HUMAN EYE & COLOURFUL WORLD

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HUMAN EYE

It is the most delicate and complicated natural optical instrument which enables us to see the wonderful world of light.

◈ STRUCTURE :

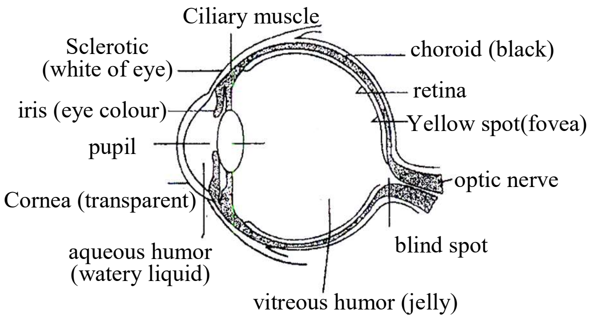
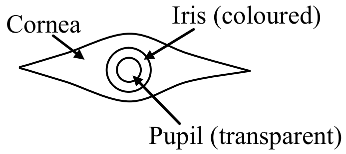


Diagram shows the section of a human eye by a horizontal plane. It is a spherical ball of diameter about 2.5 cm. Its essential parts are described below :

- **Cornea :** It is the front buldged out part of eye ball covered by transparent sclerotic.



Cornea of the eye-front view.

- **Iris :** It is the coloured region under cornea formed by choroid. Its colour differs from person to person.
- **Pupil :** It is central circular aperture in the iris. Its normal diameter is **1 mm** but it can contract in excess light and expand in dim light, by means of two sets of involuntary muscular fibres.
- **Crystalline lens :** It is a double convex lens L immediately behind iris. This is made of transparent concentric layers whose optical density increases towards the centre of the lens.
- **Ciliary muscles :** The lens is connected of the sclerotic by the **ciliary muscles.** These muscles change thickness of the lens by relaxing and exerting pressure.
- **Aqueous humour :** Anterior chamber is filled with a transparent liquid of refractive index. The liquid is called the aqueous humour.
- **Vitreous humour :** Posterior chamber is filled with a transparent watery liquid with little

common salt having some refractive index. The liquid is called the vitreous humour.

- **Retina :** It forms innermost coat in the interior of the eye. It consists of a thin membrane which is rich in nerve fibres, containing two kinds of vision cells called **rods** and **cones** and blood vessels. It is sensitive to light, for it is a continuation of the optic nerves. It serves the purpose of a sensitive screen for the reception of the image formed by the lens system of the eye.
  [The **rods** are responsible for colour vision in dim light (**Scotopic vision)**.
  The **cones** are responsible for vision under ordinary day light (**Photopic vision)**.

- **Blind spot :** The blind spot B. It is the spot where the optic nerves enter the eye. It is also slightly raised and insensitive to light, because it is not covered with choroid and retina.

Working (Action of the eye) :

The human eye is like a camera. Its lens system forms an image on a light-sensitive screen called the retina. Light enters the eye through a thin membrane called the cornea. It forms the transparent bulge on the front surface of the eyeball. The eyeball is approximately spherical in shape with a diameter of about 2.3 cm. Most of the refraction for the light rays entering the eye occurs at the outer surface of the cornea. The crystalline lens merely provides the finer adjustment of focal length required to focus objects at different distances on the retina. We find a structure called *iris* behind the cornea. Iris is a dark muscular diaphragm that controls the size of the pupil. The pupil regulates and controls the amount of light entering the eye. The eye lens forms an inverted real image of the object on the retina. The retina is a delicate membrane having enormous number of light-sensitive cells. The light-sensitive cells get activated upon illumination and generate electrical signals. These signals are sent to the brain via the optic nerves. The brain interprets these signals, and finally, processes the information so that we perceive objects as they are.

POWER OF ACCOMMODATION

The ability of the eye lens to adjust its focal length is called **accommodation.** However, the focal length of the eye lens cannot be decreased below a certain minimum limit. To see an object comfortably and distinctly, you must hold it at about 25 cm from the eyes. The minimum distance, at which objects can be seen most distinctly without strain, is called the least distance of distinct vision. It is also called the near point of the eye. For a young adult with normal vision, the near point is about 25 cm. The farthest point upto which the eye can see objects clearly is called the far point of the eye. It is infinity for a normal eye.
You may note here a normal eye can see objects clearly that are between 25 cm and infinity.

