Focal Length Of Spherical Mirrors

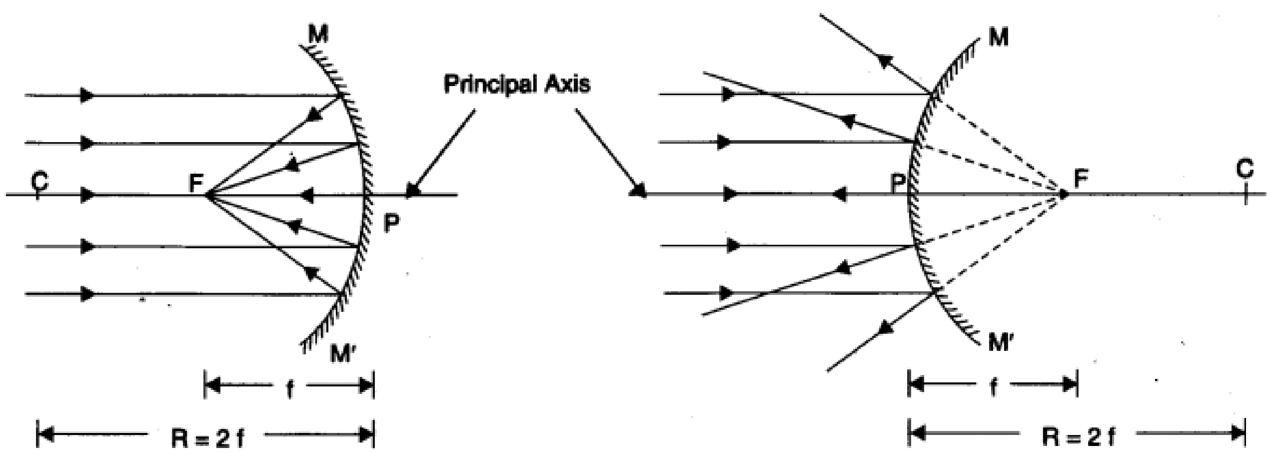
Spherical mirror

(a) Definition: A mirror whose surface is cut out of a spherical shell, is called a spherical mirror.

(b) Types: There are two types of spherical mirrors:

1. **Concave mirror:** Its outer convex surface is polished and inner concave surface reflects.
2. **Convex mirror:** Its inner concave surface is polished and outer convex surface reflects.

Terms associated with spherical mirrors



(a) Concave mirror.

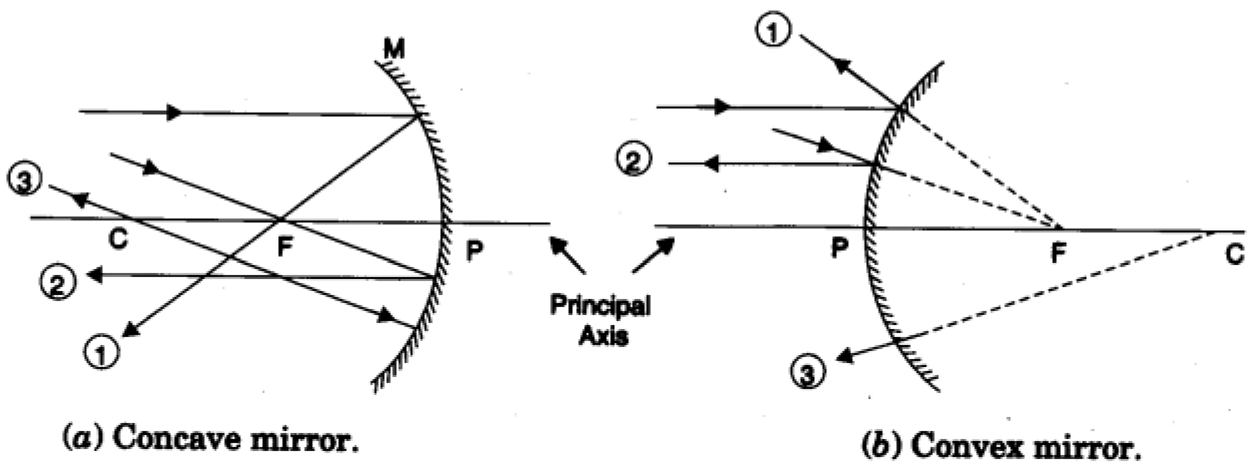
(b) Convex mirror.

