212en15

15

LIGHT ENERGY

Light is the common form of energy. It makes the objects visible to us. You might have seen in torches there is curved sheet of metal around the bulb. Can you think why it is so? You may have also seen the stars twinkling in the sky in a clear night. Also on a clear day the sky appears blue at the time of sun rise or sun set while sun near the horizon it appears orange or red.

Have you ever tried to find out the reason for such natural phenomenon? In this lesson you will find the answer to all such questions. You will also study the defects of human eyes and image formation in mirrors and lenses.

OBJECTIVES

After completing this lesson, you will be able to:

- *define reflection of light and state the laws of reflection;*
- *describe the image formation by plane and spherical mirror with suitable ray diagrams in different cases;*
- *write mirror formula and define magnification;*
- *define refraction of light and state the laws of refraction;*
- *define refractive index of a medium and states its significance;*
- *give some examples in nature showing the refraction of light;*
- *describe various types of lenses and explain image formation by convex and concave lens with the help of ray diagrams;*
- *write the lens formula and define magnification;*
- *explain power of lens and define diopter;*
- *explain the correction of defects of vision (near and far) by using lenses;*
- *explain how white light disperse through a prism and*
- *describe the scattering of light and give examples of its application in daily life.*

15.1 REFLECTION OF LIGHT

Can you think how an object becomes visible to you? When we see an object we do so because light from the object enters in our eyes. Some objects such as sun, stars, burning candles, lamp, etc. which emit light by their own are called **luminous objects**. Some other objects may bounce back a part of the light falling on them from any luminous object. This bouncing back of light after falling on any surface is called **reflection of light**.

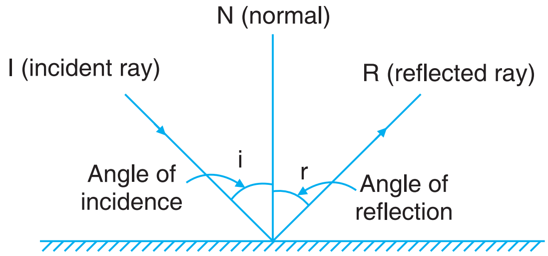


Fig. 15.1

Thus, when a beam of light comes in contact with an object, a part or all of it gets bounced back. This phenomenon is called reflection of light. Some objects having smooth and shiny surface reflect better than others. A smooth shining surface, which reflects most of the light incident on it, is called a **mirror**. In Fig. 15.1 reflection from a plane mirror is shown.

Greek mathematician Euclid explained how light is reflected. The phenomenon of reflection was translated into laws by an Arabian scientist Alhazan in about 1100 A.D.

Alhazen (Ibn al-Haytham) (965-1040)

To understand the phenomenon of reflection of light ray we define some terms. The direction of propagation of light, a beam of light consists of number of rays. The incident ray is the ray of light falling on the reflecting surface. The normal is the line drawn at 90° to the surface at the point where the incident ray strikes the surface. The light coming back from the reflecting surface is called reflected ray. The angle of incidence is the angle between incident ray and normal and angle of reflection is the angle between reflected ray and normal.

15.1.1 Laws of reflection of light

Suppose a ray of light (*IO*) falls on a reflecting surface *AB* at *O*, after reflection it goes along *OR* as shown in Fig. 15.2. The reflection of light from the surface takes place according to the following two laws.

(i) Incident ray, reflected ray and the normal at the point of incidence, all lie in the same plane.

(ii) The angle of incidence is equal to the angle of reflection i.e.,

$$\angle i = \angle r$$

During reflection, there is no change in speed, frequency and wavelength of light. Reflection of light may be classified as regular reflection and diffused reflection.

15.1.2 Regular reflection

When reflecting surface is very smooth and the rays of light falling on it are reflected straight off it, then it is called **regular reflection**, as shown in Fig. 15.2.

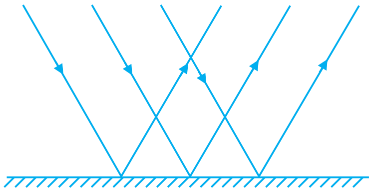


Fig. 15.2 *Regular reflection from a smooth plane surface*

15.1.2 Diffused reflection

When the reflection of light takes place from rough surface the light is reflected off in all directions as shown in Fig. 15.3 is called diffused reflection.

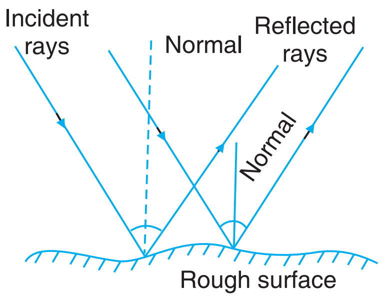


Fig. 15.3 *When surface is rough, parallel incident rays do not reflect parallel*

In diffused reflection due to roughness of the surface normal drawn at the point of incidence of parallel incident rays are not parallel, hence the reflected rays reflect in all direction but obey the laws of reflection.

15.2 FORMATION OF IMAGES DUE TO REFLECTION

You might have learnt that to see an object or image, the light from it should reach to the eyes of the observer. It means light coming from an object or image should fall on retina where from it will be sensed by brain with the help of optical nerves.

When light rays coming from the object meet or appear to meet at retina of eye, the object become visible and we say that the image of object is formed at retina.

When an object is placed infront of a mirror its image is formed by reflection. Every point on the object acts like a point source, from which a number of rays originate. In order to locate the image of the point object, an arbitrarily large number of rays emanating from the point object can be considered. However, for the sake of simplicity, we take any two rays of light (starting from the point object). The paths on reflection from the mirror (reflected rays corresponding to the incident rays) are traced using laws of reflection. The point where these two rays actually meet is the real image of the point object. If these rays appear to come from and not actually coming, the virtual image of the point is formed. Real images obtained by actual intersection of reflected rays, hence they can be projected on screen. Virtual images are obtained when the rays appear to meet each other but actually do not intersect each other, hence they cannot be cast on screen.

ACTIVITY 15.1

Take a plane mirror on paper in vertical position. Use a pipe (straw) as incident beam at certain angle and coincide its image with another pipe (straw). You have to put the second pipe in such a way that the image and this pipe remain in same line. The second pipe (straw) will represent the reflected beam. Can you touch this image? Can you cut some part of this image by cutting the paper on which it is seen? You can not do it because the image formed is a virtual image.

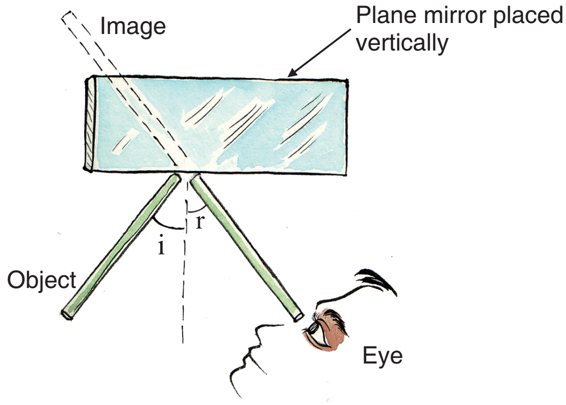


Fig. 15.4

15.3 IMAGE FORMATION IN PLANE MIRROR

To understand the image formation in a plane mirror

(i) Put the mirror M_1M_2 in a vertical position over the sheet as shown in Fig. 15.5.

(ii) Put two pins, one at '*A*' some distance away from the mirror and another one very near to the mirror at '*B*' so that, the line *AB* makes an angle with the line M_1M_2 showing the position of the mirror.

(iii) Look at the images of *A* and *B* of the two pins through the mirror, put two other pins at *C* and *D* so that all four pins *A*, *B*, *C* and *D* are in the same straight line.

(iv) Now, look at the images of all these pins closing one of your eyes and moving your face side ways. If the image of the two earlier pins and the two pins you have put just now appear to be moving together you can say your observation is free from parallax error.

(v) Join the positions of the pins by straight lines.

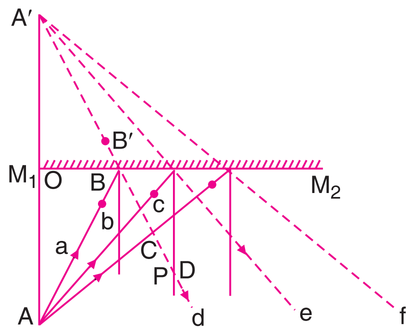


Fig. 15.5 *Image formation by a plane mirror*

(vi) Keeping the first pin as it is, take out other three pins and repeat the experiment described above by putting the pins in new positions. This way takes a few more reading.

To understand the formation of image, you may consider the light rays emerging out of the object A. We have drawn only three rays namely (a), (b), and (c). These rays after striking the mirror M_1M_2 get reflected in the direction (d), (e) and (f), respectively, (as above shown in Fig. 15.5) obeying the laws of reflection.

It is clear that these reflected rays never meet with each other in reality. However, they appear to be coming emerging out from the point A′, inside the mirror i.e., if the reflected rays (d), (e) and (f) are extended in the backward direction, they will appear to meet with each other at A'. Thus at A' we get the image of object A.

From the above activity we find that the image formed by a plane mirror has the following **characteristics**.

