Reflection of Light

Laws of Reflection and Image Formation by Plane Mirror

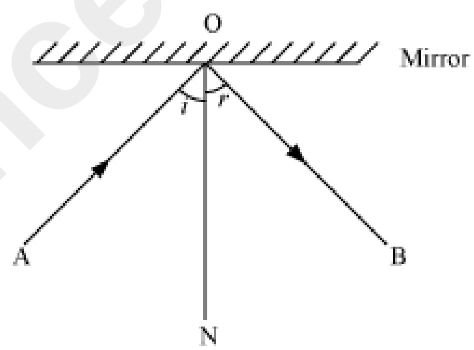
We are able to see things because of our sense of sight. It enables us to see beautiful landscapes, buildings, stars, moon, and everything else around us. **Have you ever wondered how we are able to see these objects?**

We are able to see different objects when light from these objects enters our eyes. This light may have been emitted by the object or reflected by it. We cannot see in dark. **Can you explain why?**

Laws of reflection

Consider a ray of light falling on a plane mirror. When the ray of light hits the mirror, it gets reflected in a certain direction. The ray of light which was incident on the mirror is known as the **incident ray,** whereas the ray of light reflected by the mirror is known as the **reflected ray**.

A straight line drawn perpendicular to the surface of the mirror at the point of incidence is known as **normal (N)** to the surface. The angle made by the incident ray with the normal is known as the **angle of incidence** (i). The angle made by the reflected ray with the normal is known as the **angle of reflection(r).**



Reflection from a plane mirror

Is it possible to find the direction of a reflected ray? Let us perform an activity to find out.

Activity:

Remember that in the activity, you have to take incident ray, reflected ray and normal on the same piece of paper. This shows that **incident ray, reflected ray and normal lie in the same plane**. This is the **second law of reflection**.

Reflection of light ray incident normally on a plane mirror

When a light ray is incident normally on a plane mirror, then the angle between the normal and the incident ray will be 0^{o} i.e. $\angle i = 0^{o}$. Thus, following the law of reflection of light, angle of reflection will also be 0^{o} i.e. $\angle r = 0^{o}$.

This shows that the light rays retraces its path after reflection if it is incident normally on a plane mirror or any reflecting surfaces.

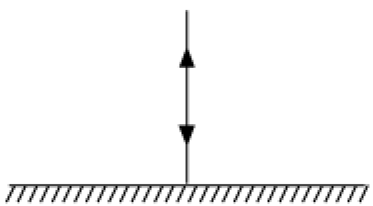


Image formation of a point object by a plane mirror:

Consider a plane mirror MM_1 and a point object O is placed in front of it. Rays from the point object travel in all directions but for its image formation (*I*) only two rays would be sufficient to consider.

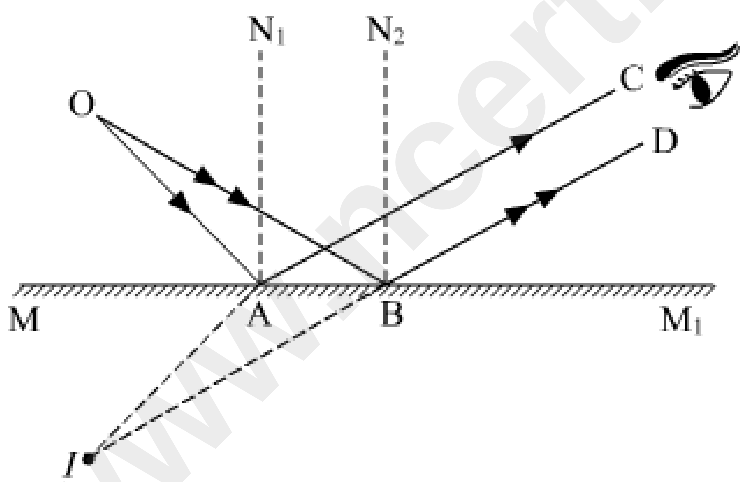
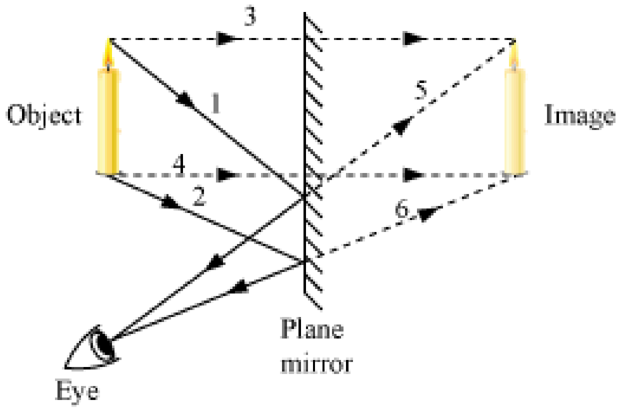


Image formation of an extended object by a plane mirror:

Take a candle and place it in front of a plane mirror. Mark the two rays coming from it as **1** and **2**. After reflecting from the mirror, these rays reach your eye.



However, these rays appear to be coming from somewhere inside the mirror. Also, the left part of the candle appears on the right and its right part appears on the left. This is known as **lateral inversion.**

Characteristics of image formed by plane mirror

- virtual and erect
- same size as of object
- laterally inverted
- image distance and object distance are same and perpendicular from mirror

Virtual images are those images which cannot be obtained on screen. But there are some images which can be obtained on screen. Such images are called real image.

Uses of plane mirror

- It is used as a looking glass.
- It is used to increase the effective length of an optician's room.
- In periscope, two parallel plane mirrors are inclined at 45 degrees with vertical walls such that they are facing each other.
- In kaleidoscope, three plane mirrors are inclined with each other at 60 degrees.
- It is used in solar heaters and cookers to heat substances by reflecting the sunlight towards the substances.

Differences between an image and a shadow

Image	Shadow
An image is formed by the reflection of light from a surface.	A shadow is formed when the path of light is blocked by an opaque object.

An image shows the details of an object.	A shadow does not show the details of the object.
An image has same colour as the object.	A shadow is always black.

