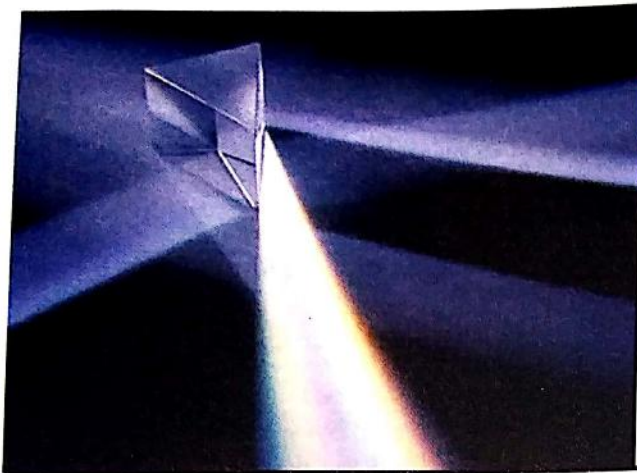




5

Light Energy

Theme : An object lying at the bottom of a vessel filled with water usually appear to be at different depth than it actually is. This is due to bending of light rays when it travels from water to air. This phenomenon is called refraction. Light bends when it passes obliquely from one medium to the other. Due to refraction, a mirage is observed on a hot sandy desert. Atmosphere also refract the rays coming from the sun. This causes advanced sunrise and delayed sunset. Previous learning emphasized on reflection of light by a plane mirror. How images are formed by a curved (concave) mirror is now dealt upon along with rules used to construct ray diagrams.

In this chapter you will learn to

- ☞ define refraction;
- ☞ discuss examples of refraction;
- ☞ describe a spherical mirror;
- ☞ describe a concave and a convex mirror;
- ☞ define the terms, principal axis, centre and radius of curvature, focus and focal length for a spherical mirror;
- ☞ describe rules for making ray diagrams for spherical mirror;
- ☞ distinguish between real and virtual images;
- ☞ use a ray diagram to show formation of a real image by a spherical mirror;
- ☞ describe the characteristics of a real image formed by a spherical mirror;
- ☞ describe dispersion of white light by a prism into constituent colours;
- ☞ display a scientific attitude while making models;
- ☞ show a creative mind set while studying real world optical phenomena;
- ☞ Communicate logical reasoning and explanations effectively using scientific terms.

LEARNING OBJECTIVES

- Revising previous concepts learnt by children
- Building on children's previous learning
- Demonstrating the phenomenon of refraction
- Engaging children in pairs, individually or small groups in activities related to refraction
- Explaining refraction with suitable examples
- Demonstrating how concave and convex mirrors work
- Representing of concave and convex mirrors through diagrams
- Explaining the terms i.e. Focus, principal axis, centre of curvature, radius of curvature with the help of diagrams to children
- Engaging children in activities related to image formation by a concave mirror using ray diagram.
- Explaining real and virtual images
- Demonstrating the dispersion of white light into component colours

KNOWING CONCEPTS

- Refraction :
 - Definition
 - Examples of refraction
- Curved mirrors :
 - Convex
 - Concave
 - Reflecting surface (Convex and concave)
 - Use of curved mirrors
 - Terms related to curved mirrors — Focus, principal axis, centre of curvature, radius of curvature
 - Rules for making ray diagrams of spherical mirrors
 - Real and virtual images
 - Ray diagrams with curved mirrors where real images are formed
- Dispersion of white light into constituent colours.

SPEED OF LIGHT IN DIFFERENT MEDIA

In class VII, we have read that light travels faster in air than in water or glass. The speed of light in air is $3 \times 10^8 \text{ m s}^{-1}$, in water it is $2.25 \times 10^8 \text{ m s}^{-1}$ and in glass it is only $2 \times 10^8 \text{ m s}^{-1}$. In the language of Physics, we say that glass is optically denser than water and water is optically denser than air or air is optically rarer than both water and glass.

Thus, a medium is said to be denser if the speed of light in it decreases, while it is said to be rarer if the speed of light in it increases. But in no medium, it can be more than $3 \times 10^8 \text{ m s}^{-1}$.

REFRACTION OF LIGHT

Light travels in a straight line path in a medium. But when a ray of light travelling in one transparent medium falls obliquely on the surface of another transparent medium, it travels in the other medium in a direction different from its initial path.

The change in direction of path of light when it passes from one optically transparent medium to another, is called **refraction of light**.

It has been experimentally observed that

- (1) When a ray of light travels from a rarer to a denser medium (say, from air to water or from air to glass), it bends towards the normal as shown in Fig. 5.1.

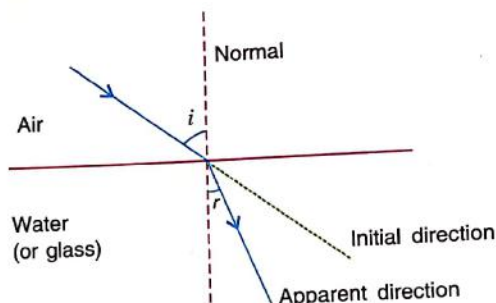


Fig. 5.1 A ray travelling from rarer to denser medium bends towards the normal

- (2) When a ray of light travels from a denser to a rarer medium (say, from water to air or from glass to air), it bends away from the normal as shown in Fig. 5.2.

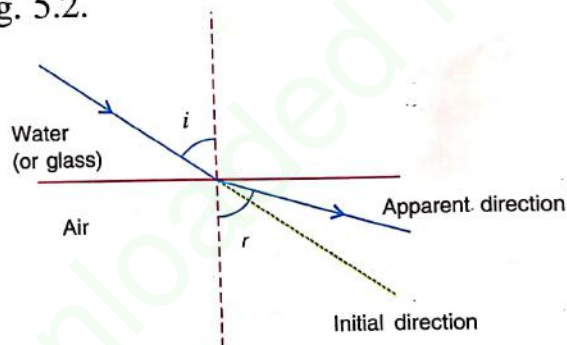


Fig. 5.2 A ray travelling from denser to rarer medium bends away from normal

- (3) When a ray of light falls normally on the surface separating the two media, it passes undeviated (i.e., along the same path) as shown in Fig. 5.3.

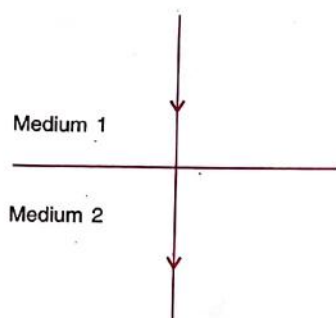


Fig. 5.3 A ray falling normally on the surface separating the two media, passes undeviated

Note : When a ray of light passes from one transparent medium to another transparent medium having the same refractive index, it also remains undeviated.

SOME TERMS RELATED TO REFRACTION OF LIGHT

- (1) **Incident ray :** The ray of light falling on the surface separating the two media, is called the **incident ray**.
- (2) **Refracted ray :** The ray of light travelling in the other medium in the changed direction, is called the **refracted ray**.
- (3) **Normal :** The perpendicular drawn on the surface separating the two media, at the point where the incident ray strikes it, i.e. at the point of incidence, is called the normal.
- (4) **Angle of incidence :** The angle between the incident ray and the normal is called the angle of incidence ' i '
- (5) **Angle of refraction :** The angle between the refracted ray and the normal is called the angle of refraction ' r '.

Fig. 5.4 shows a light ray AO passing from a rarer medium (air) into a denser medium (glass). XY is the surface separating the two media. AO is the incident ray, OB is the refracted ray. NOM is the normal at the point of incidence O, $\angle AON$ is the angle of incidence $\angle i$ and $\angle BOM$ is the angle of

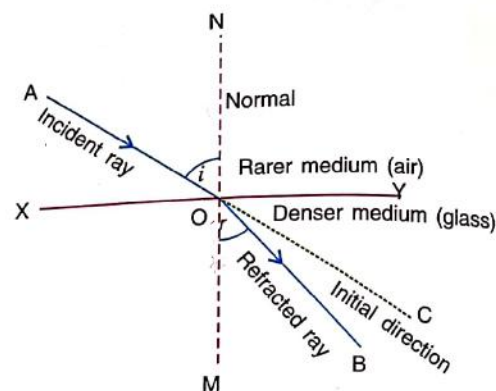


Fig. 5.4 Light ray in going from a rarer to a denser medium bends towards the normal

refraction $\angle r$. It is clear from the diagram that when the ray of light travels from air to glass, it bends towards the normal i.e., instead of moving along its earlier direction shown by the dotted line OC, the ray bends towards the normal and moves along OB (i.e. $\angle r < \angle i$).

Fig. 5.5 shows a light ray AO passing from a denser medium (glass) to a rarer medium (air). XY is the surface separating the two media. It is clear from the diagram that the incident ray AO bends away from the normal and is refracted as OB (i.e. $\angle r > \angle i$).