- This image is virtual (i.e. it is not real), erect and the same in size as the object.
- The object distance and the image distance from the mirror are found to be equal.

i.e., $$OA = OA'$$

Hence, the image of a point in a plane mirror lies behind the mirror along the normal from the object, and is as for behind the mirror as the object is in front. It is an erect and virtual image of equal size.

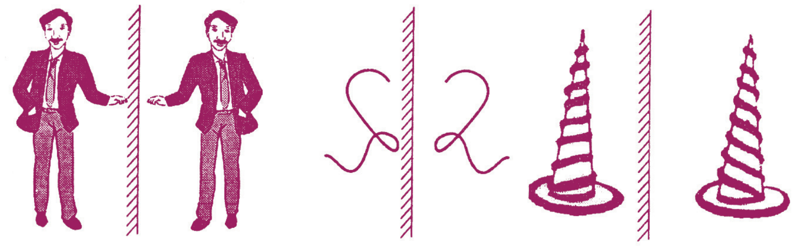
Notes

15.3.1 A few facts about reflection

Put your left hand near a plane mirror. What do you see in the image formed by reflection? The image of your left hand appears as right hand of the image as shown in Fig. 15.6(a). Similarly, the number 2 will appear in an inverted fashion on reflection as shown in Fig. 15.6 (b).

Hence, due to reflection in a plane mirror left handedness is changed into right handedness and vice-versa. This is known as lateral inversion. However, the mirror does not turn up and down. The reason for this is, that the mirror reverses forward and back in three dimensions (and not left and right), i.e., only z-direction is reversed resulting in the change of left into right or vice-versa.

For example a left handed screw will appear to be a right handed screw on reflection as shown in Fig. 15.6 (c).



mirror (a) mirror (b) mirror (c)

Fig. 15.6 *Lateral inversion in image formed by a plane mirror*

Similarly, if you read the sentence । ॅनाप हि पाछ लामक कि पाछ in a mirror it will appear as

आप का कमाल आप ही जानें।

In a plane mirror the distance of the image is same as the distance of object from the mirror. If object distance from the mirror changes, the distance of image from the mirror will also change in the same way. It means if an object moves with velocity v towards the mirror, image will also move with same velocity v towards the mirror and at every time the distances of the object and image from the mirror remain equal. However, the velocity of image towards the object will be $2v$.

By drawing a ray diagram you conclude that you can see your full image in a plane mirror whose height is half of your height. See the ray diagram in Fig. 15.7.

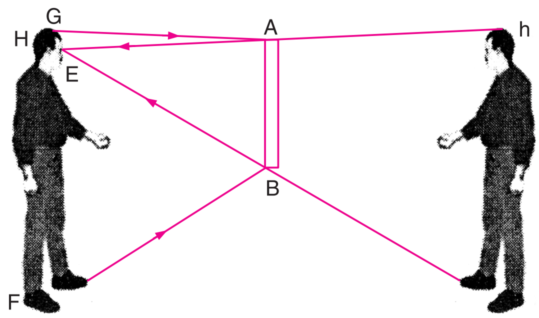


Fig. 15.7 *Size of plane mirror to see the full image*

Think and Do

Take a L-shaped object and try to get the images as given below and describe the position of object in each case

A	
B	
C	
D	

Do you know

Our eyes can notice the light of wavelength 400 nm (nanometre) to 70 nm. The light in this range of wavelength is called visible light. The light of wavelength more than 700 nm (i.e., of red colour) is called **infrared light** and less than the wavelength of 400 nm (i.e., of violet colour is called **ultra-violet light**. All sources of light emit the combination of these three types of lights. Sun is a source which emits very high percentage of visible light. In sun light 50% visible light, 40% infrared light and 10% ultra-violet light are present. Sun is the ultimate source of all types of energy for us. Sun radiates 3.92×10^{26} joule of energy every second. Out of total energy radiated by sun about 0.0005% of energy reaches to earth. Earth receives 1.388 joule of energy per unit area every second from the sun.

Do you know

The earlier fact about the nature of light was given by Pythagoras, a Greek philosopher, in 6th century B.C. The objects are visible because of light travelling from eyes to the object and then back again. This theory could not stand the test of times and modified. This was due to the contributions of Newton (1642-1727) and Huygen (1670).

ACTIVITY 15.2

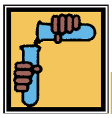
Place the following objects infront of a plane mirror and draw their corresponding images in the given table.

Notes

Table 15.1

Object	Image
#	....
O	....
काम	....
P	....
OH	....

Try to draw conclusion from this activity regarding image formation in a mirror.



ACTIVITY 15.3

Place a plane mirror at angle of 30°, 45° 60° and 90° with horizontal. Now place an object (linear) in such a way that its image formed by plane mirror is always straight. Note down the angle made by object with horizontal in the given table.

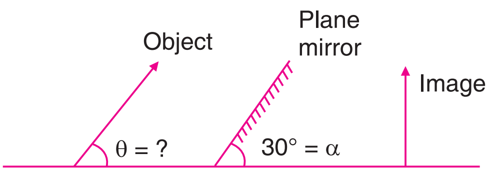
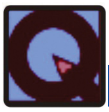


Fig. 15.8

Table 15.2

Angle of mirror α	Angle of object θ
30°	....
45°	....
60°	....
90°	....



INTEXT QUESTIONS 15.1

1. In column A, some sources of light are given. In column B, you have to write whether these are lumineus or non-lumineus.

Source (A)	Nature of source (B)
1. Glowing bulb	1. ....
2. Burning candle	2. ....
3. Moon	3. ....
4. Fire fly	4. ....
5. Shining steel plate	5. ....

2. Write two differences between real and virtual image.
3. When you are standing infront of a plane mirror, a virtual and correct image of you is formed. If some one is taking a photograph of it using camera, what will be the nature of image on photograph?
4. A light ray is falling on a plane mirror at 30° as shown in the diagram. If plane mirror is rotated by 30° without changing the direction of incident ray, by what angle the reflected ray will rotate?

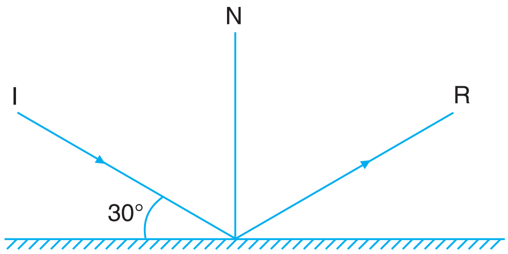


Fig. 15.9

5. An object of height 10 cm is placed infront of a plane mirror of height 8 cm. What will be the height of image formed? Taking the distance of object from the mirror 6 cm, draw the ray diagram.
6. The image of an object placed at 10 cm from the mirror is formed at 10 cm behind the mirror. If the object is displaced by 4 cm towards the mirror, by what distance will the image be displaced with respect to the (i) mirror (ii) object?
7. An object is moving with velocity 6 ms^{-1} towards a plane mirror, what will be the velocity of image towards the (i) mirror (ii) object?
8. Some letters are given in following boxes. Make the meaningful words related to reflection of light choosing the horizontal and vertical sequencing.

N	E	P	R	E	C	T
O	P	X	V	R	T	U
R	L	V	I	R	T	U
M	A	L	R	E	A	L
A	N	I	T	C	A	R
L	E	O	U	T	A	E
A	I	M	A	G	E	J
N	K	N	L	E	N	C

9. The distance and height of an object placed infront of a plane mirror are given in column A and B respectively. In column C and D the distance of image and height of image are given but not in same order. Correct the order.

Distance of object (A)	Height of object (B)	Distance of image (C)	Height of image (D)
10 cm	5 cm	10 cm	10 cm
5 cm	10 cm	5 cm	8 cm
6 cm	8 cm	6 cm	5 cm

15.4 REFLECTION AT SPHERICAL MIRRORS

A spherical mirror is a section of a hollow sphere whose inner or outer surface is polished. Thus, there are mainly two types of spherical mirrors (i) convex mirror and (ii) concave mirror.

(i) **Convex mirror:** It is a mirror in which the reflection takes place from the bulging surface (i.e. inner side is painted and reflected surface is polished to make the surface smooth as shown in Fig. 15.10.

(ii) **Concave mirror:** It is a mirror in which the reflection takes place from the cave side surface (i.e. outer side is painted and the inner or cave side surface is polished to make the reflected surface smooth as shown in Fig. 15.10.

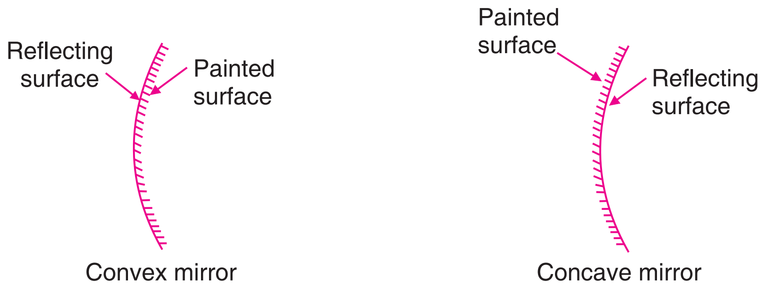


Fig. 15.10

To understand the reflection at spherical surface certain important terms are very useful. They are shown below in Fig. 15.11.

