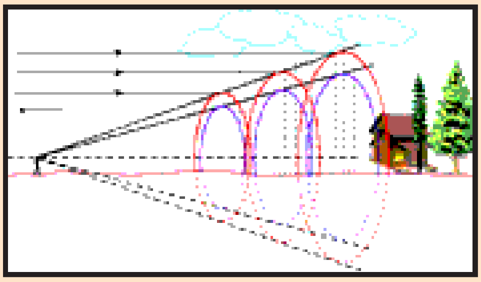
Chapter 7



Human Eye and Colourful world

You have studied refraction of light through lenses in the previous chapter. You have learnt about nature, position and relative size of image formed by lenses for various distances of objects. In class IX, chapter VI on sense organs in Biological science text book, explained the structure of the human eye. The human eye functions on the principle of sensation of vision. We see objects because the light scattered from them falls on the eye. The eye has a lens in its structure.

In the previous chapter, you learned that the focal length of lens and object distance determine the nature, position and size of image.

- What is the function of lens in human eye?
- How does it help to see objects at long distances and short distances?
- How is it possible to get the image at the same distance on the retina?
- Are we able to see all objects in front of our eye clearly?
- How do the lenses used in spectacles correct defects of vision?

To answer these questions, you need to understand the structure and functioning of the human eye.

Let us do the following activities to know about some interesting facts about our vision.

Least distance of distinct vision

Activity 1

Take a text book and hold it with your hands in front of you at a certain distance. Now try to read the contents on the page. Slowly move the book towards your eye till it is very close to your eyes.

- What changes do you notice?

You may see that printed letters on the page of the text book appear blurred or you feel strain in the eye.

Now slowly move the book backwards to a position where you can see clear printed letters without straining your eye. Ask your friend to measure the distance between your eye and text book at this position. Note down its value. Repeat the activity with other friends and note down the distances for distinct vision in each case.

Find the average of all these distances of clear vision.

- What value do you get for average distance?

From this activity you will come to know that to see an object comfortably and distinctly, you must hold it at a distance about 25 cm from your eyes. This distance is called least distance of distinct vision. This varies from person to person and with age. At a young age (say below 10 years) the muscles around the eye are strong and flexible and can bear more strain. Therefore the least distance of distinct vision at this age is as close as 7 to 8 cm. In old age the muscles cannot sustain more strain hence the least distance of distinct vision shifts to a larger value, say, about 1 to 2 m or even more.

- Are you able to see the top and bottom of an object placed at a distance of about 25 cm from your eye irrespective of its shape?

Let us find out.

Activity 2

Collect a few wooden sticks used in cloth roller in clothes store (or) collect waste PVC pipes that are used for electric wiring. Prepare sticks or pipes of 20 cm, 30 cm, 35 cm, 40 cm, 50 cm from them. Place a retort stand on a table and stand near the table such that your head is beside the vertical stand (see fig 1). Adjust the clamp on the horizontal rod and fix it at a distance of 25 cm from your eyes. Ask one of your friends to fix a wooden stick of 30 cm height to the clamp in a vertical position as shown in fig1.

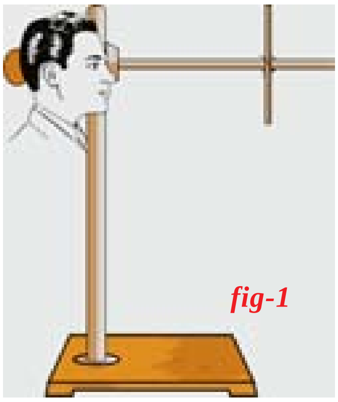


fig-1

Now keeping your vision parallel to horizontal rod of the stand, try to see the top and bottom of wooden stick kept in vertical position.

- Are you able to see both ends of the stick simultaneously without any movement (shaking) in your eyes?

In activity-1, you learned that least distance for distinct vision is about 25 cm. It varies from person to person. If you are not able to see both end of the stick at this distance (25 cm), adjust the vertical stick on the horizontal rod till you are able to see both ends of the stick at the smallest possible distance from your eye. Fix the vertical stick at this position with the help of the clamp.

Without changing the position of the clamp on the horizontal rod, replace this stick of 30 cm length with other sticks of various lengths one by one and try to see the top and bottom of the stick simultaneously without any change in the position of eye either upwards downwards or side ways.

- Are you able to see both ends of the sticks in all these cases? If not why?

Let us know.

Observe the following figure-2. You can see the whole object AB which is at a distance of 25 cm (least distance of distinct vision) because the rays coming from the ends A and B of the object AB will enter the eye. Similarly you can also see whole object CD with eye as explained above. Let us assume that AB moves closer to the eye to a position $A^{I}B^{I}$ as shown in figure2.

- Will you be able to see the whole object now?

From the figure 2, you notice that you will be able to see only the part (EF) of the object A^{I} B^{I} because the rays coming from E and F enter your eye. The rays coming from A^{I} and B^{I} cannot enter your eye.

The rays coming from the extreme ends of an object form an angle at the eye. If this angle is below 60^0, we can see the whole object. If this angle is above 60^0, then we can see only the part of the object.

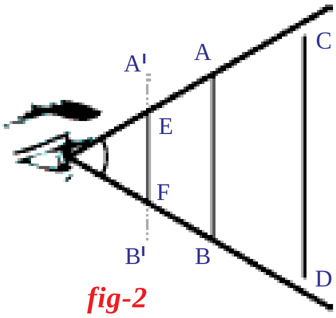


fig-2

This maximum angle, at which we are able to see the whole object is called angle of vision. The angle of vision for a healthy human being is about 60^0. It varies from person to person and with age.

You have learnt that the value of least distance of distinct vision is about 25 cm and the value of angle of vision of human beings is about 60^0. You also learnt that these values change from person to person and with age of person.

- Why do the values of least distance of distinct vision and angle of vision change with person and age?

To answer the above question, we need to understand the structure of eye and its functioning.

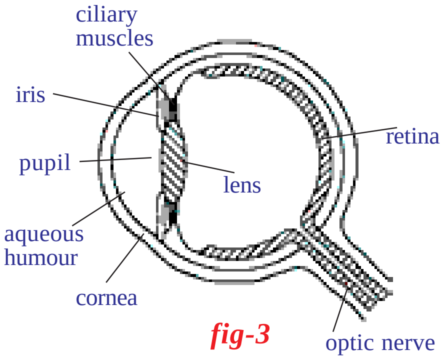


fig-3

Structure of human eye

The human eye is one of the most important sense organs. It enables us to see the object and colours around us.

Figure 3 shows schematically the basic components of human eye. The eye ball is nearly spherical in shape. The front portion is more sharply curved and is covered by a transparent protective membrane called the 'cornea'. It is this portion which is visible from outside. Behind the cornea, there is place filled with a liquid called aqueous humour and behind this a crystalline lens which is responsible for the image formation. Between the aqueous humour and the lens, we have a muscular diaphragm called 'iris' which has a small hole in it called pupil. Iris is the coloured part that we see in an eye.

