glass. In other words, glass is optically denser medium as compared to water.

When light goes from air (optically rarer medium) to glass (optically denser medium) such that the light in air makes an angle with the normal to the interface separating air and glass, then it bends from its towards the normal when it original direction of propagation. Similarly, if light goes from glass to air, again it bends from its original direction of propagation. The phenomena of bending light from its path is known as refraction. We have seen that the speed of light in different media is different, so we can say that refraction of light takes place because the speed of light is different in different media. Thus, the cause of refraction can be summarised as follows:
The refraction of light takes place because speed of light changes when light goes from one medium to another medium.

LAWS OF REFRACTION

Refraction of light follows the following two laws :
1. The incident ray, the refracted ray and the normal to the surface separating the two media ail lie in the same plane.
2 The ratio of the sine of the incident angle $(\angle i)$ to the sine of the refracted angle $(\angle r)$ is constant for a pair of two media.

i.e., $$\frac{\sin i}{\sin r} = \text{constant} \qquad \ldots(1)$$

This constant is known as the refractive index of the medium in which refracted ray travels with respect to the medium in which incident ray travels.

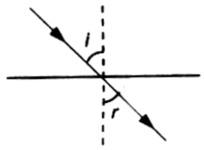
Refractive index of second medium with respect to the first medium is denoted by n_{21}

Refract meter is device used to measure the refractive index of a substance.

Thus, eqn. (1) can be written as

$$n_{21} = \frac{\sin i}{\sin r} \qquad \ldots(2)$$

This law is also known as Snell's law as it was stated by Prof. Willebrord Snell (Dutch mathematician and astronomer).



Note : No refraction takes place if the refractive indices of two media in contact are equal. This is because, in such situation, $n_{21} = \frac{n_2}{n_1} = 1 \therefore$ From Snell's law, $\frac{\sin i}{\sin r} = 1$ or $\angle i = \angle r$.

That Is, incident angle is equal to refracting angle.

REFRACTIVE INDEX

Speed of light in vacuum is maximum and is equal to $3 \times 10^8\ ms^{-1}$. In air, speed of light is little smaller than in vacuum. But for all practical purposes, we consider the speed of light in air equal to the speed of light in vacuum. However, speed of light decreases in denser media like water, glass etc. It means when light goes from air to some other medium like water and glass, its speed decreases.

The amount of change in the speed of light in a medium depends upon the property of the medium. This property is known as refractive.

index of the medium. Refractive index is a measure of how much the speed of light changes when it enters the medium from air.

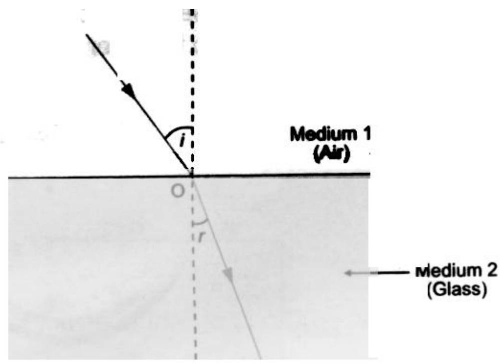
Absolute Refractive index. Absolute refractive index of a medium is defined as the ratio of the speed of light in vacuum or air to the speed of light in the medium. It is denoted by n.

i.e. Refractive index,

$$n = \frac{\text{Speed of light in air or vacuum } (\text{c})}{\text{Speed of light in medium } (\text{u})}$$

or $\quad n = \frac{c}{\upsilon}$ where, $c = 3 \times 10^8\ ms^{-1}$

Refractive index is a pure number. It has no unit.



Relative Refractive Index

Consider a material medium 2 surrounded by another material medium 1. Let the light goes from medium 1 to the medium 2, then the refractive index of medium 2 with respect to medium 1 is known as the relative refractive index of medium 2. It is given by

$$n_{21} = \frac{\text{speed of light in mediumku1}(\upsilon_1)}{\text{speed of light in mediium } 2(\upsilon_2)}$$

i.e., $\quad n_{21} = \frac{\upsilon_1}{\upsilon_2} \qquad \ldots(1)$

Multiply and divide R.H.S. of eq. (1) by c (speed of light in air), we get

$$n_{21} = \frac{c\upsilon_1}{c\upsilon_2} = \left(\frac{c}{\upsilon_2}\right) \times \left(\frac{\upsilon_1}{c}\right) = \left(\frac{c/\upsilon_2}{c/\upsilon_1}\right) \qquad \ldots(2)$$

