CHAPTER 9 LIGHT

REFLECTION AND REFRACTION

Important terms

Light is a type of energy that can be converted into other types of energy. Light does not require a physical medium to propagate.

Light's velocity in air or vacuum is $3 \times 10^8\ m / s$.

Rectilinear propagation of light

Light travels in a straight line in a homogeneous transparent medium, which is known as rectilinear propagation of light.

REFLECTION OF LIGHT

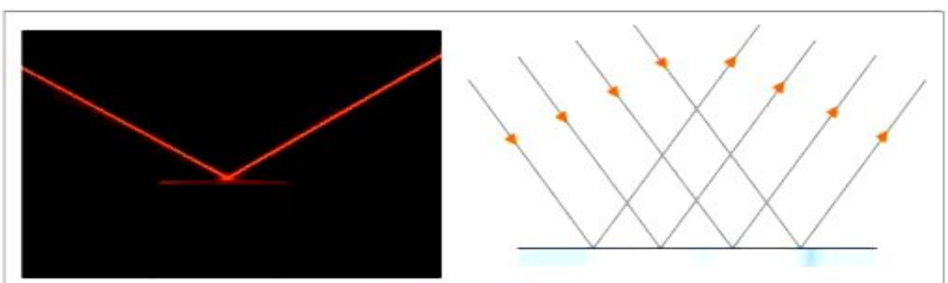
Reflection of light describes the phenomenon by which a ray of light changes its propagation direction when it encounters a boundary between different media through which it cannot pass.

There are two types of reflection of light:

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

Regular reflection

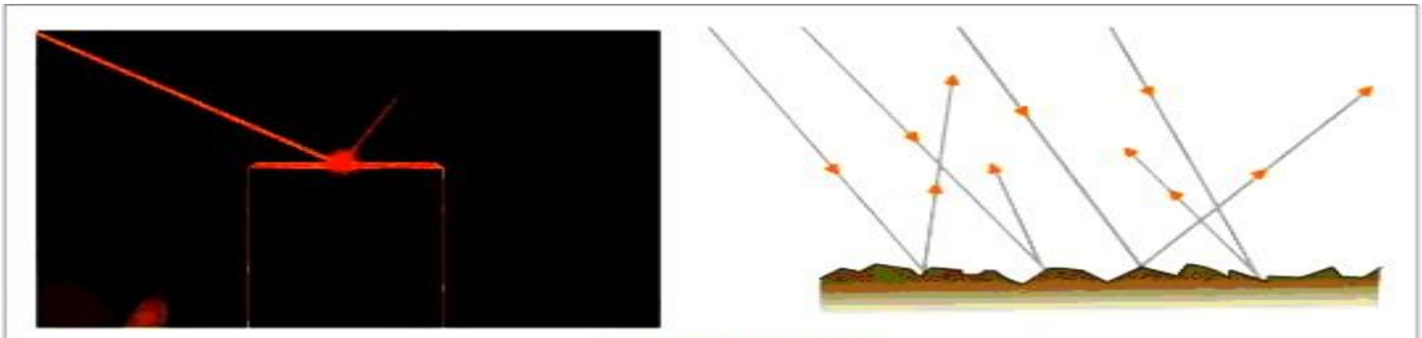
The perfect, mirror-like reflection of light is known as specular or regular reflection. Regular reflections include reflections in mirrors, water surfaces, and highly polished floors.



Specular Reflection

Irregular reflection:

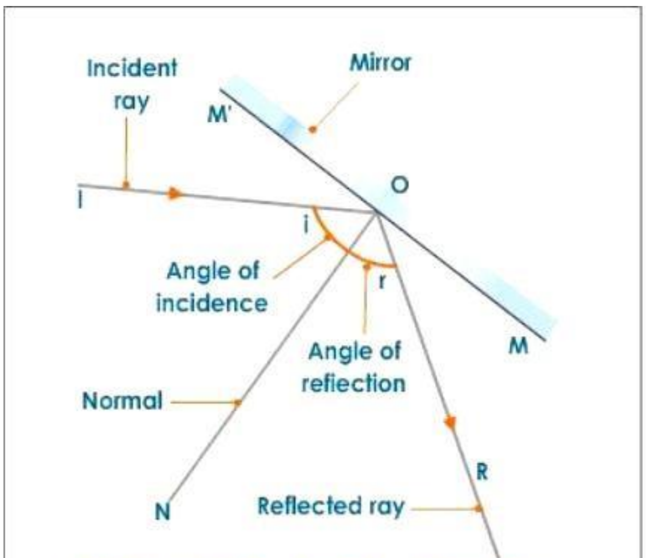
Irregular reflection, also known as diffused reflection, occurs when a ray of light strikes a rough or unpolished wall or wood. In this case, the incident light is reflected in different directions by different parts of the surface. There is no definite image formed in such cases, but the surface becomes visible. It is commonly referred to as light scattering. As a result of the diffused reflection, non- luminous objects become visible



Diffuse Reflection

Reflection of light by a plane surface:

The diagram depicts how a light ray is reflected by a plane surface. Assume mm' is a reflecting surface. When a light ray strikes mm' in the direction IO, it is reflected along the direction OR. The incident ray is denoted by IO, the point of incidence by o, and the reflected ray by OR.



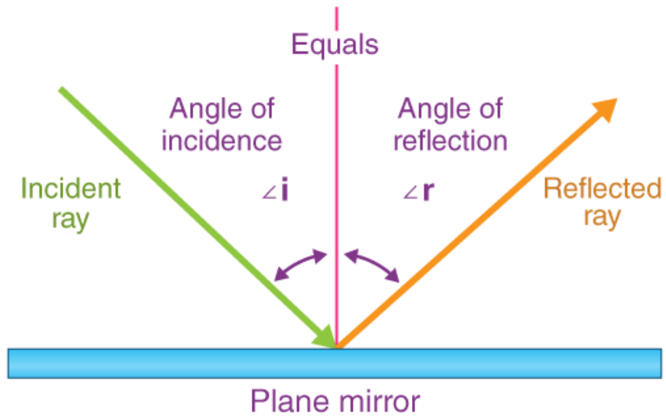
Reflection of a Ray of Light by a Plane Mirror

Let on be the perpendicular normal to the surface mm' at the point of incidence. The angle of incidence, denoted by the letter i is the angle formed by the incident ray with the normal at the point of incidence. The angle of reflection 'r' is the angle formed by the reflected ray and the normal at the point of incidence. A reflecting surface is something like a mirror.

Laws of reflection:

The laws of reflection are observed to apply to any plane surface's reflection.

- **the incident ray, reflected ray, and normal at the point of incidence all lie in the same plane, according to the laws of reflection.**
- **The angle of incidence equals the angle of reflection.**



Difference between real image and virtual image

Real Image	Virtual Image
Formed when light rays actually meet.	Formed when light rays appear to meet.
Can be obtained on screen.	Can't be obtained on screen.
Inverted	Erect
Example: image formed on cinema screen and formed by concave mirror.	Example: image formed by plane mirror or convex mirror.

Nature of image formed by a plane reflecting surface:

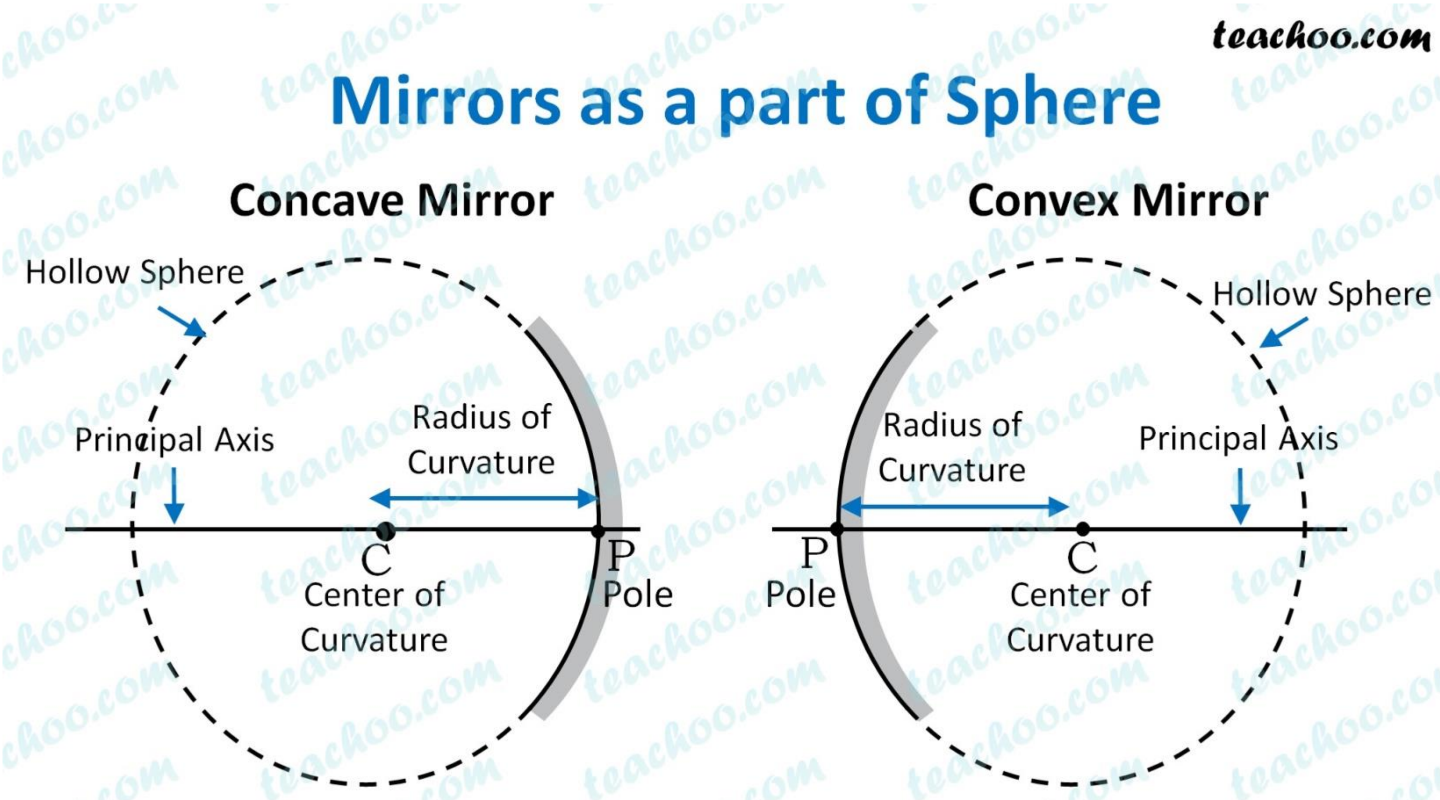
- Virtual and erect
- Size of image is equal to size of object
- The image is formed as far behind as the object is in front of it
- Laterally inverted

Spherical mirrors:

- A spherical mirror is a mirror with a polished, reflecting surface that is part of a hollow sphere of glass or plastic. One of the two curved surfaces of a spherical mirror is coated with a thin layer of silver, followed by a coat of red lead oxide paint. As a result, one side of the spherical mirror is opaque, while the other is a highly polished reflecting surface. The opaque side of a mirror is always shaded in a diagram.