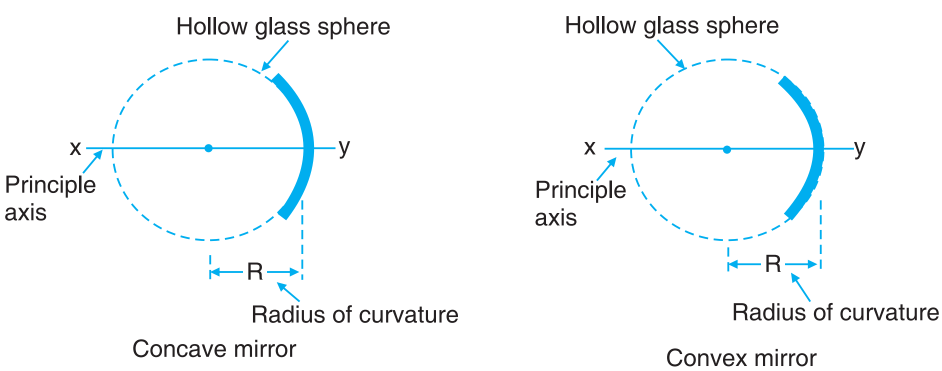


Fig. 15.11 *Some important terms of spherical mirrors*

Notes

(i) **Pole (P):** It is the mid point of the spherical mirror. Point P is the pole in Fig. 15.11.

(ii) **Centre of curvature (C):** It is the centre of a hollow sphere of which the spherical mirror is a part. It can be determined by finding the point of intersection of two normal drawn at the spherical surface of the mirror. The point C is the centre of curvature in Fig. 15.11.

(iii) **Radius of curvature (R):** It is the distance between the pole and centre of curvature of the mirror. CF is the radius of curvature in Fig. 15.11.

(iv) **Principal axis:** It is an imaginary line joining the pole to the centre of curvature. Extended line CP is the principal axis in Fig. 15.11.

(v) **Principal focus (F):** The rays of light parallel and closed to the principal axis of the mirror after reflection, either pass through a point (in concave mirror) or appear to be coming from a point (in convex mirror) on the principal axis; this point is called principal focus of the mirror. Point F is the principal focus in Fig. 15.11.

(vi) **Focal length (f):** It is the distance between the pole and the principal focus of the mirror. PF is the focal length in the Fig. 15.11.

15.5 RELATIONSHIP BETWEEN FOCAL LENGTH AND RADIUS OF CURVATURE

Consider the reflection of light of ray IM at M at a concave mirror. CM is the normal drawn at the surface which passes through centre of curvature and MF is the reflected ray which passes through the focal point.

$\angle i = \angle r$ (as we know that angle of incidence and reflection are equal)

$\therefore$ in ΔCMF,

$$MF = CF$$

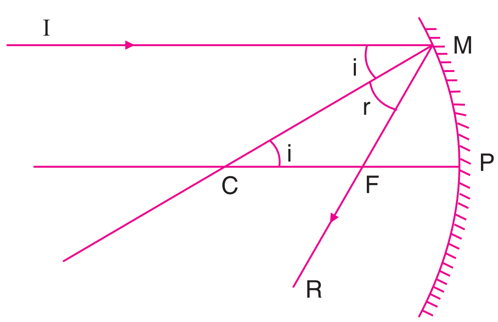


Fig. 15.12

For small aperture of the mirror,

$$MF = PF$$

$$\Rightarrow \quad PC = PF + CF = PF + PF = 2PF$$

$$R = 2f$$

where R = radius of curvature and f is the focal length of the mirror.

15.6 RULES OF IMAGE FORMATION BY SPHERICAL MIRRORS

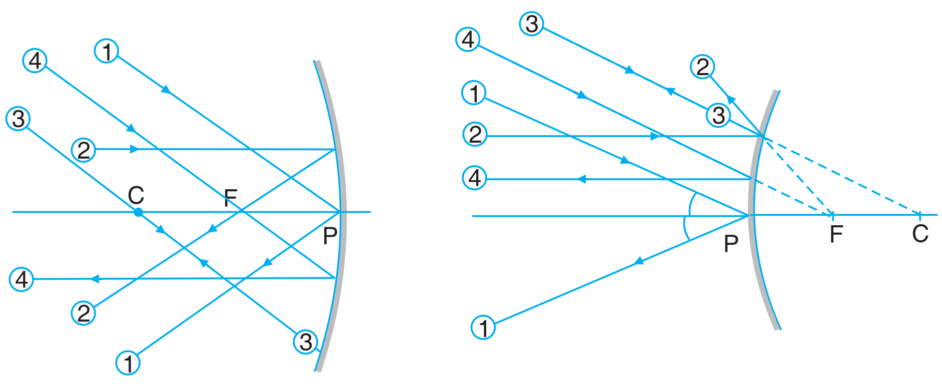
The ray diagram for image formation by mirrors can be drawn by taking any two of the following rays. The point where these two rays meet or appear to be coming from the point will be the image point which determines the position of image.

(i) **Ray striking the pole:** The ray of light striking the pole of the mirror at an angle is reflected back at the same angle on the other side of the principal axis (Ray no 1 in Fig. 15.13).

(ii) **Parallel ray:** For concave mirror the ray parallel to the principal axis is reflected in such a way that after reflection it passes through the principal focus. But for a convex mirror the parallel ray is so reflected that it appears to come from principal focus. (Ray no. 2 in Fig. 15.13)

(iii) **Ray through centre of curvature:** A ray passing through the centre of curvature hits the mirror along the direction of the normal to the mirror at that point and retraces its path after reflection (Ray no. 3 in Fig. 15.13)

(iv) **Ray through focus:** A ray of light heading lowards the focus or incident on the mirror after passing through the focus returns parallel to the principal axis.

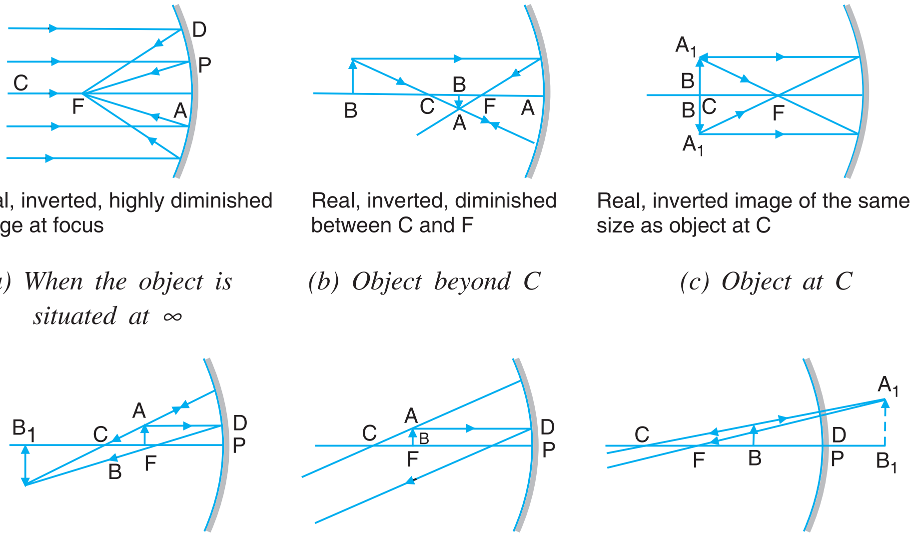


(a) (b)

Fig. 15.13 *Image formation by spherical mirror (a) concave mirror (b) convex mirror*

15.6.1 Formation of image by concave mirror

Using the above rules of image formation, the ray diagram for the image formed for different positions of an object are given below.



Real, inverted, highly diminished image at focus

(a) When the object is situated at ∞

Real, inverted, diminished between C and F

(b) Object beyond C

Real, inverted image of the same size as object at C

(c) Object at C

Real, inverted, enlarged image beyond C

(d) Object between C and F

Real, inverted, highly enlarged image at infinity

(e) Object at F

Virtual, erect, enlarged mage behind the mirror

(f) Object between F and P

Fig. 15.14 *Image formation by a concave mirror*

15.6.2 Formation of image by convex mirror

Image formation in convex mirror is shown in Fig. 15.15.

