Chapter 10 - Light

Important Terms

Light is a form of energy and can be transformed into other forms of energy.
Light does not require a material medium for its propagation.
The velocity of light in air or vacuum is 3 x 10^8 m/s.

Rectilinear Propagation of Light

In a homogenous transparent medium light travels in a straight line and this is known as rectilinear propagation of light.

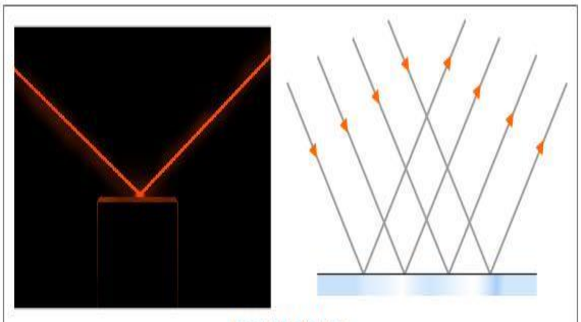
Reflection of Light

The phenomenon by which a ray of light changes the direction of propagation when it strikes a boundary between different media through which it cannot pass is described as the reflection of light

There are two types of reflection of light:

- **Regular reflection or specular reflection**
- **Irregular reflection or diffused reflection**

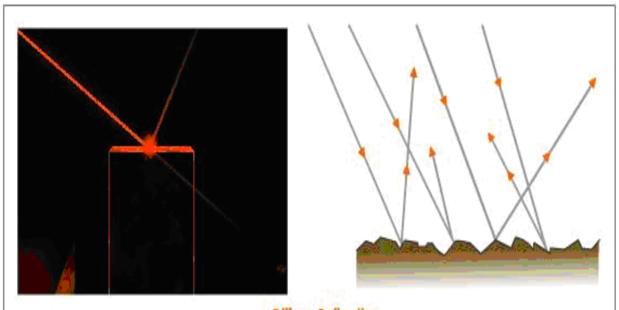
Regular Reflection



Specular Reflection

Specular or regular reflection is the perfect, mirror-like reflection of light.
Reflection in a mirror, a water surface and highly polished floors, are examples of regular reflections.

Irregular Reflection:

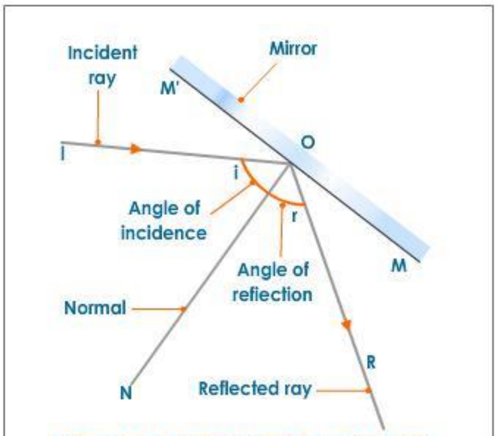


Diffuse Reflection

Irregular reflection or diffused reflection takes place when a ray of light is incident on a wall or wood, which is not smooth or polished. In this case, the different portions of the surface reflect the incident light in different directions. In such cases no definite image is formed, but the surface becomes visible. It is commonly known as scattering of light. Thus diffused reflection makes non-luminous objects visible.

Reflection of Light by a Plane Surface:

The figure shows how a ray of light is reflected by a plane surface. Let MM' represent a reflecting surface. When a ray of light is incident on MM' in the direction IO it gets reflected along the direction OR. IO is the incident ray; O is the point of incidence and OR is the reflected ray.



Reflection of a Ray of Light by a Plane Mirror

Let ON be the normal drawn perpendicular to the surface MM' at the point of incidence. The angle which the incident ray makes with the normal at the point of incidence is called the angle of incidence and is denoted by the letter 'i'. The angle that the reflected ray makes with the normal at the point of incidence is called the angle of reflection 'r'. Mirror is an example of a reflecting surface.

Laws of Reflection:

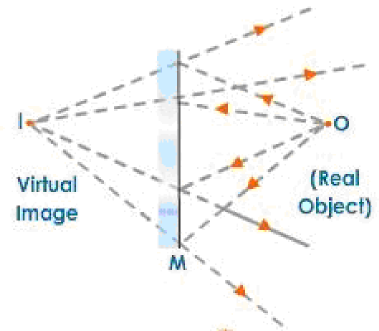
The reflection at any plane surface is found to obey the laws of reflection. The laws of reflection are:

The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane.

The angle of incidence is equal to the angle of reflection.

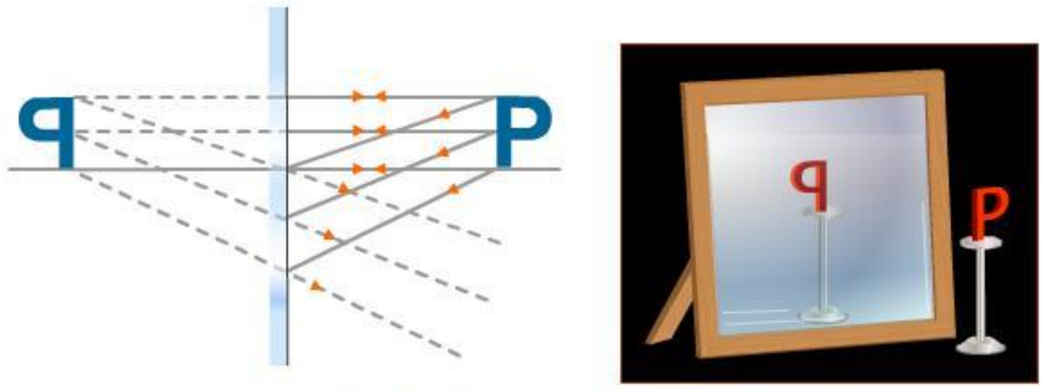
Nature of Image Formed By a Plane Reflecting Surface:

An image can be real or virtual. A real image is formed when the rays of light actually intersect after reflection. A virtual image is formed when the light rays after reflection do not actually intersect but appear to diverge from it (these rays of light intersect when produced backwards).



(i)
Virtual Image Formed by a Plane Mirror

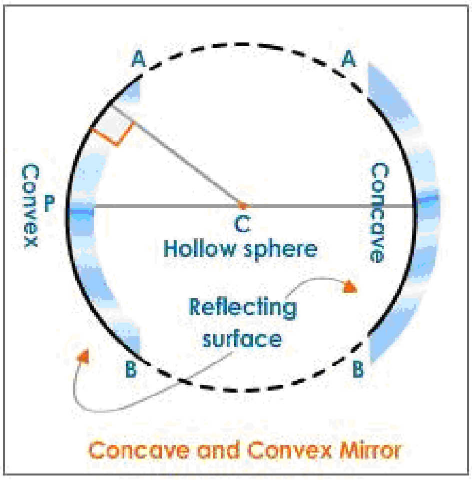
Ray Diagrams of Plane Mirrors:
The following rays are usually considered while constructing ray diagrams:
A ray of light incident on a plane mirror at 90 degree gets reflected from the mirror along the same path.
A ray of light falling on a plane mirror at any angle gets reflected from the mirror such that the angle of incidence is equal to the angle of reflection. The image is formed at a point where the reflected rays appear to meet.


Formation of Image by a Plane Mirror

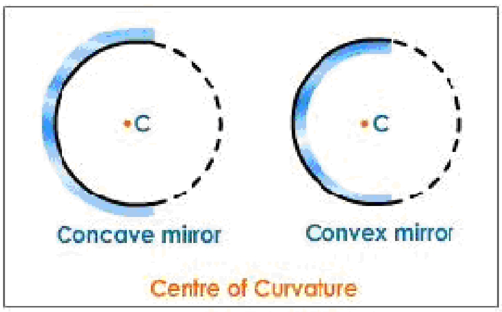
Spherical Mirrors:
A mirror whose polished, reflecting surface is a part of a hollow sphere of glass or plastic is called a spherical mirror.
In a spherical mirror, one of the two curved surfaces is coated with a thin layer of silver followed by a coating of red lead oxide paint. Thus, one side of the spherical mirror is opaque and the other side is a highly polished reflecting surface. In a diagram the **opaque side** of a mirror is always shown **shaded**.
In the diagrams given here, please remember that the **opaque, non - reflecting side is shaded blue and the reflecting side is blue.**
Depending upon the nature of the reflecting surface of a mirror, the spherical mirror is classified as:
Concave mirror
Convex mirror

Concave Mirror:
Concave mirror is a spherical mirror whose reflecting surface is towards the centre of the sphere of which the mirror is a part.

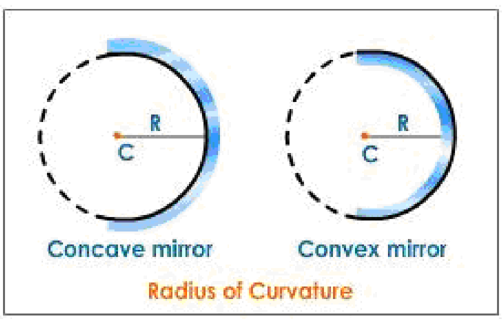
Convex Mirror:
Convex mirror is a spherical mirror whose reflecting surface is away from the centre of the sphere of which the mirror is a part.



Centre of Curvature:
Centre of Curvature is the centre of the sphere of which the spherical mirror forms a part. It is denoted by the letter C.

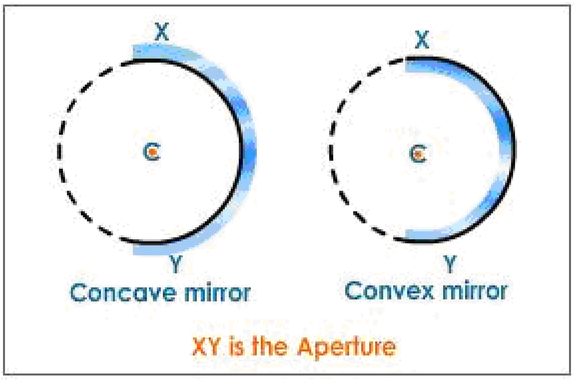


Radius of Curvature:
Radius of Curvature is the radius of the sphere of which the mirror is a part. It is represented by the letter R.