But $\quad \frac{c}{\upsilon_2} = n_1$ (absolute refractive index of medium 1) and $\frac{c}{\upsilon_2} = n_2$ (absolute refractive index of medium 2)

Hence eqn. (2) can be written as

$$n_{21} = \frac{n_2}{n_1} \qquad \ldots(3)$$

Thus, relative refractive index of medium 2 with respect to medium 1 is defined as the ratio of absolute refractive index of medium 2 to the absolute refractive index of medium 1.

Also $n_{21} = \frac{\sin i}{\sin r}$

Comparing eqns. (3) and (4), we get

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

or $n_1 \sin i = n_2 \sin r$

Factors on which the refractive index of a medium depends

Refractive index of a medium depends upon :

(i) Nature of the material of the medium

(ii) Density of the medium and $\qquad n_{21} = \frac{1}{n_{12}}$

(iii) Colour or wavelength of the light.

- ✓ Since $C > \upsilon,$ so $n > 1$
- ✓ When light travels from medium to another medium, the speed of light and its wavelength (λ) changes but frequency (f) of light remains the same.
- ✓ Since $C = f\lambda$ and $c\upsilon = f\lambda_m$

  $\therefore \qquad n = \frac{C}{\upsilon} = \frac{\lambda}{\lambda_m}$
- ✓ Thus, refractive index a medium or material depends upon the wavelength of the light falling on it. Refractive index of a medium is minimum for red light and maximum for violet light.
- ✓ Wavelength of light in medium,
- ✓ $\lambda_m = \frac{\lambda}{n} = \frac{\text{wavelength of light in air}}{\text{refractive index of medium}}$
- ✓ As $n > 1,$ so $\lambda_m < \lambda$. thus, wavelength of light decreases when it travels from air to another medium like water, glass etc.
- ✓ When a ray of light falls normally on a medium, $\angle i = 0$ and hence $\angle r = 0$. Then refraction of light does not take place.
- ✓ Optically denser (or simply denser) medium is one whose refractive index is large as compared to other medium.
- ✓ Optically rarer (or simply rarer) medium is one whose refractive index is small as compared to other medium.

Refractive index of few substances with respect to vacuum for yellow light (sodium light $5{\cdot}89 \times 10 - 7m$ or $589\,nm$) are given in table.

S. No.	Name of Substance	Refractive Index
1.	Air	1·0003
2.	Hydrogen	1·00013
3.	Carbon dioxide	1·00045
4.	Ice	1·31

5.	Water	1·333
6.	Alcohol	1·36
7.	Kerosene	1·44
8.	Carbon tetrachloride	1·46
9.	Turpentine oil	1·47
10.	Glycerine	1·501
11.	Benzene	1·52
12.	Crown glass	1·54
13.	Rock salt	1·63
14.	Carbon disulphide	1·66
15.	Flint glass	1·71
16.	Ruby	2·42
17.	Diamond	

The following table gives the value of refractive indices of a few media.

S. No.	**1**	**2**	**3**	**4**	**5**	**6**
Medium	Ice	Water	Kerosene	Flint glass	Ruby	Diamond
Refractive index	1·31	1·333	1·44	1·66	1·71	2·42

REFRACTION THROUGH A GLASS SLAB

When a ray of light falls on a glass slab obliquely (i.e., by making a certain angle with the normal), it emerges out of the glass slab parallel to its original direction of propagation. However, there is a shift in the path of the incident ray. This shift is known as lateral shift or lateral displacement.

Consider a rectangular glass slab LMNP of thickness 't. Let incident ray AO traveling in air strikes the glass slab at an angle of incidence $\angle i$ (Figure35). After refraction, the ray bends towards the normal N_1N_1'. Let the refracted ray OB makes $\angle r_1$ with the normal N_1N_1'.

According to Snell's law of refraction

$$n_{21} = \frac{\sin i}{\sin r_1} \qquad \ldots(1)$$

$\angle i \simeq \angle e$, When experiment is performed with a glass slab in the laboratory.

