



We see a number of objects around us. How do we see the objects ? We see the objects with the help of light emitted by them. Luminous objects like, the sun, lighted candles, etc. emit light of their own. We see the luminous objects with the help of light emitted by them. Then, how do we see non-luminous objects ? We see the non-luminous objects with the help of light falling on them. That is how we are reading this book.

Light travels rectilinearly in a transparent medium. The path of the light is turned back on falling on a polished surface. The phenomenon is known as reflection of light. What happens when light passes through different media ? The path of light is mostly deviated when it passes through different media. The phenomenon is known as refraction of light. White light is splitted when it suffers refraction. Refraction occurs in human eye also. In this chapter we shall study the phenomena caused by reflection and refraction of light.

11.1 Reflection of light from plane surface

It is quite a common experience that when light from a torch light is directed towards a mirror the light beam is redirected back. This redirected light beam is known as reflected light and the phenomenon is called the reflection of light. If the direction of the incident beam be altered then the direction of the reflected beam will also change correspondingly. Thus the direction of reflected light depends on the direction of the incident light. Hence, reflection occurs under some laws. These laws are known as Laws of Reflection. Before discussing these laws let us acquaint with some terms and definitions first.

By using a proper slit, the beam of light coming out of a torch-light can be made narrower and narrower. Such a narrow beam can be taken as a ray of light though, in practice, it consists of a lot of light rays. In fact a ray of light is an imaginative assumption like that of a 'straight line' in geometry which has no breadth but only length. The point where incident light ray falls is called point of incidence. The vertical line perpendicular on the surface of reflection is known as the normal on the reflective surface at the point of incidence. The angle

between the incident ray and the normal is called the angle of incidence and the angle between the reflected ray and the normal is called the angle of reflection.

Laws of reflection

- (i) The angle of incidence and the angle of reflection are always equal to each other.
- (ii) The incident ray, the reflected ray and the normal at the point of incidence are always in the same plane known as plane of incidence.

These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces. If the reflecting surface is not perfectly polished the rays in a beam of light may be reflected irregularly. Then, diffused reflection occurs. The rays reflected from this book is an example of diffused reflection.

We dress up in front of a dressing mirror. What do you see through the mirror? That is our image. The rays emitted from a point in front of the mirror after suffering regular reflection from the plane mirror appear to be emitted from an imaginary point behind the mirror. That imaginary point is the image of the point in front of the mirror. This is the virtual image formed by the plane mirror. If the reflection is not a regular reflection the rays will be reflected in different directions irregularly and they will not appear to be emitted from any single imaginary point. Hence, no image will be seen. That is why we cannot see our own image through this page. Here only diffused reflection occurs.

Activity 11.1

Use a plane mirror. Observe the image formed by it. What are the properties of the image formed by a plane mirror?

The image is always virtual and erect. The size of the image is equal to that of the object. The image formed is as far behind the mirror as the object is in front of it. The image is laterally inverted.

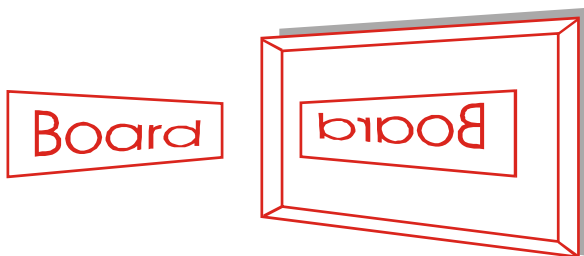


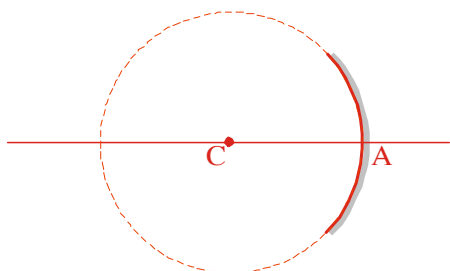
Figure 11.1

Try to answer

1. You see your image through a plane mirror at a distance of 2m from you. What is the distance of the mirror from you ?
2. A brick wall reflects the rays of light emitted from a candle lamp. But you do not see the image of the candle through the wall. What is the reason ?

11.2 Reflection from spherical mirror

Have you ever seen your own image through a curved surface like a shining spoon or side glasses of motor vehicles? How would be the image when the reflecting surface is a curved one ? To understand it let us perform the following activity.

Activity 11.2

Take a large shining spoon. Try to see your own image through its curved side. Move the spoon away. Record the change of the image. Repeat the activity using the other side of the spoon. What can you conclude from this activity?

The most common type of curved mirror is the spherical mirror.

Figure 11.2

The spherical mirror is a part of a hollow sphere. Either the inner or outer side is a reflecting surface. If the inner side is reflecting surface the mirror is known as **concave mirror**. And, if the outer side is a reflecting surface the mirror is known as **convex mirror**. Before we discuss the formation of image by spherical mirrors let us first acquaint with the terms and definitions which we will be using in the study.

Centre of curvature – Centre of curvature is the centre of the sphere of which the spherical mirror is a part.

Radius of curvature – The radius of the sphere, of which the mirror is a part, is known as radius of curvature.

Pole – The central point of the mirror or the point on the mirror directly facing the object is known as pole.

Principal axis – The straight line passing through the centre of curvature and

pole of the mirror is called principal axis.

Principal section – It is the section of the mirror obtained with a plane passing through the principal axis. In a diagram a mirror is represented by its principal section with shade on the back side of the mirror.

Principal focus – It is a point on the principal axis. The rays incident on the mirror parallel to the principal axis, after reflection pass through (in the case of concave mirror) this point or appear to diverge (in the case of convex mirror) from this point.

The rays emitted from the principal focus in the case of concave mirror after reflection emerge parallel to the principal axis. In the case of convex mirror the rays converging towards principal focus are reflected parallel to the principal axis.

Focal length – Focal length is the distance between pole and principal focus. With the help of simple geometry you will be able to show that focal length is nearly equal to half of the radius of curvature.

Aperture – Aperture is the extent of the exposed portion of the mirror.

Two types of image

If the rays from a point object after reflection appear to diverge from or actually converge to a second point. The second point is known as image of the first point. If the rays appear to diverge from the second point this image is known as **virtual image**. Virtual images are always erect. If the rays actually converge to the second point the image is known as **real image**. Real images are always inverted. Real images can be focussed on a screen.

Using a concave mirror you can focus the rays from the sun at a point in front of the mirror. This is the real image of the sun. Assuming the sun is at infinity the rays from the sun are nearly parallel to each other. They focus at a point. The distance of the point from the mirror gives the measure of focal length of the concave mirror.

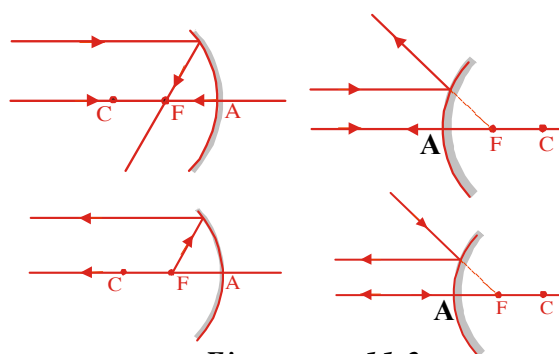


Figure 11.3

Image formed by spherical mirror

How would you locate the position of an image formed by a spherical mirror for an object, using ray diagram? To locate the position of an extended object, placed on the principal axis you can follow the following steps.

Step I – Draw the principal section of the mirror showing distinctly the position of centre of curvature (C), and principal focus (F) on the principal axis (conveniently facing towards the left)

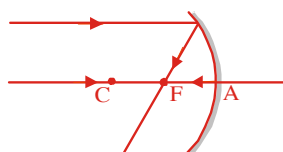
Step II– From the top of the extended object, on the principal axis trace the path of any two of the following rays

- (a) a ray, incident on the mirror parallel to the principal axis. After reflection it passes through principal focus (F) in the case of concave mirror and appears to emit from (F) in the case of convex mirror.
- (b) a ray, incident on the mirror passing through the principal focus (F) in the case of concave mirror or approaching towards the principal focus (F) in the case of convex mirror. It is reflected back parallel to the principal axis.
- (c) a ray, incident on the mirror passing through the centre of curvature (C) in the case of concave mirror or approaching towards the centre of curvature (C). It is reflected back normally. That is, it retraces back the path of the incident ray.

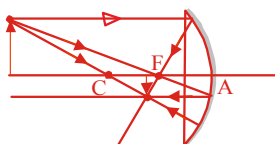
Step III–Find out the point where the two reflected rays intersect actually or intersect producing backwards.

Step IV– Draw a perpendicular from the point of intersection on the principal axis. The perpendicular represents the image of the extended object. (While drawing ray diagram use arrow-head to show the direction of the ray)

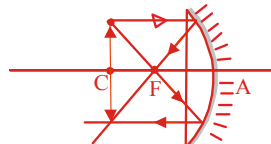
The positions of images formed by a concave mirror when the object is placed at different positions are shown in the figure 11.4.