  The spherical mirror is classified as follows based on the nature of its reflecting surface:
- **Concave mirror**
  A concave mirror is a spherical mirror with its reflecting surface oriented toward the center of the sphere of which it is a part.

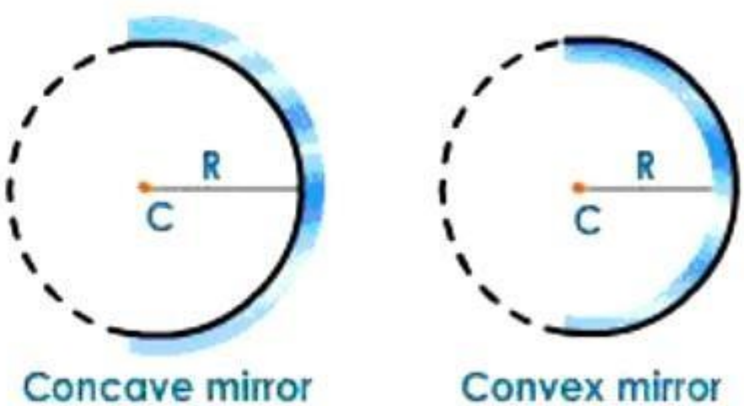
- **Convex mirror**
  A convex mirror is a spherical mirror with a reflecting surface that is angled away from the center of the sphere of which it is a part.



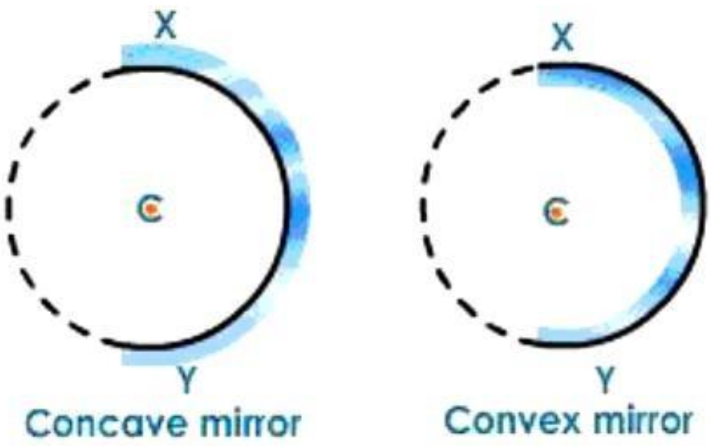
Parts of spherical mirror

Centre of curvature:
The centre of curvature is the center of the sphere, of which the spherical mirror is a part. It is represented by the letter c.

Radius of curvature: the radius of the sphere, of which the mirror is a part, is defined as radius of curvature. It is denoted by the letter r



Linear aperture: the distance between the extreme points (x and y) on the mirror's periphery is defined as the linear aperture

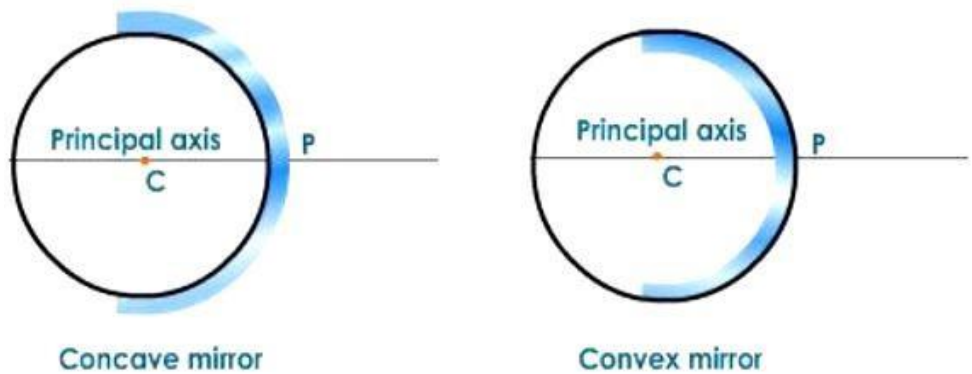


XY is the Aperture

Pole: the pole is the spherical mirror's aperture's midpoint. It is denoted by the letter p.

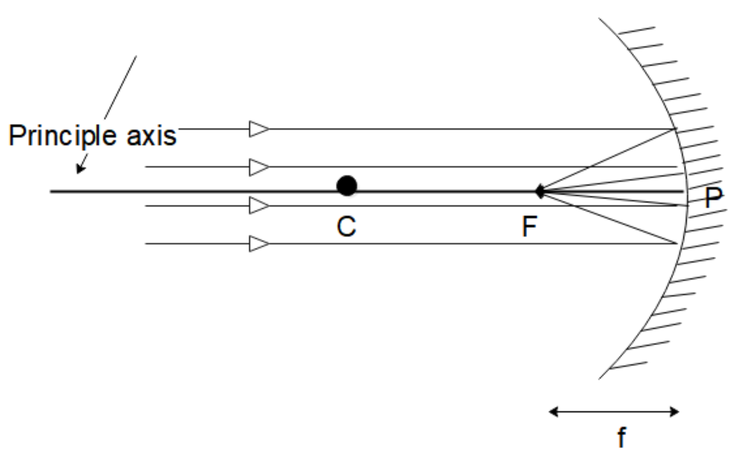
Principal axis

The principal axis of a spherical mirror is the straight line that passes through the pole and the center of curvature.

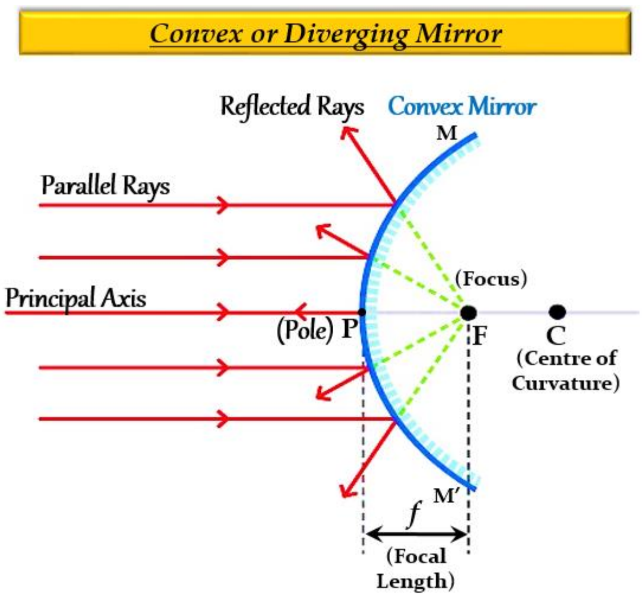


Normal: the normal at any point on the spherical mirror is the straight line formed by connecting that point to the mirror's center

Principle focus: the principal focus of a concave mirror is the point where a ray of light parallel to the principal axis will converge to the focal point



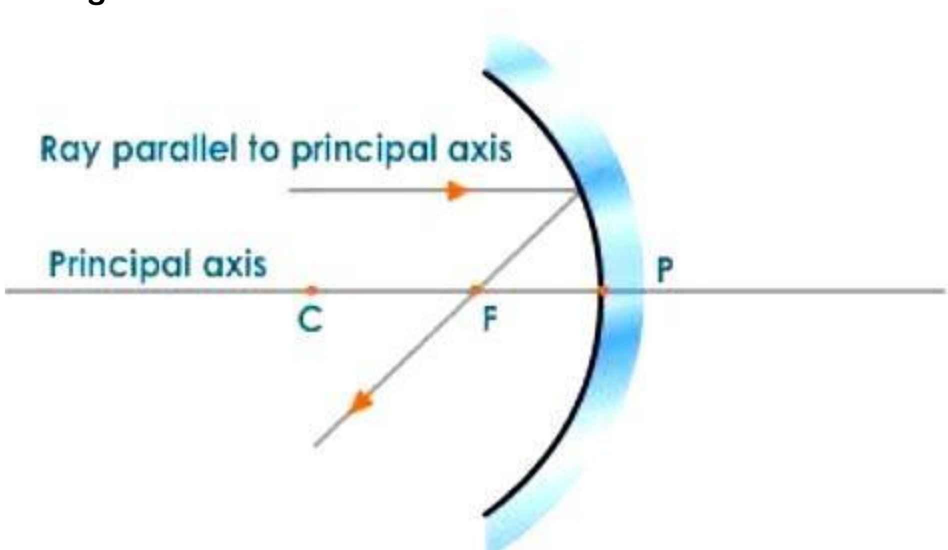
Principle focus (f) of a convex mirror: it is a point on its principal axis from which a beam of light rays, initially parallel to the principal axis, appears to diverge after being reflected from the convex mirror.