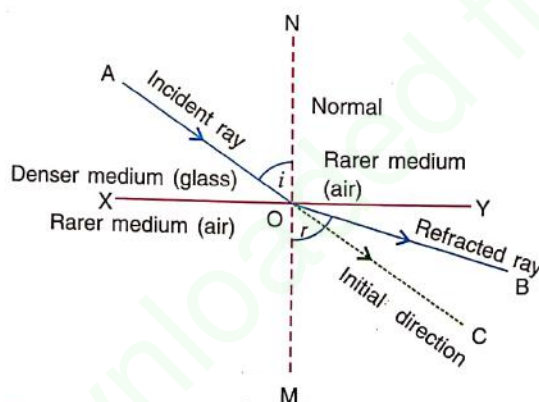


Fig. 5.5 Light ray going from a denser into a rarer medium bends away from the normal

LAWS OF REFRACTION (SNELL'S LAW)

Refraction of light obeys the following two laws also known as Snell's laws of refraction.

1. The incident ray, the normal at the point of incidence and the refracted ray, all lie in the same plane.
2. For a given pair of media and given colour of light, the ratio of the sine of angle of incidence i to the sine of angle of refraction r is a constant i.e.,

$$\frac{\sin i}{\sin r} = \text{constant}$$

This constant is denoted by the symbol μ (read as mew).

It is known as the refractive index of the second medium with respect to the first medium. It is given as

$$\mu = \frac{\text{Speed of light in first medium}}{\text{Speed of light in second medium}}$$

For example, if a ray of light travels from air to water, then the constant $\mu = \frac{\sin i}{\sin r}$ is the refractive index of water with respect to air.

It is given as

$$\mu = \frac{\sin i}{\sin r} = \frac{3 \times 10^8 \text{ m s}^{-1}}{2.25 \times 10^8 \text{ m s}^{-1}} = \frac{4}{3} \text{ (or 1.33)}$$

Similarly, if a ray of light travels from air to glass, then $\mu = \frac{\sin i}{\sin r} = \frac{3 \times 10^8 \text{ m s}^{-1}}{2 \times 10^8 \text{ m s}^{-1}} = 1.5$.

Note : The refractive index of air is 1. No medium can have refractive index less than 1.

EFFECTS OF REFRACTION

(1) The depth of water in a vessel when seen from air appears to be less

Consider a vessel containing water as shown in Fig. 5.6. Its real depth is AO. But when seen obliquely i.e. at an angle above O from air, its depth appears to be AI which is less than AO.

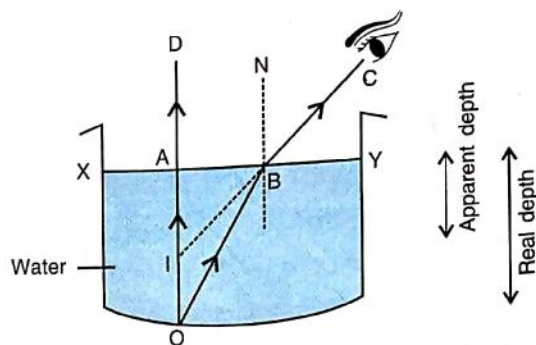


Fig. 5.6 Apparent depth of a vessel full of water

Reason : A ray of light OA from the point O at the bottom of vessel is incident normally on the water-air, surface XY. It travels straight along AD in air. Another ray OB incident from water on the surface XY, when passes to air, bends away from the normal BN, and goes along the path BC. The two refracted rays AO and BC when produced back, meet at I. Thus I is the image of O.

Thus to the observer in air, the depth of vessel appears to be AI instead of AO, due to refraction of light from water to air. The apparent depth AI is less than the real depth AO.



Do You Know ?

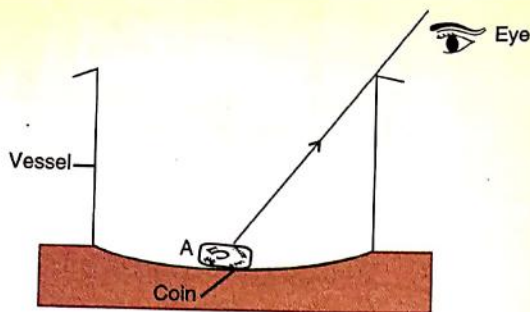
Real depth / Apparent depth = Refractive Index.

Since, refractive index of water is $4/3$, so the apparent depth is $\frac{3}{4}$ th the real depth.

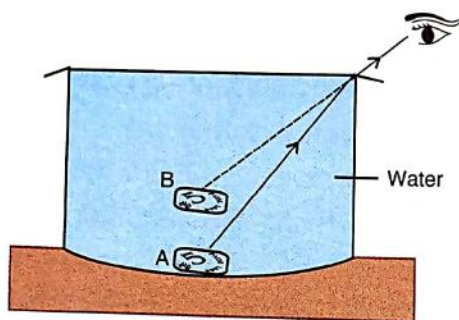
The change in depth due to refraction can be demonstrated by the following activities.

ACTIVITY 1

- (1) Take a coin and an empty glass vessel. Place the coin in the vessel. Put the vessel on a table and step back till the coin is just out of your view. It is hidden from your eye by the edge of the vessel as shown in Fig. 5.7(a).



(a) Coin at the bottom not seen by the eye



(b) Coin seen when water is added to the vessel

Fig. 5.7 A coin in water appears to be raised

- (2) Keep your eye in this position and ask your friend to pour water gradually in the vessel. You will find that when there is sufficient water in the vessel, the coin becomes visible because then it appears to be slightly raised from position A to position B as shown in Fig. 5.7(b).

Explanation : In Fig. 5.7(a), when there is no water in the vessel, the coin is not visible because the ray of light from the coin travelling in a straight line does not reach the eye.

In Fig. 5.7(b), when water is poured in the vessel, the coin becomes visible because the ray of light from the point A of the coin, travelling in a straight line changes its direction (*i.e.* it bends) at the surface of water and reaches the eye. Thus, the light ray bends as it leaves water and enters air. The ray now appears to come from a point B instead of A. In other words, the coin appears to be raised from position A to position B.

ACTIVITY 2

- (1) Take an empty beaker and a pencil. Place the pencil ABC obliquely in the beaker and look at it from the side. It appears straight as shown in Fig. 5.8(a).
- (2) Now pour water in the beaker up to its brim. You will notice that the pencil now appears to be bent as ABD at the surface of water as shown in Fig. 5.8(b).

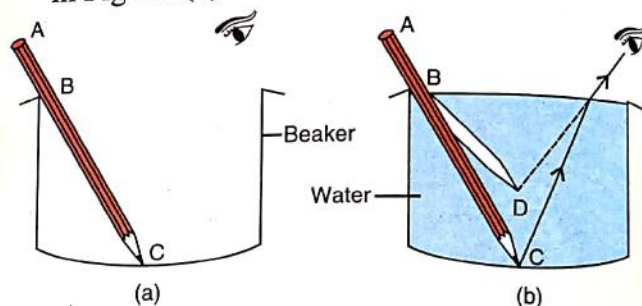


Fig. 5.8 The pencil in water appears to be bent

Explanation : The ray of light coming from the tip C of the pencil bends at the surface of water as it enters in air and it appears to be coming from the point D. In other words, it is due to refraction of light from water to air that the pencil ABC appears as ABD.

From the above, we conclude that when a light ray passes from one transparent medium to another, it bends. The direction in which light ray bends, depends upon whether light travels from a rarer medium to a denser medium or from a denser medium to a rarer medium.

EARLY SUNRISE AND LATE SUNSET

Before sunrise and after sunset, the upper atmospheric layers are warmer than the layers near the earth's surface. So the atmospheric layers near the earth's surface are denser than those above. When the sun is just below the horizon, the light from sun, while coming towards the earth, suffers refraction from a rarer to a denser layer and so it bends towards the normal at each refraction. Due to continuous bending of light rays at different successive layers, the sun can

be seen even when its actual position is just below the horizon as shown in Fig. 5.9. As a result, sun is seen in advance, a few minutes before it rises above the horizon in the morning.

Similarly, in the evening, sun is seen delayed by 3 to 4 minute longer above the horizon after the sun set.

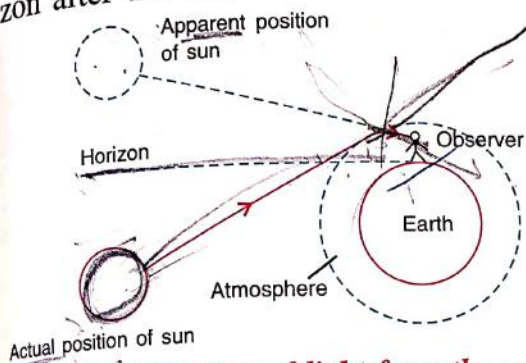


Fig. 5.9 Refraction of light from the sun in the atmosphere

MIRAGE IN A DESERT

Sometimes, in deserts, an inverted image of a tree is seen which gives a false impression of water under the tree. This is called a mirage.

The cause of mirage is the refraction of light. In a desert, the sand becomes very hot during day-time and it rapidly heats the layers of air in contact with it. Therefore, the layers of air near the ground are warmer (and hence rarer) than the upper layers. In other words, the successive upper layers are denser than those below them.