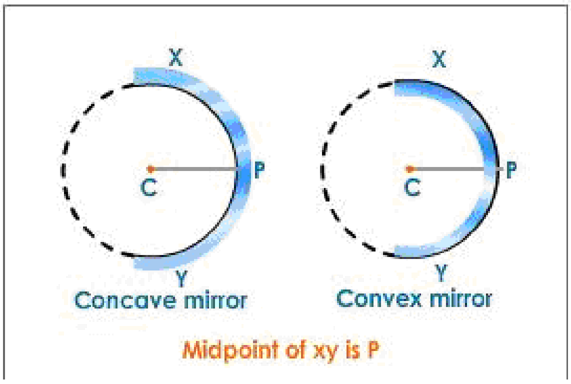
Linear Aperture:

Linear aperture is the distance between the extreme points (X and Y) on the periphery of the mirror.



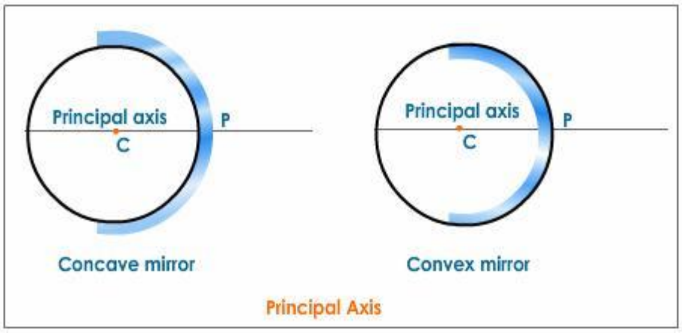
Pole:

Pole is the midpoint of the aperture of the spherical mirror. It is represented by the letter P.



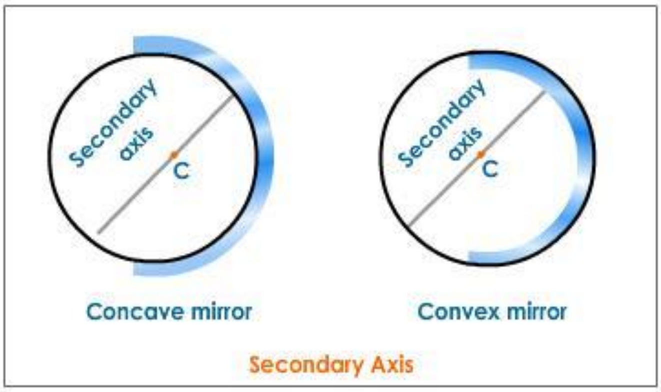
Principal Axis:

Principal axis is the straight line passing through the pole and the centre of curvature of a spherical mirror.



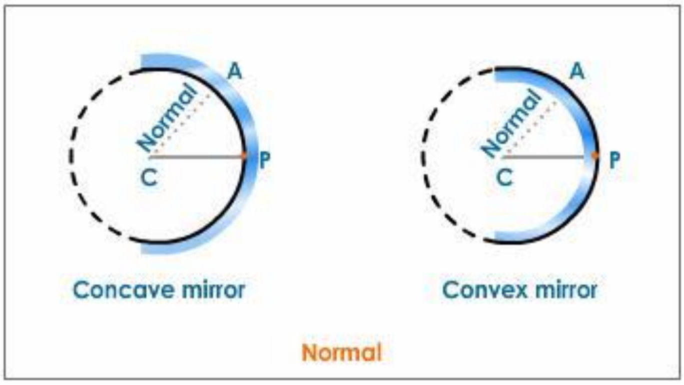
Secondary Axis:

Secondary axis is any other radial line passing through the centre of curvature other than the principal axis.

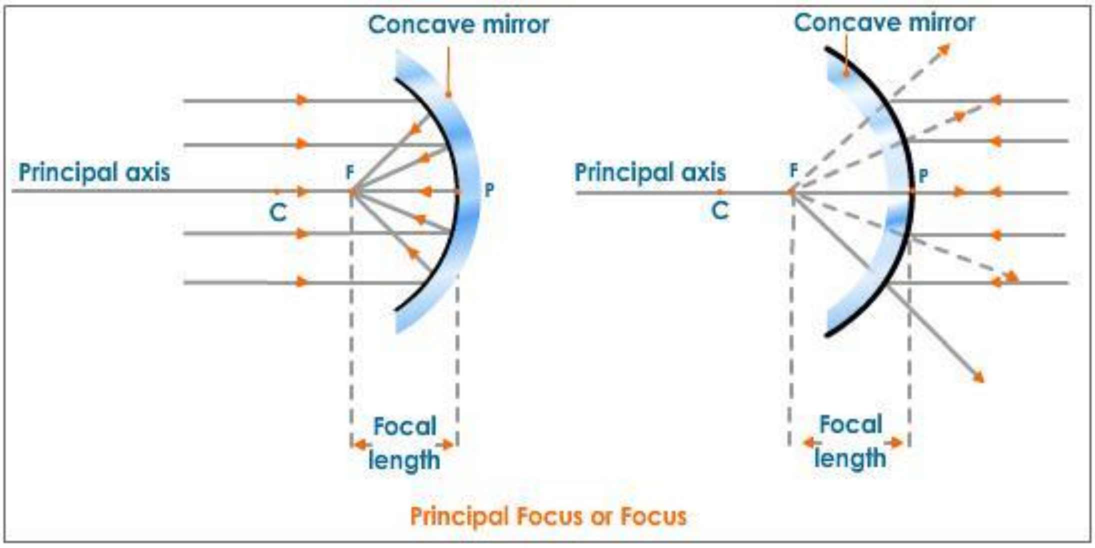


Normal:

The normal at any point of the spherical mirror is the straight line obtained by joining that point with the centre of the mirror. The normal at point A on the mirror is the line AC obtained by joining A to the centre of curvature of the mirror. Normal at any point on a spherical mirror is equal to the radius of the sphere of which the mirror is a part.



Principal Focus or Focus:



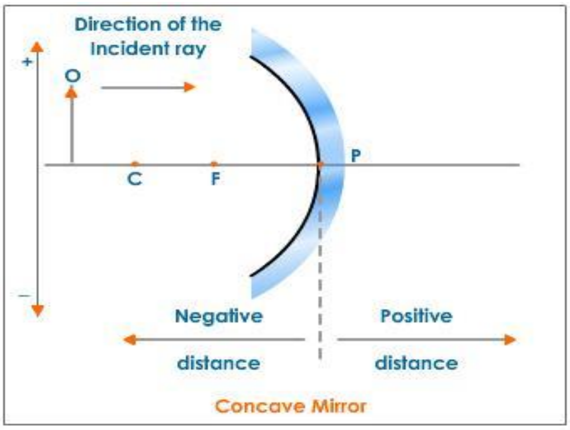
The rays of light parallel to the principal axis of a mirror after reflection, either pass through a point (in case of a concave mirror) or appear to diverge from a point (in the case of a convex mirror) on the principal axis and this point is referred to as the principal focus or focal point of the mirror.

Focal Length:
Focal length is the distance between the pole and the focus of a mirror. It is represented by the letter f.

Characteristics of Focus of a Concave Mirror and a Convex Mirror

Convex Mirror	Concave Mirror
The focus lies behind the mirror	The focus is in front of the mirror
The focus is virtual as the rays of light after reflection appear to come from the focus	The focus is real as the rays of light after reflection converge at the focus

Sign Convention for Spherical Mirrors
The following sign convention is used for measuring various distances in the ray diagrams of spherical mirrors:
Object is always placed to the left of mirror
All distances are measured from the pole of the mirror.
Distances measured in the direction of the incident ray are positive and the distances measured in the direction opposite to that of the incident rays are negative.
Distances measured along y-axis above the principal axis are positive and that measured along y-axis below the principal axis are negative.



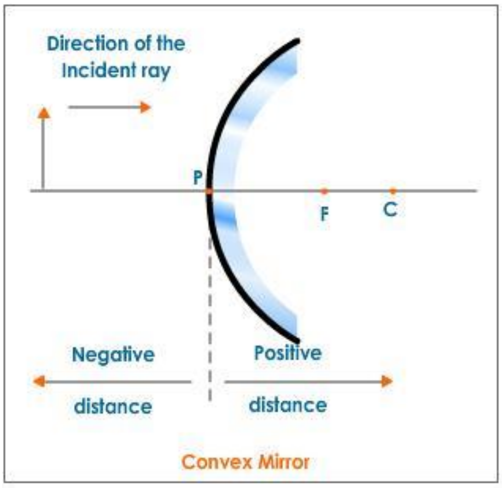


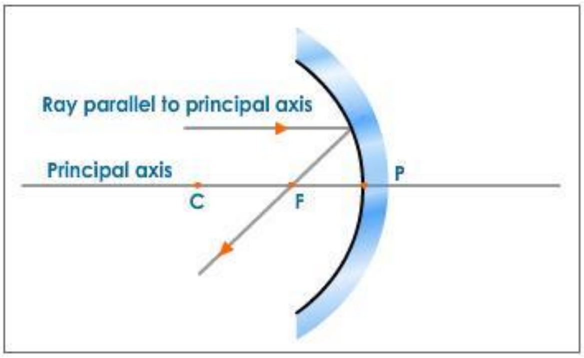
Table Showing the Sign Convention

Type of Mirror	u	v		f	R	Height of the Object	Height of the Image	
		Real	Virtual				Real	Virtual
Concave mirror	-	-	+	-	-	+	-	+
Convex mirror	-	No real image	+	+	+	+	No real image	+

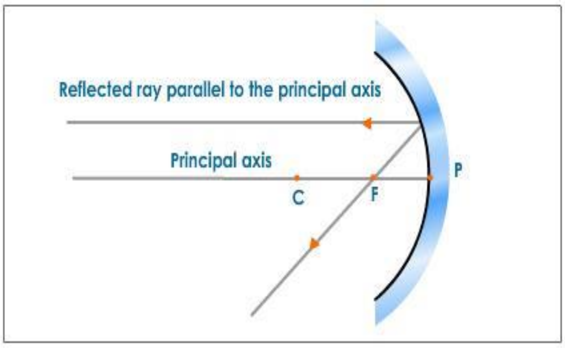
Concave Mirror

When an object is placed in front of a concave mirror, light rays from the object fall on the mirror and get reflected. The reflected rays produce an image at a point where they intersect or appear to intersect. Formation of an image by mirrors is usually shown by constructing ray diagrams. To construct a ray diagram, we need at least two rays whose paths after reflection from the mirror are known. These rays must be chosen according to our convenience. Any two of the following rays can be considered to obtain the image.