Regular and Diffused Reflection

Therefore, we can define regular and irregular reflections as

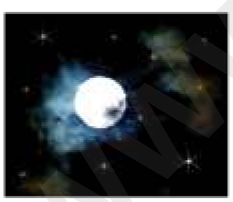
When all the reflected rays from a given smooth surface are parallel for parallel incident rays, the reflection is known as regular reflection.

And

When for a given set of incident parallel rays, the reflected rays do not remain parallel to each other, the reflection is known as diffused or irregular reflection.

The laws of reflection are valid in regular as well as irregular or diffused reflections.

Objects that give their own light are known as **luminous objects**. The sun, candle, and bulb are a few examples of luminous objects.



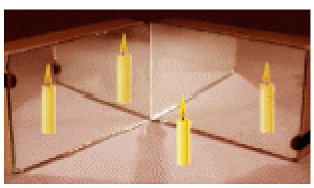
However, most objects that we see around us are visible because of the light reflected from them. For example, moon does not have its own light. It reflects the light of the sun, which incidents on it. Objects that are visible because of reflected light are known as **illuminated objects**.

Multiple Reflection

Have you ever visited a magical mirror-house where a large number of mirrors are fixed on the wall? There, you can see a large number of your own images in a single mirror.

How is this possible?

To find out, let us perform an activity. Take two plane mirrors and place them at right angles to each other. Now, place a candle between the mirrors.



How many images can you see in the mirrors? In this arrangement, three different images of the candle can be seen. When you decrease the angle between the two mirrors to 60°, then more than three images are visible. If you place two mirrors parallel to each other, then you can see infinite number of images! **How is this possible?**

This is due to multiple reflections. Let us explore.

Multiple reflections from two mirrors

A ray of light from an object gets incident on mirror **1**. Mirror **1** reflects this ray towards mirror **2**. This reflected ray from the first mirror acts as an incident ray for the second mirror. In the same way, the reflected ray from mirror **2** acts as an incident ray for the third mirror. Hence, multiple reflections take place.

You can see as many images as reflected rays. If infinite reflections take place, then they produce infinite images.

How can we calculate the number images formed by multiple reflection between two mirrors?

Well it can be calculated very easily using

Number of images formed between two mirrors= $\frac{360^{o}}{angle\ between two plane\ mirros} - 1$

Periscope

Periscope is an optical device used to see objects that are not along the line of sight. Let us see the working principle of a simple periscope.

Periscopes are used in submarines. Crew members can see the ships above water, while they remain underwater.

Kaleidoscope

It is a tube which consists of mirrors fixed inside a cylindrical box. This tube also contains loose colour beads or pebbles. It functions on the principle of multiple reflections of light. When light enters the tube, it undergoes multiple reflections. Hence, it forms a large number of images of the coloured beads. When rotated, a beautiful symmetric coloured image is formed.

In a kaleidoscope, you cannot get the same pattern of the coloured image again. This is because each time you rotate the tube, relative positions of the loose colour beads change.

Dispersion of light

So, you have seen that when light coming from the sun is allowed to pass through a prism, it breaks down into different colours. This splitting of light into different colours is known as **dispersion**.

Let us perform another activity to understand this better.

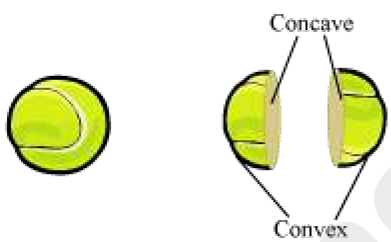
Take a cardboard sheet and make a small hole in it. Now, place a small mirror in a bowl filled with water. Make sure that the mirror faces the sun. Now, hold the cardboard between the mirror and a paper sheet and obtain the reflected sunlight from the mirror on the white paper sheet. When the sheet of paper is adjusted properly, you will see that the reflected light has different colours.

Reflection of Light by Spherical Mirrors

Light travels in a straight line and can change its direction when incident on a shiny surface.

Jatin looks inside a polished steel bowl and gets surprised to find his face appearing inverted inside the bowl. Furthermore, the image of his face changes its size as the bowl is moved towards or away from him. However, when he looks on the outer side of the same bowl, he finds his image to be erect.

Why does this happen? This happens because the curved surface of the bowl acts as special kind of mirror, known as a **spherical mirror**. A spherical mirror can be made from a spherical ball.



Take a tennis ball and cut it into two equal halves.

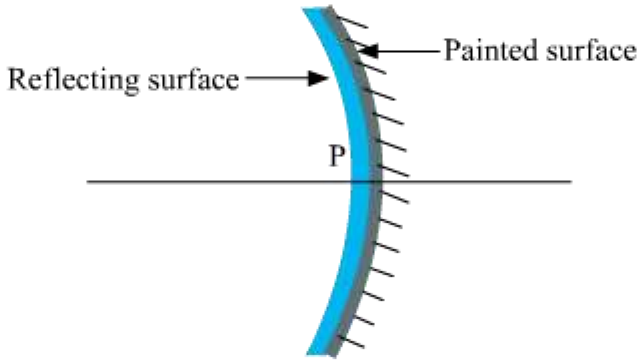
The inner surface of each half is known as the concave surface, while the outer surface is called the convex surface.

There are two types of spherical mirrors

i) Concave mirrors

ii) Convex mirrors

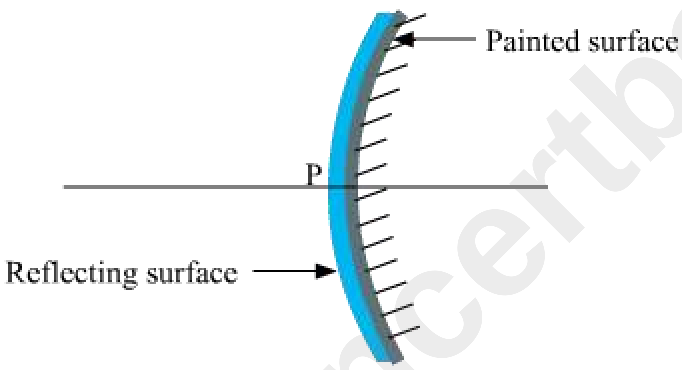
Concave mirrors



Concave mirror

A concave mirror is a spherical mirror whose reflecting surface is curved inwards. In a concave mirror, reflection of light takes place from the inner surface. This mirror resembles the shape of a '**cave**'. A Painted surface is a non-reflecting surface.