When a ray of light from sun after reflection from the top of a tree travels from a denser to a rarer layer, it bends away from the normal. As a result, in refraction at the surface of separation of successive layers, each time the angle of refraction increases and the angle of incidence of ray going from denser medium to rarer medium also increases, till a stage is reached when the angle of refraction becomes 90° . On further

increase in angle of incidence, the ray of light travelling from a denser to a rarer layer, is not refracted, but it suffers reflection. This reflected ray now travels from the rarer to the denser layer, so it bends towards the normal, at each refraction. On reaching the eye of the observer, an inverted image of the tree is seen. Thus it gives a false impression of a pool of water in front of the tree (Fig. 5.10).

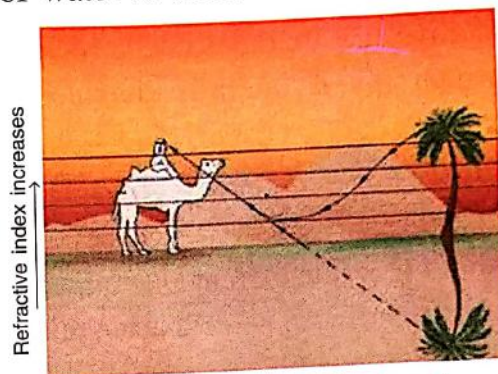


Fig. 5.10 Mirage in desert

REFRACTION OF LIGHT THROUGH A RECTANGULAR GLASS BLOCK

Fig. 5.11 shows a rectangular glass block PQRS. A light ray AB falls on the surface PQ. NBM is the normal at the point of incidence B to the surface PQ. At the surface PQ, the ray AB enters from air to glass, so it bends towards the normal NBM and travels along BC. At the surface RS, another refraction

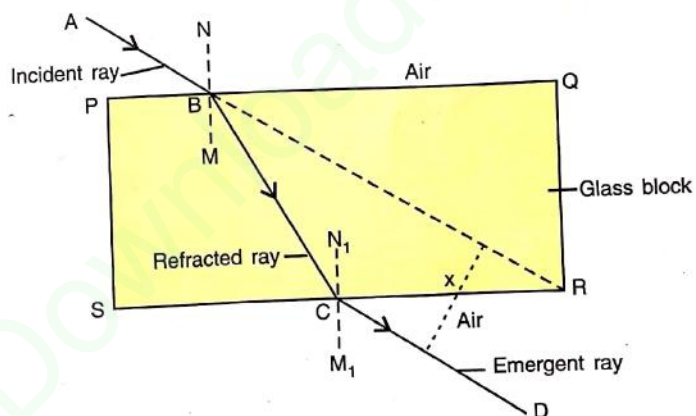


Fig. 5.11 Refraction of light through a rectangular glass block

occurs. N_1CM_1 is the normal at the point of incidence C to the surface RS.

The ray BC now enters from glass to air, so it bends away from the normal N_1CM_1 and travels along CD. The ray AB is called the incident ray, BC the refracted ray, and CD the emergent ray.

The emergent ray CD is parallel to the incident ray AB. Thus, both the incident and emergent rays are in the same direction, but the emergent ray is laterally displaced from the incident ray. (In Fig. 5.11 lateral displacement is shown by x).

PRISM

A prism is a transparent medium bounded by five plane surfaces with a triangular cross section. Two opposite surfaces of prism are identical and parallel triangles, while the other three surfaces are rectangular and inclined on each other as shown in Fig. 5.12.

In symbol form, it is represented by the triangle ABC.

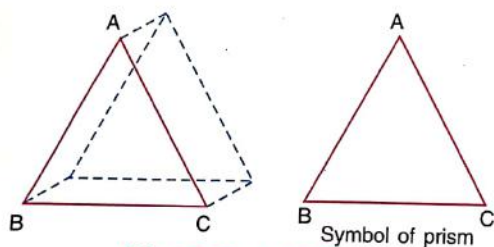


Fig. 5.12 A prism

REFRACTION OF LIGHT THROUGH A PRISM

Fig. 5.13 shows a prism ABC. A ray of light PQ of single colour falls obliquely on the face AB of the prism. This ray enters from air to glass (i.e., from a rarer medium to a denser medium), so it bends towards the normal NQM to the face AB and travels along QR. At the face AC of the prism, another refraction occurs. The ray QR now enters

from glass to air (i.e., from a denser medium to a rarer medium), so it bends away from the normal $N'RM'$ to the face AC and travels along RS. Thus, for the incident ray PQ, the refracted ray inside the prism is QR and the emergent ray outside the prism is RS. Thus, on passing through a prism, the light ray bends towards the base of the prism.

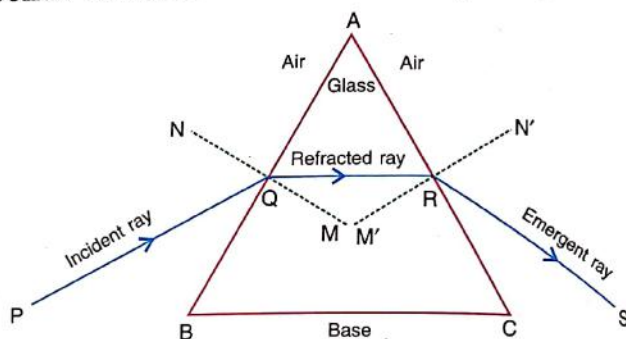


Fig. 5.13 Refraction of light through a prism



Do You Know?

The emergent ray through a prism is not in direction of the incident ray, but it bends towards the base of the prism because in a prism, refraction occurs at two inclined surfaces. On the other hand, in a rectangular glass block, refraction of light occurs at two parallel surfaces, so the emergent ray is in direction of the incident ray, but laterally displaced.

DISPERSION OF WHITE LIGHT

Newton allowed white light from the sun to enter a dark room through a small aperture in a window and placed a glass prism in the path of light rays. The light coming out of the

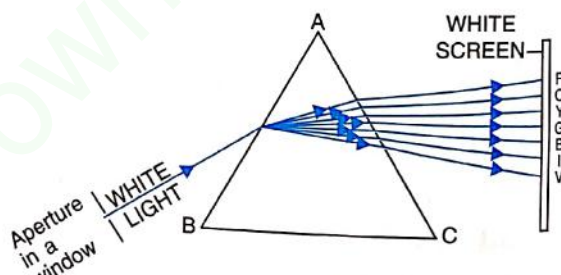


Fig. 5.14 Dispersion of light by a prism

prism was received on a white screen. On the screen, a coloured patch like a rainbow was found as shown in Fig. 5.14. This patch was termed as spectrum.

Starting from the side of the base of the prism, the colours in the spectrum on the screen are in the following order :

Violet (V), Indigo (I), Blue (B), Green (G), Yellow (Y), Orange (O), and Red (R). The order of colours in the spectrum can easily be remembered by the word **VIBGYOR**. Thus, spectrum is the coloured band obtained on a screen on passing the white light through a prism.

From the above experiment, Newton concluded that white light is a mixture of seven colours*.

Note that the prism does not produce colours, but it simply separates the colours which already exist in white light.

Thus, if white light is passed through a prism, it splits into different colours. This is called **dispersion of light**.

CAUSE OF DISPERSION

In class VII, you have read that white light of sun is composed of seven prominent colours, namely, violet, indigo, blue, green, yellow, orange and red. The speed of light of all colours is same in air or vacuum, but it differs in a transparent medium such as glass or water. In a transparent medium (such as glass or water), the speed of violet light is minimum and of red light is maximum. Therefore, the refractive index μ of a transparent medium is also different for lights of different colours.

* More precisely there are a number of colours mixed with one another but the prominent colours are seven.

Since, refractive index

$$= \frac{\text{speed of light in air}}{\text{speed of light in medium}},$$

the refractive index of a medium is maximum for the violet light and minimum for the red light. Therefore, when white light enters a prism, it splits into its constituent colours while refraction at the first surface of the prism. These colours get farther separated from each other on refraction at the second surface of prism.



Do You Know?

In rainy season, sometimes after the rains, you see a rainbow in the sky, just opposite to the sun. It is due to dispersion of white light of sun by the rain drops which behave like small prisms.

The dispersion of white light can be demonstrated by the following activities.

ACTIVITY 3

To see dispersion of white light.

Take a thick cardboard sheet. Make a small hole in it. Allow the sun light to pass through it in a dark room. Place a prism in the path of sun light coming through the hole and then a white screen behind the prism as shown in Fig. 5.15.

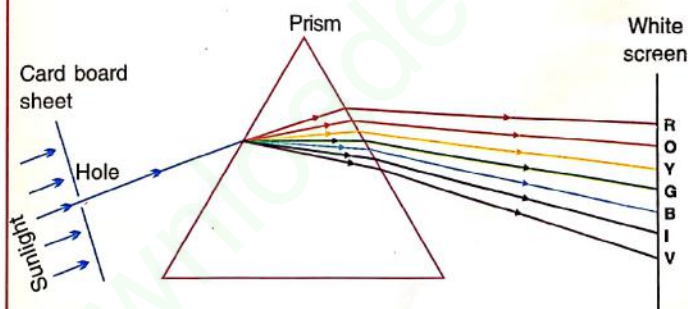


Fig. 5.15 Formation of spectra by a prism

You will see that a band of colours is obtained on the screen with colours violet, indigo, blue, green, yellow, orange and red in order from the base of the prism upwards as shown in Fig. 5.15.