They are OB suffers refraction at B and emerges out of the glass slab performed with a glass slab into the air.

Let the emergent ray BC makes an angle e with the normal N_2N_2'. According to Snell's law of refraction,

$$n_{12} = \frac{\sin r_1}{\sin e} \qquad \ldots(2)$$

We known $n_{21} = \dfrac{1}{n_{12}}$ ...(3)

Substituting the values of eqn. (1) and (2) in eqn (3), we get

$$\frac{\sin i}{\sin r_1} = \frac{1}{\frac{\sin r_1}{\sin e}} = \frac{\sin e}{\sin r_1}$$

or $\sin i = \sin e$ or $\angle i = \angle e$

Factors on which Lateral Shift depends
(i) Lateral shift caries directly peopartional to the thickness of glass slab.
(ii) Lateral shift varies directly proportional to the incident angle.
(iii) Lateral shift varies directly proportional to the refractive index of glass slab.
(iv) Lateral shift varies inversely proportional to the wavelength of incident light.

This shows that in refraction through a rectangular slab the incident ray and emergent ray are parallel to each other.

Lateral shift (or displacement). The perpendicular distance between the original path of incident ray and the emergent ray coming out of a glass slab is called lateral shift.

In figure 35, lateral shift = DE.

Lens is a transparent medium bounded by two refracting surfaces. Out of these two refracting surfaces at least one is spherical. Thus, a lens may have two spherical surfaces or one spherical and other plane.

Types of Lenses

Lenses are of two types :

(i) convex lens or converging lens (ii) concave lens or diverging lens

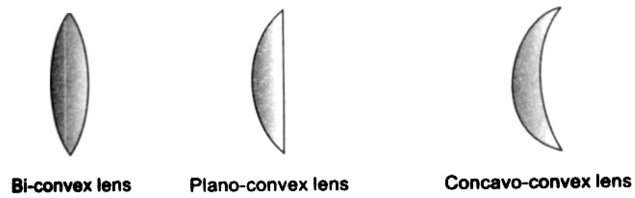
Convex lens

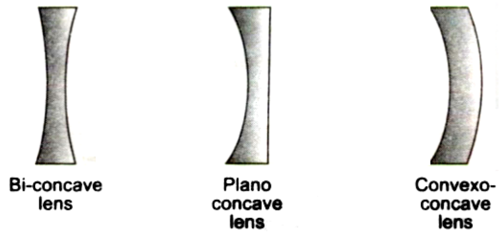
A lens having both spherical surfaces or one spherical surface and other plane surface such that it is thick in the middle and thin at the edges is known as convex lens.

Convex lenses are of three types :

(a) Bi-convex or double convex lens (b) Plano-convex lens

(c) Concavo-convex lens





CONCAVE LENS

A lens having both spherical surfaces or one spherical and other plane surface such that it is thin in the middle and thick at the edges is known as concave lens.

The concave lenses are of three types :

(a) Bi-concave or Double concave lens

(b) Plano-concave lens

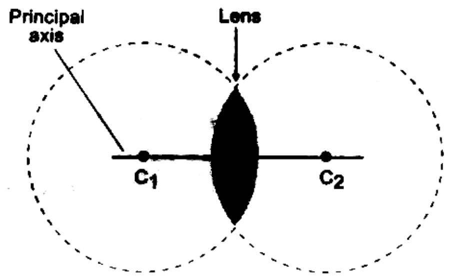
(c) Convexo-concave lens

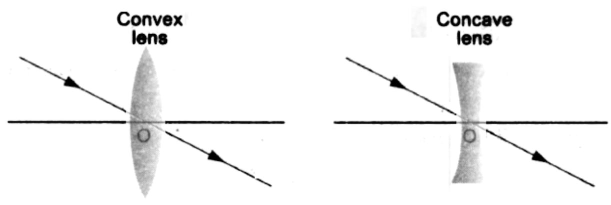
Convex lens acts a magnifying glass

SOME TERMS USED IN LENSES

1. Principal axis. A line joining the centre of curvatures of two spherical surfaces forming a lens is called principal axis.

A line joining C_1 and C_2 in figure 38 is a principal axis of the lens.