The pupil appears black because any light falling on it goes into the eye and there is almost no chance of light coming back to the outside. Iris helps in controlling the amount of light entering the eye through 'pupil'. In low light condition, the iris makes the pupil to expand so that more light is allowed to go in and in the case of bright (or) excess light condition, it makes the pupil contract and there by prevent the excess light not to go into eye. Thus 'iris' enables pupil to act as a "variable aperture" for entry of light into the eye.

The lens is hard in the middle and gradually becomes soft towards the outer edge. The light that enters the eye forms an image on the retina. (It covers the rear part of eyeball). The distance between the lens and retina is about 2.5 cm i.e., for any position of object in front of the eye the image distance is fixed and about 2.5 cm.

- How can we get this same image distance for various positions of objects?
- Can you answer this question using concepts of refraction through lenses?

In the previous chapter, you have learnt that for different positions of object, the image distance remains constant only when there is a change in focal length of lens. Further, the focal length of a lens depends on the material by which it has been made and radii of curvature of lens. We need to change focal length of eye lens to get same image distance for various positions of object in front of the eye. This is only possible when the eyelens is able to change its shape.

- How does eye lens change its focal length?
- How does this change take place in the eye ball?

Let us know

The ciliary muscle to which eye lens is attached (see fig-3) helps the eye lens to change its focal length by changing the radii of curvature of the eye lens.

When the eye is focussed on a distant object, the ciliary muscles are relaxed so that the focal length of eye lens has its maximum value which is equal to its distance from the retina. The parallel rays coming into the eye are then focussed on to the retina and we see the object clearly.

When the eye is focussed on a closer object, the ciliary muscles are strained and focal length of eye-lens decreases. The ciliary muscles adjust the focal length in such a way that the image is formed on retina and we see the object clearly. This process of adjusting focal length is called "accommodation". However these muscles cannot strain beyond a limit and hence if the object is brought too close to eyes, the focal length cannot be adjusted to form an image on the retina. Thus there is a minimum distance for distinct vision of an object which is roughly equal to 25 cm as we have learned in activity-1.

- Does eye lens form a real image or virtual image?
- How does the image formed on retina help us to perceive the object without change in its shape, size and colour?

Let us know

The eye-lens forms a real and inverted image of an object on the retina. The retina is a delicate membrane, which contains about 125 million receptors called 'rods' and 'cones' which receive the light signal (rods-identify the colour: cones-identify the intensity of light). These signals are transmitted to the brain through about 1 million optic-nerve fibres. The brain interprets these signals and finally processes the information so that we perceive the object in terms of its shape, size and colour.

In our previous discussion, you have learnt that eye-lens itself changes its focal length in accordance with distance of the object with the help of ciliary muscles.

- Is there any limit to the change of focal length of the eye-lens?
- What are the maximum and minimum focal lengths of the eye lens? How can we find them?

Let us find

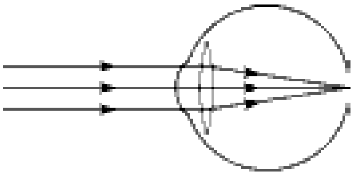


fig-4(a)

When the object is at infinity, the parallel rays from the object falling on the eye lens are refracted and they form a point sized image on retina (see fig-4a).

In this situation, eye-lens has a maximum focal length.

When the object is at infinity,

$u = -\infty$; $v = 2.5$ cm (image distance which is equal to distance between eye-lens and retina)

using the formula $1/f = 1/v - 1/u$

$1/f_{max} = 1/2.5 + 1/\infty$

$1/f_{max} = 1/2.5 + 0$

$f_{max} = 2.5$ cm

we get, $f_{max} = 2.5$ cm

consider that an object is placed at distance of 25 cm from our eye. In this situation eye has minimum focal length.

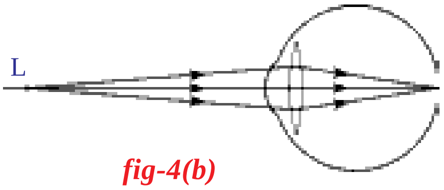


fig-4(b)

Here $u = -25$ cm; $v = 2.5$ cm

Using the formula $1/f = 1/v - 1/u$

$1/f_{min} = 1/2.5 + 1/25$

$1/f_{min} = 11/25$

$f_{min} = 25/11 = 2.27$ cm

If the position of an object is between infinity and the point of least distance of distinct vision, then the eye lens adjusts it's focal length in between 2.5 cm to 2.27 cm to form a clear image on the retina.

The ability of eye-lens to change its focal length is called "accommodation of lens".

- What happens if the eye lens is not able to adjust its focal length?
- What happens if the focal length of eye lens is beyond the range of 2.5 cm to 2.27 cm?

Let us find out.

Sometimes the eye may gradually lose its ability for accommodation. In such conditions the person cannot see an object clearly and comfortably. The vision becomes blurred due to defects of the eye lens. There are mainly three common defects of vision.

They are:

i. Myopia

ii. Hypermetropia

iii. Presbyopia.

Myopia

Some people cannot see objects at long distances but can see nearby objects clearly. This type of defect in vision is called ‘Myopia’. It is also called ‘near sightedness’. For these people the maximum focal length is less than 2.5 cm. In such cases the rays coming from distant objects, after refraction through the eye lens, form an image before the retina as shown in figures 5(a) and (b).

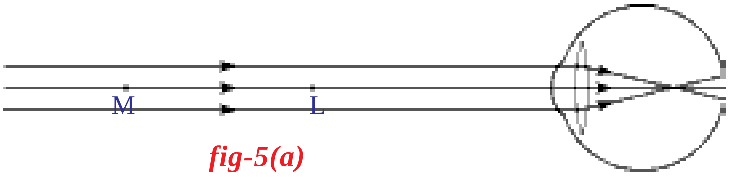


fig-5(a)

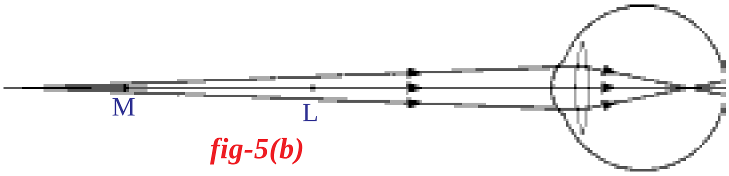


fig-5(b)

A healthy person can see objects at all distances more than 25 cm clearly but a person with myopia can see objects clearly up to a certain distance. Let the extreme point from where an object appears clearly to a person with myopia be ‘M’ (shown in figure 5(c)).