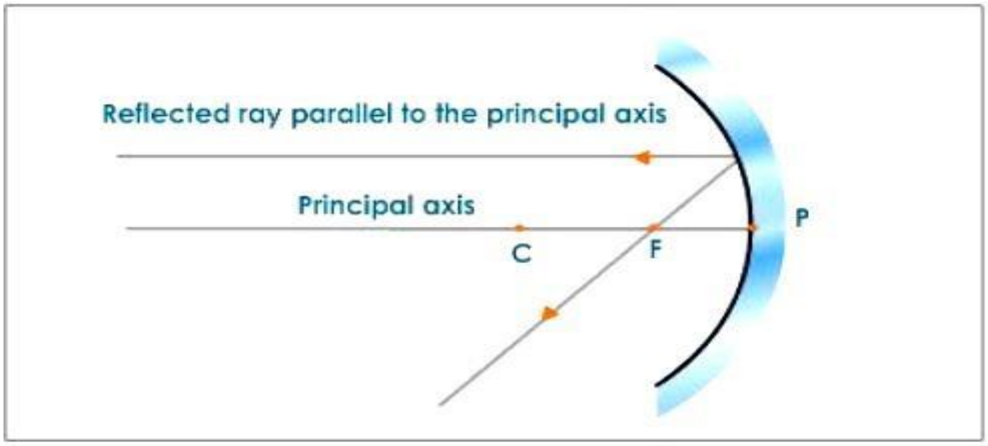
Focal length: the focal length of a mirror is the distance between the pole and the focus. It is symbolized by the letter f.

Rules for Image formation by spherical mirrors:

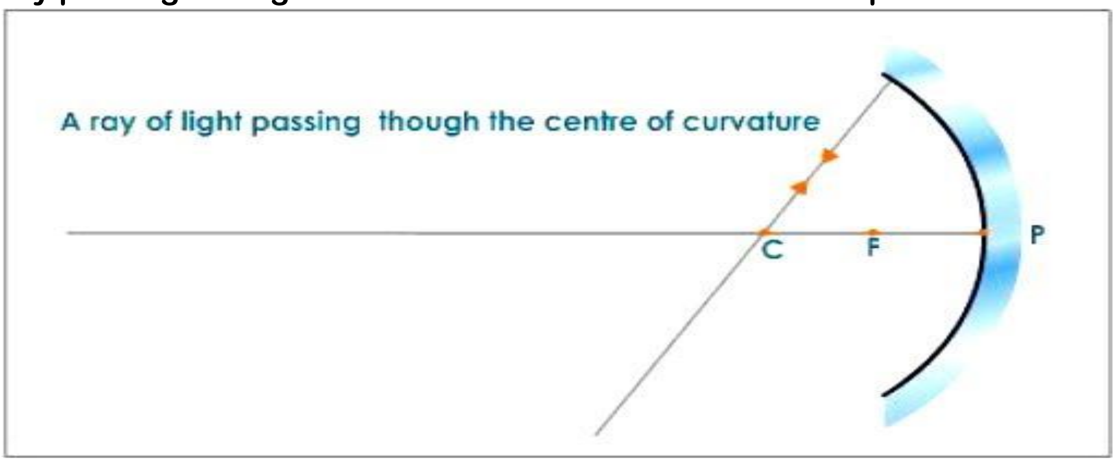
To obtain the image, any two of the following rays can be considered.
After reflection from a concave mirror, a ray of light parallel to the principal axis passes through its focus.



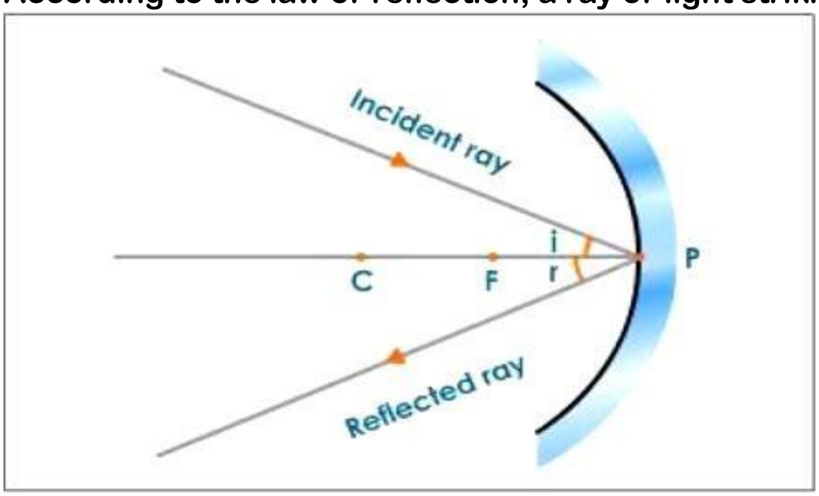
After reflection, a ray of light passing through the focus of a concave mirror emerges parallel to the principal axis.



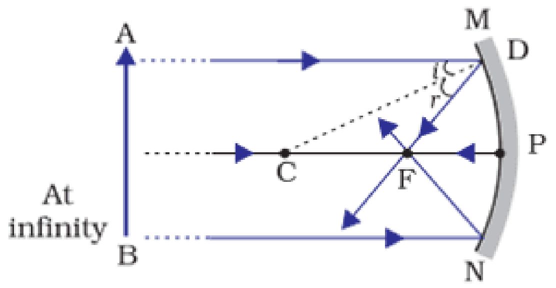
As the ray passing through the center of curvature acts as a normal to the spherical mirror, a ray passing through the center of curvature retraces its path after reflection



According to the law of reflection, a ray of light striking the mirror at its pole is reflected



Formation of image by a concave mirror
When the object is at infinity
When an object is placed at infinity, its rays are parallel to each other
. The image is at f
real& inverted
The image is of point sized



When the object is placed beyond c

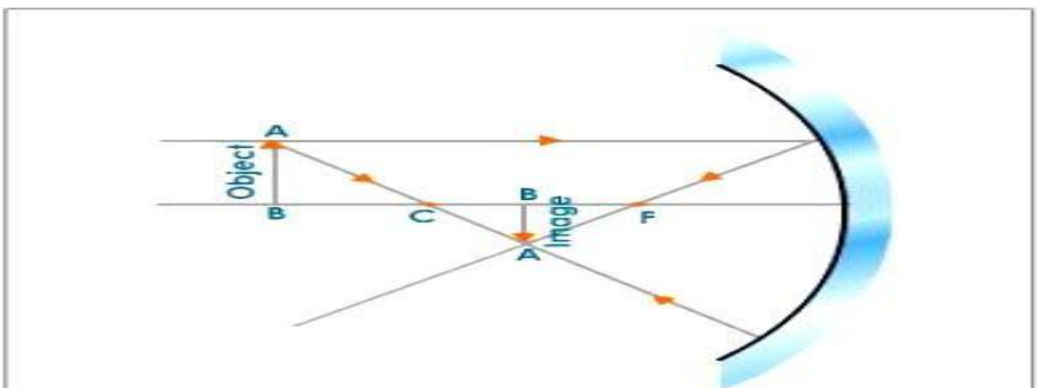
The two rays considered in order to obtain the image are: a ray that passes through the center of the curvature. A ray that runs parallel to the principal axis.

After reflection, the ray passing through the center of curvature retraces its path, and the ray parallel to the principal axis passes through the focus. After reflection, these rays intersect at a point between c and f.

The image is inverted, real, and shrunk. The image is: between c and f

Real inverted

Diminished



When the Object is Placed Beyond C

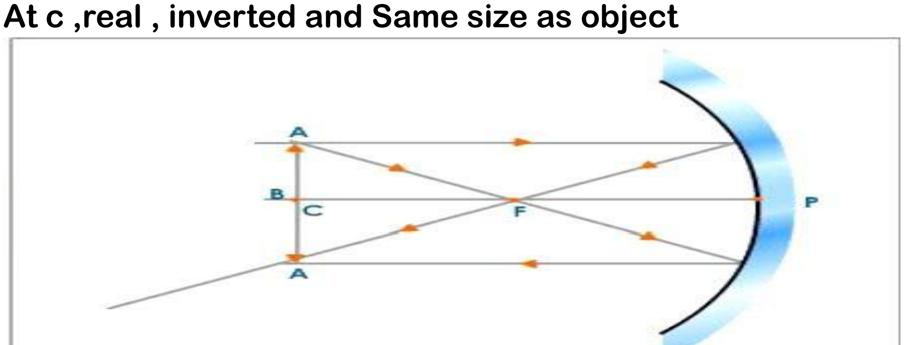
When the object is placed at the centre of curvature

In this section, we will look at two rays, one parallel to the principal axis and the other passing through the focus. After reflection, the ray of light parallel to the principal axis passes through the focus. After reflection, the other ray that passes through the focus emerges parallel to the axis. Following reflection, these rays

Collide at the center of curvature to form an inverted image that is real and the same size as the object.