Convex mirrors



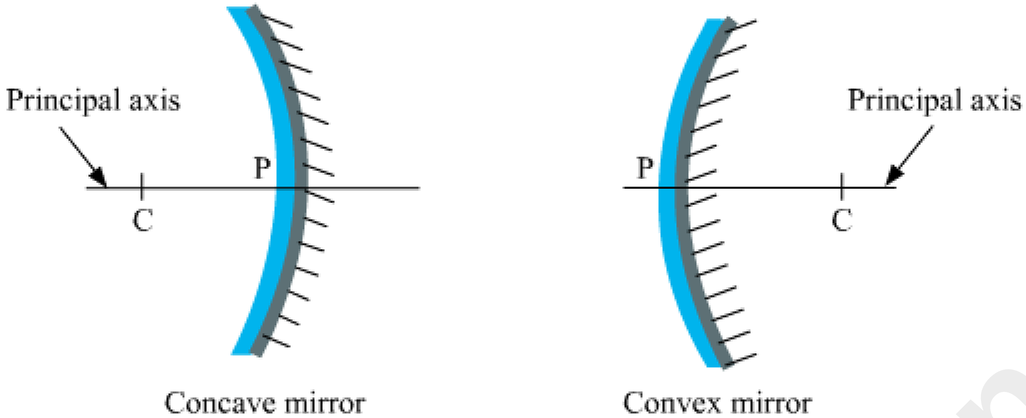
Convex mirror

A convex mirror is a spherical mirror whose reflecting surface is curved outwards. In a convex mirror, the reflection of light takes place from its outer surface. A Painted surface is a non-reflecting surface.

Hence, the inward surface of the steel bowl or a spoon acts as a concave mirror, while its outer surface acts as a convex mirror.

There are some definitions associated with spherical mirrors, which will prove helpful in the discussion of spherical mirrors. But, before going into the definitions, let us understand the terms clearly.

So, the definitions of the terminologies are as follows:

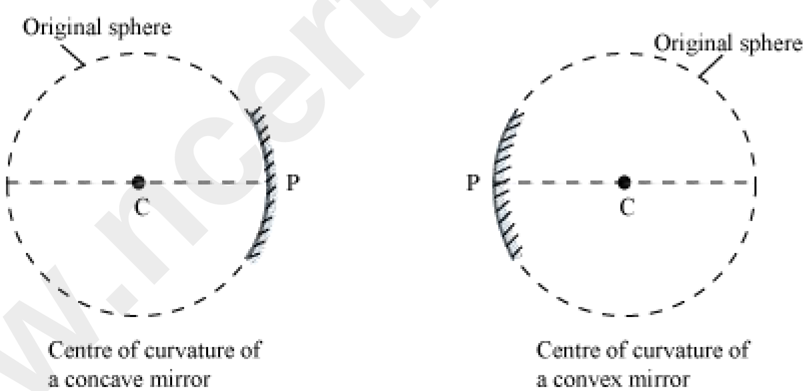


Pole of a spherical mirror

The central point of the reflecting surface of a spherical mirror is termed as the **pole**. It lies on the mirror and is denoted by the letter **(P)**.

Centre of curvature

The centre of curvature as the centre of a sphere from which the given spherical mirror (convex or concave) is obtained. It is denoted by the letter (**C)**.

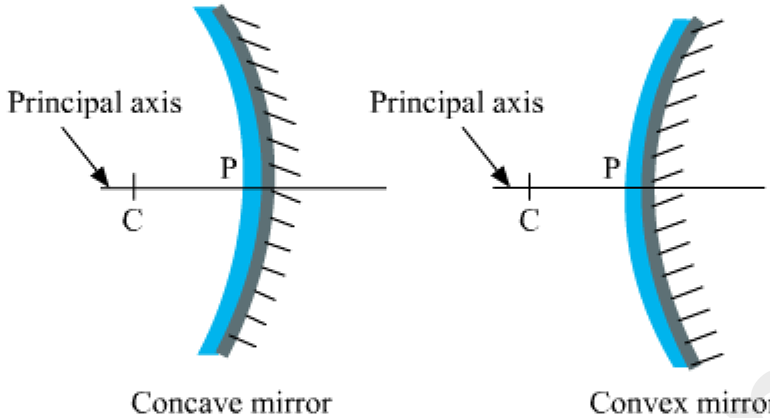


Radius of curvature

The distance between the centre of curvature and pole (**PC)** is known as the **radius of curvature**.

Principal axis of the spherical mirror

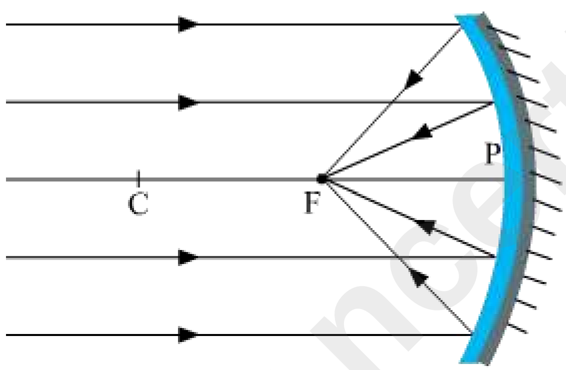
The imaginary straight line passing through the pole (P) and the centre of curvature (C) is termed as the principal axis.



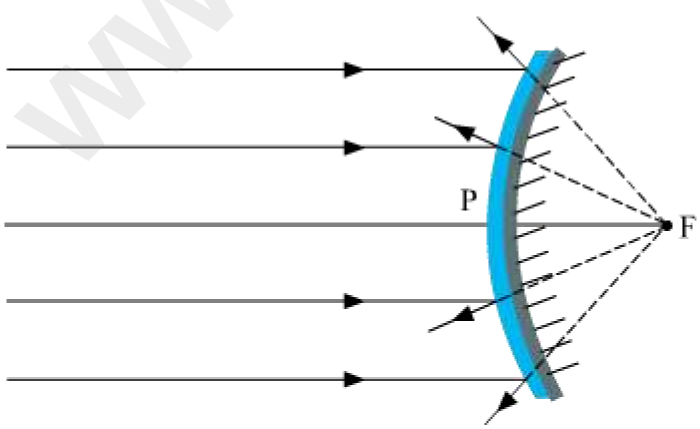
Focus

The focus **(F)** is the point on the principal axis of a spherical mirror where all the incident rays parallel to the principal axis meet or appear to diverge from after reflection.