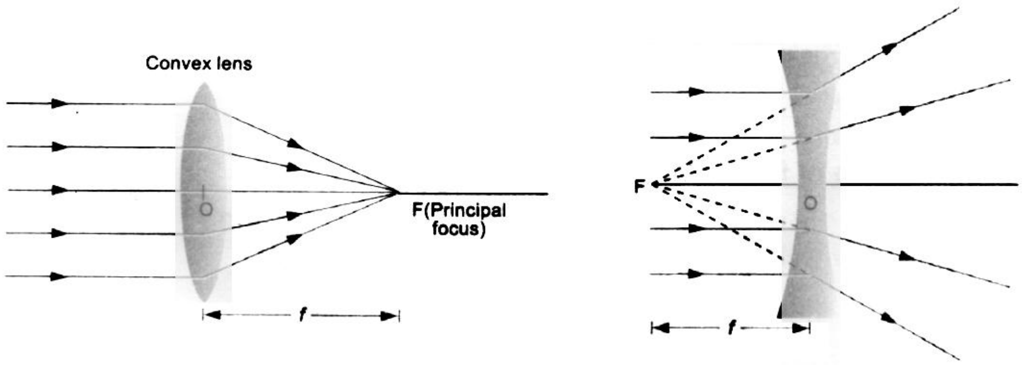




2. Optical centre. A point in or outside a lens through which rays of light pass undedicated is called optical centre of the lens. It is denoted by 0.

3. Principal focus. A point on the principal axis of a lens where all rays of light parallel to the principal axis meet or appear to meet after passing through the lens is called principal focus of the lens.

It is denoted by F. Principal focus of convex and concave lenses.



4. Focal Length. The distance between the principal focus and optical center of a lens is known as focal length of the lens.
It is denoted by { and shown in figure 40.

For concave convex and convexo-concave lens optical centre may be outside the lens.

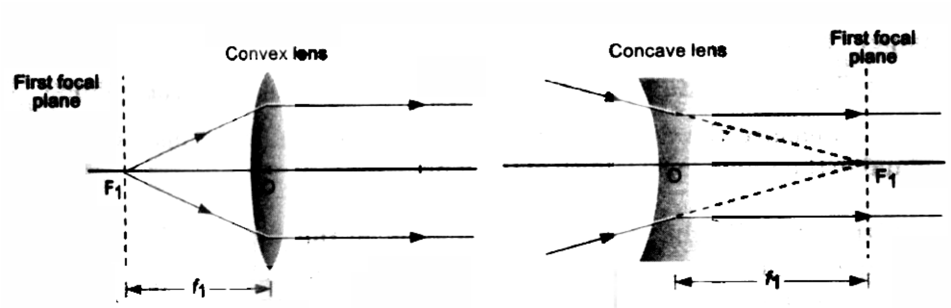
5. Principal foci. A beam of light may fall on either side of a lens. Therefore, a lens has two principal foci. They are denoted by F_1 and F_2.

Both principal foci are equidistant (equal distance) from the optical center. That is, $F_1 = F_2$.

6. First Principal focus (F1). The position of a point on the principal axis of a lens so that the rays of light starting from this point after passing through the lens travel parallel or appear to travel parallel to the principal axis is called first principal focus (F_1).

(i) A convex lens converges rays of light, so it is also known as
converging lens
(ii) A concave lens diverges rays of light, so it is known as diverging lens.

First principal focus (F_1) of a convex lens and a concave lens.

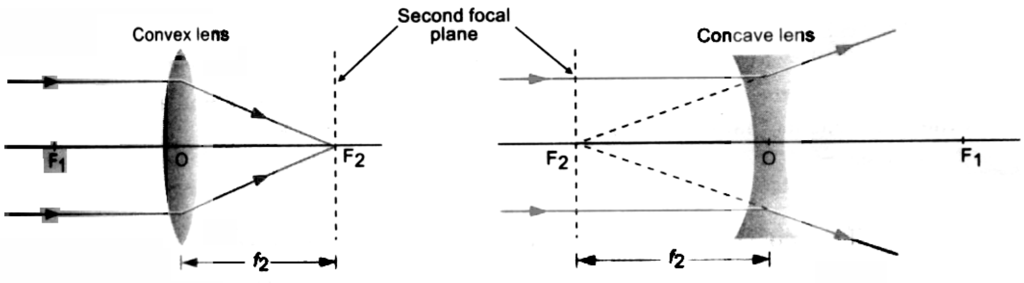


First focal plane. A vertical plane passing though the first principal focus is called first plane.
First principal focal length. The distance between the optical centre and the first principal focus is called first principal focal length. It is denoted by f_1.