The image is:

At c ,real , inverted and Same size as object



When the Object is Placed at the Centre of Curvature

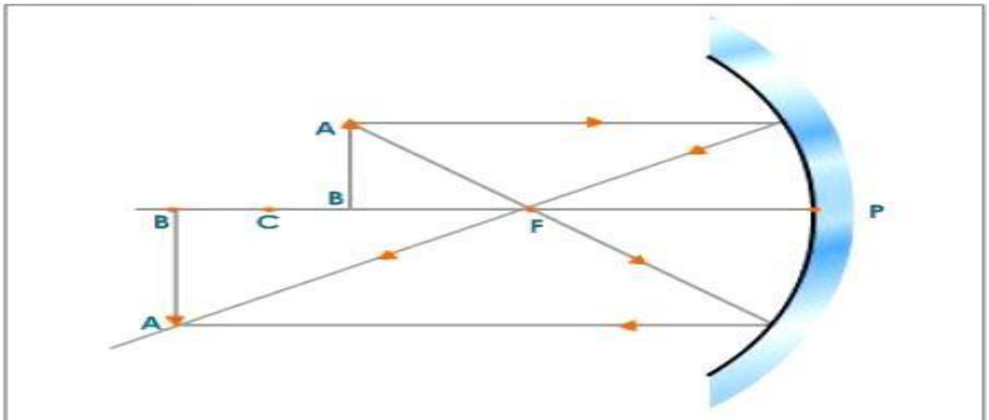
When the object is between c and f

Consider a light ray parallel to the principal axis and another ray passing through the focus. The ray that is parallel to the principal axis passes through the principal focus, and the ray that emerges parallel to the principal axis after reflection. The reflected rays collide at a point beyond c, resulting in a real, inverted, and magnified image. The image is:

Beyond c

Real

Inverted magnified

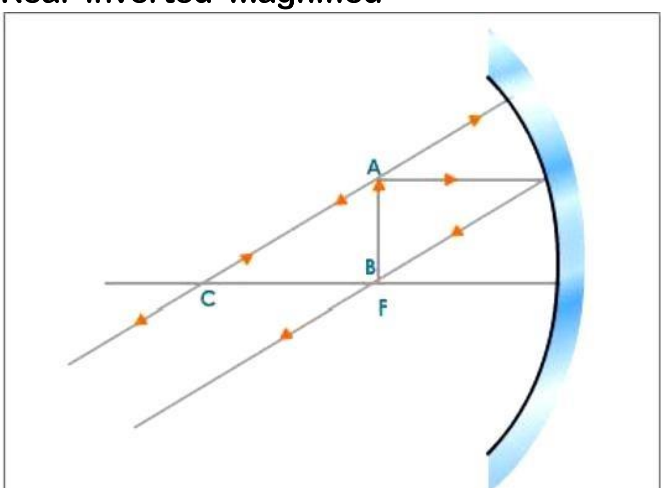


When the Object is Between C and F

When the object is at the focus

Consider a light ray parallel to the principal axis and another ray passing through the center of curvature. The ray parallel to the principal axis passes through the focus, while the ray through the center of curvature retraces its path. The reflected rays are parallel to each other and would only meet at infinity, implying that the image is formed at infinity and is a true, inverted, and enlarged image. The image is at infinity:

Real inverted magnified



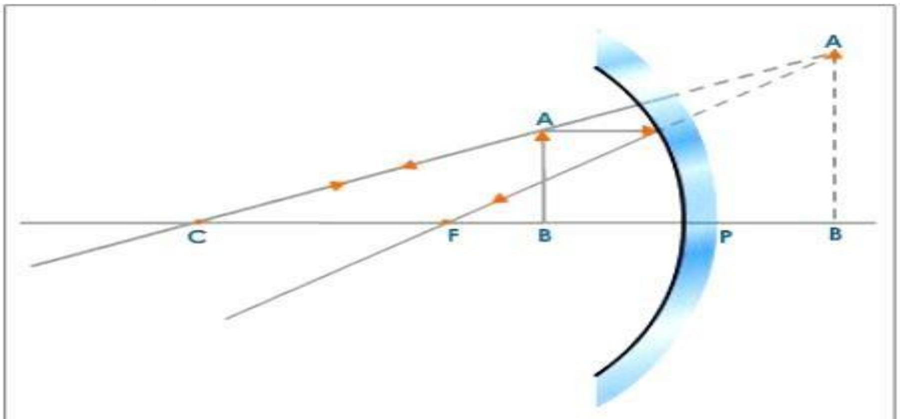
When the Object is at the Focus

When the object is between the pole and the focus

Consider a ray of light parallel to the principal axis and another ray passing through the center of curvature. After reflection, the ray that passes through the center of curvature retraces its path, and the other ray that is parallel to the principal axis passes through the focus. When the reflected rays are extended backwards, these rays appear to meet behind the mirror. The image is erect, virtual, and magnified. The image is:

Behind the mirror virtual

Erect magnified



When the Object is Between the Pole and the Focus

Uses of concave mirrors

Concave mirrors are used to obtain a parallel beam of light in the following applications: as reflectors in car headlights, search lights in torches, and so on. The light source is positioned at the concave reflector's focus for this purpose.

Light is focused on the tooth to be examined by the dentist.

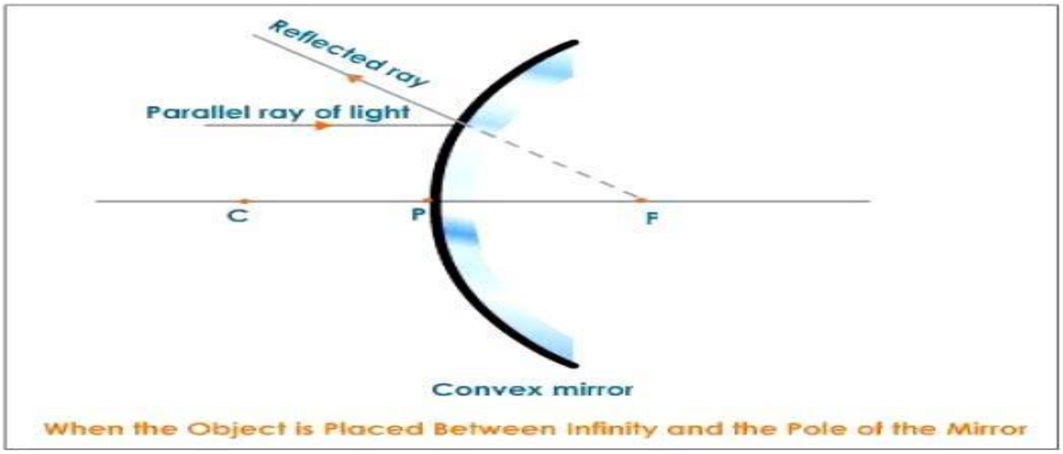
As shaving and make-up mirrors to obtain an enlarged erect image of the face

Solar radiations are concentrated in solar heating devices. The food or substance to be heated is placed in the center of a large concave reflector for this purpose. Sunlight converges on the substance after reflection and heats it.

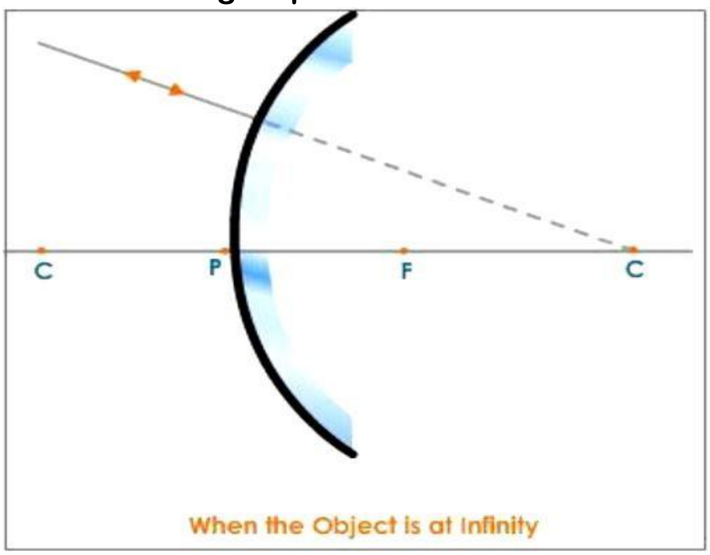
Convex mirror

When creating ray diagrams, the following rays are taken into account.

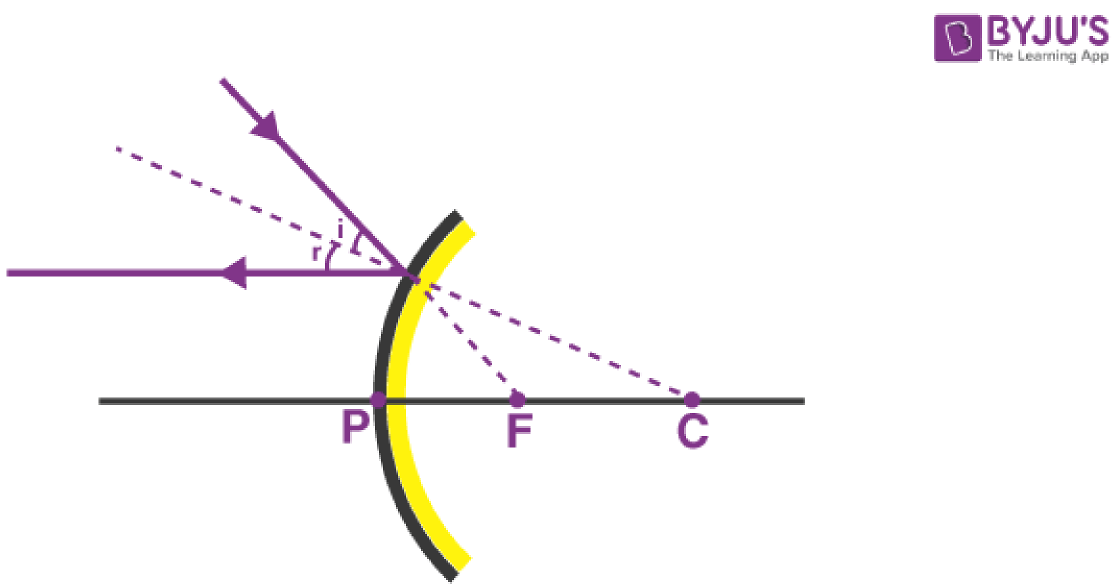
1. After reflection from a convex mirror, a ray of light traveling parallel to the principal axis appears to come from its focus behind the mirror.



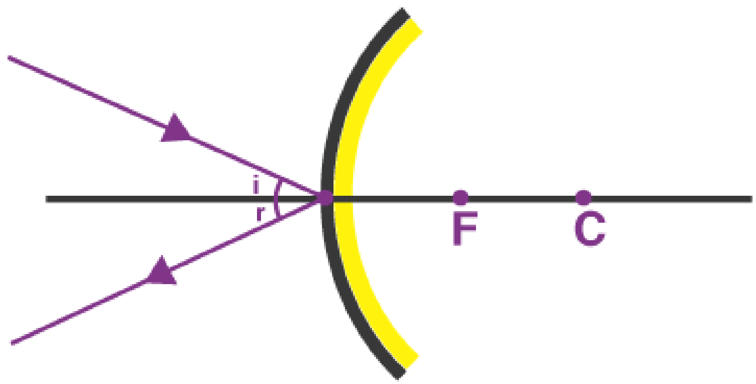
A ray of light traveling towards the mirror's center of curvature hits the mirror at 90* and is reflected along its path.