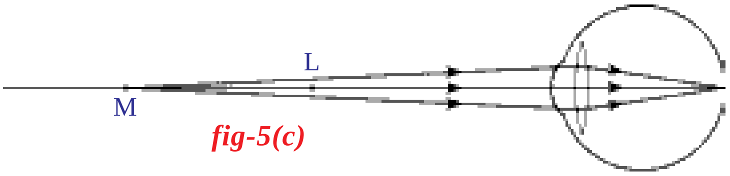


fig-5(c)

If the object is at M or in between M and point of least distance of distinct vision (L),the eye lens can form an image on the retina (see figure 5(c) and 5(d)). This point M is called ‘far point’.

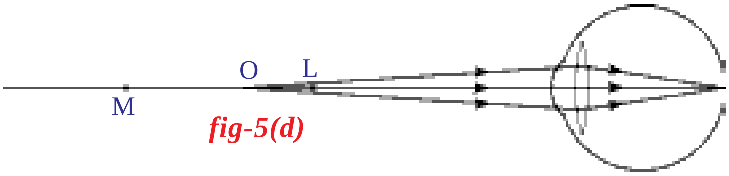


fig-5(d)

The point of maximum distance at which the eye lens can form an image on the retina is called ‘far point’.

The defect, in which people cannot see objects beyond far point is called ‘Myopia’.

- What can we do to correct myopia?

The eye lens can form clear image on the retina, when an object is placed between far point and point of least distance of distinct vision. If we are able to bring the image of the object kept beyond far point , between the far point and the point of least distance of distinct vision using a lens, this image acts as an object for the eye lens.

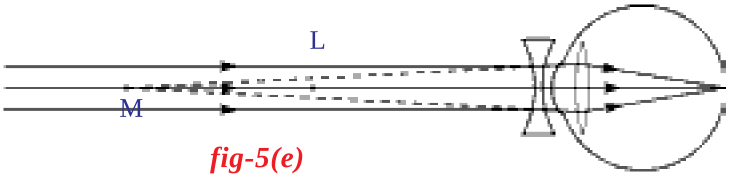


fig-5(e)

This can be made possible only when a concave lens is used (recollect image formation by refraction through a concave lens).

- How can you decide the focal length of the lens to be used to correct myopia?

To correct one’s Myopia, we need to select a lens which forms an image at the far point for an object at infinity. We need to select bi-concave lens to achieve this.

This image acts like an object for the eye lens. Hence the final image is formed on the retina.

Let us find the focal length of this bi-concave lens.

Here object distance (u) is infinity and image distance (v) is equal to distance of far point.

$u = -\infty$; v = distance of far point = $-D$

let ‘f’ be the focal length of bi-concave lens.

Using lens formula, $1/f = 1/v - 1/u$

$1/f = 1/-D \Rightarrow f = -D$

Here ‘f’ is negative showing that it is a concave lens.

- What happens when the eye has a minimum focal length greater than 2.27 cm?

Let us find out.

Hypermetropia

Hypermetropia is also known as “far sightedness”. A person with hypermetropia can see distant objects clearly but cannot see objects at near distances, because the minimum focal length of eye lens for the person of hypermetropia is greater than 2.27 cm. In such cases, the rays coming from a nearby object, after refraction at eye lens, forms an image beyond the retina as shown in figure 6 (a).

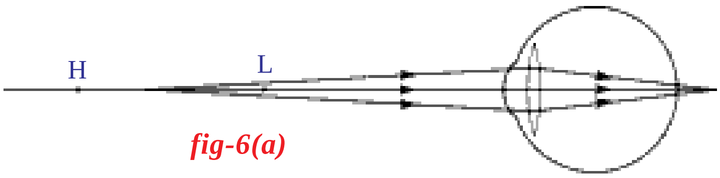


fig-6(a)

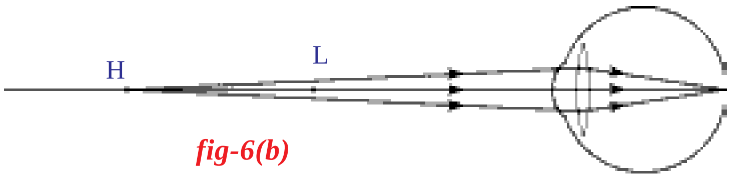


fig-6(b)

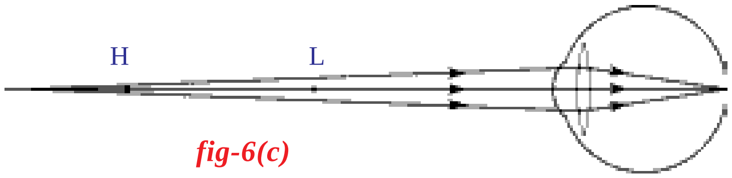


fig-6(c)

Let the point of least distance at which the eye lens forms a clear image on the retina for a person with hypermetropia be ‘H’. See figure 6(b).

If an object is at H or beyond H, the eye can form its image on retina (see figures 6(b) and 6(c)). If the object is between H and point of least distance of distinct vision (L) then it cannot form an image. See figure 6(a).

The point of minimum distance at which the eye lens can form an image on the retina is called near point (d). The people with defect of hypermetropia cannot see objects placed between near point (H) and point of least distance of distinct vision (L).

- How can you correct this defect?

Eye lens can form a clear image on the retina when any object is placed beyond near point. To correct the defect of hypermetropia, we need to use a lens which forms an image of an object beyond near point, when the object is between near point (H) and least distance of distinct vision (L).

This is possible only when a double convex lens is used.

- How can you decide the focal length of the convex lens to be used?

To find the focal length of lens, let us consider that the object is at point of least distance of distinct vision (L). Then the defect of vision, hypermetropia, is corrected when the image of the object at L is formed at the near point (H) by using a bi-convex lens as shown in figure 6(d).

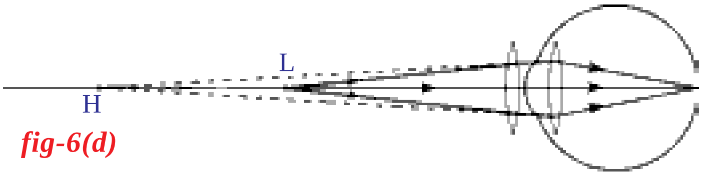


fig-6(d)

This image acts like an object for the eye lens. Hence final image due to eye is formed at retina (see figure 6(d))

Here object distance (u) = -25 cm

Image distance (v) = distance of near point = -d

Let ‘f’ be the focal length of bi-convex lens.

Using lens formula, $1/f = 1/v - 1/u$

$1/f = 1/ -d - 1/(-25)$

$1/ f = -1/d +1/25$

$1/ f = (d - 25)/25d$

$f= 25d / (d - 25)$ (f is measured in centimeters)

we know that if $d > 25$cm, then ‘f’ becomes +ve i.e., we need to use biconvex lens to correct defect of hypermetropia.