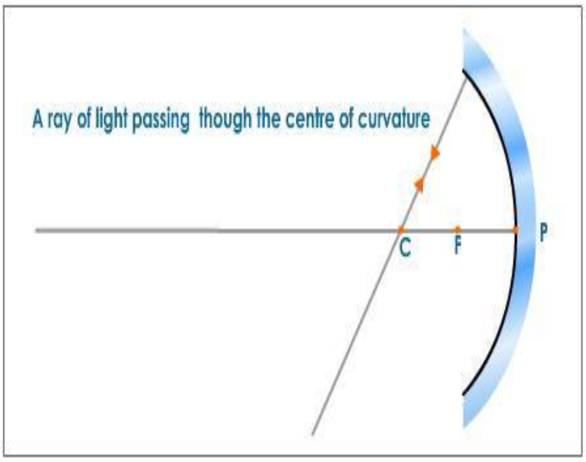
A ray of light parallel to the principal axis after reflection from a concave mirror passes through its focus.



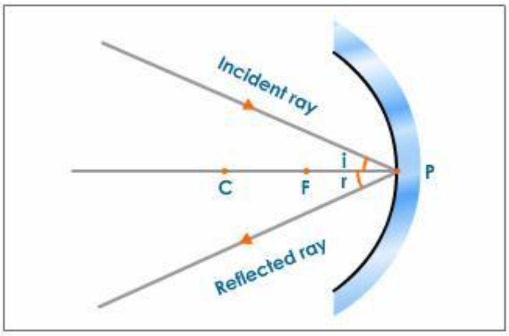
A ray of light passing through the focus of a concave mirror after reflection emerges parallel to the principal axis.



A ray of light passing through the centre of curvature of a concave mirror retraces its path after reflection as the ray passing through the centre of curvature acts as a normal to the spherical mirror.



A ray of light which strikes the mirror at its pole gets reflected according to the law of reflection.

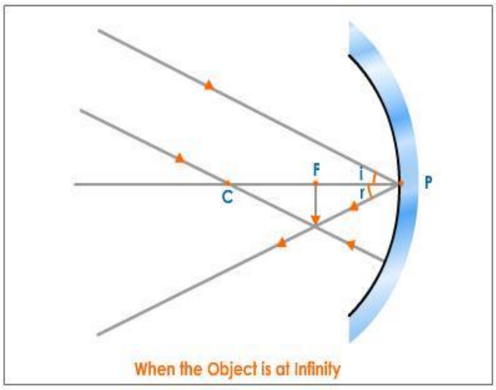


Formation of Image by a Concave Mirror

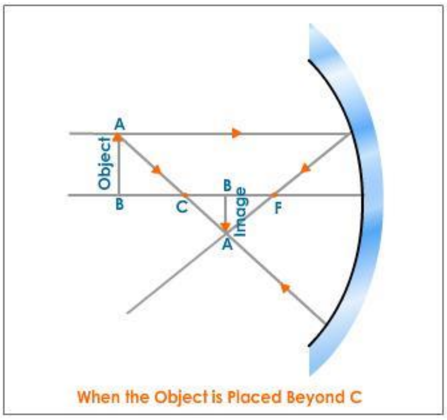
When the Object Is At Infinity

When an object is placed at infinity, the rays coming from it are parallel to each other. Let us consider two rays, one striking the mirror at its pole and the other passing through the centre of curvature. The ray which is incident at the pole gets reflected according to the law of reflection and the second ray which passes through the centre of curvature of the mirror retraces its path. These rays after reflection form an image at the focus. The image formed is real, inverted and diminished.

The image is at F
Real
Inverted
Diminished

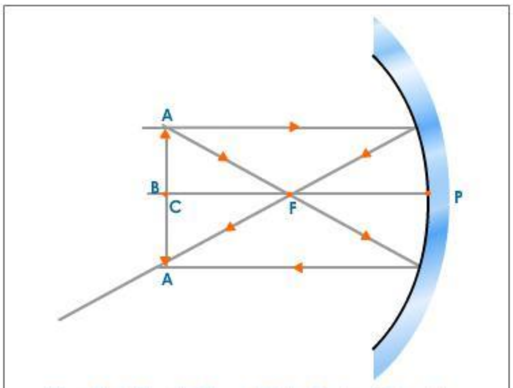


When the Object Is Placed Beyond C
The two rays which are considered to obtain the image are:
A ray passing through the centre of curvature.
A ray parallel to the principal axis.
The ray passing through the centre of curvature retraces its path and the ray which is parallel to the principal axis passes through the focus after reflection. These rays after reflection meet at a point between C and F. The image is inverted, real and diminished.
The image is:
Between C and F
Real
Inverted
Diminished



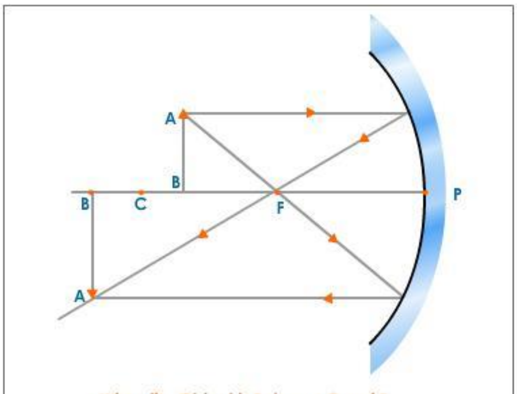
When the Object Is Placed At the Centre of Curvature
Here we consider the two rays, one parallel to the principal axis and the other passing through the focus. The ray of light which is parallel to the principal axis passes through the focus after reflection. The other ray passing through the focus after reflection emerges parallel to the axis. After reflection these rays meet at the centre of curvature to form an inverted image, which is real and of the same size as the object.

The image is:
At C
Real
Inverted
Same size as object



When the Object is Placed at the Centre of Curvature

When the Object Is Between C and F
Here we consider a ray of light which is parallel to the principal axis and another ray passing through the focus. The ray which is parallel to the principal axis passes through the principal focus and the ray which passes through the focus after reflection emerges parallel to the principal axis. The reflected rays meet at a point beyond C and the image is real, inverted and magnified.
The image is:
Beyond C
Real
Inverted
Magnified



When the Object is Between C and F

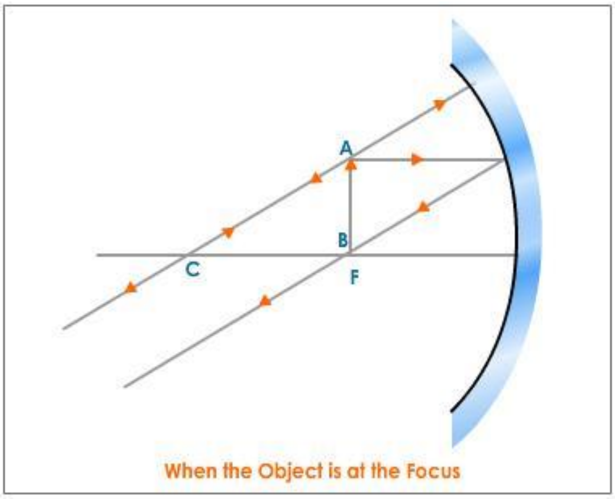
When the Object Is at the Focus
Here, we consider a ray of light which is parallel to the principal axis and another ray passing through the centre of curvature. The ray which is parallel to the principal axis passes through the focus and the ray which passes through the centre of curvature retraces its path. The reflected rays are parallel to each other, and would meet only at infinity i.e., the image is formed at infinity and it is a real, inverted and enlarged.

The image is at infinity

Real

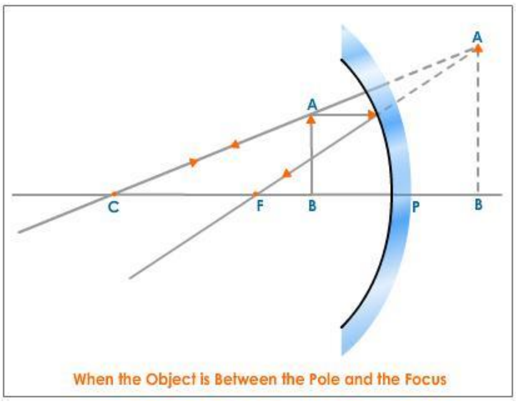
Inverted

Magnified



When the Object Is Between the Pole and the Focus

Here we consider a ray of light which is parallel to the principal axis and another ray which is passing through the centre of curvature. The ray which is passing through the centre of curvature retraces its path and the other ray which is parallel to the principal axis after reflection passes through the focus. These rays appear to meet behind the mirror when the reflected rays are extended backwards. The image is virtual, erect and magnified.



The image is:

Behind the mirror

Virtual

Erect

Magnified

Uses of Concave Mirrors

Concave mirrors are used for the following purposes:

As reflectors in the head lights of cars, search lights in torches etc. to obtain a parallel beam of light. For this, the source of light is placed at the focus of the concave reflector.


Headlight of Car

By dentist to focus light on the tooth to be examined.