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

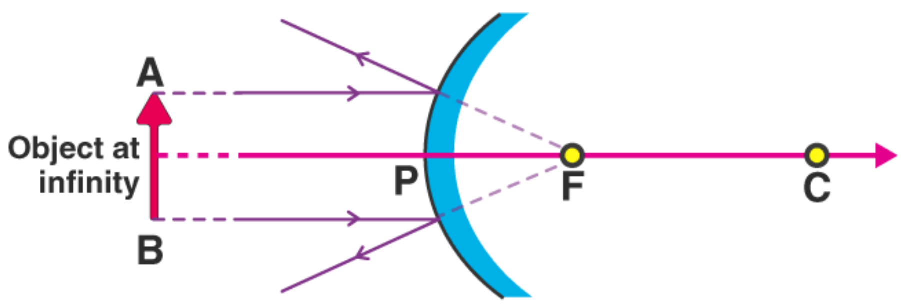


According to the laws of reflection, a ray of light incident obliquely to the principal axis and directed towards the pole of the mirror is reflected.

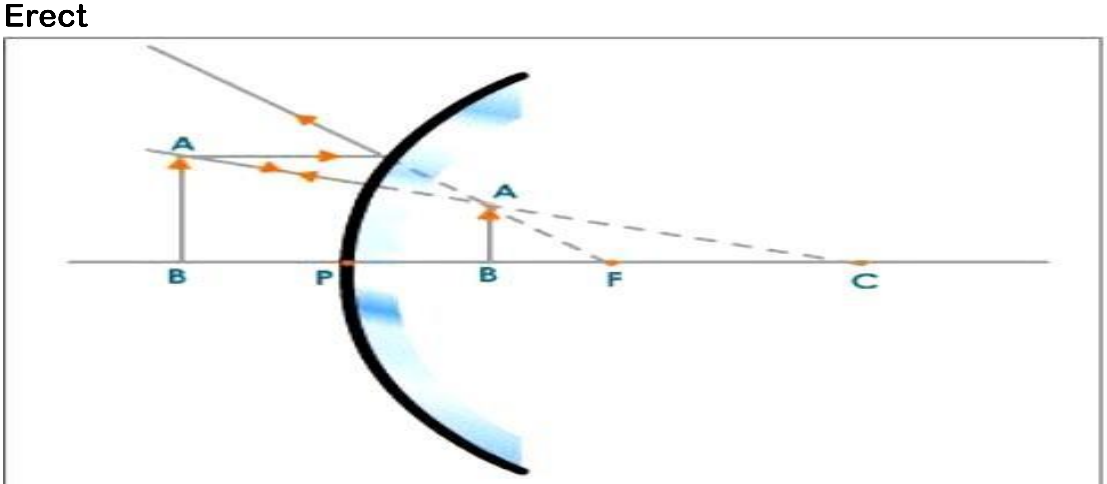


Regardless of the position, a convex mirror always produces a virtual image.
image firmation:

- **When an object is placed at infinity.**



When the object is placed between infinity and the pole of the mirror the image is:
Formed between the pole and the focus
Erect



When the Object is Placed Between P and F

Uses of convex mirror

A rear-view mirror in a car. This convex mirror provides the driver with a clear view of approaching traffic from behind because convex mirrors are curved outwards, providing a wider field of view.

In department stores, there is a vigilance mirror.

Reflectors are used in street lamps to divert light over a large area.

Mirror formula

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

Mirror Equation

Here, u is the object distance, v is the image distance and f is the focal length.

Magnification

The magnification produced by a spherical mirror indicates the extent to which an object's image is magnified in relation to the object size.

Magnification is defined as the ratio of the image's height to the object's height. The letter m is commonly used to represent it.

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

Linear Magnification, m

$$m = \frac{\text{height of image}}{\text{height of object}} = \frac{h'}{h}$$

or

$$m = -\frac{\text{image distance}}{\text{object distance}} = -\frac{v}{u}$$

$$\boxed{m = \frac{h'}{h} = -\frac{v}{u}} \quad \text{or} \quad \boxed{m = \left|\frac{v}{u}\right|}$$

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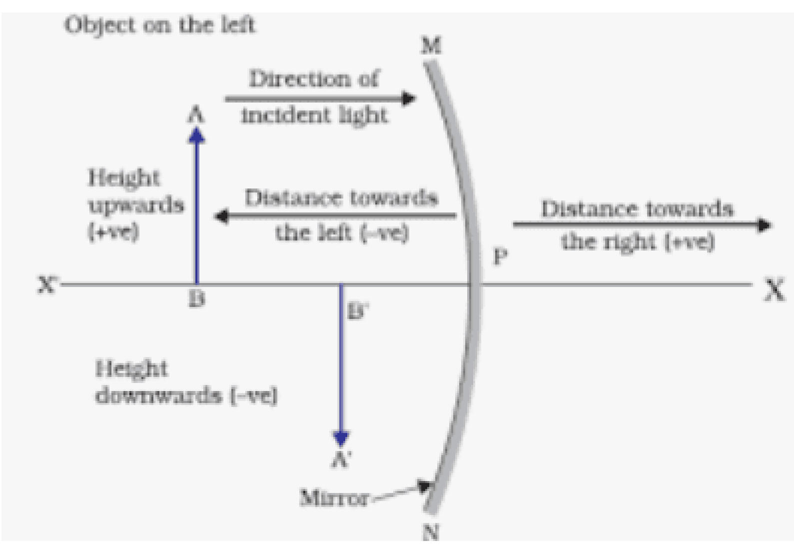
sign convention for ray diagram

Distances measured towards positive x and y axes (coordinate system) are positive, and towards negative, x and y-axes are negative. Keep in mind the origin is the pole (p). Usually, the height of the object is taken as positive as it is above the principal axis, and the height of the image is taken as negative as it is below the principal axis.

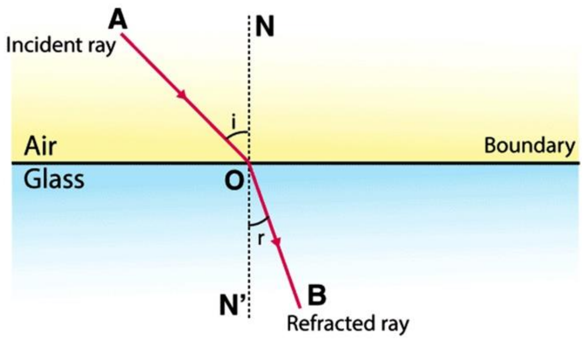


REFRACTION OF LIGHT:

The bending of light when it travels from one medium to another. This phenomenon is called refraction of light.
Cause of refraction:

The refraction of light (or change in the direction of path of light in other medium) occurs because light travels with different speeds in different media. When a ray of light passes from one medium to another, its direction (except for $\angle i=0_0$) changes because of the change in its speed.

Parts of refraction:
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:

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

2. the ratio of the sine of the angle of incidence i to the sine of the angle of refraction is constant for the pair of given media. This constant is called the refractive index of the second medium w.r.t. The first medium. This law is also called snells law

$$n_{21} = \frac{\text{Sin}\,(i)}{\text{Sin}\,(r)}$$

$$= \frac{v_1}{v_2}$$

Refractive index

Refractive index is defined as ratio of speed of light in medium 1 to speed of light in medium 2.

Refractive Index and Speed of Light

$$\text{Refractive index of Medium 2 with respect to Medium 1} = \frac{\text{Speed of Light in Medium 1}}{\text{Speed of Light in Medium 2}}$$

$$n_{21} = \frac{\text{Speed of Light in Medium 1}}{\text{Speed of Light in Medium 2}}$$

Opposite is also true

$$\text{Refractive index of Medium 1 with respect to Medium 2} = \frac{\text{Speed of Light in Medium 2}}{\text{Speed of Light in Medium 1}}$$

$$n_{12} = \frac{\text{Speed of Light in Medium 2}}{\text{Speed of Light in Medium 1}}$$

Absolute Refractive Index

We know that

$$\text{Refractive index of Medium 2 with respect to Medium 1} = \frac{\text{Speed of Light in Medium 1}}{\text{Speed of Light in Medium 2}}$$

If Medium 1 is vacuum,

our formula becomes

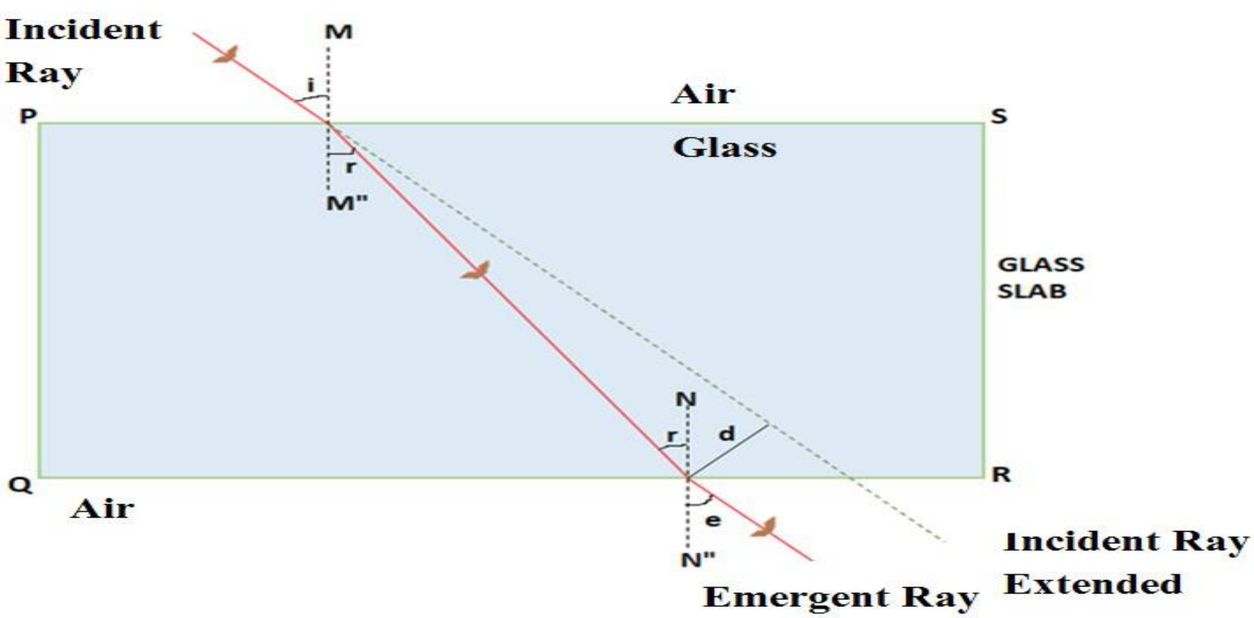
$$\text{Refractive index of Medium 2 with } \textbf{respect to Vacuum} = \frac{\text{Speed of Light in Vacuum}}{\text{Speed of Light in Medium 2}}$$

$$\textbf{Absolute Refractive index of Medium 2} = \frac{\text{Speed of Light in Vacuum}}{\text{Speed of Light in Medium 2}}$$