For concave mirrors, the focus lies on the same side of the reflecting surface.



For convex mirrors, the focus is obtained on the opposite side of the reflecting surface by extrapolating the rays reflected from the mirror surface.



Radius of curvature (***R***) and the focal length (***f***) of a spherical mirror are related as

$R = 2f$

Where, ***R*** is the distance between the centre of curvature and the pole of the mirror, while ***f*** is the distance between the focus and the pole of the mirror.

The focus of a spherical mirror always lies between the pole (P) and the centre of curvature (C).

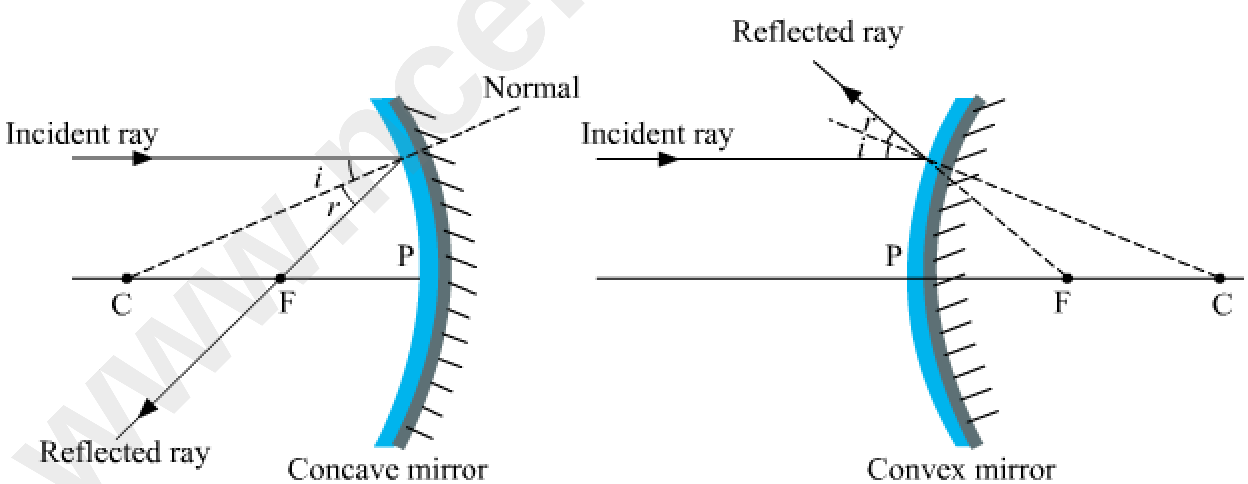
Reflection by spherical mirrors

The laws of reflection are also followed by spherical mirrors, same as the plane mirrors. The laws of reflection are:
1) The angle of incidence of light is always equal to angle of reflection of light.
2) The incident ray, the normal and the reflected ray, all lie in the same plane.

The different ways in which a ray of light is reflected from a spherical mirror are:

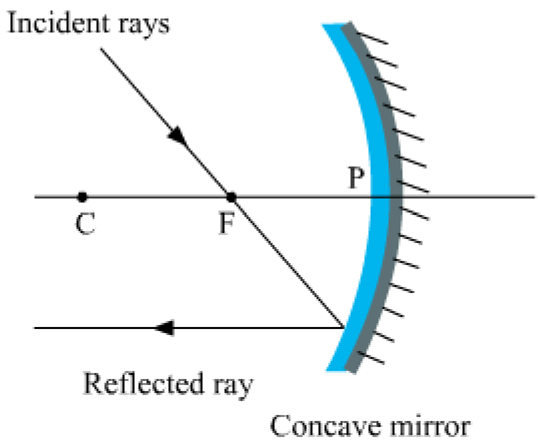
Case I: When the incident light ray is parallel to the principal axis.

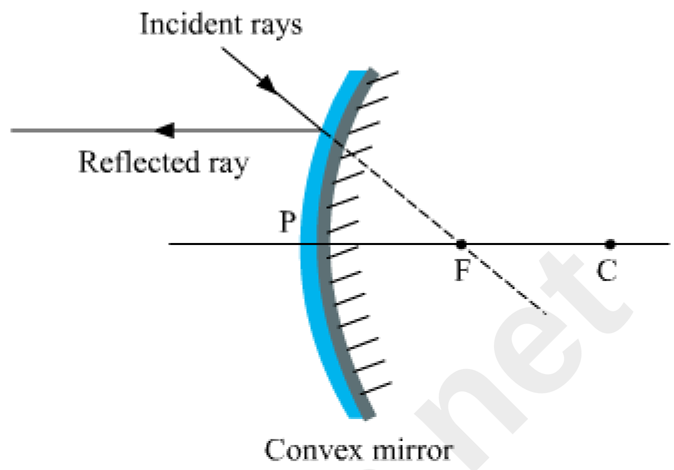
In this case, the reflected ray will pass through the focus of a concave mirror, or it appears to pass through the focus of a convex mirror.



Case II: When the incident light ray passes through the focus of a concave mirror, or appears to pass through the focus of a convex mirror.

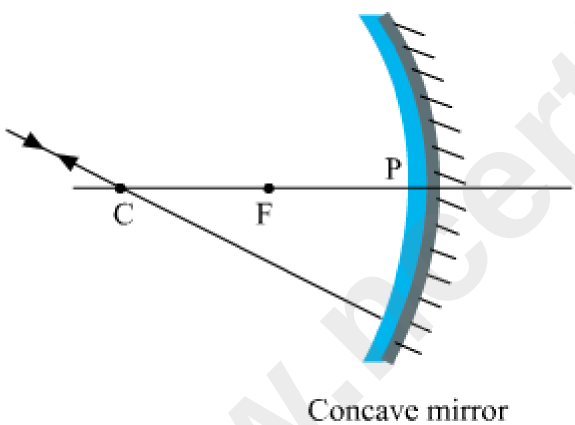
In this case, the reflected light will be parallel to the principal axis of the spherical mirror.