Presbyopia

Presbyopia is vision defect when the ability of accommodation of the eye usually decreases with ageing. For most people the near point gradually recedes away. They find it difficult to see nearby objects clearly and distinctly.

This happens due to gradual weakening of ciliary muscles and diminishing flexibility of the eye lens. This effect can be seen in aged people. Sometimes a person may suffer from both myopia and hypermetropia with ageing .

To correct this type of defect of vision we need bi-focal lenses which are formed using both concave and convex lenses. Its upper portion consists of the concave lens and lower portion consists of the convex lens.

If you go to an eye hospital to get tested for vision defects, the doctor gives you a prescription that contains some information regarding type of lens to be used to correct vision.

- Have you ever observed details in the prescription?

You might have heard people saying “my sight is increased or decreased”.

- What does it mean?

Usually doctors, after testing for defects of vision, prescribe corrective lenses indicating their power which determines the type of lens to be used and its focal length.

- What do you mean by power of lens?

Power of lens:

The degree of convergence or divergence of light rays that can be achieved by a lens is expressed in terms of its power.

The reciprocal of focal length is called power of lens.

Let ‘f’ be the focal length of lens.

Power of lens $P = 1 / f(\text{in m})$; $P = 100 / f$ (in cm)

The unit of power is dioptre.

It is denoted by the letter ‘D’.

Example1

Doctor advised to use 2D lens. What is its focal length?

Solution: Given that power of lens P = 2D

Using, $P = 100 / f$ (in cm); $2 = 100 / f$

Therefore, $f = 100/2 = 50$ cm.

The lens has focal length, f = 50 cm.

Dispersion and Scattering of Light

You might have seen a rainbow form in the sky just after a rain shower. It must have fascinated you with spectacular colours appearing as a semi-circular band of colours.

- How could the white light of the sun give us various colours of the rainbow?

In previous chapters, you have studied the behaviour of light when it refracts through plane surface and curved surfaces, such as a lens. You also studied the nature, position and relative size of image formed by lenses.

- What happens to a light ray when it passes through a transparent medium bounded by plane surfaces which are inclined to each other?
- What is a prism?

Prism

A prism is a transparent medium separated from the surrounding medium by at least two plane surfaces which are inclined at a certain angle in such a way that, light incident on one of the plane surfaces emerges from the other plane surface. To understand the behaviour of light when it is incident on the plane of a prism and passes into the prism, we need to define certain terms associated with prisms.

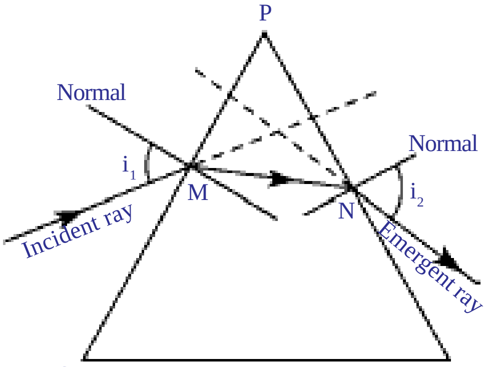


fig-7

Consider a triangular glass prism. It contains two triangular bases and three rectangular plane lateral surfaces. These lateral surfaces are inclined to each other.

Let us consider that triangle PQR represents outline of the prism where it rests on its triangular base. Let us assume that a light ray is incident on the plane surface PQ of a prism at M as shown in figure 7. Draw a perpendicular to the surface at M. It becomes a normal to that surface. The angle between the *incident ray* and normal is called *angle of incidence* (i_1). The ray is refracted at M. It moves through prism and meets the other plane surface at N and finally comes out of the prism. The ray which comes out of the surface PR at N is called *emergent ray*. Draw a perpendicular to PR at point N. The angle between the emergent ray and normal is called *angle of emergence* (i_2).The angle between the plane surfaces PQ and PR is called the *angle of the prism or refracting angle of prism* A and the angle between the incident ray and emergent ray is called *angle of* deviation(d).

Let us now take up an activity to study the refraction of light through a triangular prism.

Lab Activity

Aim: Finding the refractive index of a prism.

Material required: Prism, piece of white chart of size 20x20 cm, pencil, pins, scale and protractor.

Procedure: Take a prism and place it on the white chart in such a way that the triangular base of the prism is on the chart. Draw a line around the prism (boundry) using a pencil. Remove the prism.

- What is the shape of the outline drawn?

It is a triangle. Name its vertices as P,Q, and R.[for many prisms the triangle formed is equilateral]. The refracting surfaces could be rectangular in shape. Find the angle between PQ and PR . This is the angle of the prism (A).

Mark M on the side of triangle PQ and also draw a perpendicular to PQ at M. Place the centre of the protractor at M and along the normal. Mark an angle of 30^0 and then draw a line up to M. This line denotes the incident ray. This angle is called angle of incidence. Note it in a table (1). Draw a small arrow on it as shown in figure 8.

Place the prism in its position (triangle) again. Now fix two pins vertically on the line at points A and B as shown in figure 8. Look for the images of pins through the prism from the other side (PR) and fix another two pins at points C and D in such a way that all the four pins appear to lie along the same straight line. Do it carefully. Now remove the prism and take out pins. Draw a line joining the two pin-holes formed by the pins to meet surface 'PR', this is the emergent ray which 'emerges from' the surface PR at a point 'N'. The angle between the normal at N and the emergent ray is the angle of emergence. Measure this angle and note its value in the table (1).

Table 1

Angle of incidence (i_1)	Angle of emergence (i_2)	Angle of deviation (d)

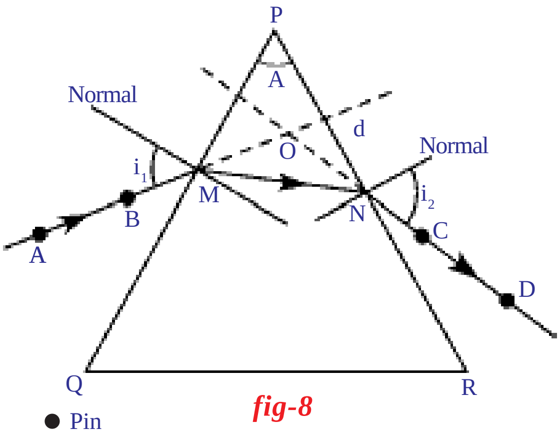


fig-8

Now join the points M and N by a straight line. The line passing through the points A,B, M,N,C and D represents the path of light when it suffers refraction through the prism.

- How do you find the angle of deviation?

Extend both incident and emergent rays till they meet at a point ‘O’. Measure the angle between these two rays. This is the angle of deviation. It is denoted by a letter ‘d’. Note it in table (1). Repeat this procedure for various angles of incidence such as 40^0,50^0 etc. Find the corresponding angles of deviation and angles of emergence and note them in table (1).

- What do you notice from the angles of deviation?