Spherical mirrors.

1. Aperture. The diameter of the circular rim of the mirror, is called the aperture of the mirror. Hence, aperture is a part of mirror, through which rays of light entered. In diagram MM' is the aperture of the mirror.
2. Pole. The centre of the spherical surface of the mirror, is called the pole of the mirror. It lies on the surface. It is denoted by P.
   In diagram, P is the pole of the mirror.
3. Centre of curvature. The centre of the spherical shell, of which the mirror is a section, is called the centre of curvature of the mirror. It lies outside the surface. Every point on the mirror surface lies at same distance from it. It is denoted by C. In diagram, C is the centre of curvature of the mirror.

4. Principal axis. The straight line passing through the pole P and the centre of curvature C of the mirror, is called principal axis of the mirror.
5. Principal focus It is a point on the principal axis of the mirror, such that the rays incident on the mirror parallel to the principal axis after reflection, actually meet at this point (in case of a concave mirror) or appear to come from it (in case of a convex mirror). It is denoted by F.
   In diagram, F is the principal focus of the mirror.
6. Radius of curvature. The distance between the pole and the centre of curvature of the mirror, is called the radius of curvature of the mirror. It is equal to the radius of the spherical shell, of which the mirror is a section.
   In diagram, PC is the radius of curvature of the mirror. It is represented by the symbol R.
7. Focal length. The distance between the pole and the principal focus of the mirror, is called the focal length of the mirror.
   In diagram, PF is the focal length of the mirror. It is represented by the symbol f. For mirrors of small aperture, f=R/2.
8. Principal section. A section of the spherical mirror cut by a plane passing through its centre of curvature and the pole, is called a principal section of the mirror. It contains the principal axis.
   In diagram, MPM’ is the principal section of the mirror cut by the plane of the book page.

Three special rays



Three special rays.

The special rays are:

1. Incident on the mirror parallel to principal axis. After reflection from the mirror, it actually passes through mirror focus F (in case of a concave mirror) or appears to come from it (in case of a convex mirror).
2. Incident on the mirror through focus F (in case of a concave mirror) or in direction of focus F (in case of convex mirror).
   After reflection from the mirror, it goes parallel to the principal axis.

3. Incident in the mirror through centre of curvature C (in case of a concave mirror) or in direction of centre of curvature C (in case of a convex mirror).
   After reflection from the mirror, it returns back along the path of incidence.

Sign convention

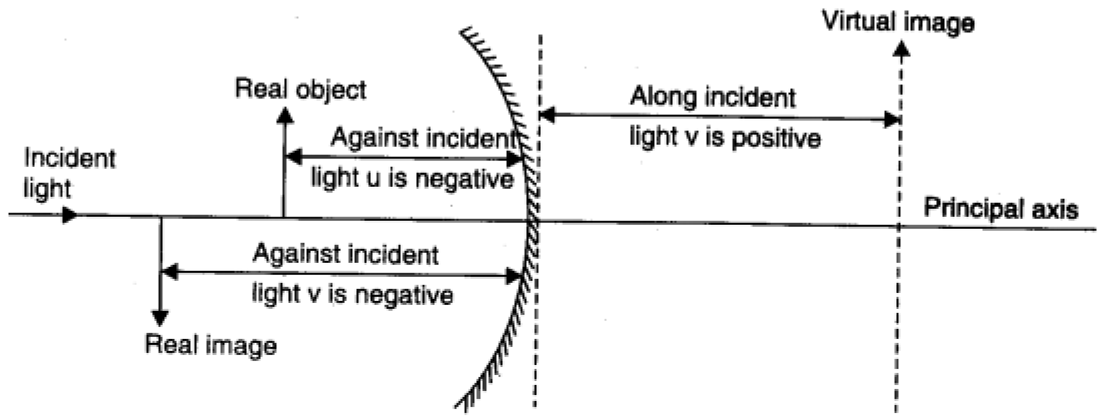
(a) Definition: It is a convention, which fixes the signs of different distances measured. The sign convention followed is the New Cartesian sign convention.
(b) Rules: It gives following rules:

1. All distances are measured from the pole of the mirror (along the principal axis).
2. The distance measured in the same direction as the direction of incident light,are taken as positive.
3. The distances measured opposite to the direction of incident light, are taken as negative.
4. The distances measured above the principal axis, are taken positive and the distance taken below the principal axis, are taken negative.

(c) Facts: According to above mentioned rules of sign convention:

1. Radius of curvature and focal length of a concave mirror are taken as negative and the same for convex mirror are taken positive.
2. The distance of an object is always negative.
3. The distance of real image is negative, while that of a virtual image is positive.
4. The size of object is always positive but size of real image is always negative while size of virtual image is positive for mirrors.

(d) Explanation: (with example) The new convention is also called cartesian coordinate convention.
Pole (P) of the mirror is taken as the origin. Reflecting face of the mirror is taken towards ‘ left. Light is made incident from left to right which makes positive direction. Object facing the mirror, is on the left of the origin. Its distance from pole measured from pole (origin) from right to left becomes negative. Real image is formed in front of the mirror to the left of pole. Its distance also becomes negative.
Virtual image is formed behind the mirror. Its distance from pole measured from left to right becomes positive.



Sign convention explained.

For concave mirror, centre of curvature and focus lie in front of it to the left of pole. Their distances (radius of curvature and focal length) become negative.
For convex mirror, centre of curvature and focus lie behind to the right. Their distances become positive.
Real object stands erect. Its height, being upward, is taken positive.
Real image is formed inverted. Its height is taken negative.
Virtual image is formed erect. Its height is taken positive.

Mirror formula

The equation relating the object distance (u), the image distance (v) and the mirror focal length (f), is called the mirror formula. It is also called Gaussian formula.

The formula is $\frac{1}{v}+\frac{1}{u}=\frac{1}{f}$

Assumptions made

Following assumptions are made in derivation of the mirror formula.

1. The mirror has a small aperture.
2. The point object lies on to the principal axis and placed perpendicular.
3. The incident rays make small angles with the mirror surface or the principal axis.

Image-real and virtual

(a) Image: When rays of light starting from a point object, after reflection (or refraction), meet at a point or appear to come from a point, then this point is called the image of the point object.
(b) Real Image: If the reflected (or refracted) rays actually meet at the point, then the image is real.
(c) Virtual Image: If the reflected (or refracted) rays appear to come from the point, then the image is virtual.
(d) Distinction: Real image of a big object (combination of real images of its different

points) is always inverted. It can be obtained on a screen.
Virtual image of a big object (combination of virtual images of its different points) is always erect. It cannot be obtained on a screen.

Parallax and its removal

(a) Parallax: The relative side way shift between two objects, at unequal distance from the eye, when the eye is moved sideways, is called parallax.
The distant object moves slowly in same direction in which the eye is moved.
The near object moves rapidly in opposite direction to which the eye is moved.