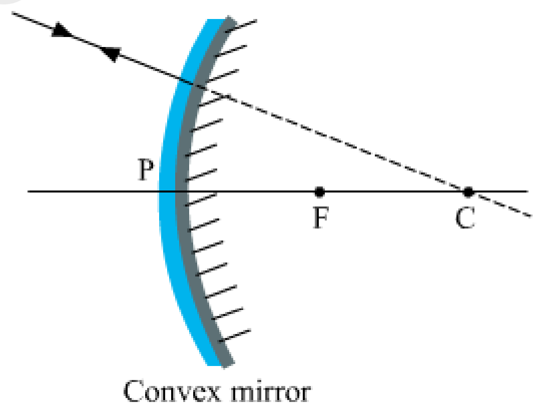




Case III: When the incident ray passes through or appears to pass through the centre of curvature.

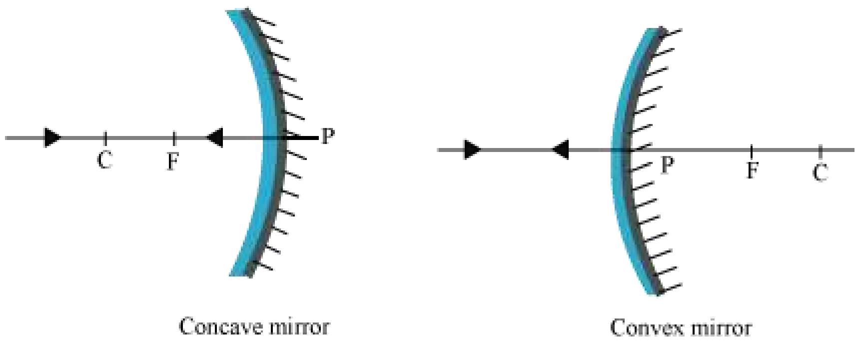
In this case, light after reflecting from the spherical surface moves back in the same path. This happens because light is incident perpendicularly on the mirror surface.





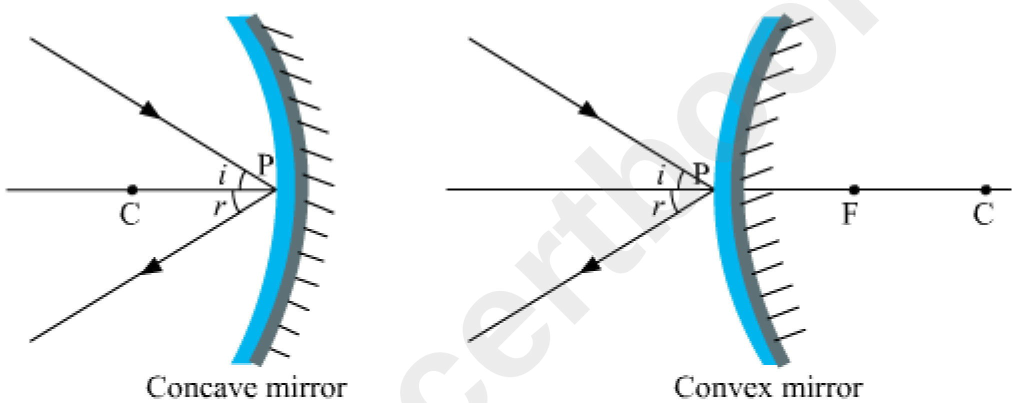
Case IV: When the incident ray is normal to the reflecting surface

In this case, the incident light ray will be reflected back by the reflecting surface of the spherical mirror, as in the case of plane mirror.



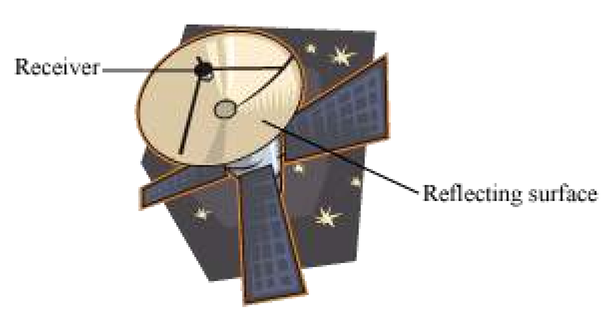
Case V: When the ray incident obliquely to the principal axis.

In this case, the incident ray will be reflected back by the reflecting surface of the spherical mirror obliquely. And making equal angles with the principal axis**.**



Four spherical mirrors of radius of curvature R_1, R_2, $R_{3,}$ and R_4 ($R_1 > R_3 > R2 > R_4$) are placed against the sunlight. Try to obtain the bright spot on a paper sheet for each mirror. **Which mirror forms the brightest spot at a maximum distance from the pole of the mirror?** Explain.

Do You Know:

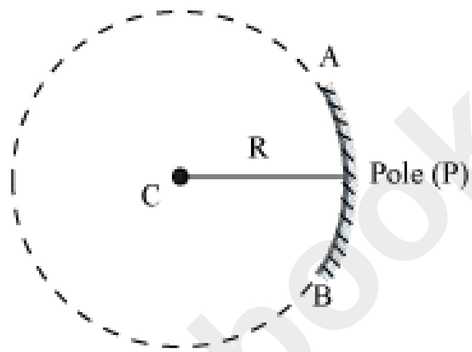
Radio telescope is a reflecting telescope that tends to reflect all parallel rays coming from distant stars, galaxies, deep space etc. to a single point. This is because the reflecting surface acts as a large concave mirror. The point where the reflected rays meet is its focus. A receiver is placed at the focus, which receives light rays and sends these rays to a computer in the form of electrical signals. As a	

result, images of a light source can be obtained on the monitor.	