ACTIVITY 4

Take a circular disc of cardboard and divide it into seven sectors. Then paint the sectors with the seven colours (violet, indigo, blue, green, yellow, orange and red) in order, as shown in Fig. 5.16.

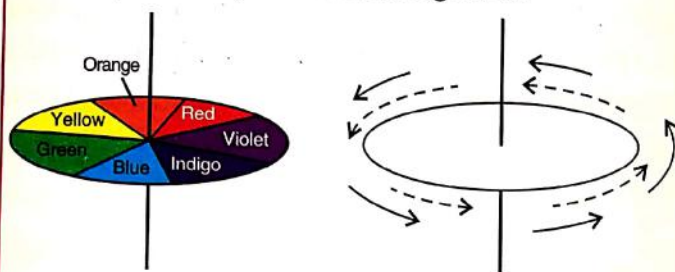


Fig. 5.16 A colour disc on rotation produces white colour

Rotate the disc rapidly. You will notice that the disc appears white.

This shows that seven colours violet, indigo, blue, green, yellow, orange and red being the constituent colours of white light, when combined produce the white effect.

Think -

SPHERICAL MIRRORS

Spherical mirrors are made by silvering the part AB of the hollow glass sphere as shown in Fig. 5.17.

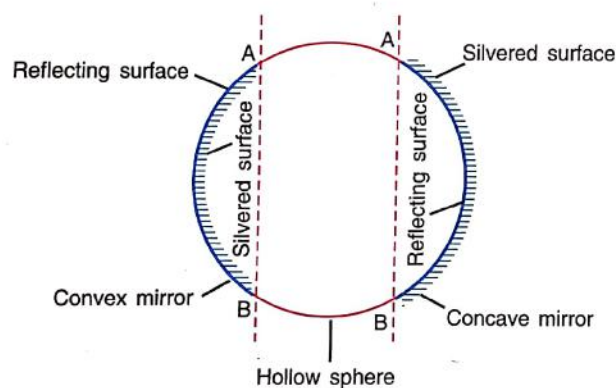


Fig. 5.17 Formation of a spherical mirror

The surface on which silvering is done, is called the silvered surface and the reflection of light takes place from the other surface which is called the reflecting surface.

Kinds of spherical mirrors

There are two kinds of spherical mirrors:

- Concave mirror and
- Convex mirror.

(i) **Concave mirror** : A concave mirror is made by silvering on the outer surface of a hollow sphere such that the reflection takes place from the inside hollow (or concave) surface as shown in Fig. 5.18 (a).

(ii) **Convex mirror** : A convex mirror is made by silvering on the inner surface such that the reflection takes place from the outer convex (or bulged) surface as shown in Fig. 5.18(b).

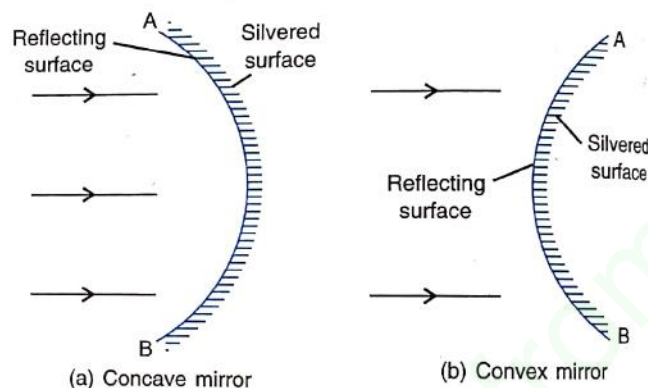


Fig. 5.18 Concave and convex mirrors

SOME TERMS RELATED TO A SPHERICAL MIRROR

- Pole** : The geometric centre of the spherical surface of the mirror is called the pole of the mirror. It is the mid point of the aperture AB of the mirror. It is represented by the symbol P in Fig. 5.19.
- Centre of curvature** : The centre of curvature of a mirror is the centre of the sphere of which the mirror is a part. It is represented by the symbol C in Fig. 5.19.

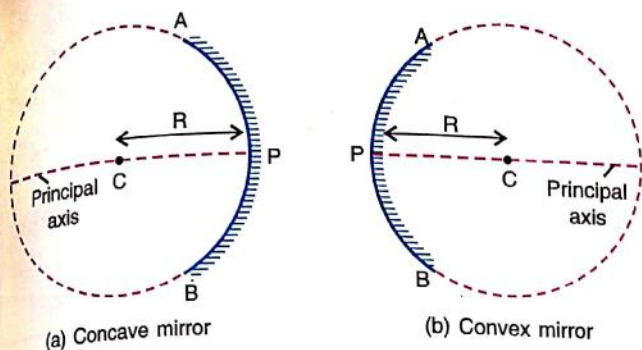


Fig. 5.19 Pole, centre of curvature, radius of curvature and principal axis of a spherical mirror

Note : The normal at any point of the mirror passes through the centre of curvature. In other words, a line joining the centre of curvature to any point of the mirror, is normal on the mirror at that point.

(3) Radius of curvature : The radius of curvature of a mirror is the radius of the sphere of which the mirror is a part. Thus, it is the distance of the centre of curvature C from any point of the surface of mirror. In Fig. 5.19, this is represented by the symbol R.

(4) Principal axis : It is a straight line joining the pole of the mirror to its centre of curvature. In Fig. 5.19, the line PC represents the principal axis. It may extend on either side of the pole.

FOCUS AND FOCAL LENGTH

In class VII, you have learnt about reflection of light at a plane mirror. When a ray of light is reflected from a plane mirror, it obeys the following two laws of reflection :

- The angle of incidence i is equal to the angle of reflection r .
- The incident ray, the reflected ray and the normal, all lie in the same plane.

The above laws of reflection of light hold for the spherical mirrors as well.

Focus : Fig. 5.20 shows the rays of light falling on a spherical mirror parallel to its principal axis. These rays are reflected by the mirror obeying the laws of reflection (*i.e.*, angle of incidence i = angle of reflection r). The normal at the point of incidence is obtained by joining this point to the centre of curvature C. The reflected rays are not parallel to each other, but they are converging towards a point in a concave mirror, while diverging from a point in a convex mirror.

In case of a concave mirror, the reflected rays meet at point F on the principal axis [Fig. 5.20(a)]. This point is called the focus of the concave mirror.

In case of a convex mirror [Fig. 5.20(b)], the reflected rays do not meet at any point, but they appear to come from a point F on the principal axis, behind the mirror. This point is called the focus of the convex mirror.

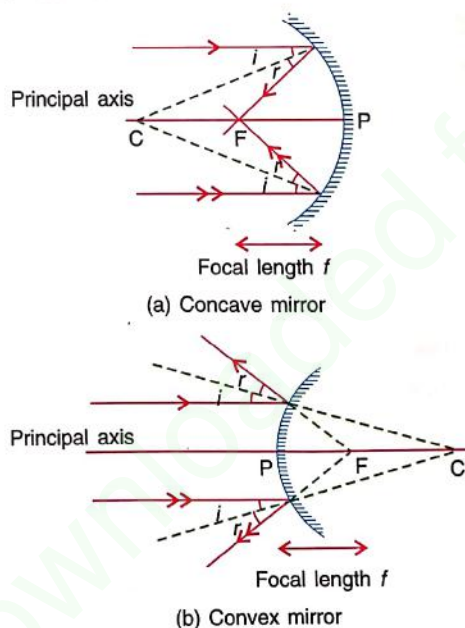


Fig. 5.20 Focus and focal length of a spherical mirror

The focus of a concave mirror is a point on the principal axis at which the light rays

incident parallel to the principal axis meet (converge) after reflection from the mirror.

The focus of a convex mirror is a point on its principal axis at which the light rays incident parallel to the principal axis, appear to meet after reflection from the mirror.

The focus is represented by the letter F.

Note : The focus of a concave mirror is real, while that of a convex mirror is virtual.

Focal length : The distance of the focus from the pole of the mirror is called the focal length of the mirror. In Fig.5.20, the focal length of mirror is marked by the distance PF. Thus,

In Fig. 5.20 focal length $f = PF$.

It can be proved (by simple geometry) that

Focal length = $\frac{1}{2} \times$ Radius of curvature
or Radius of curvature = $2 \times$ Focal length.

The approximate focal length of a concave mirror can be determined by the following simple activity.

ACTIVITY 5

To find the approximate focal length of a concave mirror

Take the concave mirror and hold it such that it faces the sun. Now place a piece of paper in front of it and adjust its distance from the mirror such that at

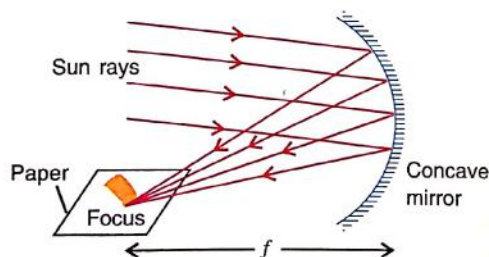


Fig. 5.21 Determination of approximate focal length of concave mirror

one position, a very small image of sun is seen on the paper. You will notice that the paper chars at this point (Fig. 5.21). This point is the focus of the concave mirror.