(a) Object at infinity

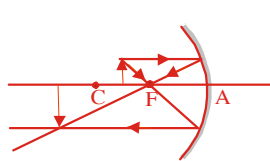


(b) Object beyond C.

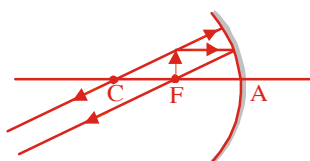


(c) Object at C.

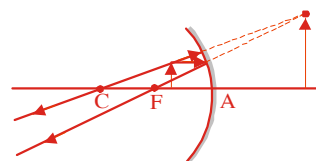
Figure 11.4(A)



(d) Object between C and F



(e) Object at F



(f) Object between F and A.

Figure 11.4(B)

The position, nature and size of the image formed when the object is placed at different distances are summarised in the following table.

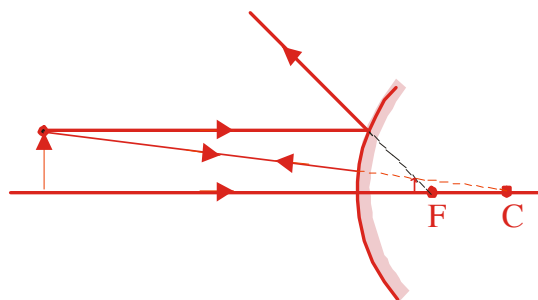
Table 11.1 Image formed by a concave mirror

Position of object	Position of image	Nature of image	Size of the image
Object at infinity	image formed at focus F	real and inverted	(infinitely) small point size
Object between infinity and C	image formed between C and F	real and inverted	smaller than the object
Object at C	image formed at C	real and inverted	same size as the object
Object between C & F	image formed between C and infinity	real and inverted	enlarged
Object at F	image formed at infinity	real and inverted	highly enlarged
Object between Pole and F	image formed behind the mirror	virtual and erect	enlarged

Study the change of the size of the image when the object is moved from C to F.

In the case of convex mirror the image formed is shown in the figure 11.5. When the object is placed in front of the convex mirror the image is formed behind the mirror, virtual, erect and diminished in size.

Study the size of the image when the object is brought very close to the mirror. What will be the size of the image when the object is placed just at the pole?

**Figure 11.5**

A plane mirror can be assumed as a spherical mirror having infinite radius of curvature.

Uses of spherical mirror

A concave mirror is used to produce parallel beam of light in the torch light, head light, search light etc. Dentists use it to see magnified image of small spots in the teeth. It is used as shaving mirror also. It is used to concentrate parallel beam of light.

In a reflecting type of telescope it is used as objective.

A convex mirror is used as rear viewer in vehicles. A convex mirror forms diminished virtual image, hence, its field of view is large. The image is also erect.

Mirror Equation

The object distance (u), image distance (v) and focal length (f) are related. Their relation is given by

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \quad \text{Where } f = \frac{r}{2} \text{ [} r - \text{radius of curvature]}$$

While using the formula and to enable to indicate whether the point whose distance is measured is in front or behind the mirror certain sign conventions are used. There are some sets of sign convention. In this book we shall follow a set of sign convention called the New Cartesian Sign Convention.

New Cartesian Sign Convention

- (i) All measurements of distance are made from the pole of the mirror.
- (ii) If the measurement from pole be along the direction of the incident ray, a (+) sign is assigned to the value.
- (iii) If the measurement from pole be against the direction of the incident ray then a (–) sign is assigned to the measurement.

Further, for convenience and for keeping similarity with that of Cartesian Co-ordinate System in assigning signs, the pole of the mirror is made coincident with the origin of the perpendicular co-ordinate system and facing to the left side so that the direction of the incident ray may be from left to right.

In the above sign convention the focal length of a concave mirror is taken to be negative while that of a convex mirror is positive.

Magnification

The relative extent of the image with respect to the object size is the magnification produced by the spherical mirror. Thus, magnification of a spherical mirror is defined as the ratio of the image height to the object height. It is generally represented by (M).

$$M = \frac{\text{height of the image}(h_i)}{\text{height of the object}(h_o)}$$

The magnification (M) is also related to the image distance (v) and object distance (u). Following the sign convention mentioned above.

$$M = \frac{(h_i)}{(h_o)} = -\frac{v}{u}$$

Using the equation above image-position corresponding to an object when placed at different positions can be solved. A few examples are given below.

Example 11.1 An object 4cm high is placed at a distance of 20cm in front of a concave mirror of radius of curvature 60cm. Find the position, nature and size of the image.

Solution

From the question we have,

image distance, $v = ?$ height of the image, $h_i = ?$ height of the object, $h_o = 4\text{cm}$.

object distance, $u = -20\text{cm}$

radius of curvature $r = -60\text{cm}$

$$\therefore \text{focal length, } f = \frac{-60}{2} = -30\text{cm}.$$

$$\text{Using the relation } \frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

We have,

$$\begin{aligned} \frac{1}{v} + \frac{1}{-20} &= \frac{1}{-30} \\ \Rightarrow \frac{1}{v} &= -\frac{1}{30} + \frac{1}{20} = \frac{-2+3}{60} = \frac{1}{60} \quad \therefore v = 60\text{cm} \end{aligned}$$

(+) sign shows that the image is behind the mirror and it is virtual.

$$\text{Again, magnification } m = \frac{h_i}{h_o} = \frac{-v}{u}$$

$$\therefore \frac{h_i}{4} = \frac{-60}{-20} = 3$$

$$\therefore h_i = 3 \times 4 = 12\text{cm.}$$

The image is formed 60cm behind the mirror, it is virtual 12 cm high and erect.

Example 11.2 An object 4cm high is placed at a distance of 40cm in front of a concave mirror of radius of curvature 60cm. Find the position, nature and size of the image.

Solution

From the question we have,

image distance, $v = ?$ height of the image, $h_i = ?$ height of the object, $h_o = 4\text{cm}$

object distance, $u = -40\text{cm}$

$$\text{focal length, } f = \frac{-60}{2} = -30\text{cm.}$$

$$\text{Using the relation } \frac{1}{v} + \frac{1}{u} = \frac{1}{f}$$

We have,

$$\begin{aligned} \frac{1}{v} + \frac{1}{-40} &= \frac{1}{-30} \\ \Rightarrow \frac{1}{v} &= -\frac{1}{30} + \frac{1}{40} = \frac{-4+3}{120} = \frac{-1}{120} \quad \therefore v = -120\text{cm} \end{aligned}$$

The (-) sign shows that the image is in front of the mirror and real.

$$\text{Again, magnification } m = \frac{h_i}{h_o} = \frac{-v}{u}$$

$$\therefore \frac{h_i}{4} = \frac{-(-120)}{(-40)} = -3$$

$$\therefore h_i = -3 \times 4 = -12\text{cm.}$$

Thus the image is formed at a distance of 120 in front of the mirror. It is real, 12cm high and inverted.

Example 11.3 It is intended to focus an image magnified 4 times on a screen using a concave mirror of focal length 20cm. Where should the object be placed?

Solution

From the question we have,

object distance, $u = ?$

magnification, $m = 4$

focal length, $f = -20\text{cm}$.

Let $(x)\text{cm}$ be the object distance

$$\therefore u = -x$$

Since, $m = \frac{v}{u}$ (numerically) where v – image distance,

u – object distance

We have, $v = 4x$. Since the image is focussed on the screen the image is real and formed in front of the mirror. So (v) is $(-)\text{ve}$.

$$\therefore v = -4x.$$

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\begin{aligned} \frac{1}{-4x} + \frac{1}{-x} &= \frac{1}{-20} \\ \Rightarrow \frac{-5}{4x} &= \frac{1}{-20} \Rightarrow \frac{4x}{5} = 20 \\ \therefore x &= \frac{20 \times 5}{4} = 25 \end{aligned}$$

Hence, object is to be placed at a distance of 25cm in front of the mirror.

Example 11.4 Find the object distance to form an image magnified 4 times by a concave mirror of focal length 20cm.

Solution

Let $(x)\text{cm}$ be the object distance

$\therefore$ Object distance, $u = -x\text{ cm}$

focal length, $f = -20\text{cm}$

magnification, $m = 4$

$$\therefore m = \frac{v}{u} \text{ [numerically]}$$

We have, $v = 4x$ [numerically]

When the image is real, $v = -4x$

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{-4x} + \frac{1}{-x} = \frac{1}{-20}$$

$$\Rightarrow \frac{-1-4}{4x} = \frac{-1}{20}$$

$$\Rightarrow \frac{-5}{4x} = \frac{-1}{20}$$

$$\Rightarrow \frac{4x}{5} = 20$$

$$\therefore x = \frac{20 \times 5}{4} = 25\text{cm}$$

To form real image the object is to be placed at 25cm in front of the mirror.

When the image is virtual (v) is (+)ve.

$$\therefore v = +4x$$

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{+4x} + \frac{1}{-x} = \frac{1}{-20}$$

$$\Rightarrow \frac{1-4}{4x} = -\frac{1}{20}$$

$$\Rightarrow \frac{-3}{4x} = \frac{-1}{20}$$

$$\Rightarrow \frac{4x}{3} = 20$$

$$\therefore x = \frac{20 \times 3}{4} = 15$$

$\therefore$ To form virtual image the object is to be placed at 15cm in front of the mirror.