Dentist's Mirror

As shaving mirrors and as make up mirrors to get an enlarged erect image of the face


Shaving Mirror

To concentrate solar radiations in solar heating devices. For this the food or substance that has to be heated is placed at the focus of a large concave reflector. After reflection, sun light converges on the substance and heats it.


Mirrors for concentrating solar radiation

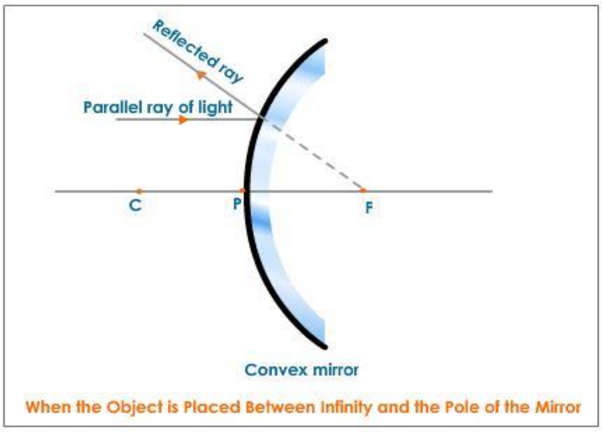
Position of the object	Position of the image	Nature and size of the image	Use
At infinity	At the focus	Real, inverted and diminished	Used by ENT surgeons and dentists
Beyond the centre of curvature	Between the focus and the centre of curvature	Real, inverted and diminished	Used in solar cookers
At the centre of curvature	At centre of curvature	Real, inverted and same size as object	Used as an erecting mirror in terrestrial telescopes
Between the focus and centre of curvature	Beyond the centre of curvature	Real, inverted and magnified	Used in hospitals and clinics to see the internal parts of the body

Position of the object	Position of the image	Nature and size of the image	Use
At focus	At infinity	Real, inverted and magnified	Used in search lights and in head lights of motor cars
Between the pole of the mirror and the focus	Appears behind the mirror	Virtual, erect and magnified	Used as a shaving mirror

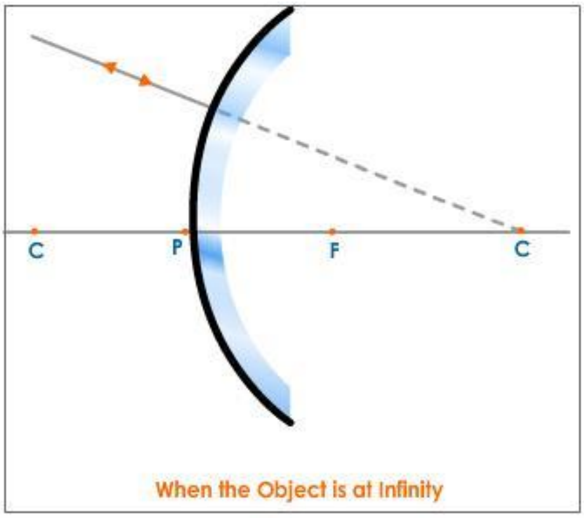
Convex Mirror

The following rays are considered while constructing ray diagrams.

A ray of light travelling parallel to the principal axis after reflection from a convex mirror appear to come from its focus behind the mirror.



A ray of light traveling towards the centre of curvature behind the mirror hits the mirror at 90^o and is reflected along its path.



A ray of light which is directed towards the principal focus of a convex mirror, after reflection will emerge parallel to the principal axis.

A ray of light incident obliquely to the principal axis, towards the pole of the mirror gets reflected according to the laws of reflection.

A convex mirror always gives a virtual image irrespective of the position of the object.

Formation of Image in a Convex Mirror

When the Object Is Placed Between Infinity and the Pole of the Mirror

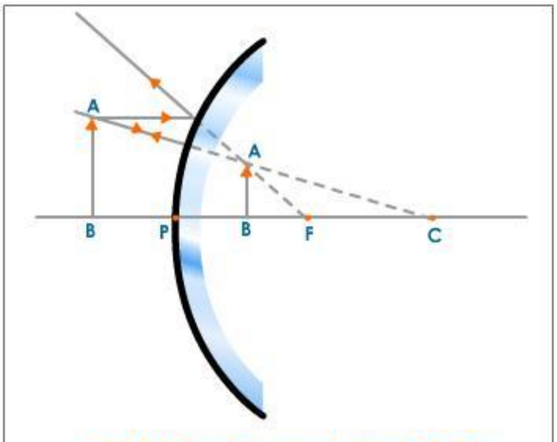
The image is:

Formed between the pole and the focus

Erect

Diminished

Virtual



When the Object is Placed Between P and F

When the Object Is At Infinity

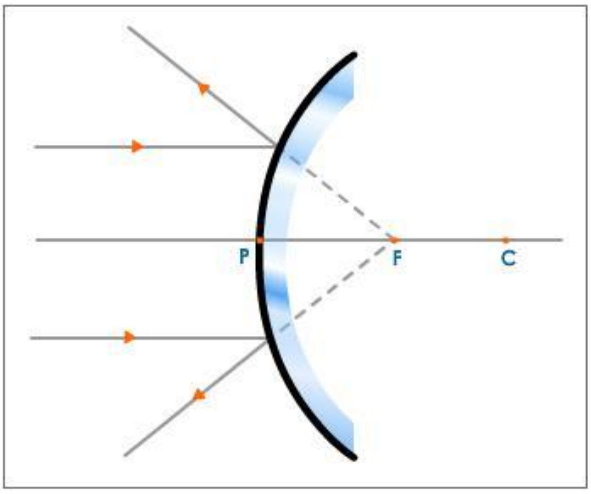
The image is:

Formed at the focus

Extremely diminished

Virtual

Erect



Uses Of Convex Mirror

Rear-view mirror in an automobile. This convex mirror gives the driver a clear view of the traffic approaching from behind as convex mirrors are curved outwards giving a wider field of view.

Vigilance mirror in departmental stores

Reflector in street lamps so as to diverge the light over a large area

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At focus	Extremely diminished	Virtual and erect
Between infinity and pole of the mirror	Between the focus and pole	Diminished	Virtual and erect

Mirror Formula

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

u – Object distance
v – Image distance
f – Focal length

Magnification

Magnification produced by a spherical mirror gives the relative extent to which the image of an object is magnified with respect to the object size.
Magnification is expressed as the ratio of the height of the image to the height of the object. It is usually represented by the letter m.

If h is the height of the object and h' is the height of the image then the magnification m produced by a spherical mirror can be written as

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

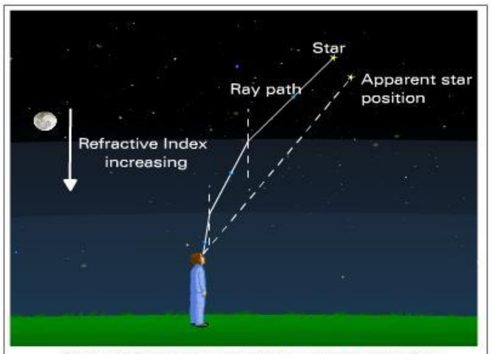
The magnification m is also related to the object distance (u) and image distance (v). It can be expressed as:

$$m = \frac{h'}{h} = -\frac{v}{u}$$

The negative sign in the value of the magnification indicates that the image is real. A positive sign in the value of the magnification indicates that the image is virtual.

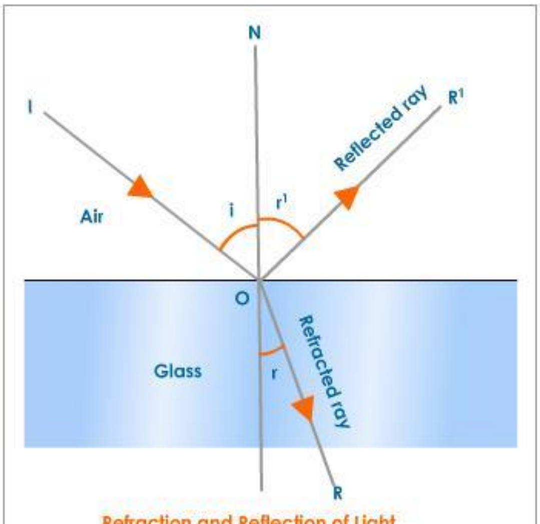
Refraction

The deviation in the path of light when it passes from one medium to another medium of different density is called refraction.



Apparent Star Position due to Atmospheric Refraction

The twinkling of stars is due to atmospheric refraction of starlight. Since light bends towards the normal the apparent position of the star is slightly different from its actual position as it passes through the atmosphere. Hence the star appears slightly higher than its actual position. Due to changing condition of earth's atmosphere the apparent position of the star changes slightly and the intensity of light reaching the eye also fluctuates. This gives rise to the twinkling effect of the star.



Refraction and Reflection of Light

Incident Ray (IO)

The ray of light striking the surface of separation of the media through which it is traveling is known as the incident ray.

Point of Incidence (O)

The point at which the incident ray strikes the surface of separation of the two media is called the point of incidence.

Normal (N)

The perpendicular drawn to the surface of separation at the point of incidence is called the normal.

Refracted Ray (OR)

The ray of light which travels into the second medium, when the incident ray strikes the surface of separation between the media 1 and 2, is called the refracted ray.

Angle of Incidence (i)

The angle which the incident ray makes with the normal at the point of incidence, is called angle of incidence.

Angle of Refraction (r)

The angle which the refracted ray makes with the normal at the point of incidence, is called angle of refraction.

A ray of light refracts or deviates from its original path as it passes from one optical medium to another because the speed of light changes.