Measure the distance f of this point from the mirror with a metre ruler. This distance f gives the approximate focal length of the concave mirror.

RULES FOR MAKING RAY DIAGRAM IN A SPHERICAL MIRROR

1. The object is kept in front of the reflecting surface on its left side.
2. The object is always kept on the principal axis such that it is perpendicular to the principal axis and its foot touches the principal axis.
3. For constructing a ray diagram, take at least two rays of convenience whose paths can be traced after reflection.

To construct the image of an object due to reflection by a spherical mirror, any two of the following three rays can be constructed according to our convenience.

Convenient rays :

- (i) **A ray passing through the centre of curvature is reflected along its own path :** A line joining the centre of curvature to any point on the surface of mirror is always normal to it. Thus, a ray passing through the centre of curvature is incident normally on the spherical mirror. Its angle of incidence is zero, therefore, the angle of reflection is also zero. It means that the ray gets reflected back along its own path (Fig. 5.22).

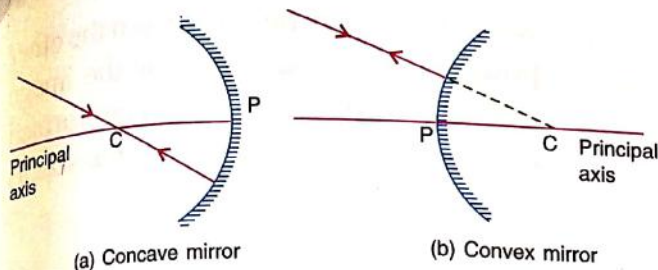


Fig. 5.22 A ray passing through the centre of curvature is reflected along its own path

(ii) A ray parallel to the principal axis :

A ray of light incident parallel to the principal axis, after reflection passes through the focus in case of a concave mirror or appears to come from the focus in case of a convex mirror (Fig. 5.23).

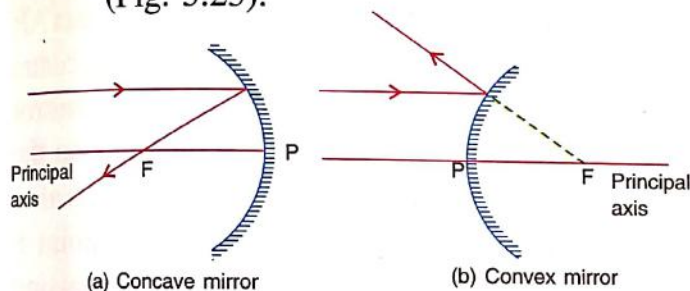


Fig. 5.23 A ray parallel to the principal axis after reflection either passes or appears to pass through focus

(iii) A ray passing through the focus :

A ray passing through the focus in case of a concave mirror or appearing to pass through the focus in case of a convex mirror, gets reflected parallel to the principal axis (Fig. 5.24).

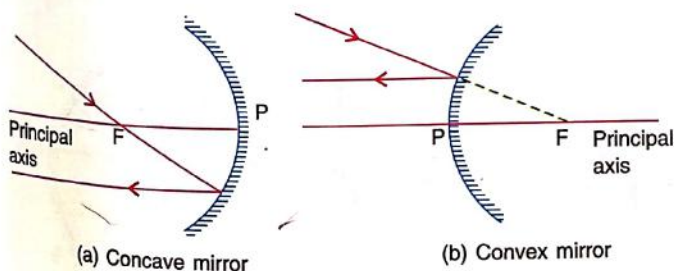


Fig. 5.24 A ray passing through the focus or appearing to pass through the focus, gets reflected parallel to the principal axis

To construct the image formed by a mirror, we take at least two rays incident on the mirror from a given point of the object. The point where the rays after reflection from the mirror, meet or appear to meet, gives the image of that point of the object.

REAL AND VIRTUAL IMAGE

If the reflected rays actually meet at a point, the image is real, but if the reflected rays appear to meet at a point when produced backwards, the image is virtual. A real image can be obtained on a screen, but a virtual image cannot be taken on a screen. A real image is inverted, but a virtual image is erect.

Distinction between real and virtual images

Real Image	Virtual Image
1. A real image is formed when the reflected rays actually meet at a point.	1. A virtual image is formed when the reflected rays meet on producing them backwards.
2. It is inverted.	2. It is erect or upright.
3. It can be obtained on a screen.	3. It cannot be obtained on a screen.

IMAGES FORMED BY A CONCAVE MIRROR

- 1. When an object is at infinity :** When an object is at infinity, the image is formed at focus. It is a real, inverted and highly diminished image (Fig. 5.25)

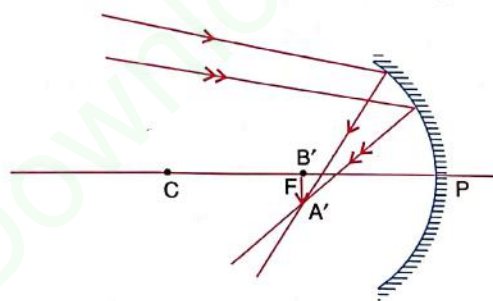


Fig. 5.25 A real, inverted and highly diminished image is formed when the object is at infinity

- 2. When an object is beyond the centre of curvature :** An object AB is placed beyond the centre of curvature C of the concave mirror (Fig. 5.26). A ray AD is incident on the mirror parallel to the principal axis. This ray after reflection passes through the focus F along DA'. The other ray AE passing through the centre of curvature C after reflection retraces its path EA (i.e., it gets reflected along EA). The two reflected rays DA' and EA intersect at A'. Thus, A' is the real image of the point A. When we take rays incident from other points of the object, we will find that A'B' is the image of AB which is between C and F. The image formed is real, inverted and smaller in size than the object.

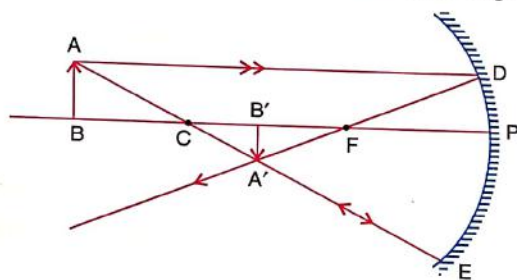


Fig. 5.26 A real, inverted and smaller image is formed between centre of curvature and focus

- 3. When an object is at the centre of curvature :** An object AB is placed at the centre of curvature C of the concave mirror (Fig. 5.27). A ray AD incident on the mirror parallel to its principal axis after reflection passes through the focus F along DA'. The other ray AE incident on the mirror through the focus F after reflection becomes parallel to the principal axis along EA'. The two reflected rays DA' and EA' intersect at point A'. Hence, A' is the real image of the point A. In the same

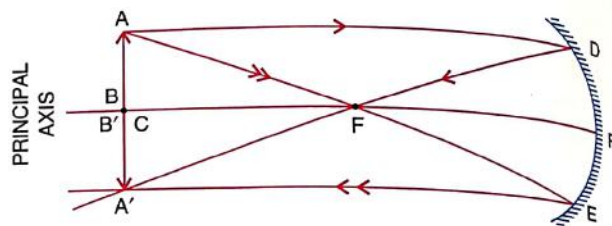


Fig. 5.27 A real, inverted image of the same size is formed at the centre of curvature

- 4. When an object is between the centre of curvature and focus :** An object AB is placed between focus F and the centre of curvature C of the concave mirror (Fig. 5.28). A ray AD incident on the mirror parallel to the principal axis after reflection passes through the point F along DA'. The other ray AE passing through the focus F after reflection becomes parallel to the principal axis along EA'. The two reflected rays DA' and EA' intersect at A'. Thus, A' is the real image of A. In a similar way, taking rays incident from other points of the object, A'B' is the image of AB formed beyond C. The image thus formed is real, inverted and of bigger size than the object.

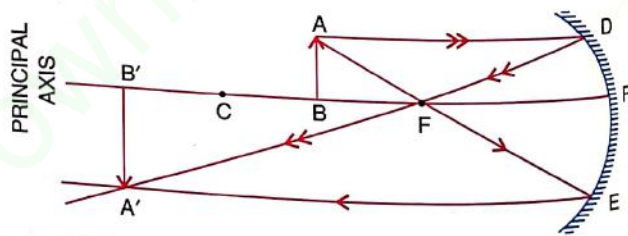


Fig. 5.28 A real, inverted and magnified image is formed beyond the centre of curvature

5. **When an object is at the focus :**
When an object is at the focus, the image formed is at infinity. It is real, inverted and highly magnified (Fig. 5.29).