You will notice that the angle of deviation decreases first and then increases with increase in the angle of incidence.

- Can you draw a graph between angle of incidence and angle of deviation?

Take angle of incidence along X- axis and the angle of deviation along Y- axis. Using a suitable scale, mark points on a graph paper for every pair of angles. Finally join the points to obtain a graph (smooth curve). Check your graph with graph shown in figure 9.

- From the graph, can you find the minimum of the angles of deviation?

Yes we can. Draw a tangent line to the curve, parallel to X- axis, at the lowest point of the graph. The point where this line cuts the Y- axis gives the angle of minimum deviation. It is denoted by D. Draw a parallel line to y-axis through the point where the tangent touches the graph. This line meets x-axis at a point showing the angle of incidence corresponding to the minimum deviation. If you do the experiment with this angle of incidence you will get an angle of emergence equal to the angle of incidence. Look at your table (1).

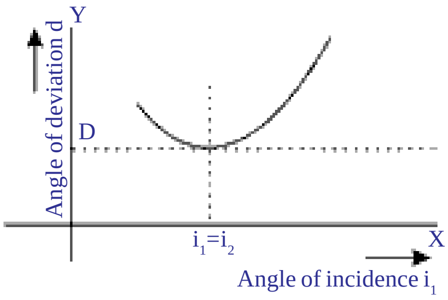


fig-9

- Is there any relation between the angle of incidence and angle of emergence and angle of deviation?
- Can you find refractive index of a prism? If yes, how?

Let us find out.

Derivation of formula for refractive index of a prism

Observe the ray diagram in the figure 10(a).

From triangle OMN, we get

$d = i_1 - r_1 + i_2 - r_2$

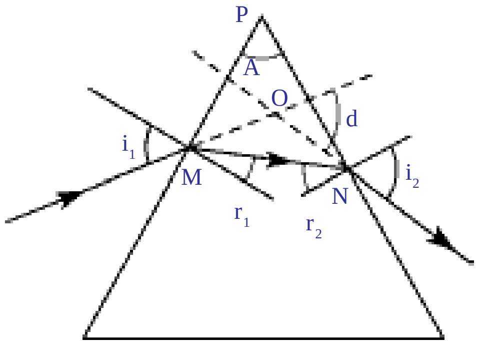


fig-10(a)

$d = (i_1+i_2) - (r_1+r_2)$ ——— (1)

From triangle PMN, we have

$A + (90^0-r_1) + (90^0-r_2) = 180^0$

By simplification, we get

$r_1 + r_2 = A$ ———(2)

From (1) and (2), we have

$d = (i_1+i_2) - A$

$A+d = i_1+i_2$ ———(3)

This is the relation between angle of incidence, angle of emergence, angle of deviation and angle of prism.

From Snell's law, we know that $n_1 \sin i = n_2 \sin r$

Let n be the refractive index of the prism.

Using Snell's law at M, with refractive index of air

$n_1 = 1;\ i = i_1;\ n_2 = n;\ r = r_1$, gives

$\sin i_1 = n \sin r_1$ ———(4)

similarly, at N with $n_1 = n;\ i = r_2;\ n_2 = 1;\ r = i_2$, gives

$n \operatorname{Sin} r_2 = \operatorname{Sin} i_2$ ———(5)

We know that at the angle of minimum deviation (D), the angle of incidence is equal to the angle of emergence i.e., $i_1 = i_2$. Observe figure 10(b). You will note that MN is parallel to the side QR, actually ray MN is parallel to the base of the prism. (See figure 10(b)).

When $i_1 = i_2$, angle of deviation (d) becomes angle of minimum deviation (D).

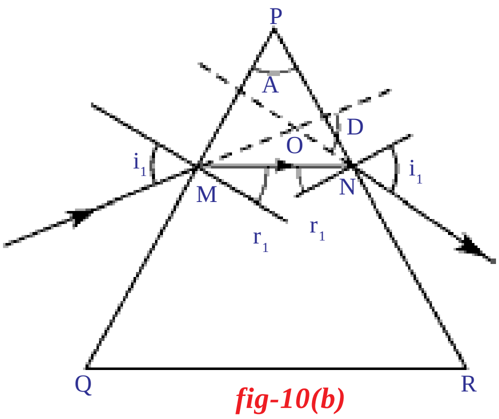


fig-10(b)

Then equation (3) becomes

$A+D = 2i_1$

or $i_1 = (A+D)/2$

When $i_1 = i_2$ then, it is clear that $r_1 = r_2$

So from equation (2) we get,

$2r_1 = A$

or $r_1 = A/2$

Substituting i_1 and r_1 in (4) we get

$\operatorname{Sin}\{(A+D)/2)\} = n. \operatorname{Sin}(A/2)$

Therefore, $n = \operatorname{Sin}(A+D/2)/\operatorname{Sin}(A/2)$ —(6)

This is the formula for the refractive index of the prism.

Now use the results of lab activity (1) and find refractive index of the prism using equation (6)

Let us see an example.

Example 2

A prism with an angle $A = 60^0$ produces an angle of minimum deviation of 30^0. Find the refractive index of material of the prism.

Solution: Given that $A = 60^0$ and $D = 30^0$.

Using $n = \mathrm{Sin}[(A+D)/2]/\mathrm{Sin}(A/2) = \mathrm{Sin}(90^0/2)/\mathrm{Sin}(30^0)$

$= \mathrm{Sin}\ 45^0/\ \mathrm{Sin}30^0 = (1/\sqrt{2})/(1/2) = \sqrt{2}$

$\Rightarrow n = \sqrt{2}$

thus, the refractive index of the given prism $= \sqrt{2}$

Let us take up a simple activity with prism.

Activity 3

Do this experiment in the dark room. Take a prism and place it on the table near a vertical white wall. Take a thin wooden plank. Make a small hole in it and fix it vertically on the table. Place the prism between the wooden plank and wall. Place a white light source behind the hole of the wooden plank. Switch on the light. The rays coming out of the hole of plank become a narrow beam of light. Adjust the height of the prism such that the light falls on one of the lateral surfaces. Observe the changes in emerged rays of the prism. Adjust the prism by slightly rotating it till you get an image on the wall.

- What do you observe on the wall?
- Could you get a coloured image on the wall?
- Why does white light split into colours?
- What colours do you see?
- Can you notice any change in the angle of deviation of each colour?
- Which colour has the minimum deviation?

Let us do another experiment.

Activity 4

Take a metal tray and fill it with water. Place a mirror in the water such that it makes an angle to the water surface. Now focus white light on the mirror through the water as shown in figure 11. Try to obtain colour on a white card board sheet kept above the water surface. Note the names of the colours you could see in your book.