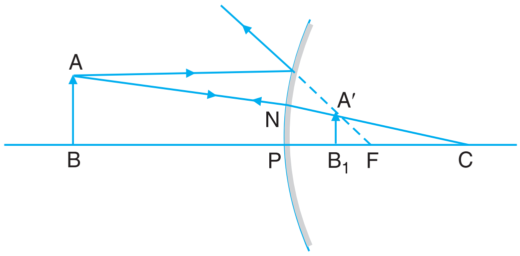


Fig. 15.15 *Image formation by a convex mirror*

The position, nature and size of the image formed in concave mirror and convex mirror can be summarized as given in table below:

Table 15.3

Position of the object	Position of image formed	Nature of image	Size of image
(A) For concave mirror			
(i) between *P* and *F*	behind the mirror	virtual	larger
(ii) at *F*	at infinitely	real	highly enlarged
(iii) between F and 2*F*	beyond 2*F*	real	larger

(iv) at $2F$	at $2F$	real	same size
(v) beyond $2F$	between F and $2F$	real	smaller in size
(vi) at infinity	at F	real	highly diminished
(B) For convex mirror			
anywhere infront of mirror	between P and F	virtual	always smaller

Do you know

- Every part of a mirror may form a complete image of an extended object from a different angle and due to super-position of these images from different points final image is formed. The brightness of the image will depend on its light reflecting area. Thus a large mirror gives a brighter image than a small one. This phenomenon was used in a popular hindi film's shooting at the Sheeshmahal of 'Amer Fort' in Jaipur (Rajasthan).
- Though every part of a mirror may form a complete image of an object, we usually see only that part of it from which light, after reflection from the mirror reaches our eyes. That is why:
  - (i) to see the full image in a plane mirror a person requires a mirror of at least half of his height.
  - (ii) to see complete image of the wall behind a person requires a mirror of at least (1/3) of the height of the wall and the should be in the middle of wall and mirror.
- If two plane mirrors are placed inclined to each other at an angle θ, the number of images of a point object formed

$$\approx \left(\frac{360°}{\theta} - 1\right), \text{ if } \left(\frac{360°}{\theta}\right) \text{ is even integer}$$

$$\approx \frac{360°}{\theta} \text{ if } \left(\frac{360°}{\theta}\right) \text{ is odd integer}$$

For example, there are 5 images formed by two mirrors at 60° angle.

- Two mirrors inclined to each other at different angles may provide same number of images, e.g. for any value of θ between 90° and 120° the number of maximum images formed is $n = 3$. This in turn implies that if θ is given, n is unique but if n is given, θ is not unique.
- The number of images seen may be different from the number of images formed and depends on the position of observer relative to object and mirrors e.g., if $\theta = 120°$ maximum number of images formed will be 3 but number of images seen may be 1, 2 or 3 depending on the position of observer.

15.6.3 Uses of mirrors

(i) Plane mirror is used

- in looking glasses,
- in construction of kaleidoscope, telescope, sextant, and periscope etc.,
- for seeing round the corners,
- as deflector of light etc..

(ii) Concave minor is used

- as a reflector in searchlight, head light of motor cars and projectors etc.,
- for converging solar radiation in solar cookers,
- in flood lights to obtain a divergent beam of light to illuminate buildings,
- in reflecting telescopes etc..

(iii) Convex mirror is used

- as a rear view mirror in motor cars, buses and scooters,
- as safety viewers at dangerous corners and on upper deck of double decker buses etc..

15.7 SIGN CONVENTION AND MIRROR FORMULA

To measure distances with respect to a curved mirror, following convention is followed:

(i) All distances are measured from the pole of the mirror.

(ii) The distances measured in the direction of incident light, are taken as positive.

(iii) The distances measured in opposite direction of incident light, are taken as negative.

(iv) The distances above the principal axis are taken positive, whereas those below it are taken as negative.

You have seen the image formation in concave mirror. When an object is placed at $2f$ (centre of curvature) the image is formed at $2f$. If f be the focal length of the concave mirror, u distance of object and v the distance of image, then

$$u = -2f$$

and $$v = -2f$$

and f can be given as

$$\frac{1}{f} = \frac{1}{-2f} + \frac{1}{-2f}$$

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

This is called mirror formula and it can also be verified for convex mirror. Use this formula and justify the image formation given in image diagrams.

15.8 MAGNIFICATION IN SPHERICAL MIRRORS

Often we find that a spherical mirror can produce magnified image of an object. The ratio of the size of the image to the size of the object is called **linear magnification.**

i.e., linear magnification $(M) = \dfrac{\text{size of the image } (I)}{\text{size of the object } (O)} = \dfrac{v}{u}$

where v = image distance from mirror, u = object distance from mirror.

INTEXT QUESTIONS 15.2

1. An object is placed infront of a concave mirror as shown in the Fig. 15.16. Write the position and nature of the image. What is the focal length of the mirror?

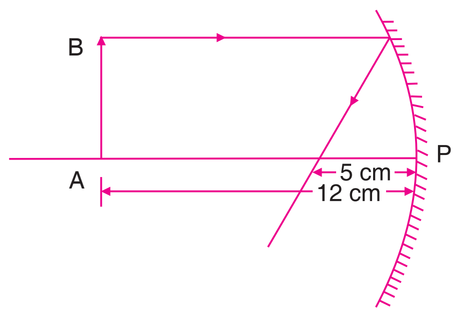


Fig. 15.16

2. In what condition, the image formed by concave mirror is virtual?
3. At what position will the reflected ray shown in Fig. 15.17 intersect the principal axis beyond focus or before focus?

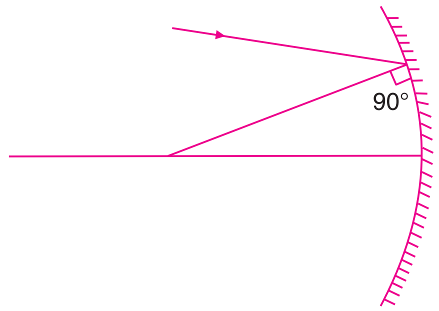


Fig. 15.17

4. What type of image will be formed if an object is placed beyond centre of curvature infront of a concave mirror?
5. Find the position of the object placed infront of a concave mirror of focal length 20 cm if image is formed at the distance of 30 cm from the mirror.
6. Write two uses of concave mirror.
7. Write the nature of image formed in convex mirror.
8. Find the position of the image formed in convex mirror of focal length 12 cm when object is placed at the distance of (i) 8 cm, (ii) 12 cm and (iii) 18 cm from the mirror.
9. Complete the following table with corresponding positions of object and image in case of concave mirror.

Position of object	Position of image
(i) at F	(i) ....
(ii) between F and $2F$	(ii) ....
(iii)	(iii) between F and $2F$
(iv)	(iv) beyond $2F$
(v) beyond $2F$	(v) ....

10. Write two uses of convex mirror.
11. Does concave mirror always converges the light rays?
12. Write the conditions to produce a magnified image in concave mirror.

15.9 REFRACTION OF LIGHT

Have you ever seen a coin placed at the bottom of a tumbler filled with water? The coin appears at smaller depth as its actual depth. Why does it happen so? We see an image where the light rays meet or at the point where light seems to be coming from.

When light comes out from water, it bends due to which the coin appears vertically displaced as shown in Fig. 15.18. Does it always happen? No, it does happen only when light passes from one medium to another obliquely. The bending of light depends upon the density of the medium.

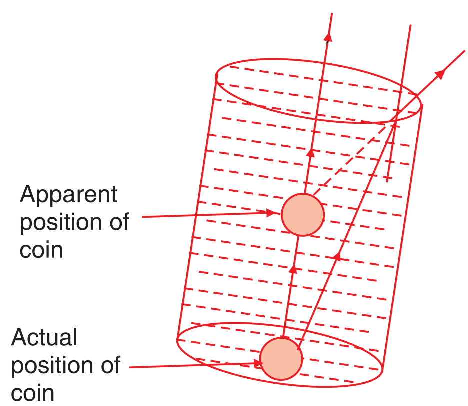


Fig. 15.18 *Coin placed in a tumbler filled with water*

When light passes from denser medium to rarer medium it bends away from the normal. When it passes from rarer medium to denser medium it bends towards the normal. This **phenomenon of bending of light is called refraction of light**. Refraction of light is shown in Fig. 15.19.

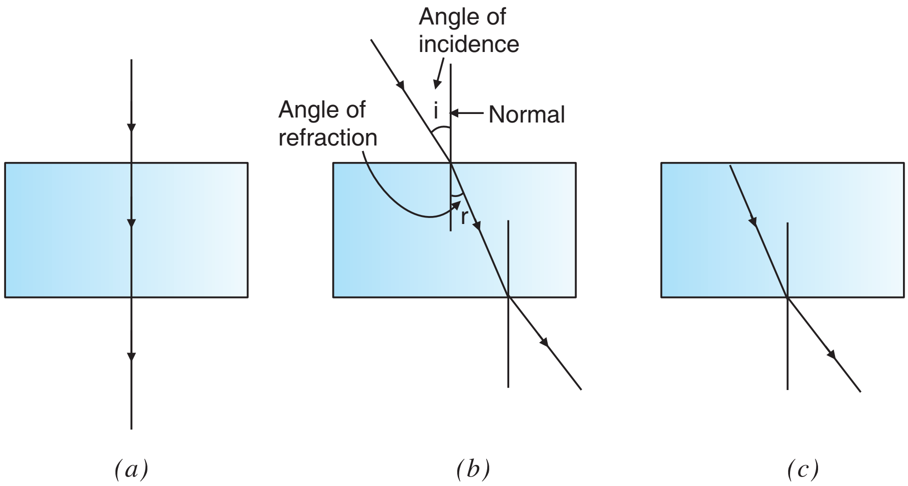
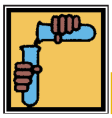


Fig. 15.19 *Refraction of light*

In Fig. 15.19 (b) and (c) light deviate from its path but in Fig. 15.19 (a) it does not deviate from its path. Is it refraction or not? Certainly it is refraction, for normal incidence light rays do not deviate from their paths. During refraction the frequency of the light remains unchanged but its wavelength changes hence the speed of light also changes.



ACTIVITY 15.4

To study the refraction of light place a glass slab on a dressing sheet fixed on a wooden drawing board, sketch a pencil boundary. Draw a line *OC* meeting the boundary line obliquely. Fix the pins *A* and *B* on that line. Now look for these pins from the other side of the glass slab.