Refractive index 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



Lenses

A lens is a portion of a transparent refracting medium bounded by two generally spherical or cylindrical surfaces, or one curved and one plane surface. Convex lenses and converging lenses are the two types of lenses.

Convex lens

A convex lens is one that is thicker in the center and thinner at the edges. A convex lens has at least one surface that bulges out in the middle. Convex lenses are classified as bi-convex or double-convex, plano - convex lens and concavo - convex lens based on their shape.

Concave lens

A concave lens is one that is thinner in the center and thicker at the edges. These lenses, like convex lenses, are classified as:

Bi-concave plano - concave

Convexo - concave

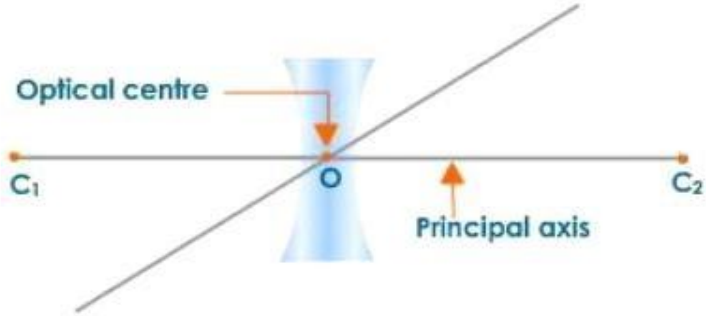
Terminology used in optics

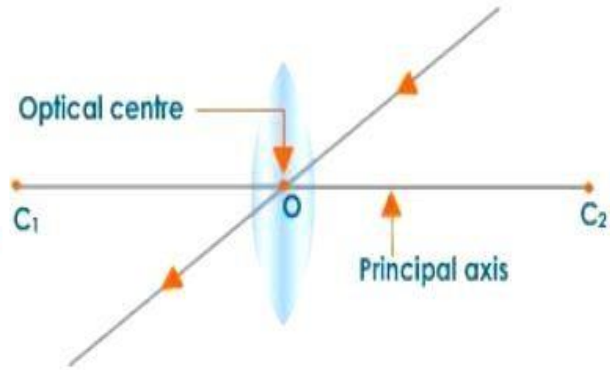
Optical centre

It is represented by the letter o. A ray of light passing through the optical center of a lens does not deviate in any way. It is also known as an optic center.

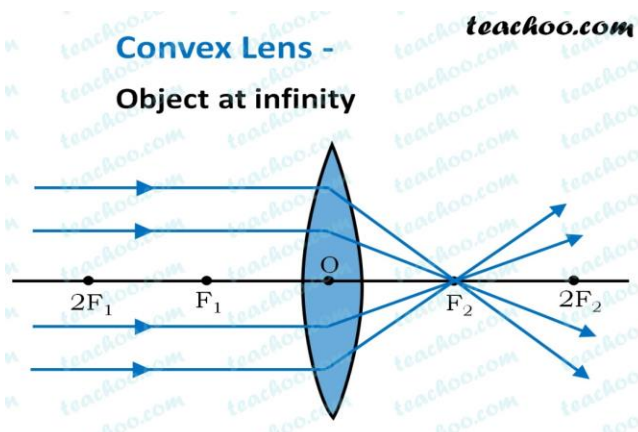
Principal axis

The principal axis is the straight line that connects the centers of curvature of a lens's two curved surfaces.





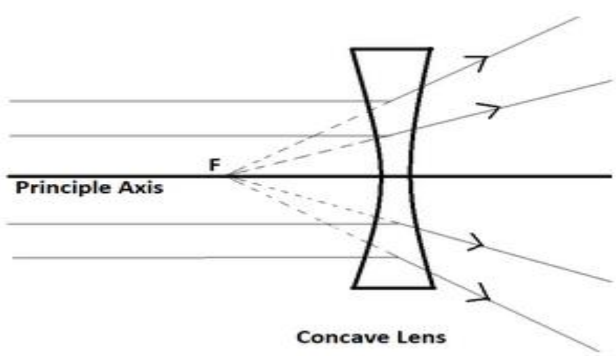
Principal focus of convex lens



a principle focus of a convex lens is defined as the point on the principal axis on which the light rays coming parallel to the principal axis converge after getting refracted from the convex lens.

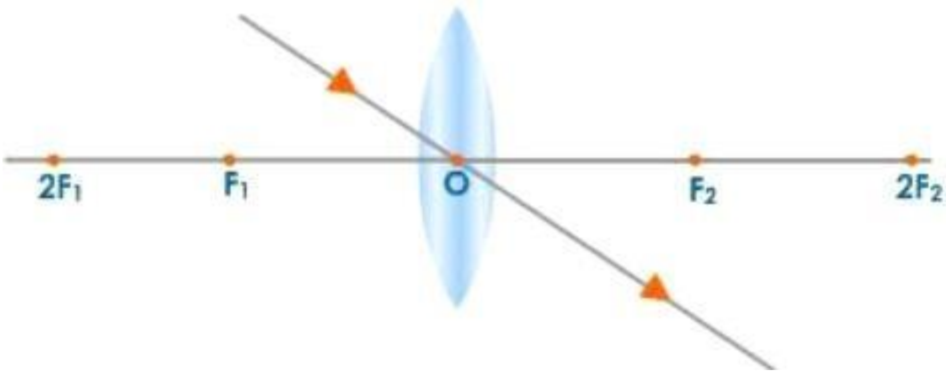
Principle focus of concave lens:

The principal focus of a concave lens is that point on the principal axis on which the rays of light that get diverged after refraction through the lens, when produced backwards, tend to meet. The refracted rays appear to diverge from the principal focus of a concave lens.

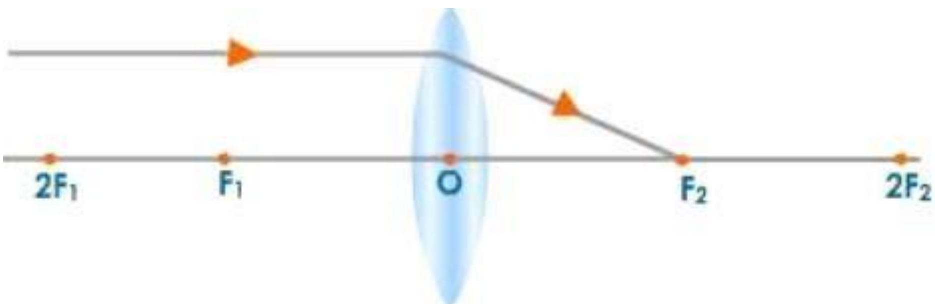


Formation of image by a convex lens

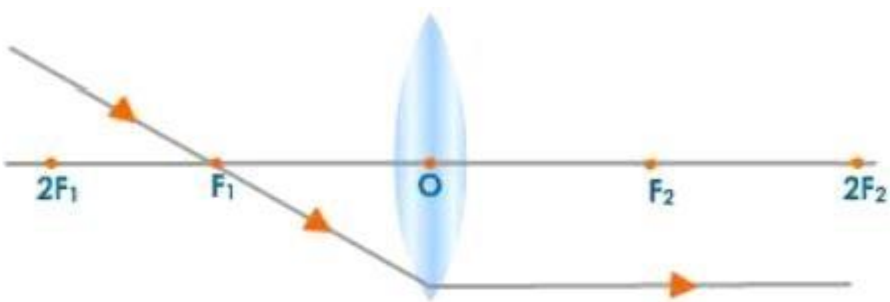
A ray of light passing through the lens's optical center travels straight and without deviation. Only in the case of a thin lens does this hold true.



After refraction, an incident ray parallel to the principal axis passes through the focus.