Example 11.5 A dentist uses a concave mirror of focal length 10cm to see a small spot on a patient's teeth. Find the magnification produced if a virtual image is formed at 25cm behind the mirror.

Solution

From the question we have,

focal length, $f = -10\text{cm}$

image distance, $v = +25\text{cm}$

object distance $u = ?$

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\begin{aligned}\frac{1}{25} + \frac{1}{u} &= \frac{1}{(-10)} \\ \Rightarrow \frac{1}{u} &= -\frac{1}{10} - \frac{1}{25} = \frac{-5-2}{50} = \frac{-7}{50} \\ \therefore u &= -\frac{50}{7}\end{aligned}$$

$$\therefore \text{magnification, } m = \frac{-v}{u} = \frac{-25 \times 7}{-50} = 3.5$$

Example 11.6 A convex mirror of radius of curvature 4m is used for rear view in an automobile. A person appears to be at 1m behind. What is the actual distance of the person?

Solution

From the question we have

object distance, $u = ?$

focal length, $f = +\frac{4}{2} = 2\text{m}$ [(+) ve since the mirror is convex]

image distance, $v = 1\text{m}$.

Using the equation $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$

We have,

$$\begin{aligned}\frac{1}{1} + \frac{1}{u} &= \frac{1}{2} \\ \Rightarrow \frac{1}{u} &= \frac{1}{2} - \frac{1}{1} = \frac{1-2}{2} = -\frac{1}{2} \\ \therefore u &= -2\end{aligned}$$

Hence, the actual distance of the object (person) is 2m.

Try to answer

1. A concentrated image of the Sun can be focussed at 50cm away from a mirror. What is the focal length of the mirror ? [Ans. 50 cm]
2. A concave mirror forms a real image having the same size as the object at a distance of 40cm in front of the mirror. What is the focal length of the mirror? (Ans. 20 cm)
3. An object is placed at a distance of 50cm in front of a concave mirror of focal length 25cm. Find the image distance. If the object is 10cm high what will be the nature and size of the image ?
[Ans. 50 cm, real inverted, 10 cm high]
4. An object is placed at a distance of 50 cm in front of a convex mirror of focal length 25 cm. Find the image distance. What will be its nature ?
[Ans. 16.67 cm, virtual and erect]
5. An object is placed at a distance of 15 cm in front of a concave mirror of focal length 30 cm. Find the nature and position of the image ?
[Ans. Virtual erect ; 30 cm behind the mirror]
6. An object is placed at a distance of 15 cm in front of a convex mirror of focal length 30 cm. Find the nature and position of the image.
[Ans. Virtual, erect, 10 cm behind]

11.3 Refraction through plane interface

The bottom of a vessel containing clear water appears to be raised up. When a thick glass slab is placed over some printed matter, the letters appear raised up when viewed through the glass slab. A straight pole inserted slantly in clear water appears to be bent at the surface of water. How can you account for such experiences ?

Light travels in straight line in a uniform transparent medium. When light passes from one medium into another obliquely on the interface its path gets deviated at the interface of the two media. This is known as refraction of light.

Why does light suffer refraction ? The speed of light is different in different media. In vacuum and air (approximately) under normal condition light travels at 3,00,000km per second. In water the speed of light is about 2,25,000 km per second. The medium in which the speed of light is smaller is known as optically denser medium. Thus, water is optically denser than air. When light enters from

one medium to another obliquely on the interface, to enable to negotiate the change of speed, the path of the light is bent starting from the interface. Thus refraction takes place.

The ratio of the speed of light in vacuum to the speed of light in a medium i.e. the reciprocal of relative speed of light in a medium to the speed in vacuum is called refractive index of the medium. The ratio of the speed of light in two different media gives the relative refractive index of the second medium with respect to the first medium.

If v_o – represents speed of light in vacuum

v_a – represents speed of light in medium (A)

v_b – represents speed of light in medium (B)

$$\frac{v_o}{v_a} = \frac{1}{\left(\frac{v_a}{v_o}\right)} = \text{refractive index of (A)} = (\eta_A)$$

$$\frac{v_o}{v_b} = \frac{1}{\left(\frac{v_b}{v_o}\right)} = \text{refractive index of (B)} = (\eta_B)$$

$$\frac{v_a}{v_b} = \frac{1}{\left(\frac{v_b}{v_a}\right)} = \text{refractive index of (B) with respect to (A)} = [{}_A\eta_B]$$

We have,

$$\frac{v_a}{v_b} = \frac{v_a v_o}{v_o v_b} = \frac{\frac{v_o}{v_b}}{\frac{v_o}{v_a}} = \frac{\text{refractive index of (B)}}{\text{refractive index of (A)}}$$

$$\therefore [{}_A\eta_B] = \frac{\eta_B}{\eta_A}$$

When a ray of light passes from one medium to another the amount of deviation and the sense of deviation of its path are determined by the ratio of the refractive indices of the two media. When a ray of light enters a denser medium the path of the ray is deviated towards the normal on the interface at

the point of incidence. When the ray of light is refracted to a rarer medium the path is deviated away from the normal on the interface at the point of incidence.

To understand the phenomenon further let us perform the following activity.

Activity 11.3

Fix a sheet of paper on a drawing board. As shown in the figure 11.6 draw the boundary of a glass slab (ABCD). Remove the glass slab and draw a normal NOM on the side AB at O.

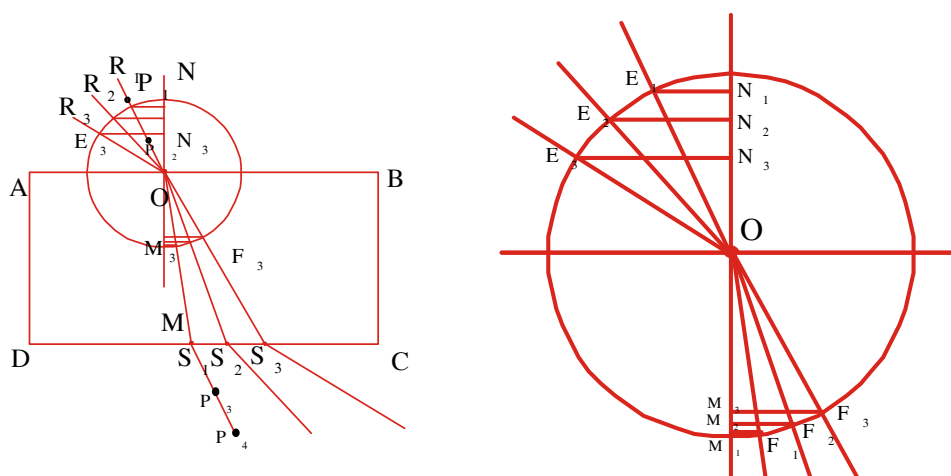


Figure 11.6

Draw a line R_1O making an angle i_1 to the normal ON . Fix two pins P_1 and P_2 upright on the line R_1O . Place the glass slab in the former position.

Look the two pins P_1 and P_2 through the glass slab and fix two pins P_3 and P_4 so that these two pins and the images of the former pins P_1 and P_2 lie on a straight line.

Draw a straight line passing through the two pins P_3 and P_4 meeting the side CD at S_1 .

Join OS_1 . Now OS_1 is the path of the refracted ray inside the glass slab corresponding to the incident ray R_1O . Thus angle MOS_1 is the angle of refraction r_1 .

Observe the path OS_1 is not in the same line as R_1O . It is deviated closer to the normal.

Repeat the same activity using R_2O and R_3O as two more incident rays

making angle of incidence i_2 and i_3 to the normal ON. OS_2 and OS_3 are the refracted rays making angle of refraction r_2 and r_3 to the normal respectively.

The incident rays, refracted rays and normal on the refracting surface at the point of incidence lie in the same plane.

Draw a circle of suitable radius with centre O cutting the incident rays at E_1 , E_2 and E_3 and refracted rays at F_1 , F_2 and F_3 .

Draw perpendiculars E_1N_1 , E_2N_2 and E_3N_3 from these points on the normal ON also F_1M_1 , F_2M_2 and F_3M_3 on the normal OM.

Measure the length of the perpendiculars and find the ratio of $\frac{E_1N_1}{F_1M_1}$, $\frac{E_2N_2}{F_2M_2}$, $\frac{E_3N_3}{F_3M_3}$ and compare the results. The ratios are found the same.