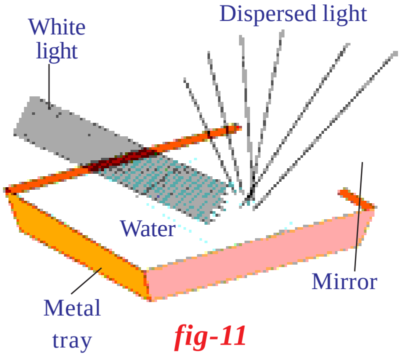


fig-11

In activity (3) and (4), we observe that white light is splitting into certain different colours.

- Is this splitting of white light into colours explained by using ray theory?

It is not possible to explain the splitting of white light into different colours using ray theory.

- Why is this so?

Let us see

Dispersion of Light

In activity 3, we observe that the angle of deviation is minimum for red as compared to the angles of deviation of other colours and maximum for violet.

The splitting of white light into different colours (VIBGYOR) is called **dispersion**.

In our previous discussion, we learnt that for a particular refractive index of prism there must be only one angle of minimum deviation and according to Fermat's principle, light ray always chooses the path of least time. But in activity-3,we noticed that light has chosen different paths.

- Does this mean that the refractive index of the prism varies from colour to colour?
- Is the speed of light of each colour different?

The situation we witnessed in activities (3) and (4) rule out ray theory of light. We can consider that white light is a collection of waves with different wavelengths. Violet colour is known to have the shortest wavelength while red is of the longest wavelength.

According to wave theory, light can be thought of a wave propagating in all directions. Light is an electromagnetic wave. Here no particle physically oscillates back and forth. Instead, the magnitude of electric and magnetic fields, associated with the electromagnetic wave, vary periodically at every point. These oscillating electric and magnetic fields propagate in all directions with the speed of light.

- Can you guess now, why light splits into different colours when it passes through a prism?

The reason lies in the fact that, while the speed of light is constant in vacuum for all colours, it depends on the wavelength of light when it passes through a medium. We know that refractive index is the ratio of speeds in vacuum and in the medium. Consequently, the refractive index of a medium depends on wavelength of light. When white light passes through a medium, each colour selects its least time path and we have refraction of different colours to different extents. This results in separation of colours, producing a spectrum on the wall and in the mirror as we saw in activities (3) and (4). It has been experimentally found that refractive index decreases with an increase in wavelength. If we compare the wave lengths of seven colours in VIBGYOR, red colour has longest wavelength and violet colour has shortest wavelength. The refractive index of red is low hence it suffers low deviation.

We noticed that when white light passes through a prism, it splits into seven colours. Let us assume that you have sent a single colour ray through the prism.

- Does it split into more colours? Why?

We know that the frequency of light is the property of the source and it is equal to number of waves leaving the source per second. This cannot be changed by any medium. Hence frequency doesn't change due to refraction. Thus coloured light passing through any transparent medium retains its colour.

While refraction occurs at the interface, the number of waves that are incident on the interface in a second must be equal to the number of waves passing through any point taken in another medium. This means that the frequency of the light wave remains unaltered while its wavelength changes depending on the medium through which it passes. We know that the relation between the speed of wave (v), wavelength (λ) and frequency (f) is.

$v = f\lambda$ (frequency (f) may be denoted by υ)

For refraction at any interface, v is proportional to λ. Speed of the wave increases with increase in wavelength of light and vice versa.

- Can you give an example in nature, where you observe colours as seen in activity 3?

Your answer certainly is a rainbow. That is a good example of dispersion of light.

- When do you see a rainbow in the sky?
- Can we create a rainbow artificially?

Let us see how.

Activity 5

Select a white coloured wall on which the sun rays fall. Stand in front of a wall in such a way that the sun rays fall on your back. Hold a tube through which water is flowing. Place your finger in the tube to obstruct the flow of water. Water comes out through the small gaps between the tube and your finger like a fountain. Observe the changes on the wall while the water shower is maintained; you can see colours on the wall.

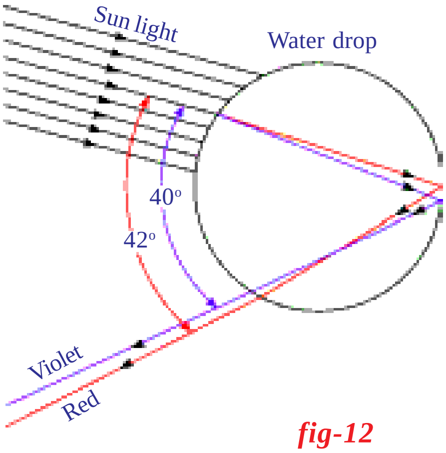


fig-12

- How is that you are able to see colours on the wall?
- Are the sun rays coming back to your eyes from the wall or from water drops?

Let us find out.

The beautiful colours of the rainbow are due to dispersion of the sunlight by millions of tiny water droplets. Let us consider the case of an individual water drop.

Observe figure 12. The rays of sunlight enter the drop near its top surface. At this first refraction, the white light is dispersed into its spectrum of colours, violet being deviated the most and red the least. Reaching the opposite side of the drop, each colour is reflected back into the drop because of total internal reflection. Arriving at the surface of the drop, each colour is again refracted into air. At the second refraction the angle between red and violet rays further increases when compared to the angle between those at first refraction.

The angle between the incoming and outgoing rays can be anything between 0^0 and about 42^0. We observe bright rainbow when the angle between incoming and outgoing rays is near the maximum angle of 42^0. Diagrammatically it is shown in figure 12.Although each drop disperses a full spectrum of colours, an observer is in a position to see only a single colour from any one drop depending upon its position.

If violet light from a single drop reaches the eye of an observer, red light from the same drop can't reach his eye. It goes elsewhere possibly downwards of the eye of the observer (see in figure 13). To see red light, one must look at the drop higher in the sky. The colour red will be seen when the angle between a beam of sunlight and light sent back by a drop is 42^0. The colour violet is seen when the angle between a sunbeam and light sent back by a drop is 40^0. If you look at an angle between 40^0 and 42^0, you will observe the remaining colours of VIBGYOR

- Why does the light dispersed by the raindrops appear as a bow?