(b) Removal: In laboratory, the parallax is to be removed between the tip of real inverted image of object needle and the tip of erect image needle. It is done as described below.
Heights of image needle (I) and object needle (O) (See Ray Diagram Experiment 1 : Section B) are so adjusted that their tips be on a horizontal straight line passing through the pole (P) of the mirror. One eye (preferably left) is closed and open (right) eye is moved to a position from where the tips of the inverted image and the erect image needle are seen in a line touching each other. The eye must be at a distance of about 30 cm from the tips.
The eye is moved towards right. If the two tips get separated, there is parallax.
If the tip of the image needle moves towards left (or right) with respect to the image tip, image needle is nearer to (or away from) the eye. The image needle is moved towards (or away from) the mirror. The parallax (relative shift) is reduced. The image needle is moved little by little till the shifting of the tips has stopped.
When this has been done, we say that the parallax has been removed 'tip to tip'

Optical bench

A metallic optical bench consists of two metal rods of length about 1.5 m fitted parallel to each other on two metallic stands fitted near their ends. The stands have levelling screws. One rod is cylindrical and graduated along its length in milli-metre scale. Other rod has a square cross-section.
There are four uprights which have groove in there bases to slide along the two parallel rods. Stands on two uprights are fixed while two have sideway lateral moving stands.
In determination of focal length of mirrors, the mirror is mounted on the right most upright with mirror facing towards left. Optical needles to serve as object and image needle are mounted on the left uprights which face the mirror.
In determination of focal length of lenses, the lens is mounted on an upright kept in the middle of the bench. The optical needles are mounted on the uprights to the left and the right of the lens upright.
The flat bases of the uprights have an index marks. These marks help us in noting the positions of the uprights on the metre scale. From these positions, various distances can be found out.

Index correction (bench correction)

(a) Introduction. Actual distance between the mirror and the needle is the distance between the pole of the mirror and the tip of the needle. Observed distance is the difference of the positions of the index marks on the base of mirror upright and needle upright. The two are not always equal.

(B) Definition. The difference of the actual distance and the observed distance, is called index correction.
It is also called bench-correction.

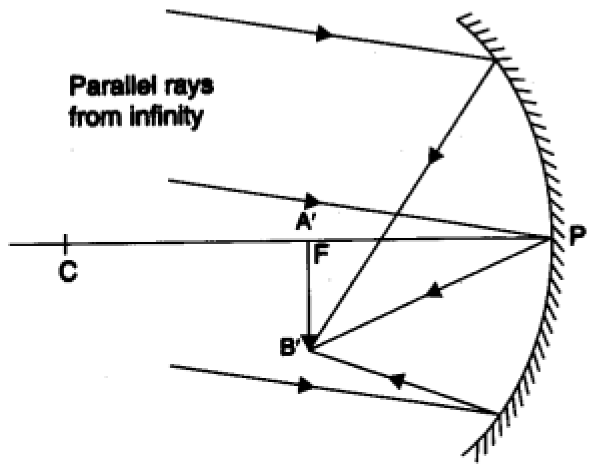
(c) Determination. A knitting needle is held horizontal with its one tip at the pole of the mirror and the other at the tip of the optical needle. Its length (x) is measured by optical bench scale. The observed distance (y) is found by taking difference of the positions of the index marks on the base of mirror upright and needle upright.
The difference (x – y) gives the end correction.

(d) Application. The index correction is algebraically added to all observed distances.

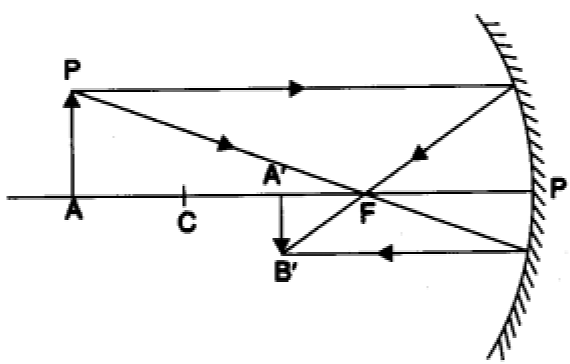
Position, nature, and size of image when objects is put in different position in front of a concave mirror

It is given below in tabular form.