Take a pin and fix it on the sheet such that *A*, *B* and *E* are in a straight line. Now fix another pin *F* such that it is in a straight line with pins *A*, *B* and *E*. Remove the slab and the pins.

Draw a line joining the points *F* and *E* to meet the boundary at *D*. The line *ABC* gives the direction of incident ray on the glass slab while the line *DEF* gives the direction of emergent ray. The line *CD* gives the direction of refracted ray within the glass slab. Draw normal N_1CN_2 at *C* and N_3DN_4 at *D* to the boundaries. Now you can conclude that the ray of light, when going from a rarer (air) to a denser (glass) medium, it bends towards the normal. Also, the ray of light when goes from denser to rarer medium it bends away from the normal.

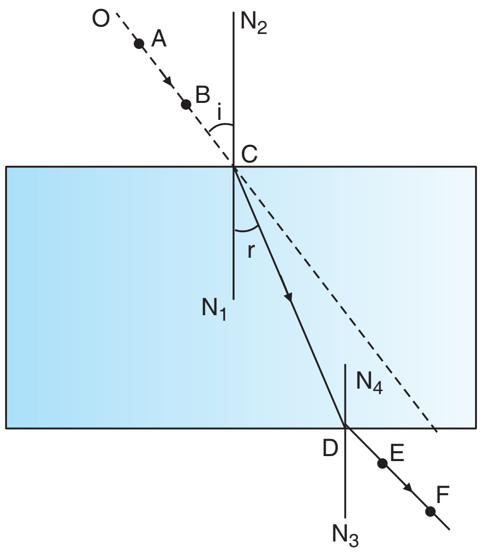


Fig. 15.20 *Refraction through a glass slab*

15.9.1 Refractive Index of the Medium

When light travels from one medium to another its speed changes. A ray of light from a rarer medium to a denser medium slows down and **bends towards the normal.** On the other hand the ray of light going from a denser medium to a rarer medium is speeded up and **bends away from the normal.** It shows that the speed of light in different medium varies. Different s medium have different abilities to bend or refract light. This bending ability of a medium is known as the index of refraction or refractive index. It is defined as the ratio of the speed of light in vacuum to that in the material medium.

Therefore, refractive index of a medium,

$$n \approx \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

15.10 LAWS OF REFRACTION

The extent, to which a ray bends, depends not only on the refractive index of medium, but also on the angle of incidence. The laws of refraction are:

(i) **First law of refraction:** The incident ray, refracted ray and the normal at the point of incidence, all lie in the same plane (Fig. 15.19).

(ii) **Second law of refraction:** How much ray of light refracted depends on that medium. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant and equal to the refractive index of that medium. This law is also called **Snell's law**.

$$\text{Refractive index } (n) \approx \frac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}}$$

or
$$n \approx \frac{\sin i}{\sin r}$$

Does the colour of light change during refraction?

The wavelength and frequency of light are related to the velocity as $v = \nu\lambda$, where ν is frequency and λ is wavelength.

ACTIVITY 15.5

Take a transparent bucket of plastic filled with water. Keep your head inside the water in bucket and hold it above the red colour light bulb as shown in Fig. 15.21. What do you observe? Is there any change in the colour of light seen by you from the water? No, there is no change in the colour of light. It means when light goes from one medium to another, only its speed and wavelength change but the frequency remains constant. It proves that colour is the function of frequency not the wavelength of light.

Fig. 15.21 *The red bulb is seen by a boy keeping his head inside the bucket filled with water*

15.11 REFRACTION THROUGH SPHERICAL SURFACE

In this section we will discuss refraction of light through a lens. A lens is a portion of a transparent refracting medium bounded by two surfaces. Depending upon the nature of surfaces lens may be of following types.

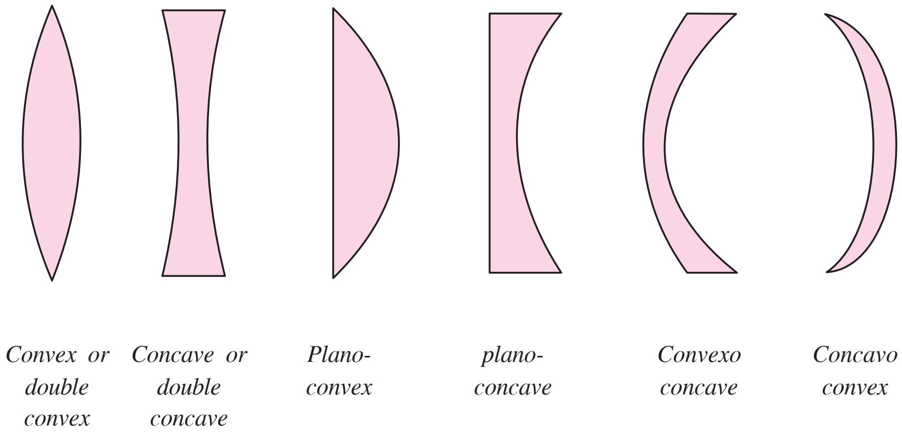


Fig. 15.22 *Different type of lenses*

(i) **Convex lens:** Convex lens has its two surfaces bulging outward. It makes the parallel rays of light to converge to a point. Hence, it is called **converging lens**. The point of convergence is called **focus** as shown in Fig. 15.23.

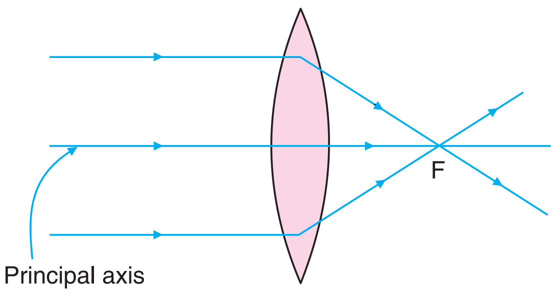


Fig. 15.23 *Converging action of a convex lens*

(ii) **Concave lens:** A concave lens has its two surfaces caving inward as shown in Fig. 15.24. It makes parallel rays of light to spread from a point. Hence it called **diverging lens**. The point where from light rays appear to diverge is called **focus** as shown in Fig. 15.24.

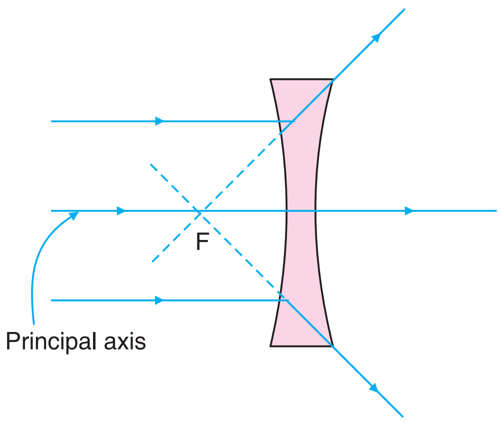


Fig. 15.24 *Diverging action of a concave lens*

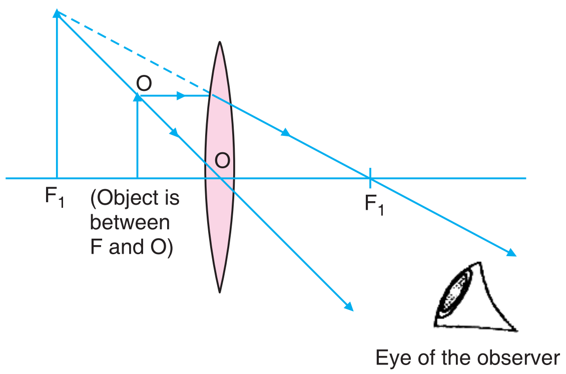
15.12 IMAGE FORMATION IN LENSES

In order to draw the image formed by any lens, only two rays are required. These two rays are:

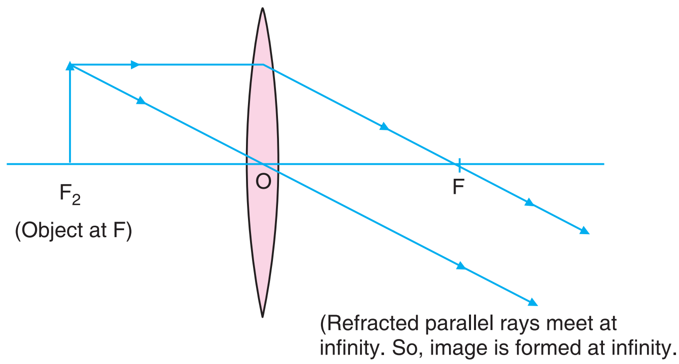
(i) A ray parallel to the principal axis of the lens converges after refraction at the principal focus of convex lens. It appears to diverge off in the case of concave lens.

(ii) A ray towards the optical centre falls on the lens symmetrically and after refraction passes through it undeviated.