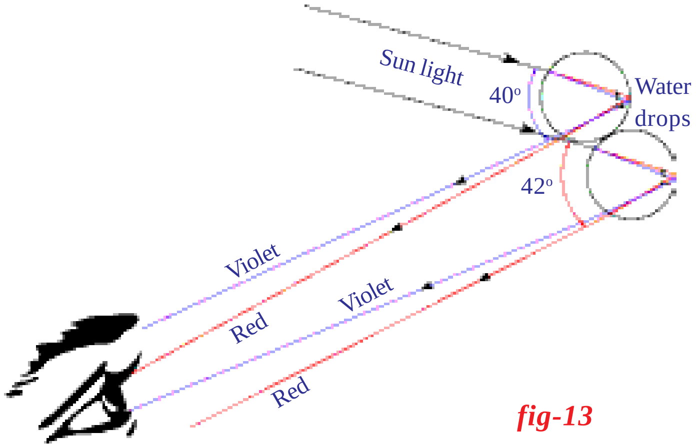


fig-13

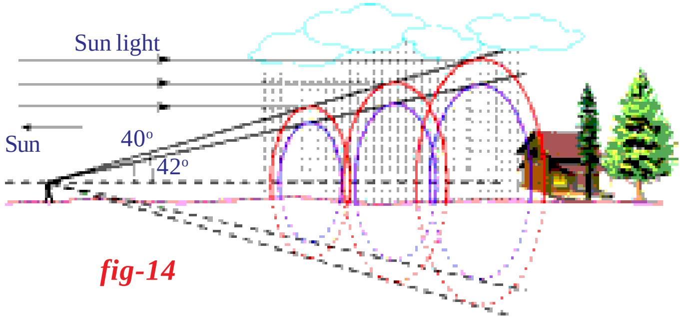


fig-14

To find answer this question, we need a little geometric reasoning. First of all, a rainbow is not the flat two dimensional arc as it appears to us. The rainbow you see is actually a three dimensional cone with the tip at your eye as shown in figure 14. All the drops that disperse the light towards you lie in the shape of the cone – a cone of different layers. The drops that disperse red colour to your eye are on the outer most layer of the cone, similarly the drops that disperse orange colour to your eye are on the layer of the cone beneath the red colour cone. In this way the cone responsible for yellow lies beneath orange and so on it till the violet colour cone becomes the innermost cone.(see in figure 14).

Think and discuss

- Can you imagine the shape of rainbow when observed during travel in an airplane? Discuss with your friends and collect information.

It is our common experience that the sky appears blue in colour on a bright dry day.

- Why is the sky blue?

To answer this question, you need to understand another phenomenon of light called scattering.

- What is scattering?

Let us see

Scattering of Light

Scattering of light is a complex phenomenon. Let us try to understand the idea of scattering.

- Do you know what happens to the free atom or molecule when it is exposed to certain frequency of light?

Atoms or molecules which are exposed to light absorb light energy and emit some part of the light energy in different directions. This is the basic process happens in scattering of light.

The effect of light on a molecule or an atom depends on the size of atom or molecule. If the size of the particle (atom or molecule) is small, it will be affected by higher frequency (lower wave length) light and vice versa.

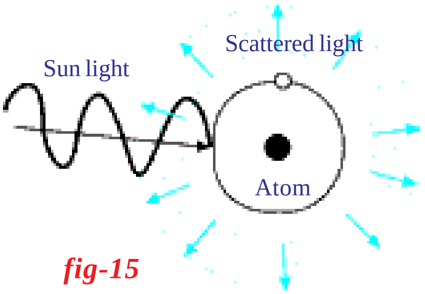


fig-15

Let us consider that a certain frequency of light is incident on an atom. Then the atom comes into vibration due to this light. This in turn releases or re-emits light in all directions with different intensity.

The intensity of light is the energy of light passing through unit area of plane, taken normal to the direction of propagation of light, in one second.

Let us consider that the free atom or free molecule is somewhere in space as shown in figure 15.

Light of certain frequency falls on that atom or molecule. This atom or molecule responds to the light whenever the size of the atom or molecule is comparable to the wave length of light. If this condition is satisfied, the atom absorbs light and vibrates. Due to these vibrations, the atom re-emits a certain fraction of absorbed energy in all directions with different intensities. The re-emitted light is called scattered light and the process of re-emission of light in all directions with different intensity is called scattering of light. The atoms or molecules are called scattering centre. Let us take the angle ‘θ’ between the incident light and a direction in which the intensity of scattered light is observed, we call this angle as angle of scattering. It is experimentally observed that the intensity of scattered light varies with angle of scattering. The intensity is maximum at 90^0 angle of scattering.

This is the reason for the appearance of clear blue colour when look at the sky in a direction perpendicular to the direction of the sun rays. If our angle of view is changed, the intensity of blue colour also changes.

Now you might have got a doubt why scattering of light gives blue colour only. Why can’t it give other colours?

Let us find out whether the scattering centres are responsible for the blue of the sky?

We know that our atmosphere contains different types of molecules and atoms. The reason for blue sky is due to the molecules N_2 and O_2. The sizes of these molecules are comparable to the wavelength of blue light. These molecules act as scattering centres for scattering of blue light.

- Why is that the sky appears white sometimes when you view it in certain direction on hot days?

Our atmosphere contains atoms and molecules of different sizes. According to their sizes, they are able to scatter different wavelengths of light. For example, the size of the water molecule is greater than the size of the N_2 or O_2. It acts as a scattering centre for other frequencies which are lower than the frequency of blue light.

On a hot day, due to rise in the temperature water vapour enters into atmosphere which leads to abundant presence of water molecules in the atmosphere. These water molecules scatter the colours of other frequencies (other than blue). All such colours of other frequencies reach your eye and the sky appears white.

- Can we demonstrate scattering of light by an experiment?

Let us try

Activity 6

Take a solution of sodium-thio-sulphate (hypo) and sulphuric acid in a glass beaker. Place the beaker in an open place where abundant sun light is available. Watch the formation of grains of sulphur and observe changes in the beaker.

You will notice that sulphur precipitates as the reaction is in progress. At the beginning, the grains of sulphur are smaller in size and as the reaction progresses, their size increases due to precipitation.

Sulphur grains appear blue in colour at the beginning and slowly their colour becomes white as their size increases. The reason for this is scattering of light. At the beginning, the size of grains is small and almost comparable to the wave length of blue light. Hence they appear blue in the beginning. As the size of grains increases, their size becomes comparable to wave lengths of other colours. As a result of this, they act as scattering centres for other colours. The combination of all these colours appears as white.

- Do you know the reasons for appearance the red colour of sun during sunrise and at sunset?

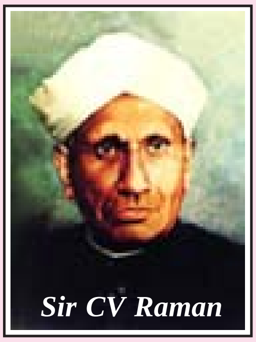
The atmosphere contains free molecules and atoms with different sizes. These molecules and atoms scatter light of different wavelengths which are comparable to their size. Molecules having a size that is comparable to the wavelength of red light are less in the atmosphere. Hence scattering of red light is less when compared to the other colours of light. The light from the sun needs to travel more distance in atmosphere during sunrise and sunset to reach your eye. In morning and evening times, during sunrise and sunset, except red light all colours scatter more and vanish before they reach you. Since scattering of redlight is very small, it reaches you. As a result sun appears red in colour during sunrise and sunset.

- Can you guess the reason why sun doesnot appear red during noon hours?