What can you conclude from these observations

$$\text{Here, } \frac{E_1N_1}{F_1M_1} = \frac{E_2N_2}{F_2M_2} = \frac{E_3N_3}{F_3M_3} = \text{a constant.}$$

$$\text{We have, } \frac{E_1N_1}{F_1M_1} = \frac{\frac{E_1N_1}{OE_1}}{\frac{F_1M_1}{OF_1}} = \frac{\text{Sin}i_1}{\text{Sin}r_1} \quad [\because OE_1 = OF_1 \text{ being radii of same circle}]$$

$$\frac{E_2N_2}{F_2M_2} = \frac{\frac{E_2N_2}{OE_2}}{\frac{F_2M_2}{OF_2}} = \frac{\text{Sin}i_2}{\text{Sin}r_2}$$

$$\frac{E_3N_3}{F_3M_3} = \frac{\frac{E_3N_3}{OE_3}}{\frac{F_3M_3}{OF_3}} = \frac{\text{Sin}i_3}{\text{Sin}r_3}$$

$$\text{Thus, we have } \frac{\text{Sin}i_1}{\text{Sin}r_1} = \frac{\text{Sin}i_2}{\text{Sin}r_2} = \frac{\text{Sin}i_3}{\text{Sin}r_3} = \text{a constant.}$$

The activity gives two results known as the laws of refraction as stated

below –

First law of refraction : The incident ray, refracted ray and normal on the refracting surface at the point of incidence lie in a plane.

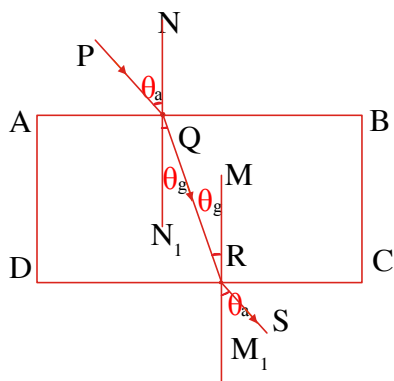
Second law of refraction : The Sine of the angle of incidence bears a constant

ratio to the sine of angle of refraction i.e. $\frac{\sin i}{\sin r} = \text{a constant}$. The ratio is also

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

(The ratio is different for different colours (frequencies) of light. Light of different frequencies travel with the same speed in vacuum, however they travel with different speed in other media. In refraction different colours deviate through different angles corresponding to the same angle of incidence).

The ability of a medium to refract light depends upon the refractive index of the medium. It is also expressed in terms of optical density. A medium with larger refractive index is optically denser. Light travels with less speed in denser medium.



Successive Refraction

Let us study a ray of light PQRS passing through a glass slab ABCD with parallel refracting surfaces AB and DC and placed in air. Fig 11.7.

For the refraction at the first interface AB

θ_a – angle of incidence

θ_g – angle of refraction

$$\therefore \frac{\sin \theta_a}{\sin \theta_g} = {}_a n_g \text{ (refractive index of glass with respect to air)}$$

Figure 11.7

Since, AB and DC are parallel to each other the angle of incidence at the interface DC will be equal to the angle of refraction at AB. Thus the refraction at DC is just the reverse to that at AB.

For the refraction at the second interface DC.

$$\frac{\sin \theta_g}{\sin \theta_a} = {}_g\eta_a \text{ (refractive index of air with respect to glass)}$$

From these two refractions we can conclude that ${}_a\eta_g = \frac{1}{{}_g\eta_a}$

Thus, refractive index of a medium (A) with respect to another medium (B) is the reciprocal of the refractive index of (B) with respect to (A).

Apparent raising of the bottom of a vessel containing water

The bottom of a vessel containing water is apparently raised up. How is it? Let us consider a point (P) at the bottom Fig. 11.8. A ray PA from the point meets the water surface normally.

It suffers no deviation and travels along AC. (As the angle of incidence is zero). Another ray PB meets the refracting surface at an angle of incidence θ_w . It is refracted away along BD making an angle of refraction θ_a . Here, $\theta_a > \theta_w$. The refracted rays BD and AC meet at Q producing backwards. Thus, the rays emitted from P appear to be emitted from Q, which is the virtual image of P. All the points at the level of P will appear to be at the level of Q. Thus the bottom appears raised up.

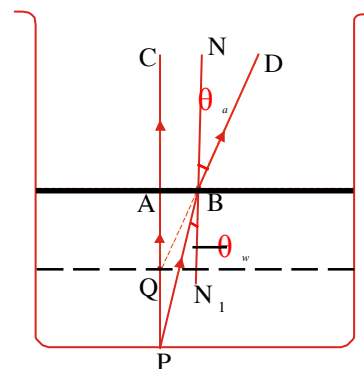


Figure 11.8

Now, PA is the real depth and QA is the apparent depth of the bottom.

With reference to the figure 11.8 the refractive index of water with

respect to air,

$${}_a\eta_w = \frac{\sin \theta_a}{\sin \theta_w}$$

$$\begin{aligned} &= \frac{\sin \angle AQB}{\sin \angle APB} = \frac{\frac{AB}{QB}}{\frac{AB}{PB}} \quad [\text{Since } \angle AQB = \theta_a \text{ and } \angle APB = \theta_w] \\ &= \frac{PB}{QB} = \frac{PA}{QA} \quad [\text{When B is close to A } PB = PA \text{ } QB = QA.] \\ &= \frac{\text{real depth}}{\text{apparent depth}} \end{aligned}$$

Example 11.7 A fish appears to be at a depth of 0.5m from the surface of water. Find the real position of the fish if refractive index of water is 1.33.

Solution From the question we have, real depth = ?

Apparent depth = 0.5m

refractive index, $\eta = 1.33$

Using the relation,

$$\text{refractive index, } \eta = \frac{\text{real depth}}{\text{apparent depth}}$$

$$\text{We have, } 1.33 = \frac{\text{real depth}}{0.5}$$

$$\therefore \text{real depth} = 1.33 \times 0.5 = 0.665\text{m.}$$

Refraction from denser to rarer medium

When a ray of light enters a rarer medium from a denser one, the path of the ray is deviated away from the normal. Hence, angle of refraction is greater than the corresponding angle of incidence. When the angle of incidence is increased the angle of refraction also increases correspondingly. For a particular angle of incidence the angle of refraction is 90° . That is, the ray emerges at the grazing angle along the interface. The angle of incidence for which the angle of refraction is 90° is called **critical angle** (figure 11.9). What will happen when the angle of incidence is increased beyond critical angle? The ray will not suffer refraction. The ray will be reflected back completely (totally) obeying the laws of reflection. The phenomenon of reflection of light approaching from a denser medium towards a rarer medium, at the interface of the two media is called total internal reflection.

Two conditions to obtain total internal reflection are :

- (i) The ray must approach a rarer medium from a denser one.
- (ii) The angle of incidence must be greater than the corresponding critical angle.

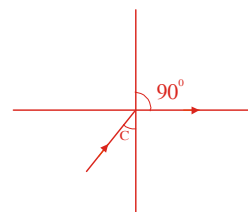
Refractive index of the denser medium is equal to the reciprocal of the sine of the critical angle.

$$\text{i.e. } \eta = \frac{1}{\sin C}$$

Assuming

Refractive index of glass = 1.52 then critical angle of glass with respect to air (vacuum) is given by

$$\sin C = \frac{1}{\eta} = \frac{1}{1.52} = 0.6579 = \sin (41.1)^\circ \therefore C = 41.1^\circ$$

**Figure 11.9**

When the angle of incidence is greater than 41.1° the ray will suffer internal reflection.

In the case of diamond the refractive index is very high. It is 2.42. For diamond critical angle with respect to air (vacuum) is given by

$$\sin C = \frac{1}{2.42} = 0.4132 = \sin (24.4)^\circ$$

$$\text{Hence, } C = (24.4)^\circ$$

When a ray of light enters diamond it suffers a number of internal reflections inside diamond. The angle of incidence inside easily exceeds the critical value 24.4° . Hence total internal reflection occurs successively inside diamond and it is found exceptionally bright.

Table 11.2 Absolute refractive index of some material media

Material medium	Refractive index	Material medium	Refractive index
Air	1.0003	Rock salt	1.54
Ice	1.31	Flint glass	1.65
Water	1.33	Ruby	1.71
Kerosene	1.44	Sapphire	1.77
Crown glass	1.52	Diamond	2.42

N.B. Optically denser medium may not always possess greater mass density.

Try to answer

1. In which medium will light travel faster, water or kerosene ?
2. If the refractive index of glass is 1.5, what will be the apparent thickness of a glass plate of 1.5cm thick ?

11.4 Refraction Through Thin Lenses

Have you ever seen an object through a clean bottle of water? The object appears distorted. Have you seen an object through a small water drop? The object appears bigger. Some spectacle lenses can concentrate the light from the sun at a point. The point gets heated, sometimes it catches fire. These experiences are related with lens.

What is a lens? A lens is a transparent medium bounded with two spherical surfaces. [or, a plane surface and a spherical surface.]

There are two types of lenses. They are (i) Convex lens and (ii) Concave lens.

Convex lens – It is the type of lens in which the central portion is thicker than the peripheral portion. It always converge or tends to converge any beam of light passing through it. So, this type of lens is called as converging lens.

Concave lens – It is the type of the lens in which the central portion is thinner than the peripheral portion. When a beam of light passes through this type of lens, it always tends to diverge the beam of light. So, it is called as diverging lens.

Terms associated with thin lenses

Principal axis – It is the straight line passing through the two centres of curvature of the two surfaces of the lens.

Principal section – It is a section of the lens obtained with a plane passing through the principal axis. In a diagram a lens is represented by its principal section.