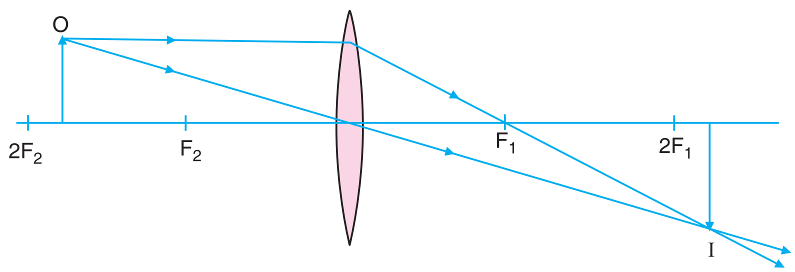
The image formations in convex and concave lenses are shown in Fig. 15.25.



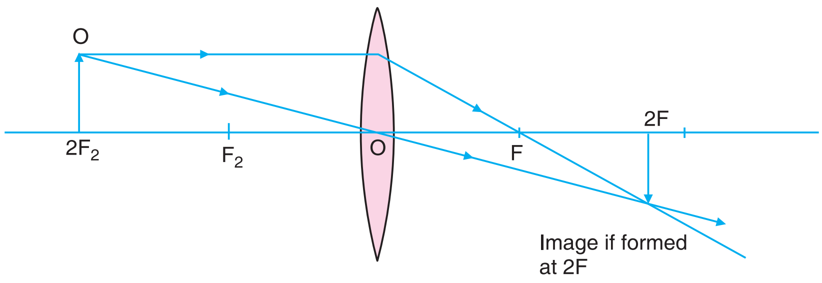
(a) Object is between focus and lens



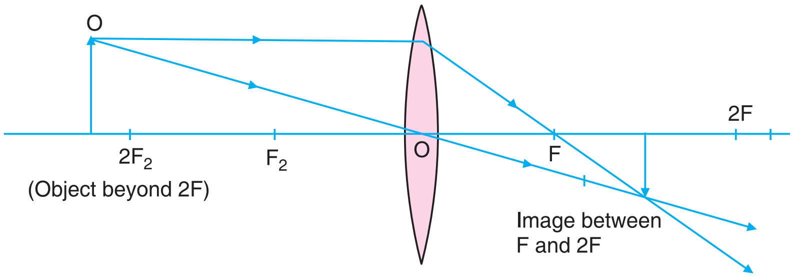
(b) Object at the first focus



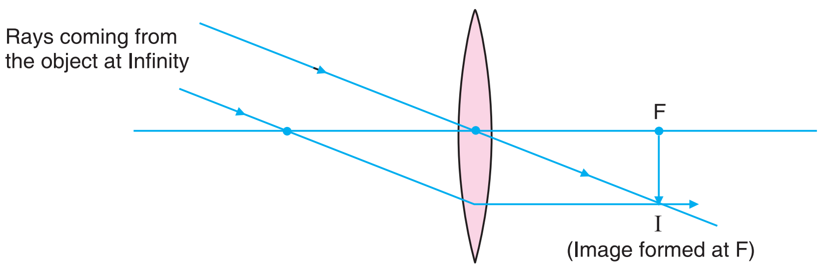
(c) Object is between F_2 and $2F_2$



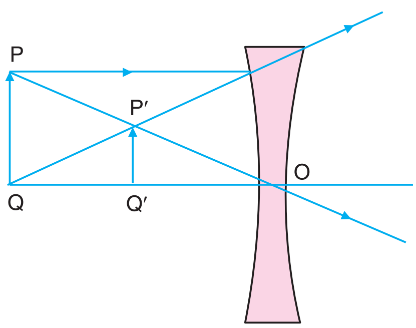
(d) Object is at $2F_2$



(e) Object is beyond $2F_1$



(f) Object placed between optical centre and first focus



(g) Image by concave lens

Fig. 15.25 *Image formation in convex and concave lens*

All these images formed for different positions of object and nature of the image can be summarized as given in the table below:

Table 15.4

Position of the object	Position of image formed	Nature of image	Size of image
(A) For convex lens			
(i) between F and pole	infront of lens	virtual and erect	enlarge
(ii) at F	at infinitely	real and inverted	highly enlarged
(iii) between F and $2F$	beyond $2F$	real and inverted	enlarge
(iv) at $2F$	at $2F$	real and inverted	same size
(v) beyond $2F$	between F and $2F$	real and inverted	smaller in size
(vi) at infinity	at F	real and inverted	highly diminished
(B) For concave lens			
anywhere infront of lens	on the same side between F and pole	virtual and erect	always smaller

15.13 SIGN CONVENTION AND LENS FORMULA

In case of spherical lenses,

(i) all distances in a lens are to be measured from optical centre of the lens

(ii) distances measured in the direction of incident ray are taken to be positive

(iii) distance opposite to the direction of incident ray are taken to be negative

(iv) the height of the object or image measured above the principal are taken positive whereas below it, are taken negative.

Using the above mentioned sign convention and the image formation in Fig. 15.25 let us assume, the distance of object from the optical centre of the lens to be u distance of image from the optical centre to be v and focal length of the lens is f then the relationship between u, v and f for lens can be shown as:

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

This is called lens formula. Focal length for convex lens is positive, for concave lens it is taken negative.

15.14 MAGNIFICATION

You would have notice that in case of some lenses, the size of the image of an object is enlarged where as in some other cases it is diminished. If we take the ratio of the size of the image to the size of the object for a particular lens it remains constant for that lens. The ratio of the size of the image to that of the object is called as the magnification of the lens.

$$\text{Magnification} = \frac{\text{size of image } (I)}{\text{size of object } (\theta)}$$

or $$m = \frac{(I)}{(O)}$$

Also $$\frac{(I)}{(O)} = \frac{v}{u}$$

or $$m = \frac{v}{u}$$

INTEXT QUESTIONS 15.3

1. Name the type of lens which always produces virtual image.
2. Draw the ray diagram for the image formation in convex lens where object is placed at (i) F (ii) between F and $2F$ (iii) beyond $2F$.
3. Draw the ray diagram for image formation in concave lens.
4. The sizes of the image and object are equal in a lens of focal length 20 cm. Name the type of lens and distance of object from the lens.
5. An object of size 10 cm is placed infront of convex lens of focal length 20 cm. Find the size of the image formed.

15.15 DISPERSION OF LIGHT THROUGH GLASS PRISM

A prism is a transparent medium bounded by any number of surfaces in such a way that the surface on which light is incident and the surface from which light emerges are plane and non-parallel. Generally equilateral, right angled isosceles or right angled prisms are used.

When white light or sun light passes through a prism it splits up into constituent colours. This phenomenon is called **dispersion** and arises due to the fact that refractive index of prism is different for different colours of light. So, different colours in passing through a prism are deviated through different angles. Rainbow, the most colourful phenomenon in nature, is primarily due to the dispersion of sunlight by rain drops suspended in air. Dispersion of light in glass prism is shown in Fig. 15.26.

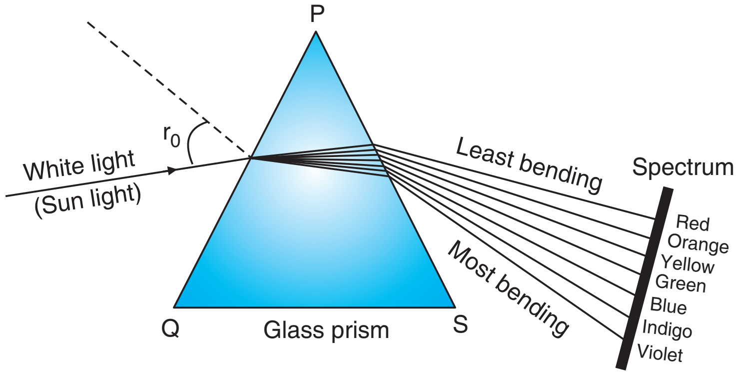
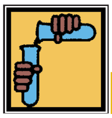


Fig. 15.26 *Dispersion of light*



ACTIVITY 15.6

To produce a spectrum (display of different colour) using a prism and sunlight

(i) Take an empty card board box. Make a rectangular opening on its cover with a knife and close it with transparent while paper to see the spectrum.

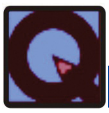
(ii) Make a thin slit with knife on the opposite side of card board box.

(iii) Place the prism on a block inside the box.

(iv) Turn the slit-side face of the box towards sun light.

(v) See the coloured strips on the transparent paper.

The frequency of colours in decreasing order is violet, indigo, blue, green, yellow, orange, and red. It can be written as VIBGYOR.



INTEXT QUESTIONS 15.4

1. When light passes from air to a medium its speed reduces to 40%. The velocity of light in air is 3×10^8 ms^{-1}. What is refractive index of the medium?
2. When sunlight is passed through prism, it splits into seven colours as shown in Fig. By numbers write corresponding colours.