Laws of Refraction

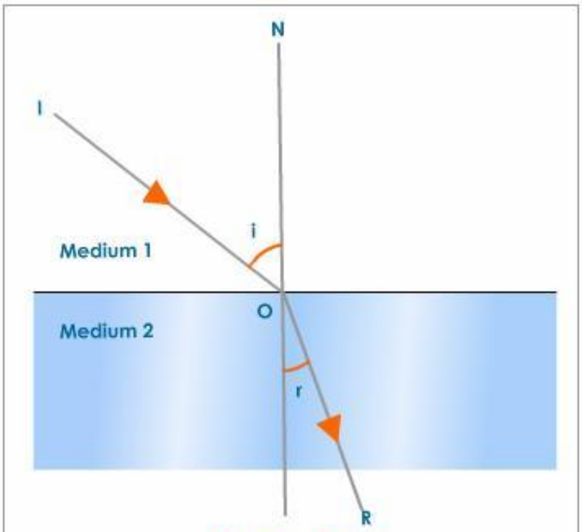
The incident ray, the refracted ray and the normal to the surface at the point of incidence all lie in one plane.

For any two given pair of media, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

The above law is called Snell's law after the scientist Willebrod Snellius who first formulated it

Thus $\frac{\sin i}{\sin r} = a\ constant = \mu$

Where μ is the refractive index of the second medium with respect to the first medium.



Refraction of Light

The refractive index of glass with respect to air is given by the relation.

$$air\ \mu glass = \frac{Speed\ of\ light\ in\ air}{Speed\ of\ light\ in\ glass} = \frac{c}{v}$$

In general, if a ray of light is passing from medium 1 to medium 2, then

$$1\mu 2 = \frac{Speed\ of\ light\ in\ medium\ 1}{Speed\ of\ light\ in\ medium\ 2}$$

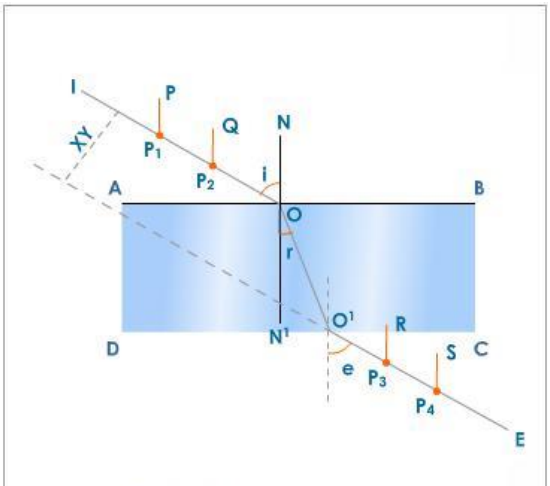
If the medium 1 is air or vacuum, the refractive index of medium 2 is referred to as the absolute refractive index.

The refractive index of a medium depends on the following factors:

The nature of the medium.

The colour or wavelength of the incident light.

Refraction of Light through a Glass Slab

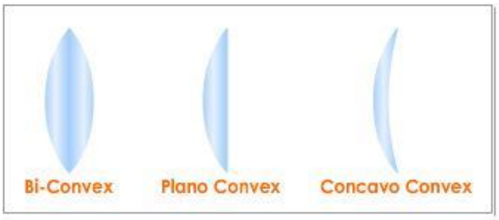


Refraction through a Glass Slab

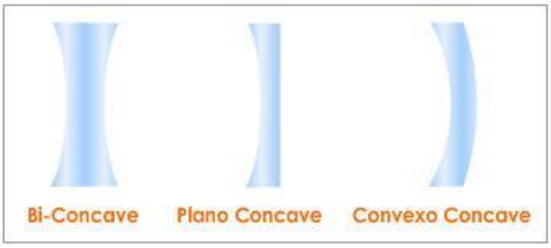
When a ray light is passing from air to glass, that is, from a rarer medium to a denser medium, the refracted ray bends towards the normal drawn at the point of incidence. In this case $\angle i > \angle r$. But when the ray of light is passing from glass to air, that is, from a denser medium to a rarer medium the refracted ray bends away from the normal. In this case $\angle r > \angle i$.
The emergent ray, O^1E which is nothing but the refracted ray emerging out of the glass slab is parallel to the incident ray. This means that the refracted ray (emergent ray) has been displaced from its original path by a distance XY. This displacement is referred to as lateral displacement.

Lenses
A lens is a portion of a transparent refracting medium bounded by two surfaces which are generally spherical or cylindrical or one curved and one plane surface.
Basically, the lenses are classified as;
Convex lens or converging lens.
Concave or diverging lens.

Convex Lens
A lens which is thicker in the middle and thinner at the edges is called a convex lens.
In a convex lens at least one of its surfaces is bulging out at the middle. According to their shapes the convex lenses are classified as;
bi-convex or double convex lens
Plano - convex lens
concavo - convex lens

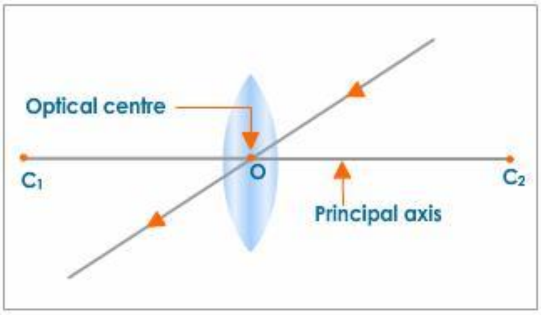


Concave Lens
A lens which is thinner at the middle and thicker at the edges is called a concave lens.
Like convex lenses these lenses are also classified as:
bi-concave
Plano - concave
convexo - concave



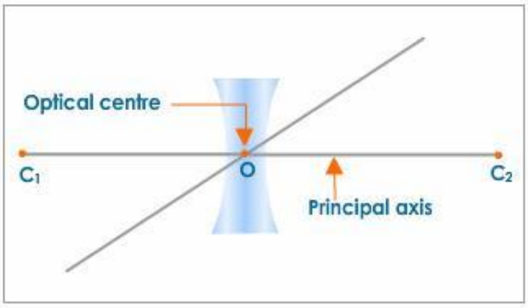
Terminology Used in Optics

Optical Centre



It is the centre of a lens. It is denoted by the letter O. A ray of light passing through the optical centre of a lens does not suffer any deviation. It is also referred to as optic centre.

Principal Axis



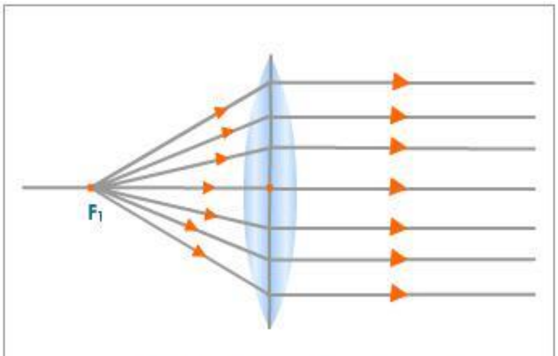
Principal axis is the straight line joining the centers of curvatures of the two curved surfaces of a lens.

Principal Foci

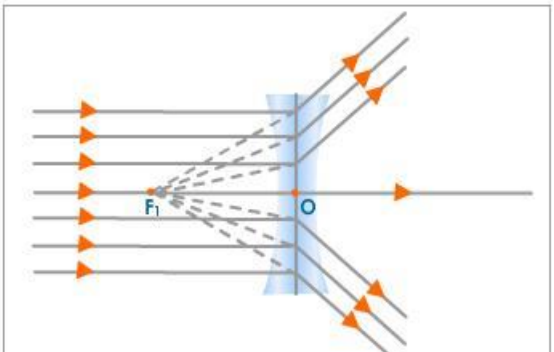
Rays of light can pass through the lens in any direction and hence there will be two principal foci on either side of the lens and they are referred to as the first principal focus and the second principal focus of a lens.

First Principal Focus (F_1)

It is a point on the principal axis of the lens such that the rays of light starting from it (convex lens) or appearing to meet at the point (concave lens) after refraction from the two surfaces of the lens become parallel to the principal axis of the lens.



First Principal Focus of a Convex Lens

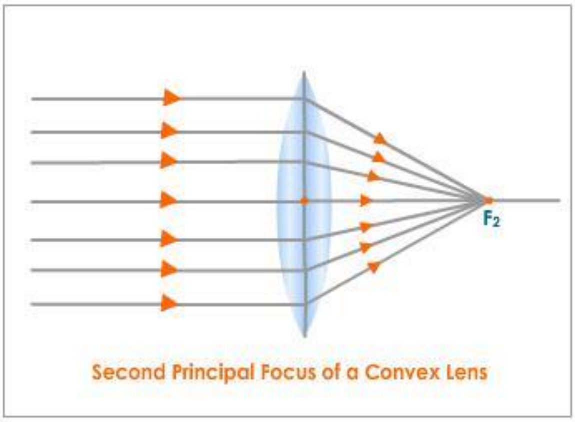


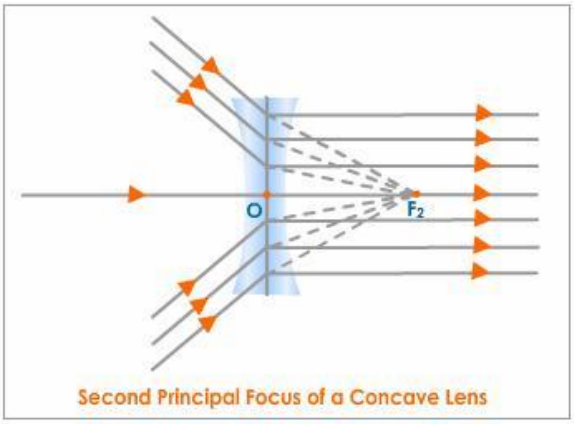
First Principal Focus of a Concave Lens

The distance from the optic centre to the first focus is called the first focal length (f_1) of the lens.

Second Principal Focus (F_2)

It is a point on the principal axis of the lens such that the rays of light parallel to the principal axis of the lens after refraction from both the surfaces of the lens pass through this point (convex lens) or appear to be coming from this point (concave lens).





The distance from the optic centre to the second principal focus is called the second focal length (f_2) of the lens.

If the medium on both sides of the lens is same then the first and the second focal lengths will be equal.

Focus of a convex lens is real whereas that of the concave lens is virtual.