Optical centre (O) – It is a point on the principal axis of the lens. Any ray passing through this point does not suffer deviation.

First principal focus (F_1) – It is a point on the principal axis. The rays diverging from this point in the case of convex lens or the rays converging towards this point in the case of concave lens, are refracted by the lens parallel to the principal axis.

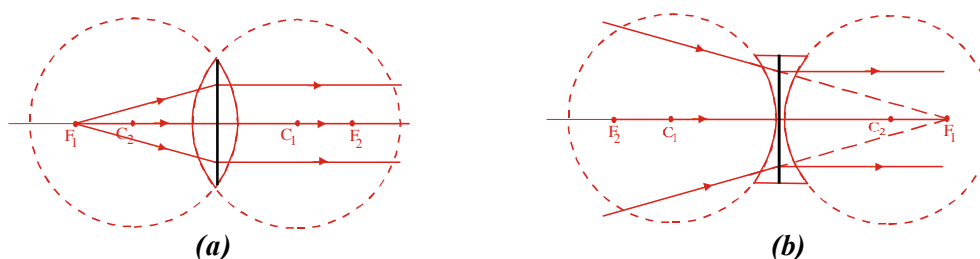


Figure 11.10

Second principal focus (F_2) – It is a point on the principal axis. The rays incident on the lens parallel to the principal axis after refraction actually converge to this point or appear to diverge from this point.

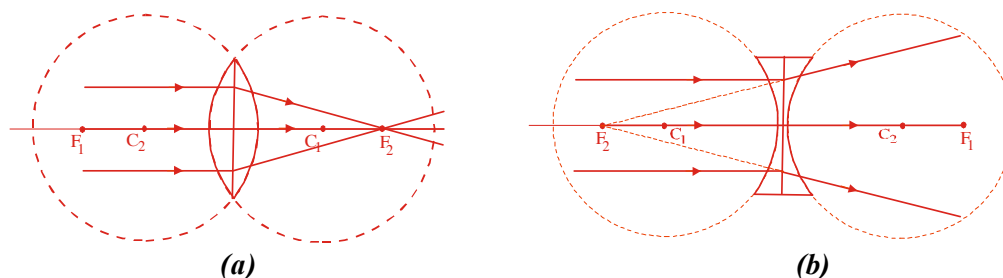


Figure 11.11

Focal length (f) – It is the distance of either first principal focus or second principal focus from the optical centre.

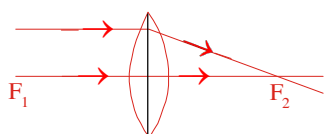
Image formed by lens

To locate the position of the image of an extended object, placed on the principal axis using ray diagram you can follow the following steps.

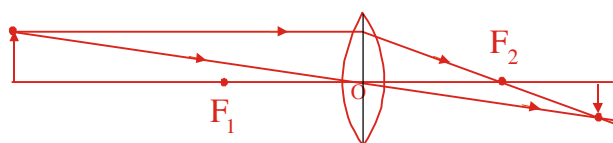
- Step I** Draw the principal section of the lens showing the position of optical centre (O), first principal focus (F_1) and second principal focus (F_2) on the principal axis. (distance of F_1 and F_2 from O will be equal).
- Step II** From the top of the object placed on the principal axis conveniently on the left side of the lens trace the path of any two of the following rays.
- (i) The ray passing through the optical centre O . It does not suffer any deviation.
 - (ii) The ray incident parallel to the principal axis. It is refracted through the second principal focus (F_2) in the case of convex lens. In the case of concave lens it is refracted as if it emerges from the second principal focus (F_2).
 - (iii) The ray incident on the lens through first principal focus (F_1) in the case of convex lens or incident towards the first principal focus (F_1) in the case of concave lens. It is refracted parallel to the principal axis.
- Step III** Find out the point where the two refracted rays intersect actually or intersect producing backward. It is the image of the point on the top of the object.

Step IV Draw a perpendicular from the point on the principal axis. The perpendicular represents the image of the extended object.

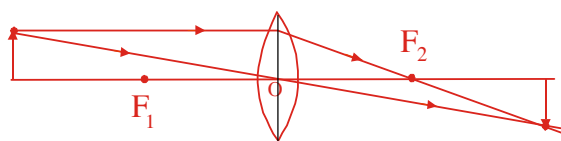
The following ray diagrams show the image formed by the convex lens when the object is placed at different distances. From the diagrams study the position, nature, and size of the image.



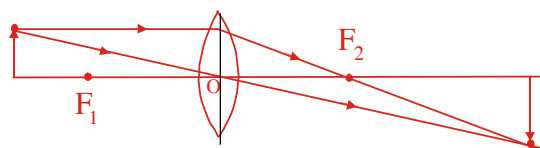
(a) object placed at infinity



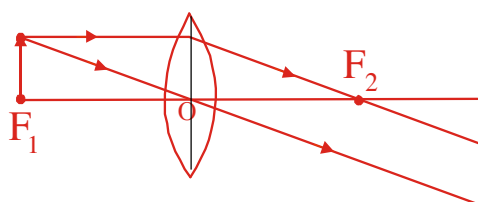
(b) object placed at a distance greater than $2f$



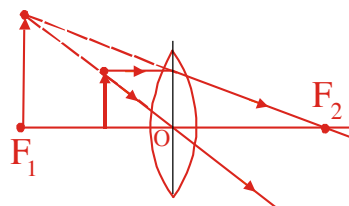
(c) object placed at a distance equal to $2f$



(d) object placed at a distance less than $2f$ and greater than f



(e) object placed at a distance equal to f



(f) object placed at a distance less than f

Figure 11.12

The position, nature and size of the image formed by a convex lens when the object is placed at different distances are summarised in the following table.

Table 11.3

Position of the object	Position of the image	Nature of image	Size of the image
At infinity	At the principal focus (F_2)	Real and inverted	highly diminished
At a distance $>2f$	At a distance greater than (f) and less than $2f$	Real and inverted	diminished
At a distance $= 2f$	At a distance equal to $2f$	Real and inverted	same size
At a distance $< 2f$ and greater than f	At a distance greater than $2f$	Real and inverted	Magnified
At focus	At infinity	Real and inverted	Infinitely magnified
At a distance $< f$	On the same side as the object.	Virtual and erect	Magnified

Ray diagrams of the image formed by concave lens :

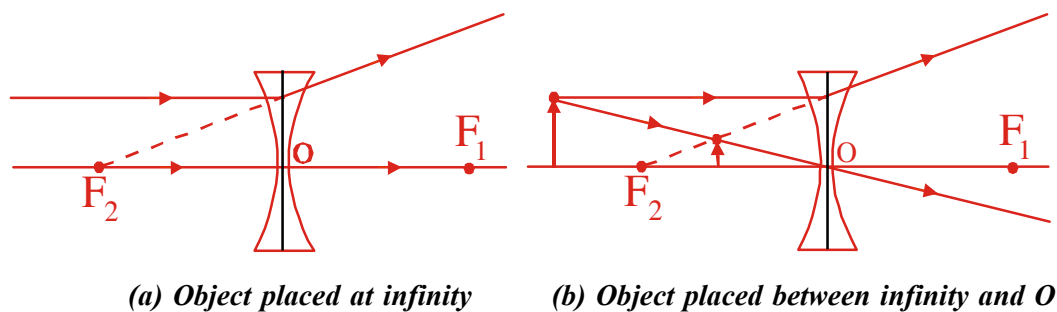


Figure 11.13

From these diagrams we can conclude that concave lens always forms virtual, erect and diminished image for real object.

Lens formula

The image distance (v) formed by a lens depends upon the object distance (u) and focal length (f). Their relation is given by the formula

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

While using the formula we shall follow a sign convention similar to the one used for spherical mirror. In the case of lens all measurements are taken

from the optical centre of the lens. According to this convention focal length of a convex lens is positive and that of a concave lens is negative.

Magnification – The ratio of the size of the image to the size of the object is called magnification (m). It is also related to the image distance (v) and the object distance (u). The relation is given by

$$\text{Magnification } (m) = \frac{\text{height of the image } (h_i)}{\text{height of the object } (h_o)} = \frac{\text{image distance } (v)}{\text{object distance } (u)}$$

$$\text{i.e. } m = \frac{h_i}{h_o} = \frac{v}{u}$$

Power of lens

The converging or diverging ability of a lens is called power of the lens. This ability depends upon the value of focal length. Larger the focal length, lesser is the power of lense. Power of a lens is measured by the reciprocal of the focal length.

$$\text{Power, } P = \frac{1}{f}$$

When the focal length is expressed in metre the power is expressed in dioptre(D). One dioptre is the power of a lens whose focal length is 1 metre. Thus, $1\text{D} = 1\text{m}^{-1}$.

Example 11.8 An object 3cm high is placed at a distance of 20cm from a convex lens of focal length 12cm. Find the position, nature and size of the image.