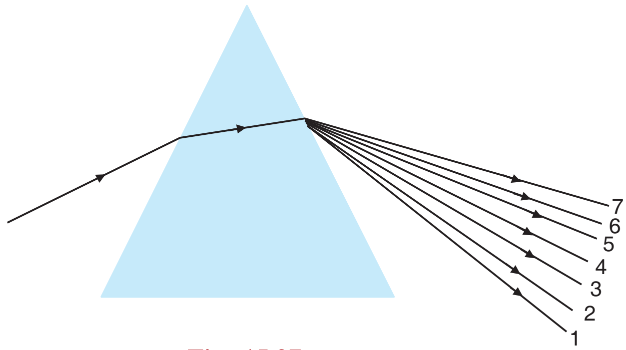


Fig. 15.27

3. How do r and δ change for same angle of incidence i if the prism shown in Fig. is immersed in water

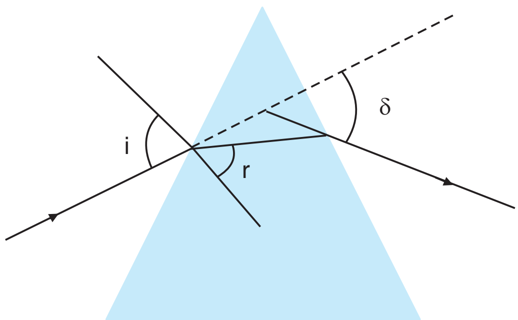


Fig. 15.28

4. Why does white light split into seven colours when it passes through a prism?
5. Write a natural phenomenon of dispersion of light.

15.16 EYE AND ITS DEFECTS

In eye a convex lens forms real, inverted and diminished image at the retina. The lens can changes its convexity to form a suitable image as the distance between eye lens and retina fixed. The human eye is most sensitive to yellow-green light having wavelength 5550 Å, the least to violet 4000 Å and red 7000 Å.

The size of an object as perceived by eye depends on its **visual angle.** When an object is distant, its visual angle θ_1 and image I_1 at retina is small hence it will appear small. If it is brought near the eye, the visual angle $\theta°$ is large and hence size of image I2 will increase as shown in Fig. 15.29.

The far and the near points for normal eye are usually taken to be at infinite and 25 cm respectively. It means a normal eye can see very distant objects clearly but near objects only if they are at a distance greater than 25 cm from the eye. The ability of eye to see objects from infinite distance to 25 cm is called power of **accommodation.**

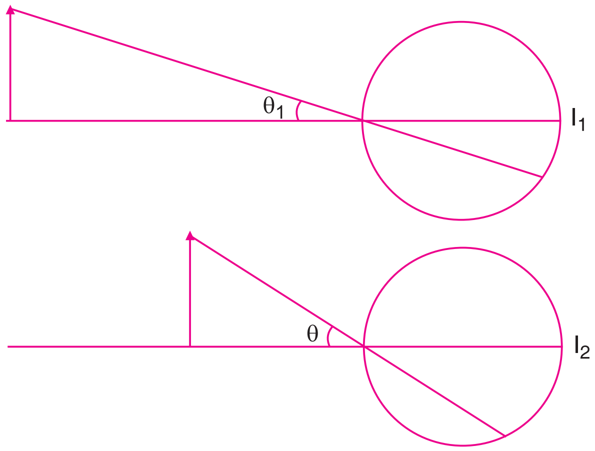
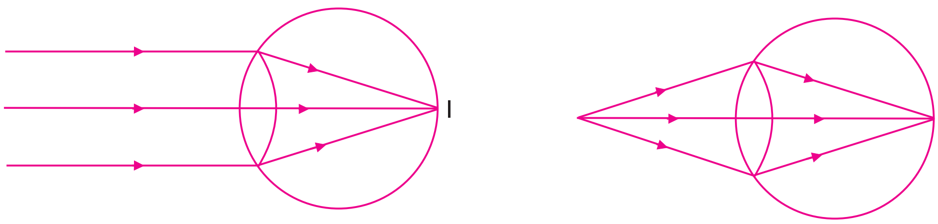


Fig. 15.29 *Image formation in eye*

If an object is at infinity, i.e., parallel beam of light enters the eye, the eye is least strained and said to **relaxed** or **unstrained**. However, if the object is at the least distance of distinct vision (= 25 cm), eye is under the maximum strain and visual angle is maximum. (The angle made by object at eye is called visual angle).

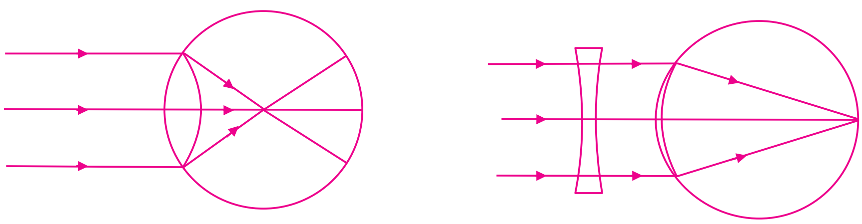


Relaxed eye *Maximum strained eye*

Fig. 15.30

If image of the object does not form at retina the eye has some defects of vision. Following are the common defects of vision.

(i) **Myopia:** In this defect the distant objects are not clearly visible i.e., far point is at a distance lesser than infinity and hence image of distant object is formed before the retina as shown in Fig. 15.31. This defect is removed by using diverging (concave) lens. Myopia is also called short sightedness or near sightedness.



Maypic eye *Corrected eye*

Fig. 15.31

(ii) **Hyper metropia:** It is also called long sightedness or far sightedness. In it the near objects are not clearly visible i.e. near point is at a distance greater than 25 cm. So the image of near object is formed behind the retina. This defect is removed by using converging lens as shown in Fig. 15.32.

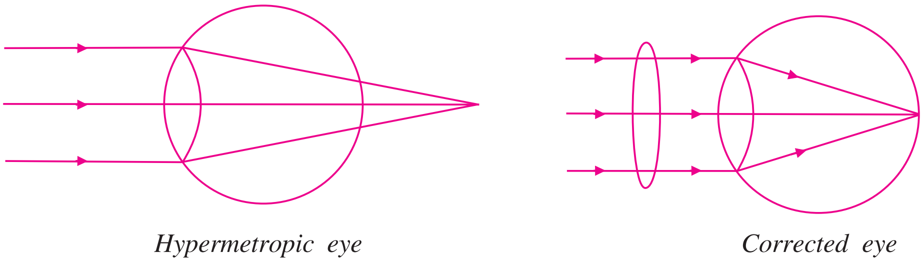


Fig. 15.32

(iii) **Presbypia:** In this defect both near and far object are not clearly visible i.e., far point is lesser than infinity and near point greater than 25 cm. This can be removed either by using two separate spectacles one for myopia and other for hypermetropia or by using bifocal lens. It is an old age disease. At old age ciliary muscles lose their elasticity so they can not change the focal length of eye lens effectively and eye losses its power of accommodation.

(iv) **Astigmatism:** It is due to imperfect spherical nature of eye lens. The focal length of eye lens is in two orthogonal directions become different so they can not see objects in two orthogonal directions simultaneously. This defect in direction can be removed by using cylindrical lens in a particular direction.

INTEXT QUESTIONS 15.5

1. Identify the eye having defective vision from the following diagrams. Write the type of defect in vision. How this defect can be removed?

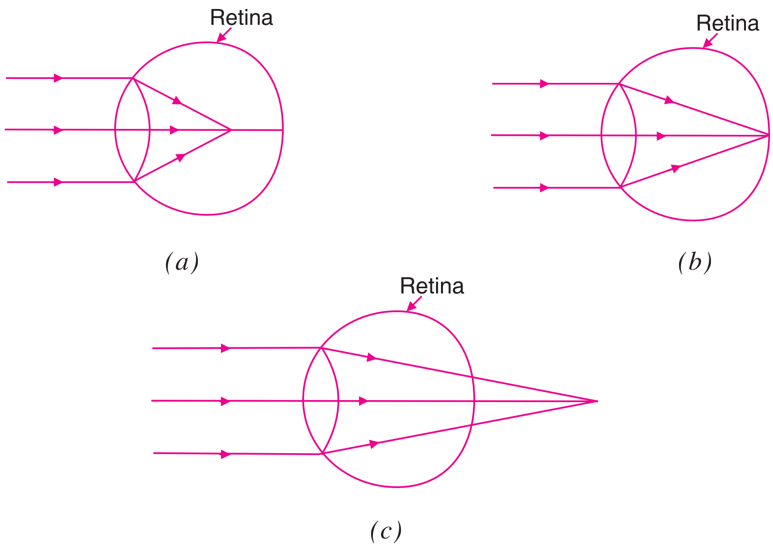


Fig. 15.33

2. Three students Riya, Tiya and Jiya in a class are using sphericals of power $+2D$, $+4D$ and $-2D$. What type of defect in vision they have?
3. How does the focal length of the eye changes when a lens is used to correct the defect of vision in case of (i) short sightedness and (ii) long or for sightedness

WHAT YOU HAVE LEARNT

- Light is a form of energy which makes the objects visible to us.
- When light falls on a smooth and rigid surface and comes back to the same medium, the phenomenon is called reflection.
- In reflection, the angle of incidence is equal to the angle of reflection. Also the incident ray, reflected ray and normal drawn at the point of incidence all lie in the same plane.
- In plane mirror, the virtual image of the size of object and at equal distance from the mirror is formed.
- Spherical mirrors are of two types (i) concave and (ii) convex.
- In spherical mirrors radius of curvature is double of the focal length
- When object is placed infront of a concave mirror at F, between F and $2F$, at $2F$, beyond $2F$, the image will be formed at infinity, beyond $2F$, at $2F$ and between F and $2F$ respectively.
- When an object is placed between F and pole of the concave mirror, the image is formed behind the mirror, virtual and enlarge in size.
- In convex mirror image is always formed between F and pole, smaller in size and virtual nature.
- When light goes from one medium to another its speed changes and the light ray bends. This phenomenon is called refraction of light.
- In refraction, the ratio of sine of angle of incidence to the sine of angle of refraction is constant called refractive index.
- When light goes from rarer to denser medium it bends towards the normal and angle refraction remains less than the angle of incidence.
- When light goes from denser to rarer medium it bends away from the normal and angle of refraction remains greater than the angle of incidence.
- A transparent medium bounded by two well defined surfaces is called lens. There are two types of lens (i) which converges light (convex lens) and (ii) which diverges light (concave lens)