Sign Convention for Spherical Lenses

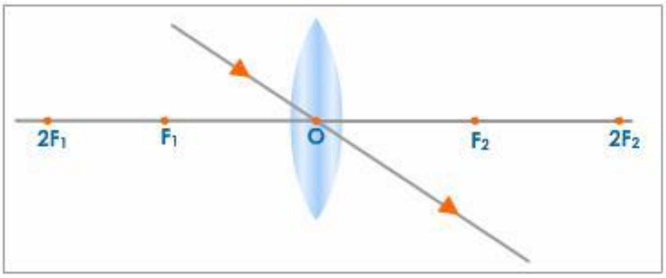
All distances are measured from the optical centre of the lens.

The distances measured in the direction of the incident light are taken as positive and the distances measured in the direction opposite to the direction of incident light are taken as negative.

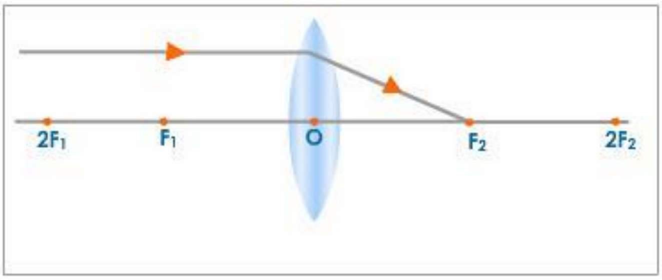
All measurements made above the principal axis are taken as positive and the measurements made below the principal axis are taken as negative, i.e., object height is always taken as positive and the image height is positive only for virtual image.

Formation of Image by a Convex Lens

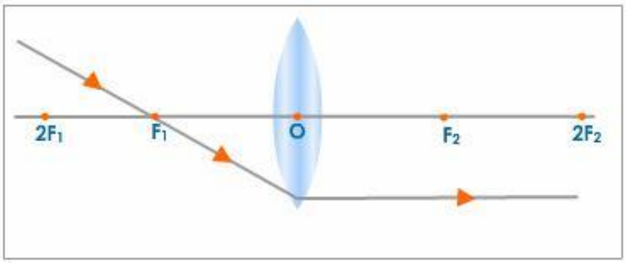
A ray of light passing through the optical centre of the lens travels straight without suffering any deviation. This holds good only in the case of a thin lens.



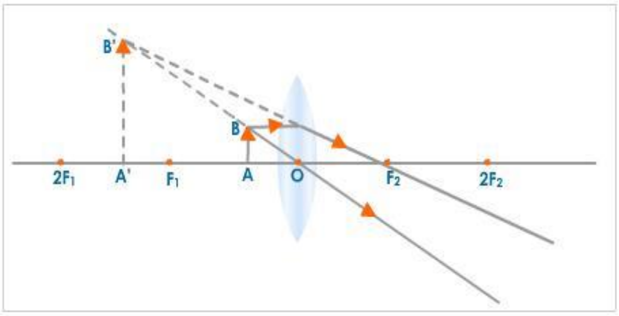
An incident ray parallel to the principal axis after refraction passes through the focus.



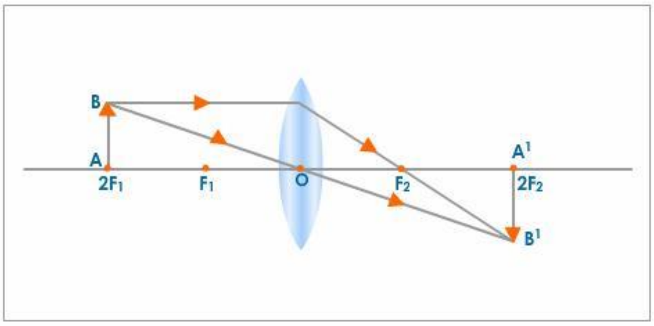
An incident ray passing through the focus of a lens emerges parallel to the principal axis after refraction.



When the Object is Placed between F_1 and O

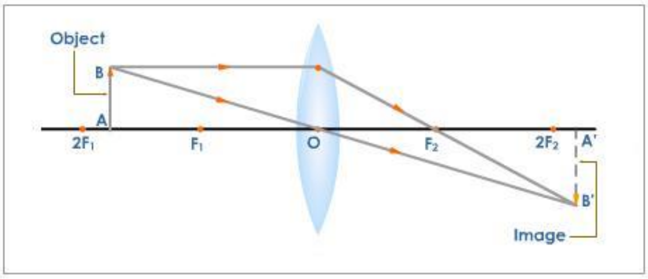


The image is:
Formed behind the object
Virtual
Erect
Magnified
When the Object is placed at $2F_1$



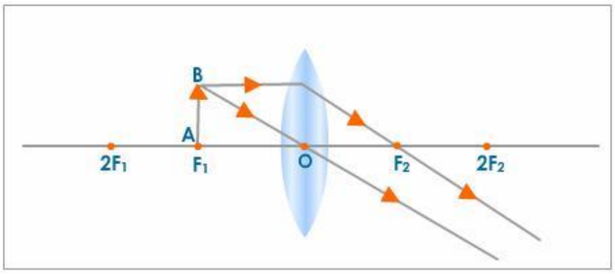
The image is:
Formed at $2F_2$
Real
Inverted
Same size as the object

When the Object is placed Between F_1 and $2F_1$



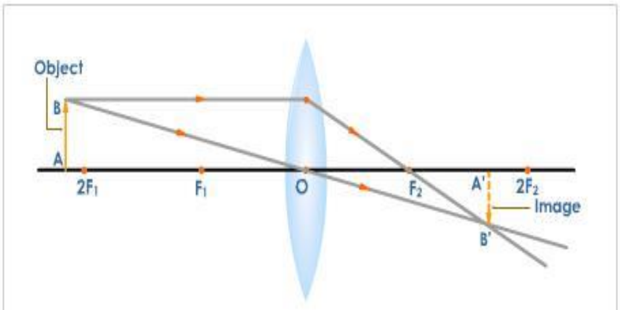
The image is:
Formed beyond $2F_2$ Real Inverted Magnified

When the Object is placed at F_1



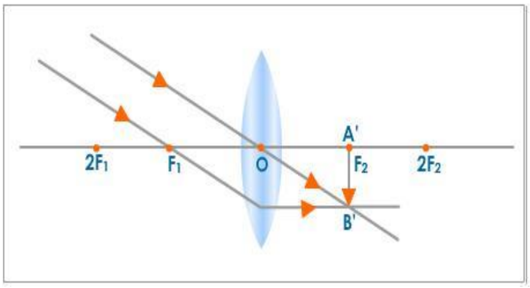
The image is: formed at infinity real inverted magnified

When the Object is placed beyond $2F_1$



The image is: formed between F_2 and $2F_2$ real inverted diminished

When the Object is placed at Infinity
When the object is at infinity, the rays coming from it are parallel to each other.



The image is: formed at F_2 inverted real highly diminished

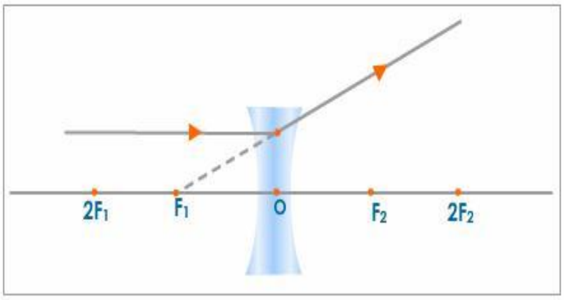
The table gives at a glance the position, size and nature of the image formed by a convex lens corresponding to the different positions of the object and also its application.

Position of the object	**Position of the image**	**Nature of the image**	**Size of the image**	**Application**
Between O and F_1	On the same side of the lens	Erect and virtual	Magnified	Magnifying lens (simple microscope), eye piece of many instruments
At $2F_1$	At $2F_2$	Inverted and real	Same size	Photocopying camera
Between F and $2F_1$	Beyond $2F_2$	Inverted and real	Magnified	Photographic camera, terrestrial telescopes, Photocopier used for replication
At F_1	At infinity	Inverted and real	Magnified	Search lights
Beyond 2F1	Between F_2 and $2F_2$	Inverted and real	Diminished	objective lens of a telescope
At infinity	At F2	Inverted and real	Diminished	photographic camera

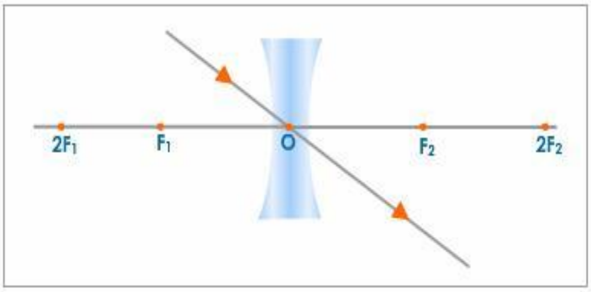
Convex lens is also used in spectacles the correct the eye defect hypermetropia.

Formation of Image by a Concave Lens

An incident ray of light coming from the object parallel to the principal axis of a concave lens after refraction appears to come from its focus.

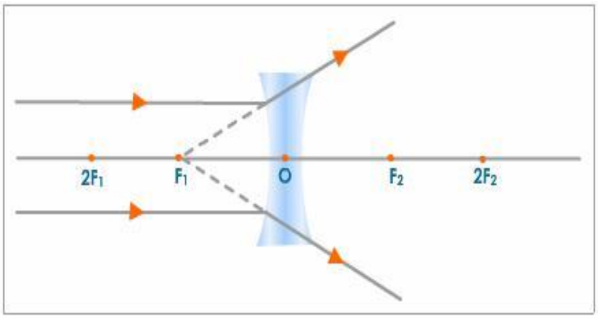


An incident ray of light passing through the optical centre comes out of the lens without any deviation.