Solution

From the question we have,
object distance, $u = (-) 20\text{cm}$
focal length, $f = (+) 12\text{cm}$.
Image distance, $v = ?$

By the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have

$$\frac{1}{v} - \frac{1}{(-20)} = \frac{1}{12}$$

$$\Rightarrow \frac{1}{v} + \frac{1}{20} = \frac{1}{12}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{12} - \frac{1}{20} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$$

$$\therefore v = 30\text{cm}$$

$$\text{magnification, } m = \frac{v}{u} = \frac{30}{-20} = -1.5$$

$$\frac{h_i}{h_o} = -1.5 \therefore h_i = -1.5 \times 3 = -4.5\text{cm}$$

Therefore, the image is formed at a distance of 30cm on the positive side i.e. on the other side of the lens. The image will be inverted and real. The size of the image is 4.5cm.

Example 11.9 An object is placed at a distance of 10cm from a convex lens of focal length 15cm. Find the position, nature and magnification of the image.

Solution

From the question we have

object distance, $u = (-)$ 10cm

focal length, $f = (+)$ 15cm.

Image distance, $v = ?$

By the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{v} - \frac{1}{-10} = \frac{1}{15}$$

$$\Rightarrow \frac{1}{v} + \frac{1}{10} = \frac{1}{15}$$

$$\Rightarrow \frac{1}{v} = \frac{1}{15} - \frac{1}{10} = \frac{2-3}{30} = \frac{-1}{30}$$

$$\therefore v = -30\text{cm}$$

$$\text{magnification, } m = \frac{v}{u} = \frac{-30}{-10} = +3$$

The image is formed at a distance of 30cm on the (–)ve side i.e. on the same side as the object. The magnification is +3. The image is erect and virtual.

Example 11.10 Find the image position of an object kept at a distance of 4cm from a concave lens of focal length 12cm. What is the magnification as well ?

Solution

From the question we have

object distance, $u = (-) 4\text{cm}$

focal length, $f = (-) 12\text{cm}$.

image distance, $v = ?$

By the formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

We have,

$$\frac{1}{v} - \frac{1}{-4} = \frac{1}{-12}$$

$$\Rightarrow \frac{1}{v} + \frac{1}{4} = \frac{-1}{12}$$

$$\Rightarrow \frac{1}{v} = \frac{-1}{12} - \frac{1}{4} = \frac{-1-3}{12} = \frac{-4}{12} = \frac{-1}{3}$$

$$\therefore v = -3\text{cm}$$

$$\text{magnification, } m = \frac{v}{u} = \frac{-3}{-4} = 0.75$$

The image is formed at a distance of 3cm on the (-)ve side that is on the same side as the object. The magnification is (+)ve 0.75. The image is erect and virtual.

Try to answer

1. A lens can focus an image having the same size as the object on a screen 1m away from the lens. What is the focal length of the lens ?
2. An object is seen magnified through a lens. What is the type of the lens convex or concave ?
3. An object is seen diminished through a lens. What is the type of lens – convex or concave ?

(Numerical problems)

4. An object is placed at a distance of 50cm in front of a convex lens of focal length 25cm. Find the image distance. If the object is 10cm high what will be the nature and size of the image ? [Ans. 50 cm, real inverted, 10 cm high]

5. An object is placed at a distance of 50 cm in front of a concave lens of focal length 25 cm. Find the image distance. What will be its nature ?

[Ans. 16.67 cm, virtual and erect]

6. An object is placed at a distance of 15 cm in front of a convex lens of focal length 30 cm. Find the nature and position of the image ?

[Ans. Virtual erect ; 30 cm on the same side as the object]

7. An objects is placed at a distance of 15 cm in front of a concave lens of focal length 30 cm. Find the nature and position of the image.

[Ans. Virtual, erect, 10 cm on the same side as the object]

11.5 Human Eye and Defects of Vision

The human eye consists of a crystalline convex lens. The lens forms the image of the object (in front of the eye) on the retina. Retina contains a number of light sensitive nerves. The nerves carry the information of the image, formed on it to the brain. Then sensation of sight occurs. Only when the image is formed on the retina distinctly the object is seen clearly.

Can you see an object when it is placed at different distance ? Yes, we can see the object, placed within a wide range of distance. How is it possible ? A lens having fixed focal length can form the image of an object only at a fixed position. If the lens in the human eye has a fixed focal length, it will be able to focus the image on the retina for the object placed at a fixed position only. The eye lens can change its focal length. With the help of ciliary muscles the curvature of the eye lens can be changed. When the eye lens becomes thicker its focal length is reduced. To enable to focus the image on the retina focal length of the eye lens is adjusted. The ability of the eye lens to adjust its focal length is called **power of accommodation**. If the object is brought much closer, the eye lens may not be able to adjust its focal length any more to enable to focus the image on the retina. The nearest point upto which the eye can see is known as least distance of distinct vision (or near point). For normal eye the least distance of distinct vision is 25cm. When the eye lens is in the thinnest condition (normal condition) its principal focus lies on the retina (in the case of normal eye). The image of the object at infinity can be focussed on the retina. Thus, the far point of normal eye is infinity.

Try to read a printed page by holding it closer and closer. At what distance is it most comfortable ? Can you read upto what distance ? If you bring the printed page still closer what sensation do you feel ? Certainly you will feel a strain sensation in your eye.

Defect of vision

Can you read what is written on the blackboard of your class room from the back bench ? If not check your eye sight. When you read the book do you read with strained eye ? Perhaps you have seen some old persons reading books or newspaper keeping at arms length. Sometimes, the eye may gradually lose its power of accommodation. In such conditions, the vision becomes blurred due to refractive defect of the eye.

For a normal eye the range of vision is from 25cm to infinity. When an eye cannot see distinctly and comfortably the objects within the normal range (that is, between 25cm and infinity) the eye is said to have refractive defect of vision.

There are four common refractive defects of vision. They are (i) myopia or nearsightedness, (ii) hypermetropia or farsightedness, (iii) presbyopia or loss of accommodation, and (iv) astigmatism or loss of horizon.

(i) Myopia or Nearsightedness

The eye suffering from this defect cannot see clearly the far off objects but can see distinctly the objects nearby. The far point of the defective eye is less than infinity and near point also is less than 25cm. The defect is due to either (i) the eye ball is elongated or (ii) the eye lens becomes thicker making its normal focal length too short. In such a situation the image of the distant object is formed in front of the retina Figure 11.14(a). This type of eye defect is corrected by using a concave lens of proper focal length Figure 11.14(c).

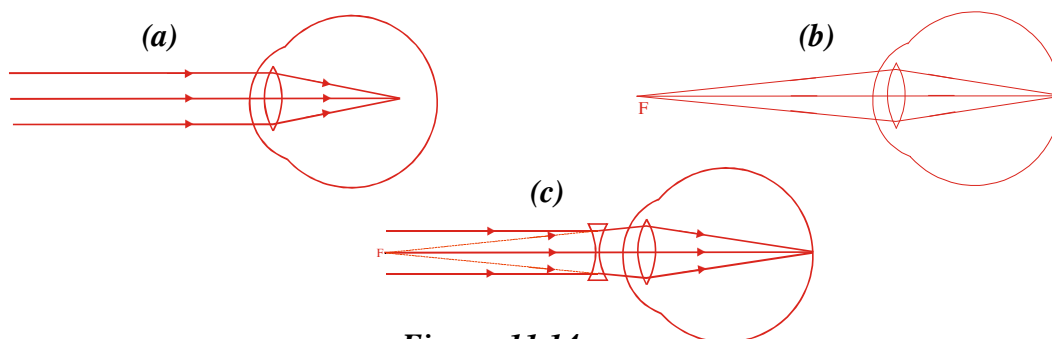


Figure 11.14

[The focal length of the concave lens is equal to the distance of the far point (F) of the defective eye Figure 11.14(b)]

(ii) Hypermetropia or Farsightedness

The eye suffering from this defect can see distant objects clearly but cannot see nearby objects distinctly. The near point of such defective eye is farther away from the normal near point i.e. 25cm. This defect may arise due to (i) shortening of eye ball length or (ii) normal focal length of the eye lens is too long. In such situation, the image of the distant object would be formed behind the retina Fig.11.15(a) if the eye lens is not adjusted by accommodation. To see the distant object the eye lens is adjusted by accommodation Figure 11.15(b). When the object is brought nearer, the eye lens is adjusted accordingly. But the ability to adjust the focal length by accommodation is exhausted when the object reaches a near point (N) which is greater than 25cm, the near point of normal eye Figure 11.15 (c). Hence the hypermetropic eye cannot see clearly objects nearer than N, which is beyond 25cm.

This defect can be rectified by using a converging or convex lens of suitable focal length Figure 11.15 (e).

(iii) Presbyopia or Loss of accommodation

Usually with ageing the flexibility of the eye lens diminishes and hence power of accommodation of the eye decreases.