During noon hours, the distance to be travelled by the sun rays in the atmosphere is less than that compared to morning and evening hours. Therefore all colours reach your eye without much scattering. Hence the sun appears white during noon hours.

Do you know?

Our beloved scientist and Noble prize winner, Sir C.V. Raman explained the phenomenon of light scattering in gases and liquids. He found experimentally that the frequency of scattered light by the liquids is greater than the frequency of incident light. This is called Raman Effect. By using this effect scientists determine the shapes of the molecules.


Sir CV Raman

So far, we have learned some ideas of the light such as refraction, dispersion and scattering. These are wonderful phenomena occuring in our surroundings. When you observe any phenomena, try to resolve the problem and appreciate the wonderful world based on the behaviour of light.

Key words

Least distance of distinct vision, Angle of vision, Accommodation of eye lens, Myopia, Hypermetropia, Presbyopia, Power of lens, Prism, Angle of prism or refracting angle of prism, Angle of minimum deviation, Dispersion, Scattering.

What we have learnt

- The least distance of distinct vision is about 25cm and the angle of vision is about 60^0.
- The ability of eye lens to change its focal length is called accommodation of lens.
- The defect in which people cannot see objects beyond far point is called **Myopia.**
- The defect in which people cannot see objects situated before near point is called **Hypermetropia.**
- **Presbyopia** is a vision defect indicating that the power of accommodation of the eye usually decreases with ageing.
- The reciprocal of focal length is called power of the lens.
- The refractive index of prism is given by
  n = Sin[(A+D)/2]/Sin(A/2)
  where A is angle of prism and D is angle of minimum deviation.
- The splitting of white light into colours (VIBGYOR) is called dispersion.
- The process of re-emission of absorbed light in all directions with different intensities by atoms or molecules, is called scattering of light.

Improve your learning

1. How do you correct the eye defect Myopia? (AS1)
2. Explain the correction of the eye defect Hypermetropia. (AS1)
3. How do you find experimentally the refractive index of material of a prism. (AS1)
4. Explain the formation of rainbow. (AS1)
5. Explain briefly the reason for the blue of the sky. (AS1)
6. Explain two activities for the formation of artificial rainbow. (AS1)
7. Derive an expression for the refractive index of the material of a prism. (AS1)
8. Light of wavelength λ_1 enters a medium with refractive index n_2 from a medium with refractive index n_1. What is the wavelength of light in second medium?
   (Ans: $\lambda_2 = n_1\lambda_1/n_2$)   (AS1)

   NOTE: For questions 9 and 10 the following options are given. Choose the correct option by making hypothesis based on given assertion and reason. Give an explanation.

   a. Both A and R are true and R is the correct explanation of A.
   b. Both A and R are true and R is not the correct explanation of A.
   c. A is true but R is false.
   d. Both A and R are false.
   e. A is false but R is true.

9. **Assertion (A):** The refractive index of a prism depends only on the kind of glass of which it is made of and the colour of light. (AS 2)

   Reason (R): The refractive index of a prism depends on the refracting angle of the prism and the angle of minimum deviation.

10. **Assertion (A):** Blue colour of sky appears due to scattering of light.

    Reason (R): Blue colour has shortest wavelength among all colours of white light. (AS 2)

11. Suggest an experiment to produce a rainbow in your classroom and explain the procedure. (AS 3)

12. Prisms are used in binoculars. Collect information why prisms are used in binoculars. (AS 4)

13. Incident ray on one of the face (AB) of a prism and emergent ray from the face AC are given in figure Q-13. Complete the ray diagram. (AS 5)

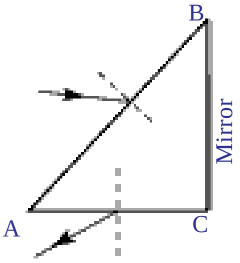


fig-Q-13

14. How do you appreciate the role of molecules in the atmosphere for the blue colour of the sky? (AS 6)

15. Eye is the only organ to visualise the colourful world around us. This is possible due to accommodation of eye lens. Prepare a six line stanza expressing your wonderful feelings. (AS 6)

16. How do you appreciate the working of Ciliary muscles in the eye? (AS 6)

17. Why does the sky sometimes appear white? (AS 7)

18. Glass is known to be a transparent material. But ground glass is opaque and white in colour. Why? (AS 7)

19. If a white sheet of paper is stained with oil, the paper turns transparent. Why? (AS 7)

20. A light ray falls on one of the faces of a prism at an angle 40^o so that it suffers angle of minimum deviation of 30^o. Find the angle of prism and angle of refraction at the given surface. (Ans:50^o, 25^o) (AS 7)

21. The focal length of a lens suggested to a person with Hypermetropia is 100cm. Find the distance of near point and power of the lens. (Ans: 33.33cm, 1D) (AS 7)

22. A person is viewing an extended object. If a converging lens is placed in front of his eye, will he feel that the size of object has increased? Why? (AS7)

Fill in the blanks

1. The value of least distance of distinct vision is about ....

2. The distance between the eye lens and retina is about ....

3. The maximum focal length of the eye lens is about ....

4. The eye lens can change its focal length due to working of .... muscles.

5. The power of lens is 1D then focal length is ....

6. Myopia can be corrected by using .... lens.

7. Hypermetropia can be corrected by using .... lens.

8. In minimum deviation position of prism, the angle of incidence is equal to angle of ....

9. The splitting of white light into different colours (VIBGYOR) is called ....

10. During refraction of light, the character of light which does not change is ....

Multiple choice questions

1. The size of an object as perceived by an eye depends primarily on [ ]

a) actual size of the object b) distance of the object from the eye
c) aperture of the pupil d) size if the image formed on the retina

2. When objects at different distances are seen by the eye which of the following remain constant?

a) focal length of eye-lens b) object distance from eye-lens [ ]
c) the radii of curvature of eye-lens d) image distance from eye-lens

3. During refraction, _________ will not change. [ ]

a) wavelength b) frequency
c) speed of light d) all the above

4. A ray of light falls on one of the lateral surface of an equilateral glass prism placed on the horizontal surface of a table as shown in fig. MCQ-4. For minimum deviation of ray, which of the following is true? [ ]

a) PQ is horizontal
b) QR is horizontal
c) RS is horizontal
d) either PQ or RS is horizontal

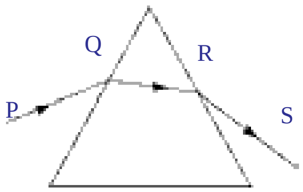


fig-MCQ-4

5. Far point of a person is 5m. In order that he has normal vision what kind of spectcles should he use [ ]

a) concave lense with focal length 5m b) concave lense with focal length 10m
c) convex lense with focal length 5m d) convex lense with focal length 2.5m

6. The process of re-emission of absorbed light in all directions with different intensities by the atom or molecule is called .... [ ]

a) scattering of light b) dispersion of light
c) reflection of light d) refraction of light