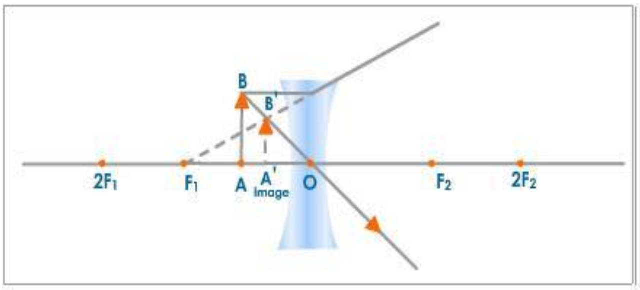
A concave lens always gives a virtual, erect and diminished image whatever may be the position of the object. Let us now draw ray diagrams to show the position of the images when the object is placed - at infinity and between O and F_1 and Any position between infinity and O.

When the Object is at Infinity



The image is: formed at F_1 erect virtual diminished

When the Object is placed at any Position between O and infinity



The image is: formed between O and F_1 erect virtual diminished

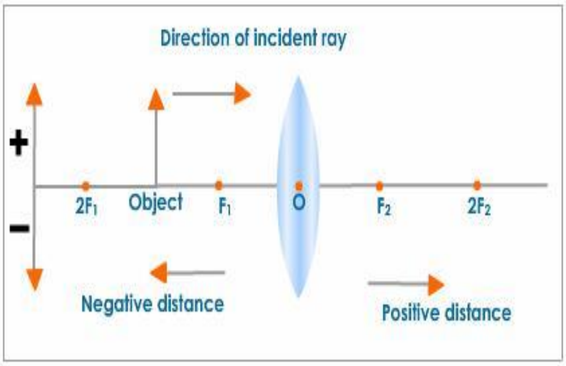
Uses of concave lens

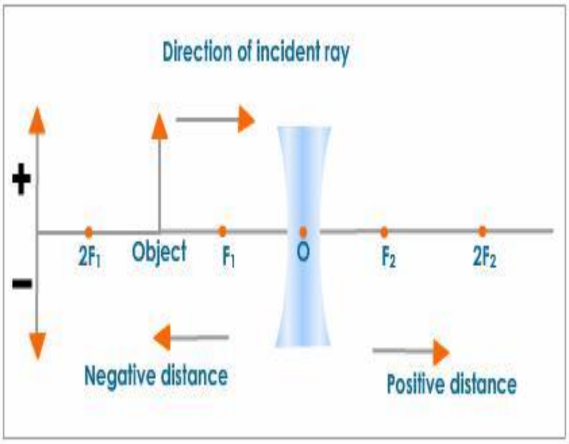
It is used in spectacles for correcting myopia.

Along with convex lens it is used to overcome defects like chromatic aberration and spherical aberration (the failure of rays to converge at one focus because of a defect in a lens or mirror).

Sign Convention for Lenses

Following sign convention is used for measuring various distances:





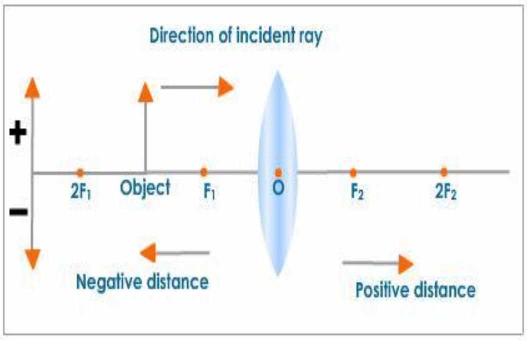
- All distances on the principal axis are measured from the optical centre.
- The distances measured in the direction of incident rays are positive and all the distances measured in the direction opposite to that of the incident rays are negative.
- All distances measured above the principal axis are positive. Thus, height of an object and that of an erect image are positive and all distances measured below the principal axis are negative.

***Note*:**

The rules are same as in case of spherical mirrors.

The following table gives the sign convention for lenses:

Following sign convention is used for measuring various distances:



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Note:
The rules are same as in case of spherical mirrors.
The following table gives the sign convention for lenses:

Type of lens	U	V	V	f	f	Height of the image (h_I)	Height of the image (h_I)	Height of the object Ho
		Real	Virtual	Real	Virtual	Real	Virtual	
Convex	-	+	-	+	No virtual focus	-	+	+
Concave	-	No real image is formed	-	No real focus	-	No real is formed	+	+

Lens Formula
The relationship between distance of the object (u), distance of the image (v) and focal length (f) of the lens is called lens formula or lens equation.
$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ -------- Lens formula
This lens formula is applicable to both convex and concave lenses.
Note:
Points to be remembered while using the lens formula. The values of the known parameters should be used with their proper sign as per the sign convention. No sign should be assigned to the unknown parameter during calculations.

Magnification
Magnification is the ratio of the size of the image (h_I) to the size of the object (h_o)

$$i.e. m = \frac{size\ of\ the\ image}{size\ of\ the\ object} = \frac{h_I}{h_O} = \frac{v}{u}$$

Magnification produced by a lens can be equal to one, greater than one or less than one depending upon the size and nature of the image.
Case I
When, height of the image (h_I) = height of the object (h_o)

$$m = \frac{h_I}{h_o} = 1$$

Thus, when the magnification is one, the size of the image is equal to the size of the object.

Case II

When $h_I > h_o$

$m = \frac{h_I}{h_o} > 1$. The image is magnified

Case III

$m = \frac{h_I}{h_o} < 1$. The image is diminished

For both type of lenses, the height of the object is always positive, while the height of the image may be + or - depending upon its nature.

As per sign convention for lenses, the height of an inverted and real image is negative and hence the magnification of a lens is negative when it produces an inverted and real image. For an erect and virtual image, the height of the image is positive. So, the magnification is positive when an erect and virtual image is formed.

Power of a Lens

Whenever a ray of light passes through a lens (except when it passes through the optical centre) it bends. The bending of light rays towards the principal axis is called convergence and bending of light rays away from the principal axis is called divergence. The degree of convergence or divergence of a lens is expressed in terms of its power. A lens of short focal length deviates the rays more while a lens of large focal length deviates the rays less. Thus power of a lens is defined as the reciprocal of its focal length in meters.

Power of a lens = $\frac{1}{Focallength\ in\ metres}$

The unit of power is dioptre

1 dioptre = $\frac{1}{metre}$

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

If there is convex lens of power 1 D then its focal length is equal 1 meter.

The power of a convex lens is positive and concave lens is negative.

If the focal lengths of the individual lenses f_1 f_2 are f_1, f_2 .... then the focal length of the equivalent lens is given by-

$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}\ or\ F = \frac{f_1 f_2}{f_1+f_2}$

In terms of the power of the lenses $P = P_1 + P_2$......

Dispersion and Scattering of light

Newton's Experiment - Dispersion of Light

Sir Isaac Newton, while studying the images of heavenly bodies formed by a lens, found that the images were coloured at the edges. In 1665, to investigate this, he performed an experiment using a prism. Newton darkened his room at Trinity College, Cambridge and allowed a beam of sunlight to pass through a small circular hole in the shutter forming a white circular patch on the opposite wall. He then placed a triangular prism in the path of the beam of light and observed that the white light was split into seven colours and that the seven colours resembled the colours of a rainbow namely violet, indigo, blue, green, yellow, orange and red (VIBGYOR).

This process of splitting of white light into its constituent colours when it is passed through a transparent medium is known as **Dispersion**.

The band of colours obtained due to the dispersion of white light is referred to as a spectrum.

From the above experiment Newton concluded that white light consists of a mixture of seven different colours.

Tracing the Path of Light through a Prism

Let us now trace the path of light through a prism.

Place a prism on a white sheet of paper with the triangular face on the sheet and trace its boundary ABC.

Fix two pins T and S on one side.

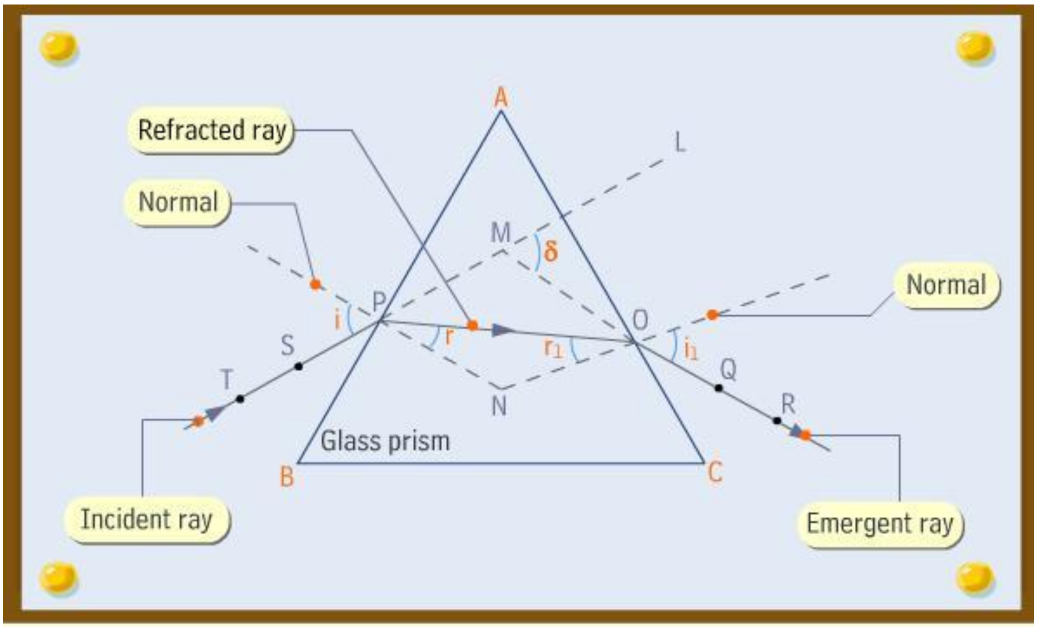
Place the prism on the boundary ABC.

Looking through the other side fix two more pins Q and R in such a way that the all four pins appear to be in the same line.

Remove the pins and mark their positions.

Join TS and RQ and extend them to meet the faces of the prism at P and O respectively.