After refraction, an incident ray passing through the focus of a lens emerges parallel to the principal axis

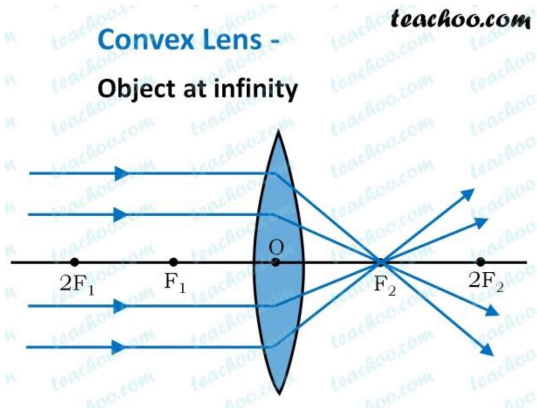


When the object is placed at infinity

When the object is at infinity, the rays coming from it are parallel to each other. The image is:

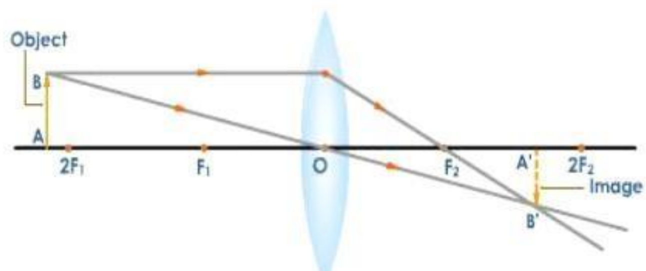
Formed at f_2 inverted real

Highly diminished

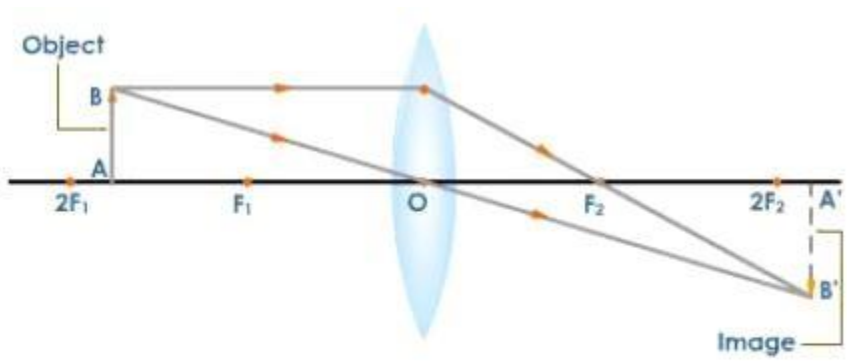


When the object is placed beyond $2f_1$

The image is: formed between f_2 and $2f_2$ real inverted diminished.



When the object is placed between f_1 and $2f_1$



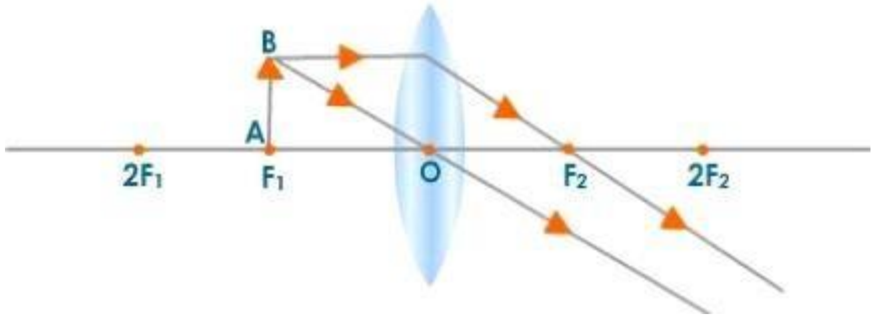
The image is:

Formed beyond $2f_2$ real

Inverted

Magnified

When the object is placed



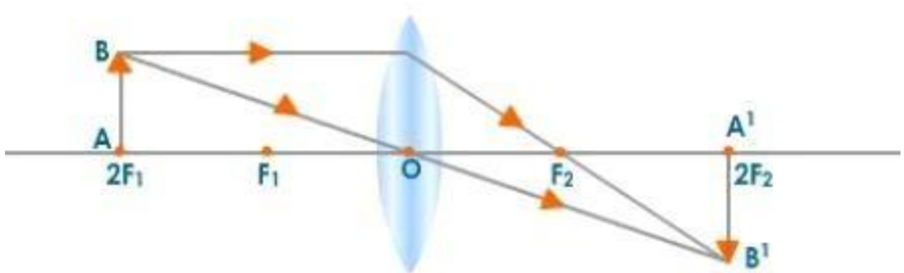
The image is:

Formed at infinity

Real

Inverted magnified

When the object is placed at $2f_1$

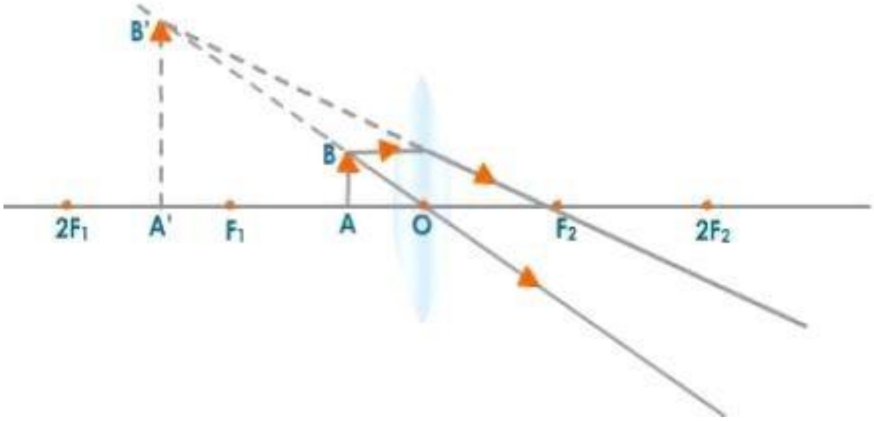


The image is:

Formed at $2f_2$ real

Inverted

When the object is placed between f_1 and o



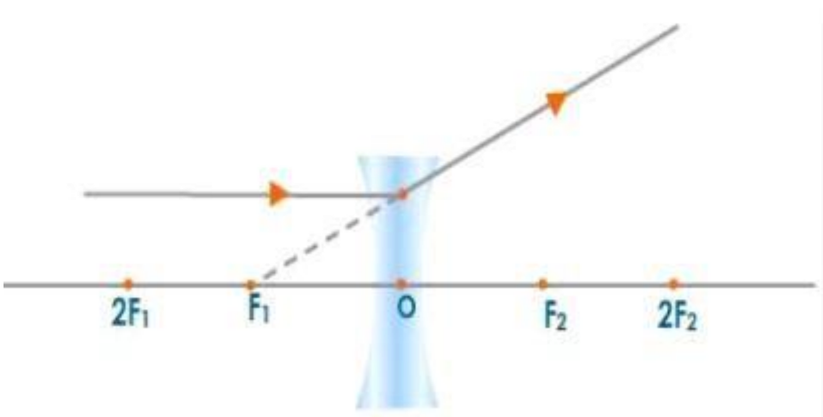
The image is:

Formed behind the object

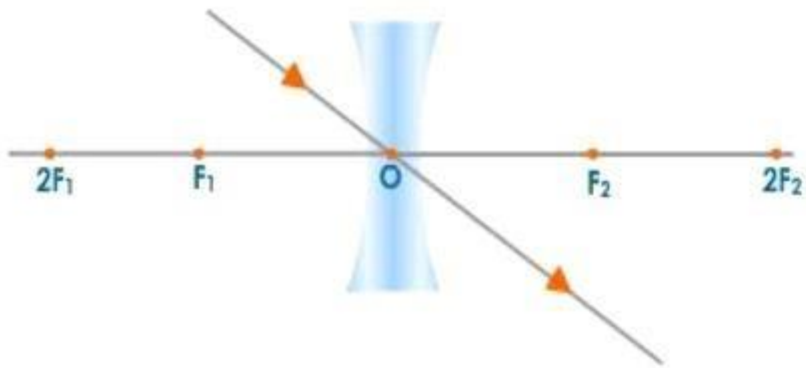
virtual erect & magnified

Formation of image by a concave lens

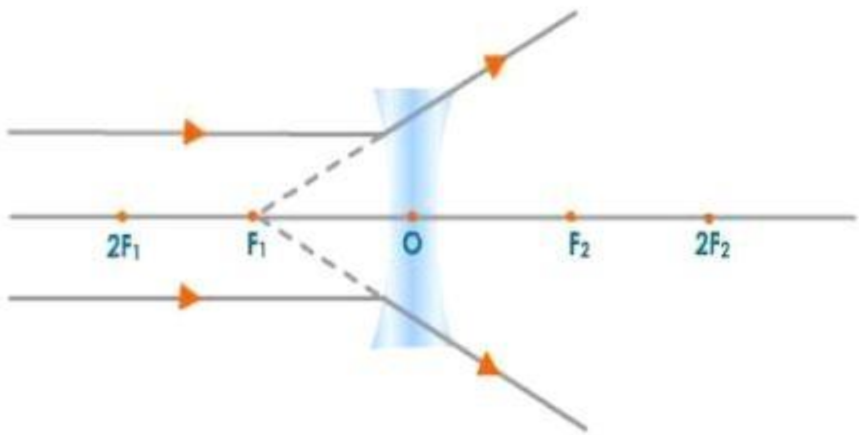
After refraction, an incident ray of light from an object parallel to the principal axis of a concave lens appears to come from its focus.



An incident ray of light that passes through the optical center exits the lens with no deviation.



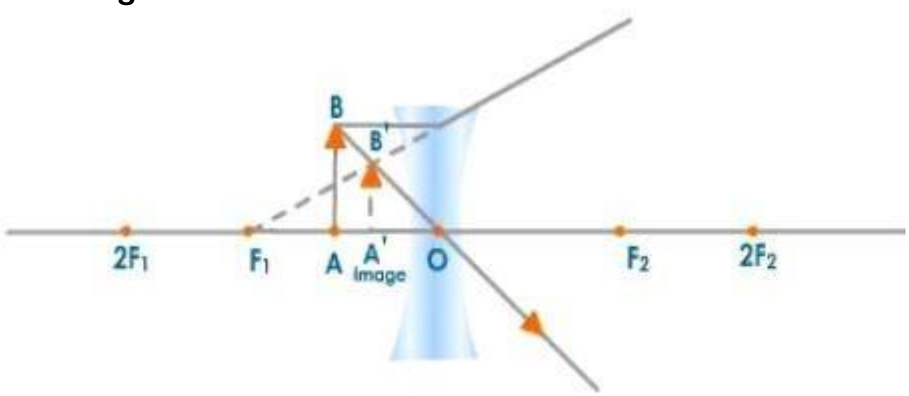
When the object is at infinity



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 f1 erect virtual diminished



Uses of the convex lens:

There are following uses:

1. It is used as hypermetropia i.e., to correct far-sightedness.
2. It is used in microscopes, telescopes and magnifying glasses to subject all the light to a specific object.
3. It is used in camera lenses because they focus light for a clear picture.