Image Formation by Spherical Mirrors and Mirror Formula

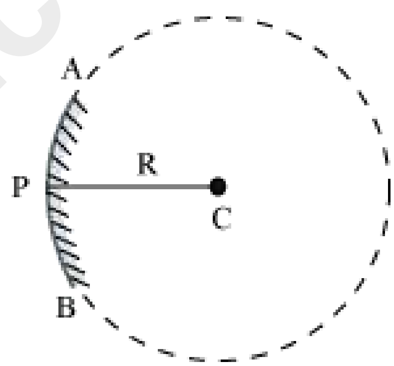
Spherical Mirror

- Concave spherical mirror − A spherical mirror whose reflecting surface is towards the centre of the sphere is called concave spherical mirror.



Concave mirror

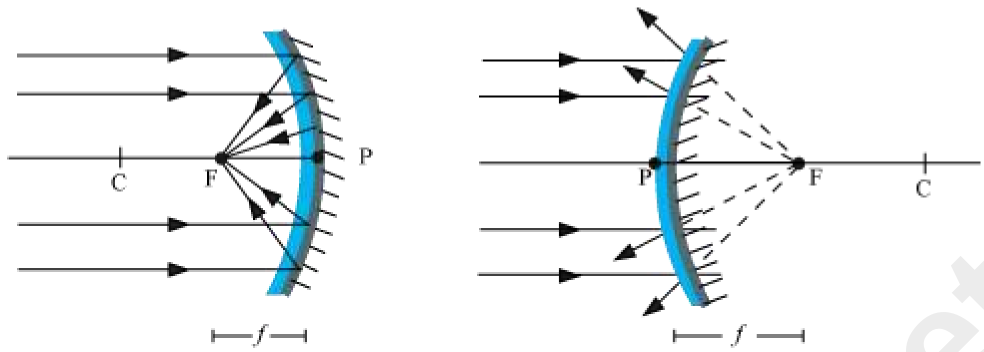
- Convex spherical mirror − A spherical mirror whose reflecting surface is away from the centre of the sphere is called convex spherical mirror.



Convex mirror

Focal Length of Spherical Mirror

- Principal focus (F) − The point at which a narrow beam of light incident on the mirror parallel to its principal axis after reflection from the mirror meets or appears to come from is called the principal focus of the mirror.



Concave mirror Convex mirror

- Focal length − The distance between the pole and the principal focus of the mirror is called the focal length (*f*) of the mirror.

- For both concave and convex spherical mirrors,

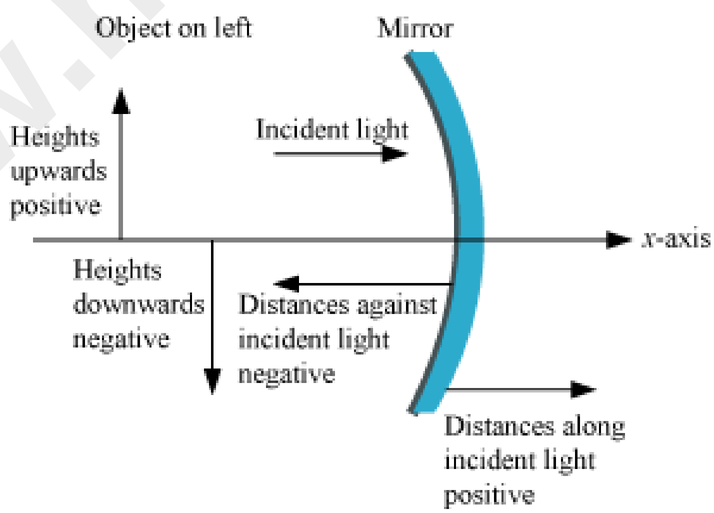
$$f = \frac{R}{2}$$

Where,

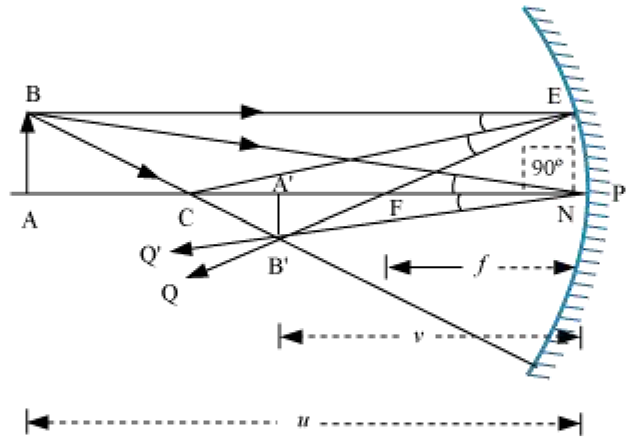
$f \rightarrow$ Focal length of the mirror

$R \rightarrow$ Radius of curvature of the spherical mirror

New Cartesian Sign Conventions



Mirror Formula



The above figure shows the ray diagram for image formation by a concave mirror.

In figure, triangles $A'B'F$ and ENF are similar.

$$\therefore \frac{A'B'}{NE} = \frac{A'F}{NF}$$

As the aperture of the concave mirror is small, the points N and P lie very close to each other.

$\therefore NF \approx PF$ and $NE = AB$

$$\frac{A'B'}{AB} = \frac{A'F}{PF}$$

Since all the distances are measured from the pole of the concave mirror, we have

$$A'F = PA' - PF$$

$$\therefore \frac{A'B'}{AB} = \frac{PA' - PF}{PF} \quad ...(i)$$

Also, triangles ABP and $A'B'P$ are similar.

$$\therefore \frac{A'B'}{AB} = \frac{PA'}{PA} \quad ...(ii)$$

From equations (i) and (ii), we obtain

$$\frac{PA' - PF}{PF} = \frac{PA'}{PA} \quad ...(iii)$$

Applying the new Cartesian sign conventions, we have

PA = − *u* (Q distance of object is measured against incident ray)

PA' = − *v* (Q distance of image is measured against incident ray)

PF = − *f* (Q focal length of concave mirror is measured against incident ray)

Substituting these values in equation (iii),

We have

$$\frac{-v-(-f)}{-f}=\frac{-v}{-u}$$

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

$$\frac{v}{f}-1=\frac{v}{u} \quad \text{or} \quad \frac{1}{f}-\frac{1}{v}=\frac{1}{u}$$

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

The above relation is called mirror formula.