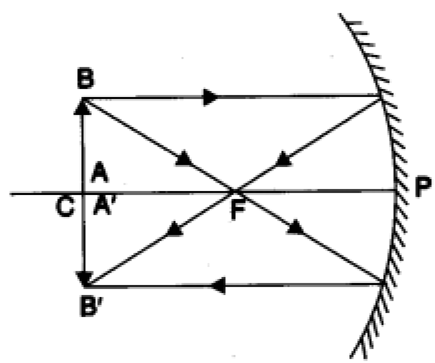
S. No.	Object position	Image			Figure
		Position	Nature	Size	
1.	At infinity	At focus F	Real-Inverted	Point sized	7.04 (a)
2.	Beyond C	Between F and C	Real-Inverted	Diminished	7.04 (b)
3.	At C	At C	Real-Inverted	Same	7.04 (c)
4.	Between C and F	Beyond C	Real-Inverted	Enlarged	7.04 (d)
5.	At F	At infinity	Imaginary-Inverted	Extremely enlarged	7.04 (e)
6.	Between F and P	Behind the mirror	Virtual-Erect	Enlarged	7.04 (f)



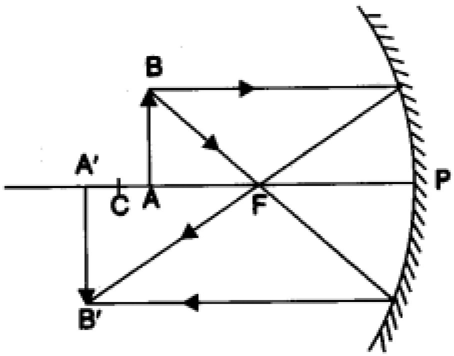
(*a*) Object at infinity



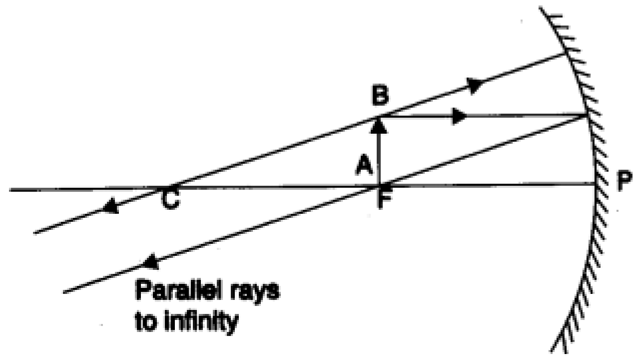
(*b*) Object beyond C



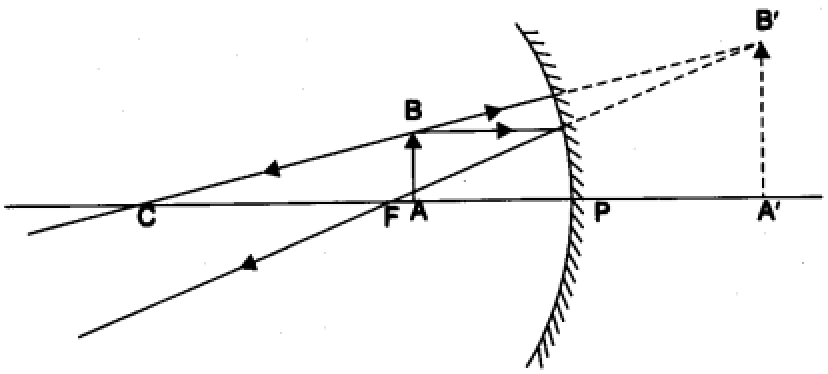
(*c*) Object at C



(*d*) **Object between C and F**



(*e*) **Object at F**



(*f*) **Object between F and P**

Special aberration

(a) Definition. The defect or drawback of a mirror due to which it makes a spread or bulging image of a point object, is called spherical aberration.
It is due to large aperture of the mirror.

(b) Explanation. For rays incident on the mirror near the axis (axial rays), f= R/2. For rays incident on the mirror near its periphery (marginal rays) F < R/2. The focus does not remain a point. Hence, the spherical aberration arises mainly due to marginal rays.

(c) Remedy. Only a small portion of the aperture (either near the axis or near the periphery) should be used.