$f_1 = OF_1$

7. Second Principal focus (F_2). The position of a point on the principal axis of a lens where a beam of light parallel to the principal axis meets or appears to meet after passing through the lens is called second principal focus (F_2).

Second principal focus (F_2) of a convex and a concave lens.



Second focal plane. A vertical plane passing through the second principal focus is called second focal plane.

First and second principal focal lengths are equal that is $f_1 = f_2$.

Second principal focal length. The distance between the optical centre and the second principal focus is called second principal focal length. It is denoted by f_2. Here, $f_2 = OF_2$.

Image formation by a convex lens

A convex lens forms real as well as virtual images of different sizes depending on the position of the object on the principal axis.

S. No.	Position of the object	Position of the Image	Size of the image	Nature of the image
1.	At infinity	At focus F_2	Highly diminished and point like	Real and inverted
2.	Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
3.	At $2F_1$	At $2F_2$	Same size as that of object	Real and inverted
4.	Between F_1 and $2F_1$	Beyond $2F_2$	Larger size than that of object	Real and inverted
5.	At F_1	At infinity	Highly magnified	Real and inverted
6.	Between four F_1 and optical centre of the lens.	On the same side of the lens as that of object	Larger size than that of object	Virtual and erect

The position, size and nature of the image formed by a convex lens for different positions of an object are given below : Image formation by a concave lens

A concave lens always forms a virtual, erect and diminished (smaller size) image irrespective of the position of the object.

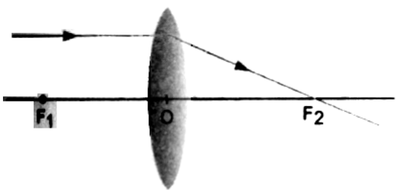
S. No.	Position of the object	Position of the image	Size of the image	Nature of the image
1.	At infinity	At the focus F_1	Highly diminished and point like	Virtual and erect
2.	Between infinity and the optical centre of the lens	Between the focus F_1 and the optical centre of the lens	Diminished	Virtual and erect

The position, size and the nature of the image formed by a concave lens for different positions of the object are given below :

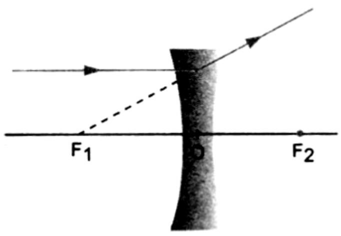
IMAGE FORMATION IN LENSES USING RAY DIAGRAMS

For geometrical construction of an image formed by a lens, any of two of the following rays of light are used (for convenience).

(i) A ray parallel to the principal axis. A ray of light parallel to the principal axis passes or appears to pass through the focus after passing through the lens.

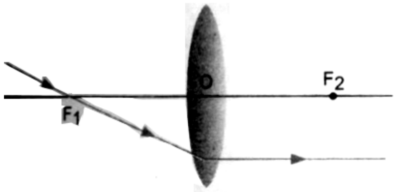


Convex lens

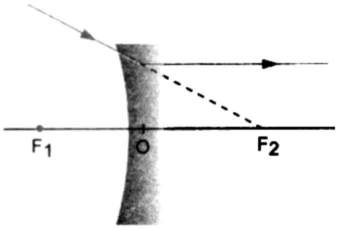


Concave lens

(ii) A ray passing through the principal focus. A ray of light passing through the focus or directed towards it travels parallel to the principal axis after passing through the lens.

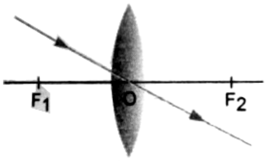


Convex lens

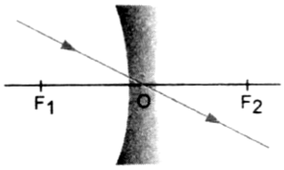


Concave lens

(iii) A ray passing through the optical centre of the lens. A ray of light passing through the optical centre of the lens go undeviated after passing through the lens.