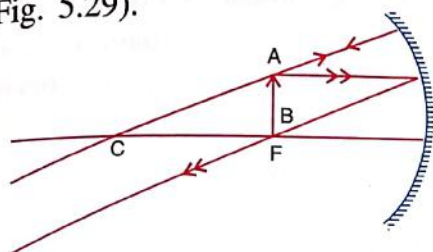


Fig. 5.29 A real, inverted and highly magnified image is formed at infinity

6. **When an object is between the focus and pole :** An object AB is placed between the pole P and focus F of a concave mirror (Fig. 5.30). A ray AD incident on the mirror parallel to the principal axis after reflection passes through the focus F along DF. The other ray AE passing through the centre of curvature C of the mirror after reflection retraces its path (i.e., it gets reflected as EC). The two reflected rays DF and EC do not actually intersect, but they simply appear to diverge from a point A' behind the mirror. This is shown by the dotted lines. Thus, A' is the virtual image of A. In a similar way, taking rays incident from other points of the object, A'B' is the image of AB

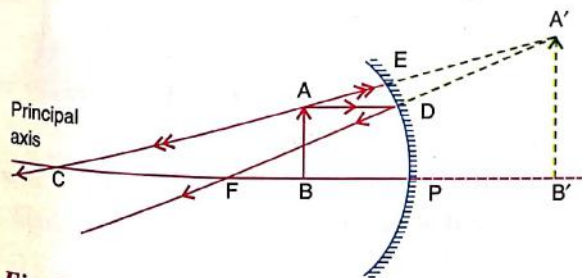


Fig. 5.30 A virtual, erect and bigger image is formed behind the mirror

formed behind the mirror. The image formed is virtual, erect and of size bigger than the object.

Thus a concave mirror forms real as well as virtual images. The image is virtual if the object is very close to the mirror before its focus. For the object at focus or beyond it, the image is real. The virtual image is always magnified for each position of object between the pole and focus of mirror. The real image is magnified if the object is at focus or between focus and centre of curvature. It is of same size when object is at centre of curvature. But it is diminished when object is beyond centre of curvature.



Do You Know ?

The image formed by a mirror (both plane mirror and spherical mirror) shows lateral inversion (i.e., the right side of object appears at left side of image or vice-versa).

Image formed by a concave mirror for different positions of the object

No.	Position of the object	Position of the image	Nature of the image
1.	At infinity	At focus (F)	Real, inverted and diminished
2.	Beyond the centre of curvature (C)	Between focus (F) and the centre of curvature (C)	Real, inverted and smaller than the object
3.	At the centre of curvature (C)	At the centre of curvature (C)	Real, inverted and of same size
4.	Between the centre of curvature (C) and focus (F)	Beyond the centre of curvature (C)	Real, inverted and bigger than the object
5.	At the focus (F)	Infinity	Real, inverted and highly magnified.
6.	Between the focus (F) and pole (P)	Behind the mirror	Virtual, erect and enlarged

Images Formed by A Convex Mirror

An object AB is placed in front of a convex mirror. A ray AD incident on the mirror parallel to the principal axis after reflection appears to diverge from focus F along DA_1 . The other ray AE passing towards the centre of curvature C, after reflection retraces its path EA as shown in Fig. 5.31. (i.e. it gets reflected back along EA). The two reflected rays DA_1 and EA do not actually meet, but they appear to meet at A' behind the mirror when produced backwards as shown by the dotted lines. Thus, A' is the virtual image of the point A. In a similar way, taking rays incident from the other points of the object, $A'B'$ is the image of AB.

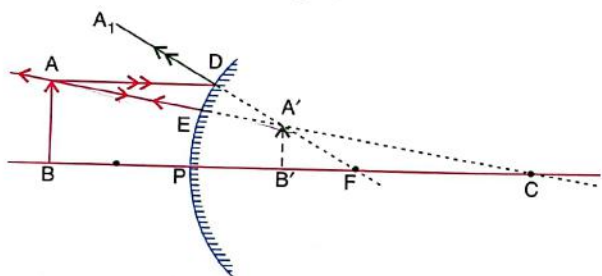


Fig. 5.31 A virtual, erect and smaller image is formed behind the mirror between F and P

As the object is brought closer to the convex mirror, the image moves towards the pole of mirror. Its size increases (but always remains smaller than the size of the object). It is virtual, erect and diminished, and is always formed between the pole and focus.

Position, size and nature of image formed by a convex mirror

No.	Position of the object	Position of the image	Size of the image	Nature of the image
1	At infinity	At focus	Diminished to a point	Virtual and upright
2.	At any other point	Between focus and pole	Diminished	Virtual and upright

Conclusion : (1) In a concave mirror, the image formed can be real or virtual, inverted or erect, diminished or of same size or enlarged, depending upon the position of object. As the object is brought from infinity towards the mirror, the image is real, inverted and diminished till the object is beyond centre of curvature. For the object at centre of curvature, the image is real, inverted and of same size. When object comes closer up to focus, the image is real, enlarged and inverted. But if object comes still closer, the image becomes virtual, erect and enlarged.

(2) In a convex mirror, the image formed is always virtual, erect, diminished and it is situated between the pole and focus, for each position of the object in front of the mirror. As the object moves closer to the mirror, the image shifts towards the pole and it increases in size. We can verify it by drawing ray diagrams for different positions of the object.

The formation of virtual image by a concave and convex mirror can be demonstrated by the following activity.

ACTIVITY 6

Take a polished steel spoon. The inside surface of the spoon is curved inwards and has a concave shape while the outside surface of the spoon is curved outwards and has a convex shape.

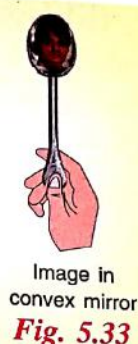
- (1) Hold the spoon in such a way that the inside surface of the spoon (concave side) is closer to you. See image of your face (Fig.5.32). It is erect and magnified. Now move the spoon away from you, you will notice that the image becomes inverted.



Fig. 5.32

- (2) Now hold the spoon with its outside surface

towards your face. Observe the image. You will observe that the image is erect but diminished as shown in Fig. 5.33. If you move the spoon away from you, the image remains always erect and diminished.



Do You Know?

A real image formed by a mirror is always formed in front of the mirror, while a virtual image is formed behind the mirror.

USES OF A CONCAVE MIRROR

A concave mirror is put to the following uses :

- As a shaving mirror,
- As a reflector,
- As a doctor's head mirror,
- To converge solar radiations in a solar cooker, and
- In flood lights as a reflector.

(i) Use of concave mirror as a shaving mirror : A concave mirror forms an erect and magnified image of an object placed close to it. This fact enables us to use it as a shaving mirror.

(ii) Use of concave mirror as a reflector : If a source of light is placed at the focus of a concave mirror, we get a parallel beam of reflected light (Fig. 5.34). This fact enables us to use it as a reflector in torch, searchlight and

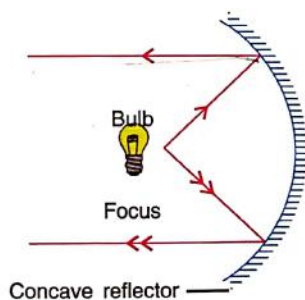


Fig. 5.34 Use of a concave mirror as a reflector

headlight of a car and other vehicles. The source of light (bulb) is placed at the focus of the concave reflector.

(iii) Use of concave mirror as a doctor's head mirror : If a parallel beam of light is incident on a concave mirror, it converges the beam to a point called focus (Fig. 5.35). This fact enables us to use it as a doctor's head mirror to concentrate light on a small area to be examined, like nose, throat, ear, teeth, etc.

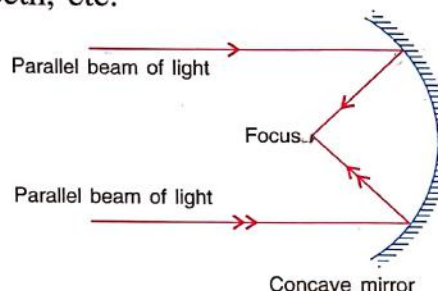


Fig. 5.35 Use of a concave mirror as a doctor's head mirror

(iv) Use of concave mirror in a solar cooker to converge the sun-rays : In a solar cooker a concave mirror is used to reflect the sun-rays so as to converge them on the cooking material placed at the focus of concave mirror.

(v) Use of concave mirror in flood lights as a reflector : In flood lights, the source of light (i.e. bulb) is placed between the pole and focus of a concave mirror so as to obtain a diverging beam of light.

USES OF A CONVEX MIRROR

A convex mirror is put to the following uses :

- As a rear view mirror,
- As a reflector in street lamps, and
- As a vigilance or anti-theft mirror.

(i) Use of convex mirror as a rear view mirror : A convex mirror diverges the

incident light rays and always forms a small and erect image between its pole and focus. This fact enables us to use it as a rear view mirror by a driver to see all the traffic behind him approaching the mirror. Fig. 5.36 shows that a convex mirror has a wider field of view than a plane mirror.