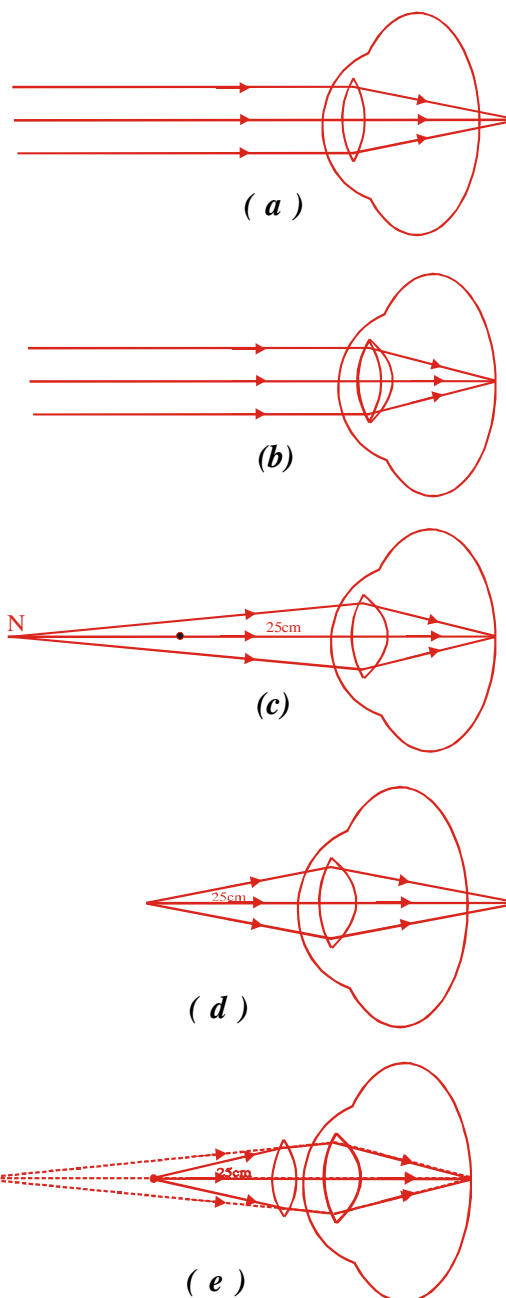


Figure 11.15

Sometimes, the eye may suffer from both myopia and hypermetropia. Such defect is known as presbyopia. The eye has a short range of vision. The near point recedes away and far point becomes close. Such defect can be rectified using bi-focal lens. A common type of bi-focal lens consists of both concave and convex lenses. The upper portion consists of a concave lens, it is used for distant vision. The lower portion is of a convex lens. It is used for near vision.

(iv) Astigmatism or Loss of horizon

An eye suffering from this defect cannot see all the directions—horizontal or vertical equally well simultaneously. The defect is due to the irregular curvature of the eye lens. The vertical and horizontal curvature of the eye lens are different. Such a defect can be removed using suitable cylindrical lens. To test astigmatism yourself do the following activity.

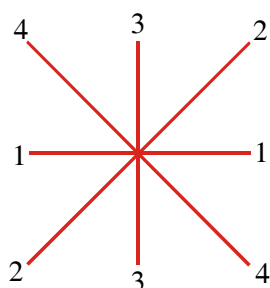


Figure 11.16

Activity 11.4

Draw four lines 1 – 1, 2 – 2, 3 – 3, 4 – 4 as shown in the diagram Figure 11.16 passing through a point with equal intensity.

Look the lines with the eye (left or right) which you are going to test. If all the lines appear equally intense the eye is not astigmatic.

If a particular line is most intense and its perpendicular line is least intense the eye is most likely astigmatic.

Rotate the diagram through 90° . Does the most intense and least intense lines interchange ? If yes further testing with expert may be required.

Try to answer

1. An eye feels comfortable in reading the book keeping at a distance of 15cm. What is the defect ? What type of lens will be used to rectify the defect ?
2. A defective eye cannot see distinctly the object beyond 1m clearly. What is the defect ? What is the power of the lens required to rectify the defect ?

11.6 Dispersion of Light

We have seen the spectacular colours in a rainbow. How is a rainbow formed ? How could the white light of the sun gives us various colours of a rainbow ?

Light consisting of a number of components with different frequencies or wavelengths is called polychromatic or composite light. Light consisting of a single wavelength is called monochromatic light.

Solar light is a polychromatic or composite light. Splitting of a composite light into its constituent colours is known as dispersion of light.

A glass prism can split white light into its constituent colours. A prism is a transparent medium having two refracting faces inclining at certain angle. When a ray of light is passed through a prism, the ray always suffers deviation. To understand how white light is splitted by a prism let us perform the following activity.

Activity 11.5

- ☞ Prepare a narrow slit in a sheet of card board.
- ☞ With the help of a plane-mirror a beam of solar light is passed through the slit.
- ☞ Take a glass prism and allow the light to pass through the prism.
- ☞ Turn the prism slowly until the light that comes out of it falls on a nearby screen.

- ☞ What do you observe ? You will find a beautiful band of colours. Observe the sequence of the colour.

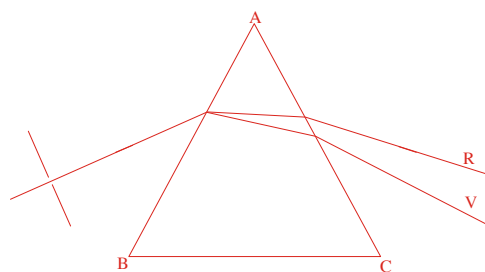


Figure 11.17

You will find that violet colour is deviated the most and red the least. If you see minutely you will find the sequence of the colours as – Violet, Indigo, Blue, Green, Yellow, Orange and Red. The acronym VIBGYOR will help you to remember the sequence of colours. The colour-band is called the spectrum.

When refraction takes place through the first refracting surface of a prism violet colour is deviated most and red colour is deviated least. Other colours are deviated in between the two extreme range. In the refraction through the second refracting surface also deviation takes place in the same sense and hence different colours are deviated further producing the colour spectrum more distinct. But in the case of glass slab the opposite refracting surfaces are parallel to each other. In this case, the composite light is splitted into its constituent

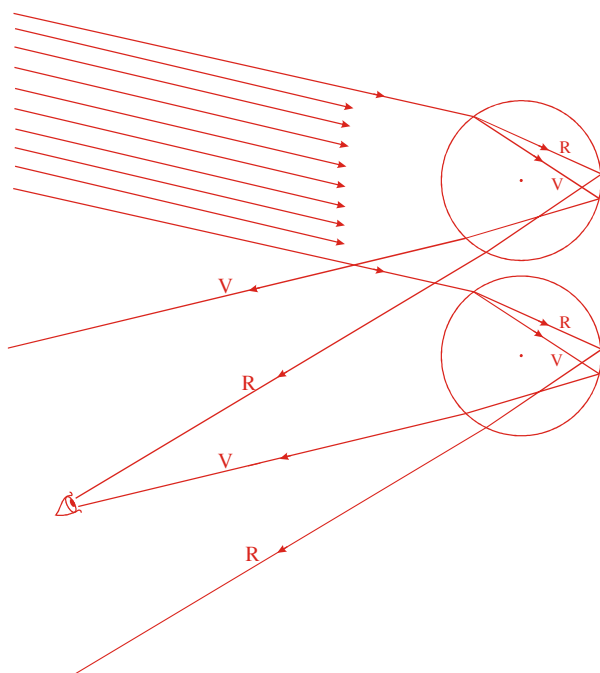


Figure 11.18

backside. A rainbow is always formed in a direction opposite to that of sun. The water droplets act like small prisms. They refract the sunlight, disperse, then internally reflected. Finally the reflected rays emerge out of the raindrop (actually suffering refraction). Due to the dispersion of light and internal reflection, different colours reach the observer's eye Figure 11.18.

Can you create a rainbow on a sunny day for your friend ?

Try to answer

1. In the morning in which direction may you observe a rainbow ?

11.7 Phenomena caused by refraction in atmosphere

Some phenomena caused by refraction in atmosphere are accounted below :

(A) Advance Sunrise and delayed Sunset

Do you know the Sun is visible to us about 2 minutes before the actual sunrise? The sunset is also delayed by about 2 minutes. The day gets elongated by about 4 minutes. The rays of the solar light coming from space undergo refraction as they penetrate the atmosphere of the earth. Further, the density of the atmosphere decreases with altitude. Thus, as the ray travels from top of the atmosphere to the surface of the earth the density of the air medium gradually

colours when refraction takes place through the first surface. When the rays are refracted through the second surface the rays emerge without any deviation from the direction of the incident ray. Splitted rays of different colours corresponding to adjacent incident rays combine to form composite emergent rays. Only the extreme sides of the beam appear coloured. Thus a glass slab cannot cause dispersion of light.

When do you see a rainbow ? It is a natural spectrum appearing in the sky. It is caused by dispersion of sunlight by tiny water droplets, present in the atmosphere. To see a rainbow the sun will be at your

increases. As a result the path of the ray is slightly, curved and the rising sun which is actually lying below the horizon appears to be a little raised and becomes visible Figure 11.19. Because of this the sun is visible slightly before it actually rises and slightly after it sets. Also the setting sun appears slightly oval in shape rather than being circular. This is due to unequal refraction of light coming from the upper and lower portion of the sun's disc.