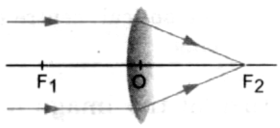
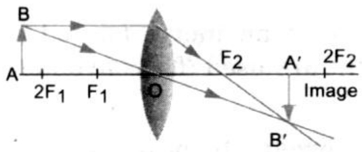
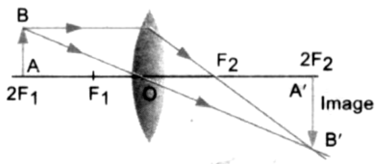
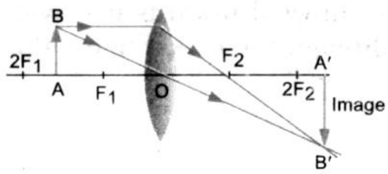
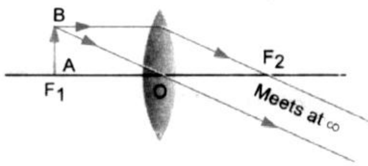
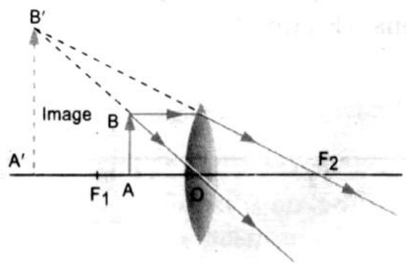


Convex lens

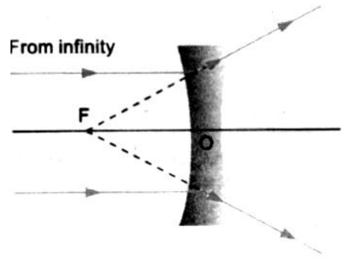
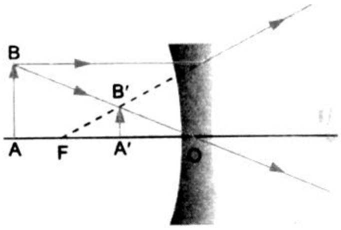


Concave lens

Ray diagrams for the formation of image by a image by a convex lens for different positions of the object are shown below :

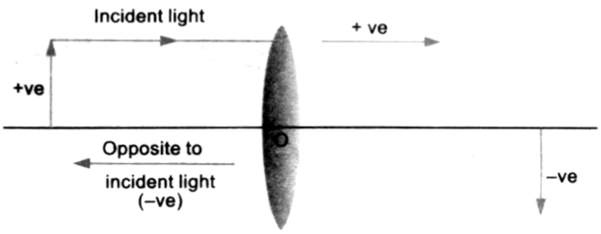
S. No.	**Position of object**	**Formation of image**	**Use of the lens**
1.	At infinity		Used in astronomical telescope
2.	Beyond $2F_1$		Used in camera
3.	At $2F_1$		Used in terrestrial telescope
4.	Between F_1 and F_2		Used in a cinema projector
5.	At F_1		Used in search lights
6.	Between focus and the optical centre of the lens		Used in a simple microscope or used as a magnifying glass

Ray diagrams for the formation of image by a concave lens for different positions of the object are shown below :

S. No.	Position of object	Formation of image
1.	At infinity	
2.	Between infinity and optical centre of the lens	

Sign Conventions (Or Cartesian Sign Conventions) For Spherical Lenses

While studying the formation of image of an object by a lens, we use certain cartesian sign conventions.
These are as follows :
1. All distance are measured from the optical centre of a lens.
2. Distance measured in the direction of the propagation of incident ray of light are taken ads position, while distances measured in a direction opposite to the direction of incident ray of light are taken as negative.
3. Upward heights with respect to the principal axis are taken as positive, wile downward heights with respect tot the principal axis are taken as negative.
These sign conventions are clear form the diagram.



LENS FORMULA AND MAGNIFICATION

Distance of an object from the optical centre of a lens is known as object distance. It is denoted by u.
Distance of image from the optical centre of a lens is known as image distance. It is denoted by υ.

Lens formula $-\frac{1}{u}+\frac{1}{\upsilon}=\frac{1}{f}$ is some for both the convex and concave lenses.