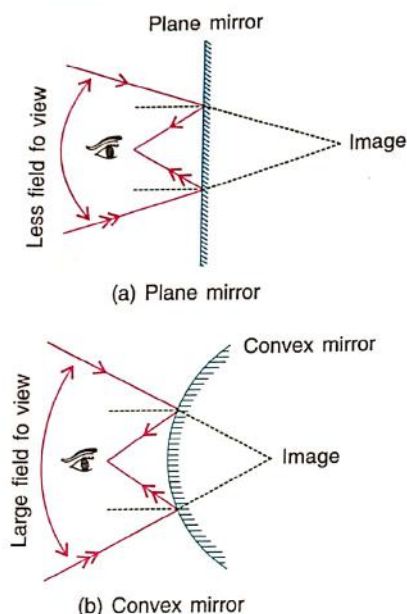


Fig. 5.36 Field of view of a convex mirror is wider than that of a plane mirror

(ii) **Use of convex mirror as a reflector in street lamps** : The fact that a convex mirror diverges the light rays incident on it, enables us to use it as a reflector in street lamps. The light from a bulb placed in front of a convex mirror diverges over a large area in the street as shown in Fig. 5.37.

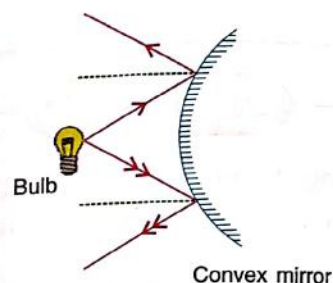


Fig. 5.37 Use of a convex mirror as a reflector in street lights

(iii) **Use of convex mirror as a vigilance mirror** : In big showrooms and departmental stores, convex mirrors are used to have a view on the customers entering in as well as going out. The mirrors so used are called vigilance or anti-theft mirrors.

RECAPITULATION

- The change in direction of path of light when it passes from one transparent medium to another, is called the refraction of light.
- The speed of light in air is $3 \times 10^8 \text{ m s}^{-1}$. In any other transparent medium (such as water, glass, etc.), the speed of light is less than that in air. The air is, therefore, optically rarer than any other transparent medium.
- When a ray of light travels from a rarer to a denser medium, it bends towards the normal.
- When a ray of light travels from a denser to a rarer medium, it bends away from the normal.
- When a ray of light falls normally on the surface separating the two media, the angle of incidence is zero, so it passes undeviated.
- Refraction takes place at the two parallel surfaces when light passes through a rectangular glass block. The emergent ray and the incident ray are in the same direction, but they are laterally displaced.
- When a light ray of single colour passes through a prism, refraction takes place at the two inclined surfaces of the prism and the light ray bends towards the third surface (called base) of the prism.
- When white light passes through a prism, it splits into seven colours namely, violet, indigo, blue, green, yellow, orange and red (VIBGYOR) with violet colour towards the base of the prism. This coloured band is called spectrum of white light.

- The splitting of white light into the constituent colours is called dispersion of light.
- Prism does not produce colours, but it simply separates the colours which already exist in white light.
- The laws of reflection are :
 - (a) The angle of incidence is equal to the angle of reflection.
 - (b) The incident ray, the reflected ray and the normal lie in the same plane.
- These laws hold true for the spherical mirrors also.
- A spherical mirror is a part of a hollow sphere.
- Spherical mirrors are of two types : (a) concave and (b) convex.
- A concave mirror is made by silvering on the outer surface of the sphere so that reflection takes place from the inner surface. A convex mirror is made by silvering on the inner surface of the sphere so that reflection takes place from the outer surface.
- The pole of a mirror is the geometric centre of its spherical surface.
- The centre of curvature of a mirror is the centre of the sphere of which the mirror is a part.
- The radius of curvature of a mirror is the radius of the sphere of which the mirror is a part.
- The principal axis of a mirror is the straight line joining its pole and the centre of curvature.
- The focus of a concave mirror is a point on the principal axis at which the light rays incident parallel to the principal axis meet after reflection from the mirror.
- The focus of a convex mirror is a point on the principal axis at which the light rays incident parallel to the principal axis appear to meet after reflection from the mirror.
- The focal length of a spherical mirror is the distance of its focus from the pole.
- Focal length = $\frac{1}{2}$ × Radius of curvature. OR Radius of curvature = 2 × focal length.
- The image formed by a mirror is real if the rays after reflection from it actually meet at a point. A real image can be obtained on a screen. It is inverted.
- The image formed by a mirror is virtual if the rays after reflection from it do not actually meet at a point, but they meet when they are produced backwards. A virtual image can not be obtained on a screen.
- A ray passing through the centre of curvature is incident normally on the spherical mirror and so it gets reflected back along its own path.
- An incident ray parallel to the principal axis after reflection, passes (in a concave mirror) or appears to pass (in a convex mirror) through the focus of the mirror.
- A ray passing through the focus (in a concave mirror) or appearing to pass through the focus (in a convex mirror) is reflected parallel to the principal axis.
- In a concave mirror, the position and nature of the image formed, depends on the position of object. For the object situated beyond the focus, the image is always real and inverted, whereas for the object situated between the focus and the pole, the image is virtual, erect and enlarged.
- In a convex mirror, the image formed is always virtual, erect and diminished for each position of object. It is situated behind the mirror between its pole and focus.
- A concave mirror is used as a shaving mirror and as a reflector in torch, searchlight and headlight of a vehicle; and also as a doctor's head mirror.
- A convex mirror is used as a rear view mirror in front of a driver and as a reflector in street lamp.

TEST YOURSELF

A. Objective Questions :

1. Write **true** or **false** for each statement :

- (a) Water is optically denser than glass.
- (b) A ray of light when passes from glass to air, bends towards the normal.
- (c) The speed of light is more in glass than in water.
- (d) The depth of a pond when seen from above appears to be less.
- (e) Light travels at a lower speed in water than in air.
- (f) Light travels in the same straight line path while passing through different media.
- (g) The angle formed between the normal and the refracted ray is known as the angle of incidence.
- (h) At the point of incidence, a line drawn at right angles to the surface, separating the two media, is called the normal.
- (i) Image is formed by a mirror due to refraction of light.
- (j) Rays of light incident parallel to the principal axis pass through the focus after reflection from a concave mirror.
- (k) A convex mirror is used as a shaving mirror.
- (l) The focal length of a convex mirror is equal to its radius of curvature.
- (m) A concave mirror converges the light rays, but a convex mirror diverges them.
- (n) A virtual image formed by a spherical mirror is always erect and situated behind the mirror.

Ans. True – (d), (e), (h), (j), (m), (n),

False – (a), (b), (c), (f), (g), (i), (k), (l)

2. Fill in the blanks :

- (a) Water is optically than air.
- (b) Air is optically than glass.
- (c) When a ray of light travels from water to air, it bends the normal.

- (d) When a ray of light travels from air to glass, it bends the normal.
- (e) When white light passes through a prism,
- (f) The splitting of white light into its constituent colours is called
- (g) A mirror is obtained on silvering the outer surface of a part of a hollow glass sphere.
- (h) Radius of curvature of a spherical mirror is its focal length.
- (i) The angle of incidence for a ray of light passing through the centre of curvature of a spherical mirror is
- (j) A mirror always forms a virtual image.
- (k) A concave mirror forms a virtual image for an object placed

Ans. (a) denser (b) rarer (c) away from

(d) towards (e) disperses (f) dispersion

(g) concave (h) two times (i) 0° (j) convex

(k) between pole and focus

3. Match the following :

Column A

Column B

- | | |
|--------------------|------------------------------------|
| (a) White light | (i) convex mirror |
| (b) Refraction | (ii) concave mirror |
| (c) Virtual images | (iii) refraction |
| (d) Real images | (iv) spectrum |
| (e) Prism | (v) ray of light from glass to air |

Ans. (a)–(iv), (b)–(v), (c)–(i), (d)–(ii), (e)–(iii)

4. Select the correct alternative :

- (a) The speed of light in air or vacuum is :
 - (i) $3 \times 10^8 \text{ m s}^{-1}$
 - (ii) $2.25 \times 10^8 \text{ m s}^{-1}$
 - (iii) 332 m s^{-1}
 - (iv) $2.0 \times 10^8 \text{ m s}^{-1}$

- (b) A ray of light moving from an optically rarer to a denser medium :
- bends away from the normal
 - bends towards the normal
 - remains undeviated
 - none of the above.
- (c) The angle between the normal and refracted ray is called :
- angle of deviation
 - angle of incidence
 - angle of refraction
 - angle of emergence.
- (d) The property of splitting of white light into its seven constituent colours is known as :
- rectilinear propagation
 - refraction
 - reflection
 - dispersion.
- (e) The seven colours in the spectrum of sunlight in order, are represented as :
- VIBGYOR
 - VIGYBOR
 - BIVGYOR
 - RYOBIVG
- (f) A ray of light passing through centre of curvature of a spherical mirror, after reflection :
- passes through the focus
 - passes through the pole
 - becomes parallel to the principal axis
 - retraces its own path.
- (g) If the radius of curvature of a concave mirror is 20 cm, its focal length is :
- 10 cm
 - 20 cm
 - 40 cm
 - 80 cm.
- (h) The image formed by a convex mirror is :
- erect and diminished
 - erect and enlarged
 - inverted and diminished
 - inverted and enlarged.