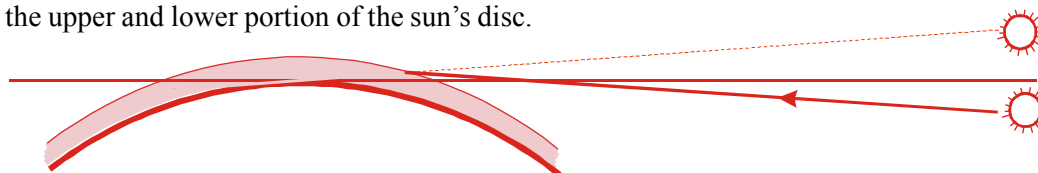


Figure 11.19

(B) Twinkling of Stars

The twinkling of star is also due to the refraction caused by the atmosphere. There are always irregular currents of hot air in the atmosphere. This causes the refractive index of the atmosphere vary continually. As a result the position of the star appears to fluctuate to an observer on earth. Further, when a sudden current of hot air crosses the line of vision, the light from the star suddenly gets deflected away and the star is temporarily lost from view. Thus the stars twinkle.

The planets and the moon do not twinkle because they are much nearer to the earth and so do not behave like a point source. Further, they appear bright. Because of the reasons they do not twinkle.

(C) Scattering of light

Atmosphere contains not only air particles, but also some more minute particles like – smoke particles, tiny water droplets, dust particles, The interaction of light wave with these tiny particles gives rise to several spectacular phenomena in nature. Blue colour of sky, reddening of the sun at sunrise and sunset are some interesting phenomena. The path of a beam of light passing through a true solution is not visible. However, its path become visible through a colloidal solutions where the size of the particles is relatively larger. When a beam of light strikes such fine particles the path of the beam is visible as diffusely reflected rays reach our eye. The phenomenon of diffused reflection is called scattering of light.

Tiny particles can diffuse the light of shorter wavelength more effectively and light ray of longer wavelength are transmitted undisturbed. Blue light has shorter wavelength than red light. The molecules of air and other fine particles have the size more effective in scattering light of shorter wave lengths

at the blue. The red light has a wavelength of about 1.8 times greater than that of blue light. Thus, when sunlight passes through the atmosphere the fine particles in air scatter the blue colour (shorter wavelengths) more strongly than red. The scattered blue light enters our eye. Thus we see the sky blue.

If the earth had not atmosphere, there would not have any scattering, then the sky would have looked dark.

Red light is not scattered or least scattered by the air and suspended particles in the atmosphere. It can penetrate through the air easily with least disturbance. So, red light is used in danger signal.

During sunrise and sunset the light rays from the sun passes through thicker layers of air and larger distance in the earth's atmosphere before reaching our eye. Almost violet and blue part of the solar light are scattered away on the way leaving only the red portion undisturbed. Therefore, the light that reaches our eye is of longer wavelengths. This gives rise to the reddish appearance of the sun.

At noon the sun is at overhead. Light from the sun would travel relatively shorter distance, so only a little portion of the blue and violet colours are scattered and the sun still appears white.

(D) Mirages

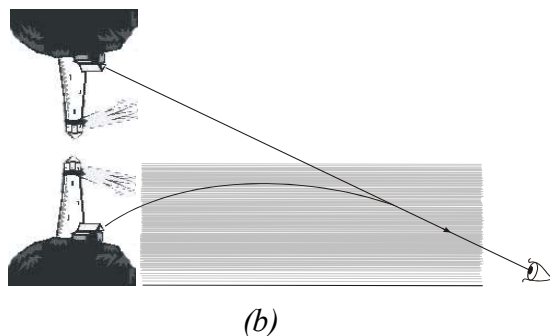
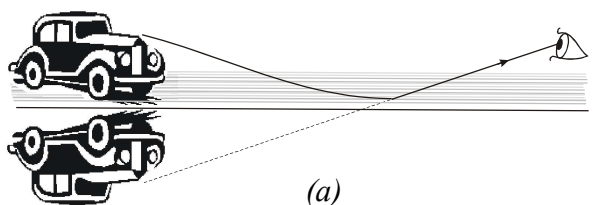


Figure 11.20

When different layers of the atmosphere are at different temperatures the layers will have different optical density. Many strange phenomena may occur – an object on the street may appear inverted as if reflection occurs on a water surface on the street Figure 11.20(a). A Ship or light house may appear floating in the sky in cold polar region. Such strange phenomena are known as mirages.

On a hot sunny day the layer of the atmosphere just above the road may become very hot and may have least optical density.

Overlying layers of air are relatively cold. As we go up higher and higher the

layer are optically denser and denser.

The rays from the top of an object on the street suffer refraction consecutively increasing angle of incidence layer after layer. At certain lower layer the angle of incidence may surpass the critical angle. Then the rays will be reflected back internally. To the observer an inverted image of the object will be seen.

In the cold polar region the optical density of the different layers of air decreases as we go higher and higher. Hence rays from the object on the surface of the sea after consecutive refraction are internally reflected back from a layer above. Hence the object is seen hanging in the sky Figure 11.20(b).

POINTS TO REMEMBER

- i. Light travels rectilinearly.
- ii. Regular reflection can cause the formation of image.
- iii. Irregular reflection cannot cause the formation of image.
- iv. The image formed by a plane mirror is laterally inverted.
- v. Concave spherical mirror can form both real and virtual images depending upon the position of object.
- vi. Convex spherical mirror can form only virtual diminished image.
- vii. Speed of light is different in different media. Hence when light travels from one medium to another its path is deviated.
- viii. The amount and sense of deviation depend upon the relative optical density of the media.
- ix. Optically denser medium may not always possess greater mass density.
- x. Apparent raising of the bottom of a vessel containing water is due to refraction.
- xi. Lens is a transparent medium bounded with two spherical surfaces.
- xii. Convex lenses have converging ability while concave lenses have diverging ability.
- xiii. The converging or diverging capacity is known as power of a lens.
- xiv. Human eye consists of a convex lens, whose focal length can be adjusted.
- xv. Refractive defects of vision can be rectified using lens of suitable nature and focal length.
- xvi. The range of vision of normal eye is from 25cm to infinity.

- xvii. Splitting of composite light into its constituent colours is known as dispersion of light.
- xviii. Dispersed pattern of a composite light is spectrum.
- xix. Rainbow is formed by dispersion, internal reflection and refraction of solar light.

EXERCISE

1. What are the properties of the principal focus of a concave mirror ?
2. The image formed by a concave mirror is observed to be real, inverted and larger than the object. Where should be the position of the object ?
3. You are given three mirrors— convex, concave and plane appearing identical. How can you identify them without touching ?
4. Name a mirror that can give an erect and enlarged image of an object.
5. Name a mirror that can give an erect and diminished image of an object.
6. Can a convex mirror form a real image of a real object ?
7. Which spherical mirror is used for shaving ?
8. Why do we prefer a convex mirror as a rear-view mirror in vehicles ?
9. The radius of curvature of a spherical mirror is 40cm. What is its focal length ?
10. A concave mirror produce three times magnified real image of an object placed at 20cm in from of it. Where is the image formed ?
11. You are given a concave mirror, a scale and a screen. How will you determine the height of a tree ?
12. A ray of light travelling in air enters obliquely into water. Does the light ray bend towards the normal or away from the normal ? Why ?
13. Light enters from air to glass having refractive index 1.5. What is the speed of light in the glass ? The speed of light in vaccum is $3 \times 10^8 \text{ ms}^{-1}$.
14. What is refraction of light ? Illustrate with example.
15. What is refractive index of a medium ?
16. Refractive indices of Kerosene and crown glass are 1.44 and 1.52 respectively. In which medium will light propagate faster and how much faster ?
17. Which one is optically denser water of refractive index 1.33 or Kerosene of refractive index 1.44 ?
18. What is total internal reflection ?

19. What is critical angle ? How is it related to the refractive index ?
20. A convex lens forms a real and inverted image of a needle at a distance of 40cm from it. Where is the needle placed in front of the convex lens if the size of the image is equal to that of the object ? Also, find the power of the lens.
21. Define 1 dioptre.
22. Find the power of a concave lens of focal length 50cm.
23. What is meant by power of accommodation of the eye ?
24. When an object is placed before a lens the lens forms a virtual image for any position of the object. Is the lens convex or concave ?
25. Name four common defects of vision. Give the causes and remedial measure.
26. A person has to use concave lens in his spectacle. Which defect of vision is he suffering from ?
27. What type of lens is used to correct (a) myopia and (b) hypermetropia ?
28. Distinguish between real image and virtual image.
29. Convex mirrors are used as side mirror in motorcycles. Explain how they are useful.
30. Why is a convex lens called converging lens ?
31. Why can you not see an object clearly if it is placed very close to your eye ?
32. A person with a myopic eye cannot see objects beyond 2m distinctly. What should be the type of corrective lens used to restore proper vision?
33. A student has difficulty of reading the black board while sitting in the last bench. What could be the defect ? How can it be corrected ?
34. What are the far point and near point of the human eye with normal vision ?
35. What is dispersion of light ?
36. Explain the reason of twinkling of star.
37. Why does the Sun appear reddish during sunset in the month of February and March particularly?
38. To an astronaut outside the atmosphere how would the sky appear ?
39. Why do we see distant objects very small ?
40. Explain the reason of advance sunrise and delayed sunset.