- In convex lens, when object is placed at F, between F and $2F$, at $2F$, beyond $2F$ infront of convex lens the image is formed at infinity, beyond $2F$, at $2F$ and between F and $2F$ respectively.
- When object is placed between F and optical centre of the convex lens, the image formed is virtual and enlarge.
- In concave lens the image is always formed between F and pole, smaller in size and virtual.
- The focal length of a mirror f is given as:

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

- The focal length of a lens is given as:

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

- The reciprocal of the focal length is called power of the lens $P=\dfrac{1}{f\,(m)}$. Its unit is diopter.
- A person who can see the objects near to him properly but can not see the distant objects has a near sight defect of vision. This defect can be removed by using a concave lens.
- A person who can see the far objects but can not see the near objects has a far sight defect of vision. This defect can be removed by using convex lens.
- When light passes through a prism it splits into its constituent colours and this phenomenon is called dispersion of light.
- Rainbow is the best known example of dispersion in nature.

TERMINAL EXERCISE

1. What happens to the speed of light when it goes from (i) denser medium to rarer medium (ii) rarer medium to denser medium?
2. Can angle of incidence be equal to the angle refraction? Justify.
3. Does a convex lens always converge light? Explain.
4. Write the nature of the image formed by concave lens.
5. In horizontal and vertical boxes of the letter grid some meaningful words regarding the properties of light are placed in different rows and column in the table below. Find at least three and define them?

C	O	A	C	O	N	C	A	V	E	C	Z
C	O	N	V	E	X	E	W	I	M	C	W
V	L	R	E	F	L	R	C	T	I	O	N
I	O	E	I	S	E	R	T	A	R	N	P
R	T	F	M	A	N	E	C	A	R	C	Y
T	A	R	A	T	S	C	T	E	O	A	X
U	M	A	G	N	E	T	O	P	R	V	W
A	C	C	E	P	Q	R	S	T	U	E	V
L	O	T	P	R	I	M	E	T	I	M	E
C	V	I	K	T	U	A	L	M	G	I	N
A	C	O	V	E	R	T	E	X	A	R	P
P	N	U	M	I	R	R	O	R	R	S	Q

6. What will be the nature of the image formed in a convex mirror and in a concave mirror each of focal length 20 cm and object is placed at the distance of 10 cm.
7. Find the position of the image formed in concave mirror of focal length 12 cm when object is placed 20 cm away from the mirror. Also find magnification.
8. In which of the following media, the speed of light is maximum and in which it is minimum.

Medium	Refractive index
A	1.6
B	1.3
C	1.5
D	1.4

9. The image of a candle formed by a convex lens is obtained on a screen. Will full size of the image be obtained if the lower half of the lens is printed black and completely opaque? Illustrate your answer with a ray diagram.
10. Can a single lens ever form a real and errect image?
11. What is dispersion of light? What is the cause of dispersion of light?
12. Why do distant object appear to be smaller and closer to each other?
13. A person looking at a net of crossed wires is able to see the vertical direction more distinctly than the horizontal wires. What is the defect due to? How is such defect of vision corrected?

14. A person can see the objects placed at a distance of 30 cm clearly but cannot see the objects placed 30 m away. What type of defect of vision he has? How is this defect of vision corrected?

15. Distinguish visible, ultraviolet and infrared light.

16. Which of the following quantities remains constant during reflection of light?

    (i) speed of light

    (ii) frequency of light

    (iii) wavelength of light

17. Write the value of angle of reflection at both the reflecting surfaces M_1 and M_2 held perpendicular to each other as shown in Fig. 15.34

Fig. 15.34

18. An object is placed infront of a plane mirror. The mirror is moved away from the object with the speed of 0.25 ms^{-1}. What is the speed of the image with respect to the mirror and with respect to the object?

19. Size of the image in a plane mirror of height 12 cm is 20 cm. What is the size of the object?

ANSWERS TO INTEXT QUESTIONS

15.1

1. 1. Luminous 2. Luminous 3. Non- luminous

   4. Luminous 5. Non- luminous

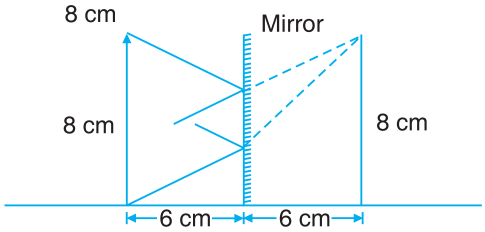
2. (i) Real image can be taken on screen while virtual can not.

   (ii) Real image is formed due to light rays meeting at the screen. While virtual image is formed due to light rays appear to meet at the screen.

3. Real

4. 60°

5.



6. (i) 4 cm (ii) 8 cm
7. (i) 6.0 ms^{-1} (ii) 12.0 ms^{-1}
8. Real, Erect, Plane, Virtual, Image
9.

Distance of object (A)	Height of object (B)	Distance of image (C)	Height of image (D)
10 cm	5 cm	10 cm	5 cm
5 cm	10 cm	5 cm	10 cm
6 cm	8 cm	6 cm	8 cm

15.2

1. Position is equal to –8.55 cm, the image is real of focal length 5 cm
2. When object is between focal point and pole of the mirror.
3. before focus
4. Real, smaller in size and inverted
5. 60 cm infront of mirror
6. Saving mirror, magnifying mirror for dentist
7. Always virtual and smaller in size
8. (i) 4.8 cm (ii) 6 cm (iii) 7.2 cm
9.

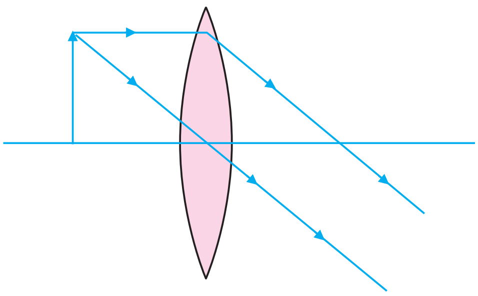
Position of object	Position of image
(i) at F	(i) at infinity
(ii) between F and $2F$	(ii) beyond $2F$
(iii) beyond $2F$	(iii) between F and $2F$
(iv) between F and $2F$	(iv) beyond $2F$
(v) beyond $2F$	(v) between F and $2F$

10. (i) in vehicle for rear view (ii) as safety viewers at dangerous corners
11. No, not always

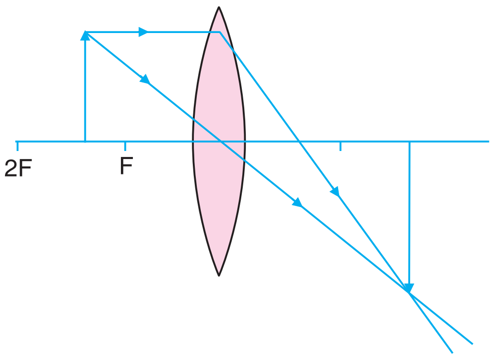
12. Object must be placed either between focal point and pole for virtual image or between F and $2F$ for real image.

15.3

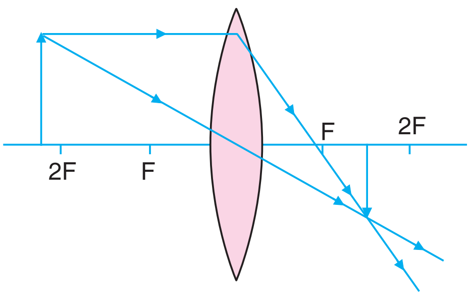
1. Concave lens
2. (i)



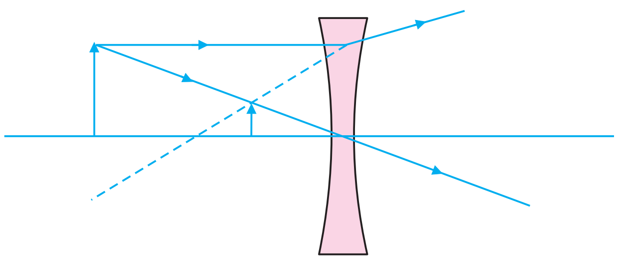
(ii)



(iii)



3.



4. Convex lens, 40 cm
5. –20 cm

15.4

1. 5/3
2. (1) Violet (2) Indigo (3) Blue (4) Green (5) Yellow
   (6) Orange (7) Red
3. r and δ both will decrease
4. Material of the prism has different value of refractive index for different colours of light.
5. Rainbow in the sky

15.5

1. (A) Shortsightedness, it can be removed by using diverging lens.
   (B) No defect
   (C) Longsightedness, it can be removed by using converging lens.
2. Riya and Tiya have longsightedness and Jiya has shortsightedness.
3. (i) increases (ii) decreases