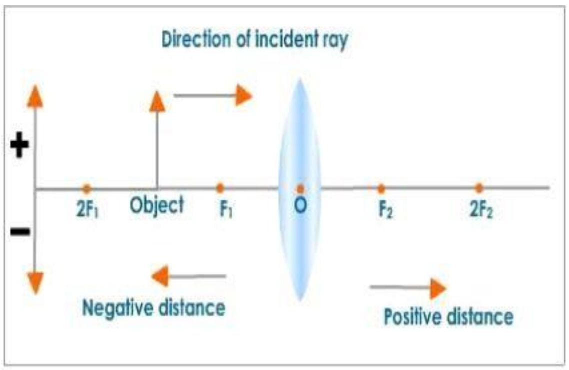
4. It is used in front of the eye to bend the incoming light sharply so the focal point shortens and the light focuses properly on the retina.
5. It is also used in projectors, binoculars, optical microscopes, and even in the peep holes that are present in the doors of our houses.

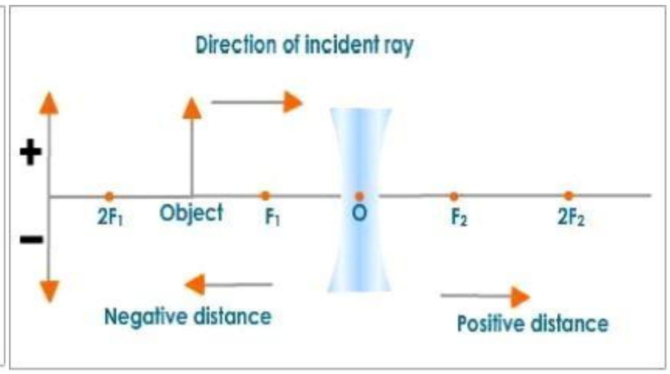
Uses of concave lens

- It is used to correct myopia in spectacles.
- It is used in conjunction with a convex lens to correct flaws such as chromatic 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

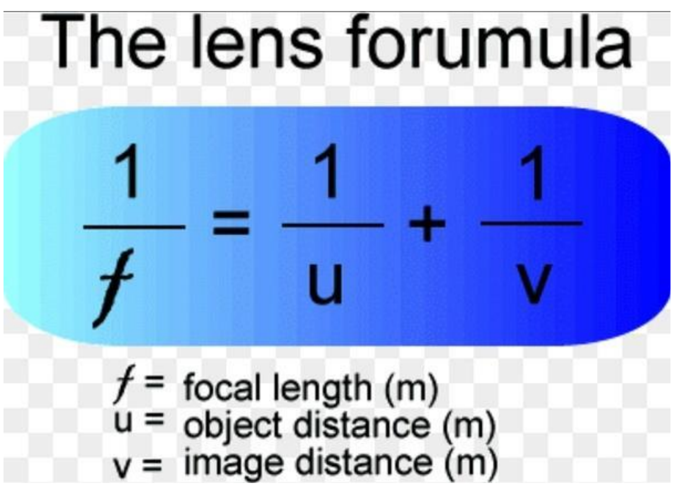
For measuring various distances, the following sign convention is used:





Lens formula

The lens formula or lens equation describes the relationship between the object's distance (u), the image's distance (v), and the focal length (f) of the lens.



This lens formula works for both convex and concave lenses.

Magnification

Magnification is defined as the ratio of image size (h_i) to object size (h_o).

$m = \frac{heightofimage}{heightofobject} m = \frac{v}{u}$

If m > 1 enlarged image

If m < 1 diminished image

Power of lens

the power of a lens is its ability to bend light. The greater the power of a lens, the greater its ability to refract light that passes through it. For a convex lens, the converging ability is defined by power and in a concave lens, the diverging ability.

Power is defined as the reciprocal of focal length.

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

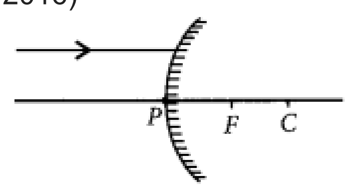
The SI unit of focal length is dioptre D.

1 dioptre is the power of lens having focal length 1 m.

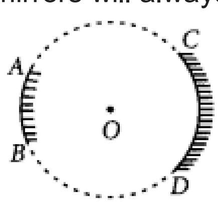
If the power is positive the then lens is convex and if the power is negative then lens is concave.

Important questions

1. If the image formed by a spherical mirror for all positions of the object placed in front of it is always erect and diminished , what type of mirror is it? Draw a labelled ray diagram to support your answer.
2. An object is placed at a distance of 30 cm in front of a convex mirror of focal length 15 cm. Write four characteristics of the image formed by the mirror.
3. A ray of light is incident on a convex mirror as shown. Redraw the diagram and complete the path of this ray after reflection from the mirror. Mark angle of incidence and angle of reflection on it. (Delhi 2016)



4. The magnification produced by a spherical mirror is -3”. List four informations you obtain from this statement about the mirror/ image.
5. AB and CD, two spherical mirrors, from parts of a hollow spherical ball with its centre at O as shown in the diagram. If arc AB = 1/2 arc CD, what is the ratio of their focal lengths? State which of the two mirrors will always form virtual image of an object placed in front of it and why? (Foreign 2016)



6. The linear magnification produced by a spherical mirror is +3. Analyse this value and state the (i) type of mirror and (ii) position of the object with respect to the pole of the mirror. Draw a ray diagram to show the formation of image in this case.
7. A concave mirror has a focal length of 20 cm. At what distance from the mirror should a 4 cm tall object be placed so that it forms an image at a distance of 30 cm from the mirror? Also calculate the size of the image formed.

8. The image of a candle flame placed at a distance of 30 cm from a mirror is formed on a screen placed in front of the mirror at a distance of 60 cm from its pole. What is the nature of the mirror? Find its focal length. If the height of the flame is 2.4 cm, find the height of its image. State whether the image formed is erect or inverted.

9. The image formed by a spherical mirror is real, inverted and its magnification is -2. If the image is at a distance of 30 cm from the mirror, where is the object placed? Find the focal length of the mirror. List two characteristics of the image formed if the object is moved 10 cm towards the mirror.

10. Draw a ray diagram to show the path of the reflected ray in each of the following cases. A ray of light incident on a convex mirror :

(a) strikes at its pole making an angle 0 from the principal axis.

(b) is directed towards its principle focus.

(c) is parallel to its principal axis.

11. A spherical mirror produces an image of magnification -1 on a screen placed at a distance of 50 cm from the mirror.

(a) Write the type of mirror.

(b) Find the distance of the image from the object.

(c) What is the focal length of the mirror?

(d) Draw the ray diagram to show the image formation in this case.

12. An object 4.0 cm in size, is placed 25.0 cm in front of a concave mirror of focal length 15.0 cm.

(i) At what distance from the mirror should a screen be placed in order to obtain a sharp image?

(ii) Find the size of the image.

(iii) Draw a ray diagram to show the formation of image in this case.

13. a) A concave mirror of focal length 10 cm can produce a magnified real as well as virtual image of an object placed in front of it. Draw ray diagrams to justify this statement,

(b) An object is placed perpendicular to the principal axis of a convex mirror of focal length 10 cm. The distance of the object from the pole of the mirror is 10 cm. Find the position of the image formed.

14. a) A security mirror used in a big showroom has radius of curvature 5 m. If a customer is standing at a distance of 20 m from the cash counter, find the position, nature and size of the image formed in the security mirror.

(b) Neha visited a dentist in his clinic. She observed that the dentist was holding an instrument fitted with a mirror. State the nature of this mirror and reason for its use in the instrument used by dentist.

15. t is desired to obtain an erect image of an object, using concave mirror of focal length of 12 cm.

(i) What should be the range of distance of a , object placed in front of the mirror?

(ii) Will the image be smaller or larger than the object? Draw ray diagram to show the formation of image in this case.

(iii) Where will the image of this object be, if it is placed 24 cm in front of the mirror? Draw ray diagram for this situation also to justify your answer.

Show the positions of pole, principal focus and the centre of curvature in the above ray diagrams

16. The refractive indices of glass and water with respect to air are 3/2 and 4/3 respectively. If speed of light in glass is 2×10^8 m/s, find the speed of light in water.

17. the absolute refractive indices of glass and water are 4/3 and 3/2 respectively. If the speed of light in glass is 2×10^8 m/s, calculate the speed of light in (i) vacuum, (ii) water

18. a) A 5 cm tall object is placed perpendicular to the principal axis of a convex lens of focal length 20 cm. The distance of the object from the lens is 30 cm. Find the position, nature and size of the image formed.

(b) Draw a labelled ray diagram showing object distance, image distance and focal length in the above case.

19. (a) Draw a ray diagram to show the formation of image by a concave lens when an object is placed in front of it.

(b) In the above diagram mark the object distance (u) and the image distance (v) with their proper sign (+ve or -ve as per the new Cartesian sign convention) and state how these distances are related to the focal length (/) of the concave lens in this case.

(c) Find the nature and power of a lens which forms a real and inverted image of magnification -1 at a distance of 40 cm from its optical centre.

20. What is meant by power of a lens? Define its S.I. unit.

You have two lenses A and B of focal lengths + 10 and -10 cm respectively. State the nature and power of each lens. Which of the two lenses will form a virtual and magnified image of an object placed 8 cm from the lens? Draw a ray diagram to justify your answer.

21. if half of a convex lens of focal length 10 cm is covered with a black paper. Can such a lens produce an image of a complete object placed at a distance of 30 cm from the lens? Draw a ray diagram to justify your answer.

A 4 cm tall object is placed perpendicular to the principal axis of a concave lens of focal length 20 cm. The distance of the object from the lens is 15 cm. Find the nature, position and size of the image