- Relation between *u*, *v*, and *R*

$Q\ f=\frac{R}{2}$, we have

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{\frac{R}{2}}$$

$$\boxed{\frac{1}{u}+\frac{1}{v}=\frac{2}{R}}$$

- Linear magnification − The ratio of the size of the image formed by a spherical mirror to the size of the object is called the linear magnification produced by the spherical mirror.

It is denoted by *m*.

$$m = \frac{I}{O}$$

Where,

I → Size of the image

O → Size of the object

In the above figure, triangles ABP and $A'B'P$ are similar.

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

Applying the new Cartesian sign conventions, we have

$A'B'$ = − I (Q height is measured downwards)

AB = + O (Q height is measured upwards)

PA = − u (Q distance is measured against incident ray)

PA' = − v (Q distance of image is measured against incident ray)

∴The above equation becomes

$$\frac{-I}{O} = \frac{-v}{-u}$$

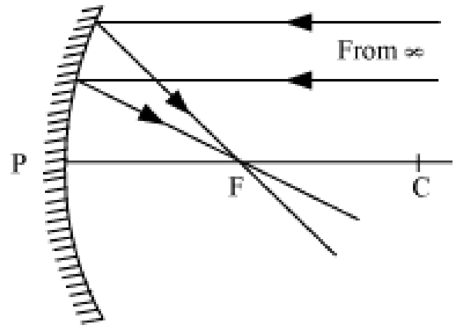
$$\text{Or, } \frac{I}{O} = \frac{-v}{u} \qquad \text{(iv)}$$

Note: The expression for magnification is same, both for the concave and convex mirrors.

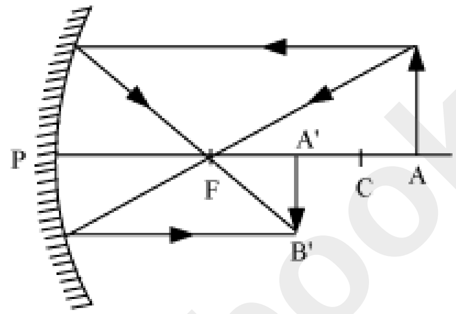
Formation of Image by Spherical Mirrors

- **Formation of image by a concave mirror**

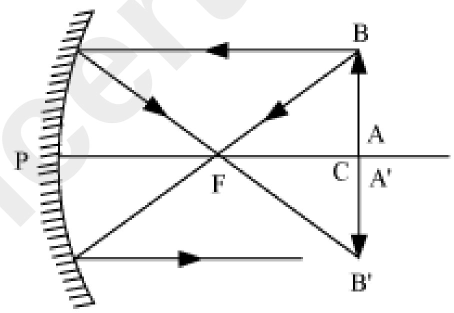
When object lies at infinity:



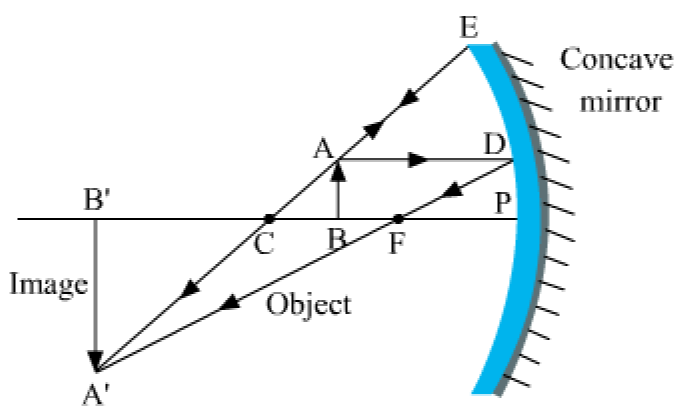
When object lies beyond C:



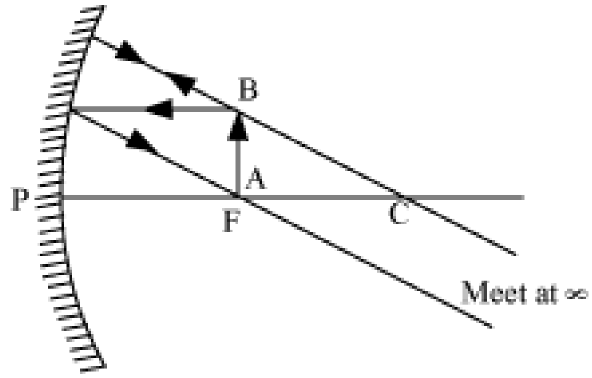
When object lies at C:



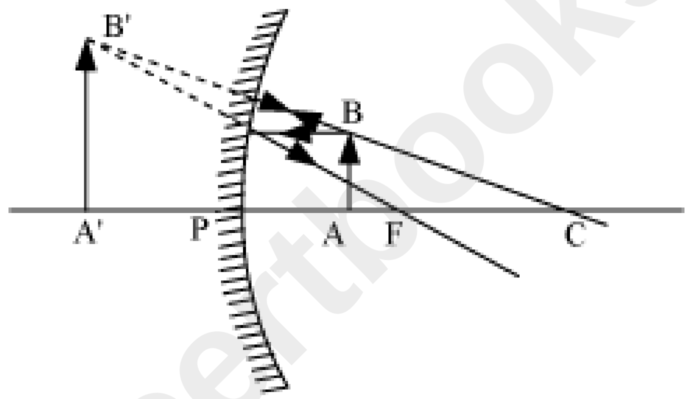
When object lies between F and C:



When object lies at F:

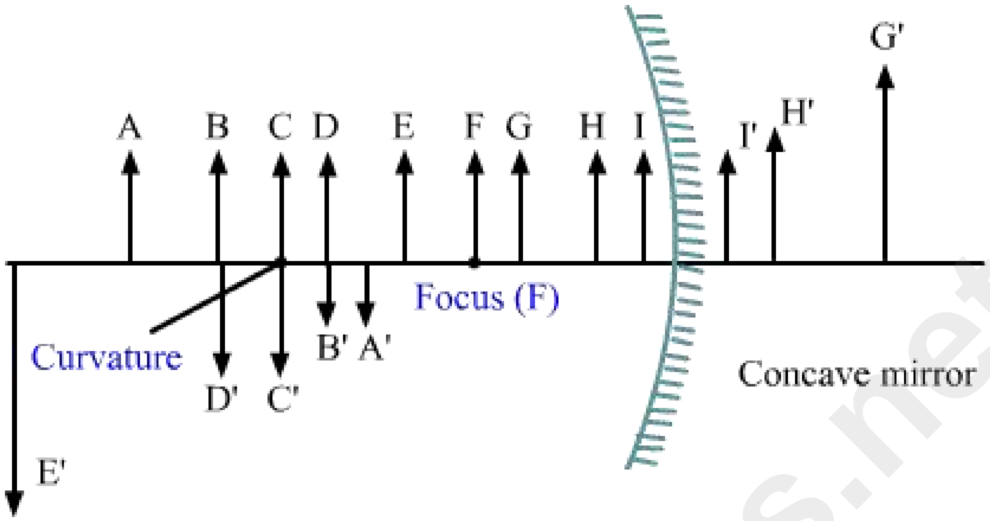


When object lies between P and F:



The discussion is summarised in the table given below.

Object position	Image position	Size of image	Nature of image
At infinity	At F	Point-sized	Real
Beyond C	Between F and C	Small	Real and inverted
At C	At C	Same as that of the object	Real and inverted
Between C and F	Behind C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between F and P	Behind the mirror	Enlarged	Virtual and erect

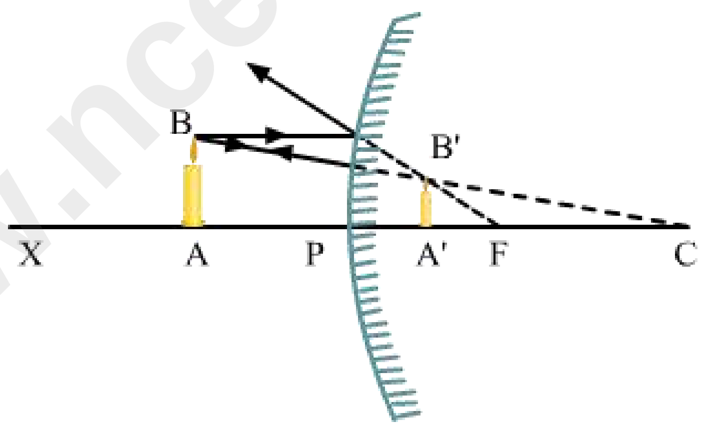


- **Formation of image by a convex mirror**

A convex mirror always produces virtual and erect images of very small size. The images formed by a convex mirror are primarily classified in two ways.

I. When the object is at infinity

In this case, the image appears to form at the focus. This image is virtual, erect and very small in size.



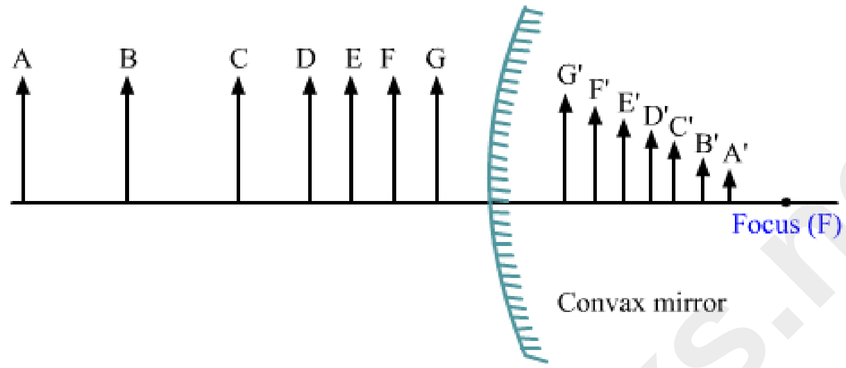
II. When the object is between the pole (P) and a point X (X lies beyond C)

In this case, the image is formed between the pole (P) and the focus (F), behind the mirror. This image is virtual, erect and small in size.

These results are summarised in the following table.

Object position	Image position	Size of image	Nature of image

At infinity	At F	Extremely small	Virtual and erect
Between P and X (X lies beyond C)	Between P and F	Small	Virtual and erect



Difference Between a Real Image and a Virtual Image

S. No.	Real Image	Virtual Image
1.	Can be obtained on a screen or wall	Cannot be obtained on a screen or wall
2.	Can be touched	Cannot be touched
3.	Formed in front of the mirror	Formed behind the mirror
4.	Formed by concave mirrors only	Formed by all types of mirrors i.e., plane, convex, and concave
5.	These images are always inverted	These images are always erect

You can distinguish between real and virtual images by checking the orientation (erect or inverted) of images and also by touching them.

Uses of Spherical Mirrors

Sanjay went to a dentist's clinic to get his decaying tooth examined. While sitting on the dentist's chair, he observed that the doctor was using a special type of mirror to examine his tooth. He wondered why the dentist had to use a different mirror for the examination.

The special mirrors used by dentists are known as dentist's mirror. This mirror is actually a concave mirror and thus, capable of producing a larger image of an object (teeth, in this case). In this section, we will discuss the uses of the properties of concave and convex mirrors in our daily life.

1. Concave mirror

A concave mirror has the capability of forming images that can be smaller or larger in size and virtual or erect, depending on the position of the object.

These mirrors are used in various medical practices. For example, doctors use this mirror for obtaining a relatively larger image of teeth, ear, skin etc.

Concave mirrors are also used in reflectors for torches and headlights in vehicles. This is because these mirrors can reflect rays of light beams as very powerful light rays.

2. Convex mirror

A convex mirror always produces a smaller, virtual, and erect image of an object.

In convex mirror, the length of the image is shorter than that of the object. Hence, it is used as a side view mirror in vehicles because the viewed area must be larger than the surface area of the mirror. The convex mirror forms images of vehicles that are spread over a relatively larger area.

Vehicle mirror

Owing to this property, convex mirrors are also used in security mirrors that we often see in shops, malls, etc.