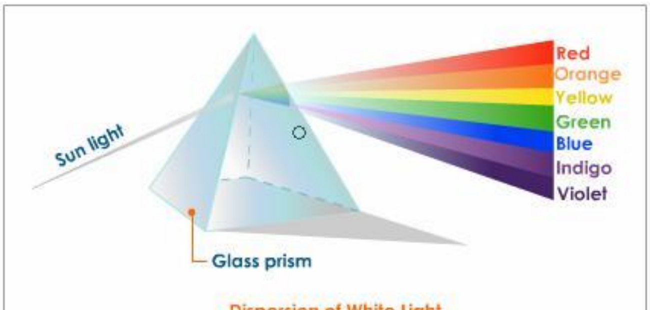
Join PO.



TP represents the incident ray
PO represents the refracted ray
And OR represents the emergent ray which is bent towards the base.
Let PN and ON be the normal at the points P and O respectively.
And let i be the angle of incidence and r the angle of refraction.
If the incident ray TP is extended forward and the emergent ray RO backwards, they meet at M, forming the angle OML.
Measure the angle OML.
This angle is called the angle of deviation.
Angle of deviation is the angle through which an incident ray deviates.
Repeat this for different values of angle of incidence.

Dispersion of White Light by a Glass Prism

Even though all colours of the visible spectrum travel with the same speed in vacuum, the speed of the colours of the visible spectrum varies when they pass through a transparent medium like glass and water. That is, the refractive index of glass is different for different colours.



Dispersion of White Light

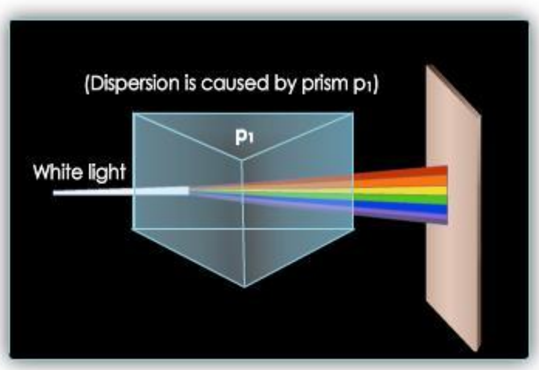
When a polychromatic light (multi coloured or light containing more than one wavelength) like white light is incident on the first surface of the prism it gets refracted. But each constituent of the white light gets refracted through a different angle, i.e., white light gets dispersed. When these colours are incident on the second surface of the prism they again undergo refraction (they get refracted from a denser to rarer medium) and the colours are separated further. Thus a beam of white light incident on a prism splits into its constituent colours to form a spectrum.
Each constituent of the white light is deviated towards the base of the prism. Violet colour suffers the maximum deviation and red the least. The spectrum obtained is impure as the colours in the spectrum do not have any sharp boundaries i.e., each colour merge gradually into the next

Recomposition of White Light

In order to get white light from the dispersed light the prisms are arranged as shown in the diagram. Recombination of the seven colours of the dispersed white light to get white light is known as recomposition of white light.

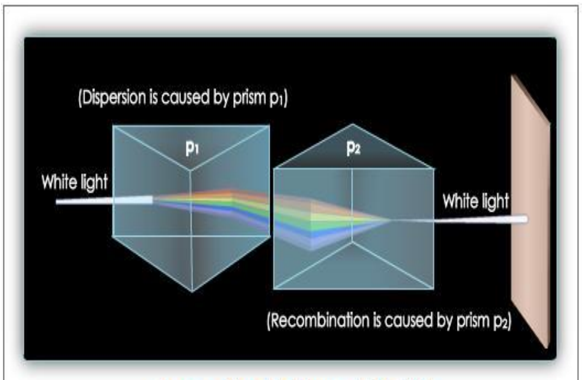
Experiment to Show the Recomposition of White Light

Place a prism (P_1) on a table and a screen behind it. Allow a narrow beam of light to be incident on the prism (P_1). The white light gets dispersed and we obtain a band of seven colours on the screen.



Dispersed White Light

Now remove the screen and place another prism P_2 of the same material in the opposite direction. Place a white screen behind P_2. A spot of white light appears on the screen. Thus the second prism has recombined the dispersed light.



Recomposition of the Dispersed White Light

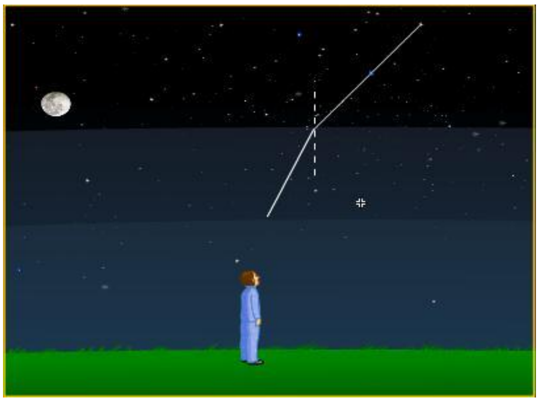
Formation of a Rainbow

The small droplets of rain water which remain suspended in air just after the rains act like a prism. When sunlight passes through these drops of rainwater, it gets dispersed and we see the seven colours of the rainbow.

Atmospheric Refraction

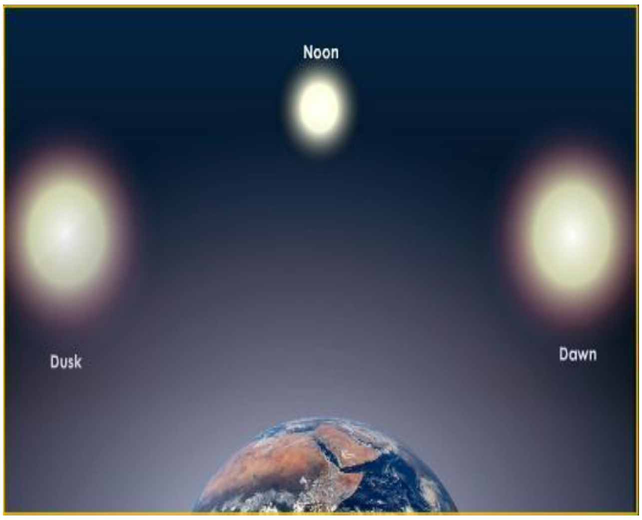
Atmospheric refraction is the shift in apparent direction of a celestial object caused by the refraction of light rays as they pass through Earth's atmosphere. The twinkling of stars and variation in size of the Sun are due to atmospheric refraction of starlight.

Twinkling of Stars



The rays of light coming from the stars travel through the layers of air of varying densities. These rays get refracted continuously and they bend towards the normal as the refraction is from a rarer to a denser medium. The movements of air and convection currents cause a change in the density of the layers of air. As a result, the position of the image of the star goes on changing after every short interval. These different positions of the images formed at short intervals of time give the impression that the star is twinkling

Variation in the Size of the Sun

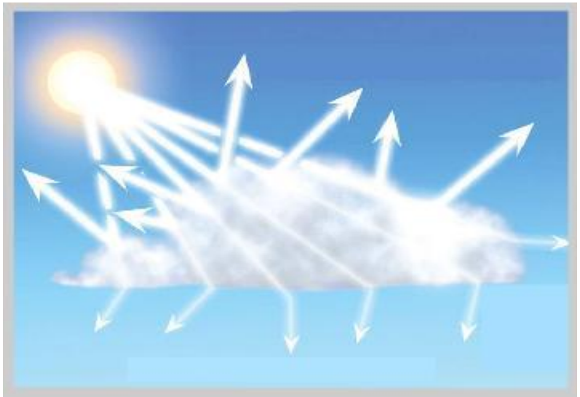


At dusk or dawn the Sun appears to be larger than at noon. This is because when the sun is near the horizon the rays of light coming from the sun have to pass through layers of air of increasing density.

Due to continuous bending of light the sun appears to be larger. At noon, the sun appears to be smaller than at dusk or dawn. This is because the rays of light that fall normally on the surface of the earth do not get refracted.

Scattering of Light

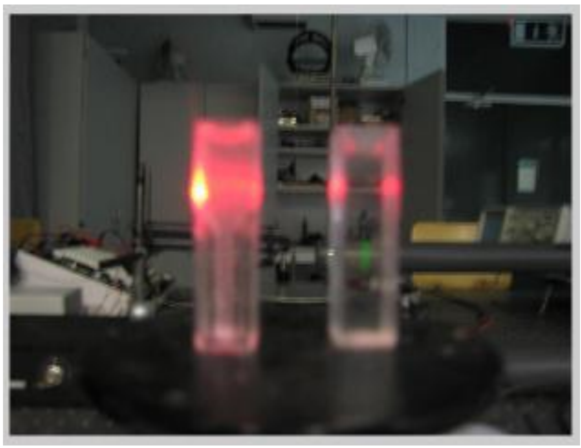
Scattering is a general physical process whereby some forms of radiation, such as light or moving particles, for example, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which it passes.



A large number of molecules are present in the earth's atmosphere. These molecules scatter light in various directions. The air is composed of many tiny particles including dust and water vapour. As the sunlight passes through the air, the shorter blue light waves are reflected and refracted by the particles while the other coloured light waves being longer are unaffected and are not reflected by the water vapour or dust in the air. Blue, therefore, is scattered the most and this explains the bluish colour of the sky. At sunset or sunrise, the sunrays have to cover large atmospheric distances to reach us and most of the blue light gets scattered and doesn't reach us. The sky as well as the sun, at sunrise and sunset, therefore looks reddish.

Tyndall Effect

The earth's atmosphere is a heterogeneous mixture of minute particles. These particles include smoke, tiny water droplets, suspended particles of dust and molecules of air. When beam of light strikes such air particles, the path of the beam becomes visible. Similarly the path of a beam of light passing through a true solution is not visible. However, its path becomes visible through a colloidal solution where the size of the particles is relatively larger. The phenomenon of scattering of light by the colloidal particles gives rise to Tyndall effect.



Tyndall effect is the visible scattering effect of light on particles path of a beam of light passing through a colloid system.