- (i) The image formed by a concave mirror is of the same size as the object, if the object is placed :
- at the focus
 - between the pole and focus
 - between the focus and centre of curvature
 - at the centre of curvature.
- (j) A convex mirror is used :
- as a shaving mirror
 - as a head mirror by a dentist
 - as a rear view mirror by a driver
 - as a reflector in torch.

Ans. (a)–(i), (b)–(ii), (c)–(iii), (d)–(iv), (e)–(i), (f)–(iv), (g)–(i), (h)–(i), (i)–(iv), (j)–(iii)

B. Short/Long Answer Questions :

- State the speed of light in (a) air, (b) water, and (c) glass.
- How does the speed of light determine the optical density of a medium ?
- Which is optically denser : water or air ? Give reason.
- Out of air and glass, which is optically rarer ? Give reason.
- What do you understand by refraction of light ?
- Describe an experiment to show that a light ray bends when it passes from one transparent medium into another transparent medium.
- Draw a ray diagram to show that the depth of a vessel containing water when seen from above, appears to be less than its real depth.
- Define the following terms :
Incident ray, Refracted ray, Angle of incidence, Angle of refraction.
- A ray of light falls normally on a glass slab. What is the angle of incidence ?
- A ray of light travels from a rarer medium to a denser medium. How will it bend ?

11. A ray of light travels from a denser medium to a rarer medium. How will it bend ?

12. The diagram given below in Fig. 5.38 shows a ray of light AO falling on a surface separating two media. Draw the refracted ray in each case.

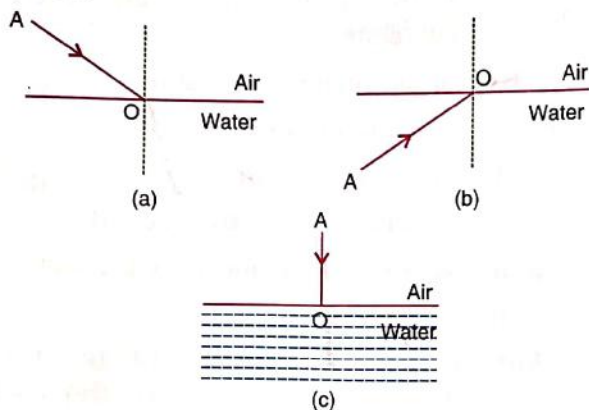


Fig. 5.38

13. Draw a diagram showing the refraction of a light ray from water to glass. Label on it the incident ray, the angle of incidence (i), and the angle of refraction (r).

14. The diagram in Fig. 5.39 shows a ray of light AO falling on a rectangular glass slab PQRS. Complete the diagram till the ray of light emerges out of the slab. Label on the diagram the incident ray, the refracted ray and the emergent ray.

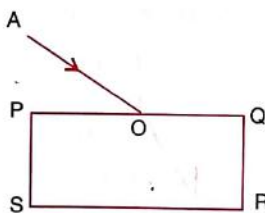


Fig. 5.39

15. Explain the following :

- A coin placed at the bottom of a vessel appears to be raised when water is poured in the vessel.
- A straight stick partly dipped in water obliquely, appears to be bent at the surface of water.
- The sun is seen before the sunrise and after the sunset.

16. What is mirage ? Give a reason for its formation.

17. What is a prism ? Draw a ray diagram to show the refraction of a light ray through a prism.

18. What do you mean by the term dispersion ?

19. A ray of white light falls on a prism. Draw a ray diagram to show that the prism disperses the white light.

20. In Fig. 5.40, AO is the ray of white light falling on a prism PQR. Complete the diagram till the light emerges out from the prism and falls on the screen.

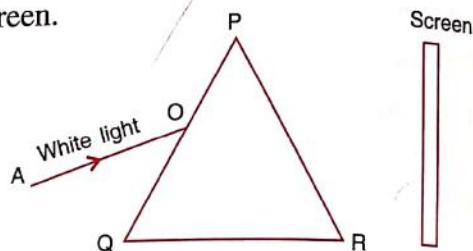


Fig. 5.40

21. What do you understand by the term spectrum ? Name the various colours present in the spectrum of sunlight.

22. You are given a disc divided into seven sectors with colours violet, indigo, blue, green, yellow, orange and red in them. What would be its colour when it is rotated rapidly ?

23. State the two laws of reflection of light.

24. What is a spherical mirror ?

25. State the two kinds of spherical mirrors and distinguish them with the aid of proper diagrams.

26. Explain the following terms :

Pole, Centre of curvature, Radius of curvature, Principal axis.

Show them on separate diagrams for each of the concave and convex mirrors.

27. What do you understand by the focus and focal length of a spherical mirror ? Show them on the separate diagrams for each of a concave mirror and a convex mirror.

28. Draw suitable diagrams to illustrate how a beam of light incident parallel to the principal axis is reflected by :

(a) a concave mirror, and (b) a convex mirror.

29. How is a spherical mirror used to converge a beam of light at a point ? Name the type of mirror used.

30. How is a spherical mirror used to diverge a beam of light from a point? Name the type of mirror used.
31. State the direction of incident ray which after reflection from a spherical mirror gets reflected along its own path. Give a reason.
32. How is the focal length of a spherical mirror related to its radius of curvature?
33. The diagram (Fig. 5.41) given below shows two parallel rays 1 and 2 incident on (a) a concave mirror; (b) a convex mirror. Draw the reflected rays and mark the focus by the symbol F.

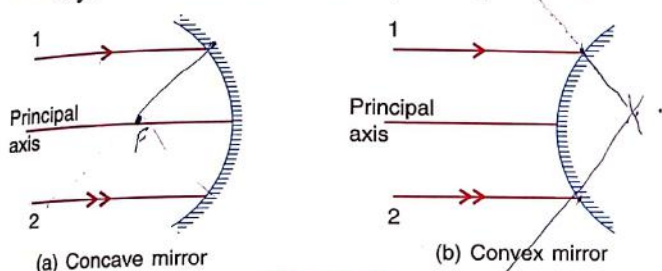


Fig. 5.41

34. Complete the following diagrams in Fig. 5.42 by drawing the reflected rays for the incident rays 1 and 2 if F is the focus and C is the centre of curvature.

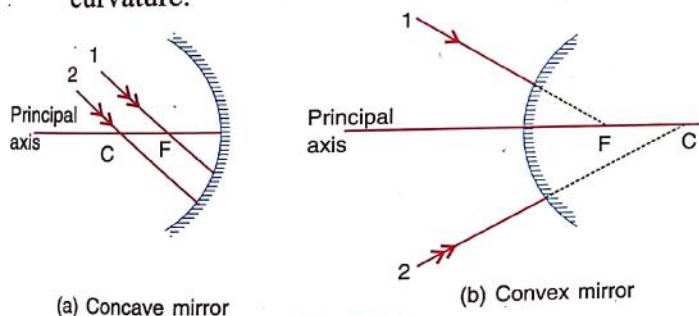


Fig. 5.42

35. Which are the two convenient rays that are chosen to construct the image by a spherical mirror for a given object? Explain with the help of suitable ray diagrams.
36. Draw a ray diagram to show the formation of image of an object placed beyond the centre of curvature of a concave mirror. State the position, size and nature of the image.
37. Draw a ray diagram to show the formation of image of an object placed at the centre of curvature of a concave mirror. State the position, size and nature of the image.

38. Draw a ray diagram to show the formation of image of an object placed between the focus and centre of curvature of a concave mirror. State the position, size and nature of the image.
39. Draw a ray diagram to show the formation of image of an object placed between the pole and focus of a concave mirror. State the position, size and nature of the image.
40. Draw a ray diagram to show the formation of image of an object placed on the principal axis of a convex mirror. State the position, size and nature of the image. What happens to the image as the object is moved away from the mirror?
41. Draw separate diagrams for the formation of virtual image of an object by
 - (a) concave mirror and
 - (b) convex mirror.
 State the difference in the two images.
42. Name the mirror which always forms an erect and virtual image. What is the size of the image as compared to that of the object?
43. Name the mirror which forms an erect, virtual and enlarged image of an object. What is the position of object relative to the mirror?
44. What is a real image? Name the mirror which can be used to obtain the real image of an object. What should be the position of the object relative to the mirror?
45. How can a concave mirror be used to obtain a virtual image of an object? Draw a diagram to illustrate your answer.
46. State two uses of a concave mirror.
47. State two uses of a convex mirror.
48. A driver uses a convex mirror as a rear view mirror. Explain the reason with the help of a ray diagram.
49. State the kind of mirror used
 - (a) by a dentist, and
 - (b) as a street light reflector.
50. Name the kind of mirror used to obtain
 - (a) a real and enlarged image,
 - (b) a virtual and enlarged image,
 - (c) a real and diminished image, and
 - (d) a virtual and diminished image.

Project Work

You are given few mirrors labelled A, B, C, D, Identify them as plane, concave or convex mirror by looking your own face in each mirror one by one and recording the size and nature of image.

Mirror	Size of image	Kind of mirror	Nature of image
A			
B			
C			
D			
E			