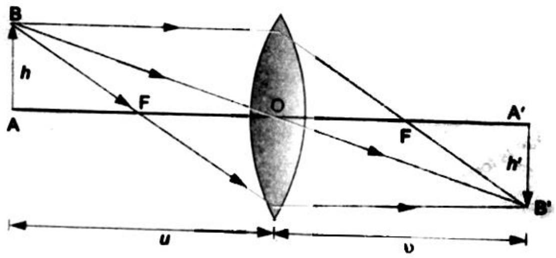
LENS FORMULA

The relation between object distance (u), image distance (v) and focal length (f) of a lens is called lens formula. The lens formula is given by

$$-\frac{1}{u}+\frac{1}{\upsilon}=\frac{1}{f}$$

or $$\frac{-1}{\text{distance of object from lenses}}+\frac{1}{\text{distance of image from lens}}=\frac{1}{\text{focal length of lens}}$$

MAGNIFICATION PRODUCED BY A LENS



The size or height of image formed by a lens depends upon the position of the object from the optical centre of the lens. It means, a lens can produce images of different size depending upon the position of a given object. The ratio of the size (or height) of the image to the size (or height) of the object is known as the magnification (m) produced

i.e., Magnification

$$(m) = \frac{\text{Size (or height) of image (A'B')}}{\text{Size (or height) of object (AB)}} = \frac{h'}{h} \quad \ldots(1)$$

MAGNIFICATION (M) IN TERMS OF u AND υ

AB is the size or height of the object and A'B' is the size or height of the image.

$\Delta's\, AOB$ and $A'OB'$ are similar

$$\therefore \quad \frac{A'B'}{AB} = \frac{OA'}{OA} \quad \ldots(2)$$

Applying sign conventions

$$A'B' = -h', AB = +h$$
$$OA' = +\upsilon, OA = -u$$

$\therefore$ Eqn. (2) becomes

$$\frac{-h'}{h} = \frac{\upsilon}{-u} \text{ or } \frac{h'}{h} = \frac{\upsilon}{u} \quad \ldots(3)$$

But $\quad m = \frac{h'}{h}$

Using eqn. (3), we get

$$m = \frac{h'}{h} = \frac{\upsilon}{u}$$

Thus, magnification of a lens $= \dfrac{\text{Image distance from lens}}{\text{Object distance from lens}}$

- ✓ Magnification (m) is positive if the image produced by a lens is virtual.
- ✓ Magnification in case of a concave lens is always positive as it always forms a virtual image.
- ✓ Magnification in case of a convex lens is positive when it forms a virtual image but magnification in case of a convex lens is negative when it forms a real image.

Power of a lens is the ability of the lens to converge or converge or diverge the rays of light falling on it.
Power of a lens is defined as the reciprocal of the focal length of the lens (expressed in metres). It is denoted by P

i.e, $\quad P = \dfrac{1}{f\,(in\,m)}$ or $P = \dfrac{100}{f\,(in\,cm)}$

Thus, we can say that a lens of small focal length has large power of converging or diverging a parallel beam of light. On the other hand, a lens of large focal length has small power of converging or diverging a parallel beam of light.

Since a convex lens converges a parallel beam of light, so is has a power of converging the beam of light. When a convex lens has a large power, it means, this convex lens strongly converges the parallel beam of light and near to its optical centre. On the other hand, when a convex lens has a small power, then this lens converges the parallel beam of light but away from its optical centre.

Unit of power of a lens is dioptre (D).

Definition of dioptre (D). power of a lens is 1 dioptre if its focal length is 1 metre.

- ✓ Power of convex lens is positive because its focal length is positive.
- ✓ Power of concave lens is negative because its focal length is negative.

Consider two lenses of focal lengths f_1 and f_2 respectively . When these lens are in contact, the combination behaves as a single lens of focal length F. thus focal length (F) is known as equivalent focal length and is given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2} \qquad \ldots(1)$$

Since $\frac{1}{f}=P,$ power of lens, so the power of the combination of two lenses is given by

$$P=P_1+P_2 \qquad \ldots(2)$$

where $P=\frac{1}{F}, P_1=\frac{1}{f_1}$ and $P_2=\frac{1}{f_2}$.

If number lenses of powers $P_1, P_2, P_3, ...$ etc. are placed in contact with each other, then power combination of lenses is given by

$$P=P_1+P_2+P_3+.... \qquad \ldots(3)$$