DEFECTS OF VISION, SYMPTOMS AND REMEDY (CORRECTION)

Defects of Vision

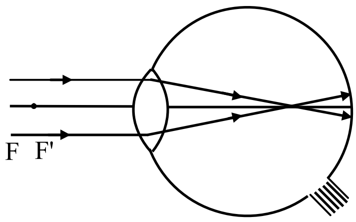
The major defects of vision are :

1. Short sightedness or myopia.
2. Long sightedness or hypermetropia.
3. Presbyopic
4. Astigmatism

1. Short sightedness or myopia

- **Symptoms :** Eye cannot see clearly beyond a certain distance. It means that the far point of the defective eye has shifted from infinity to a finite distance ahead.

- **Reasons :** It is so because the image of distant objects is formed in front of the retina. It is shown in fig.



Myopic eye vision.

- **Causes :**

(i) The lens may be **thicker** (more converging) that the normal eye lens.
(ii) The eye ball may be **elongated,**

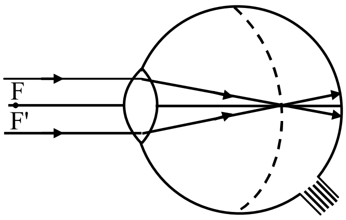


Fig. Elongated eye.

- **Correction :** The extra converging power of eye lens is compensated by using a concave (diverging) lens of proper power (focal length) as shown in fig.

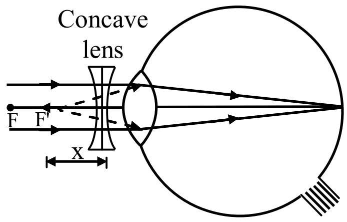


Fig. Myopia corrected by a concave lens

- **Calculation :** Let distance of far point F' from eye = x. Then for lens to be used, $u = \infty$, $v = -x$, $f = ?$

From lens formula,

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

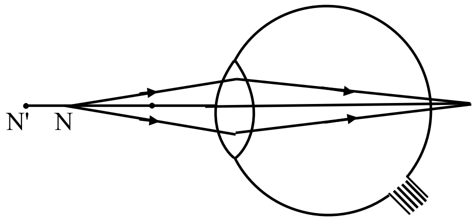
$$\frac{1}{-x} = \frac{1}{f}$$

or $\mathbf{f = -x}$

The lens used must have focal length equal to the distance of the far point from the eye (–ve sign means concave lens).

2. Long sightedness or hypermetropia

- **Symptoms :** With this defect eye cannot see clearly within a certain distance. It means that the near point of the defective eye has shifted from 25 cm to some more distance behind (away).
- **Reason :** It is so because the image of near objects is formed behind the retina. It is shown in fig.



Hypermetropic eye vision.

- **Causes :**

(i) The eye lens may be **thinner** (less converging) than the normal eye lens.
(ii) The eye ball may be **oval** distance between lens and retina becomes less than that for normal eye.

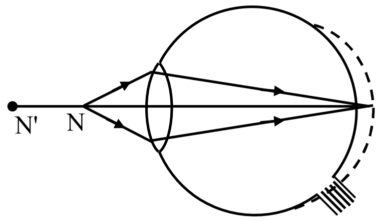


Fig. Oval eye.

- **Correction :** The deficiency in converging power of eye lens is compensated by using a convex (Converging) lens of proper power (focal length) as shown in fig.

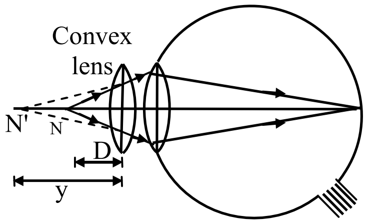


Fig : Hypermetropia corrected by a convex lens.

◆ **Calculation :** Let distance of near point N' from eye = y. Then, for lens to be used

$u = -D,\ v = -y,\ f = ?$

From lens formula,

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

$$\frac{1}{-y} - \frac{1}{-D} = \frac{1}{f}$$

$$f = \frac{yD}{y - D} \quad \text{(Which is positive } \because\ y > D)$$

This is required expression for the focal length of the convex lens to be used.

3. Presbyopic :

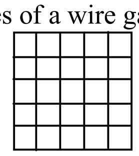
The power of accommodation of the eye usually decreases with ageing. For most people, the near point gradually recedes away. They find it difficult to see nearby objects comfortably and distinctly without corrective eye-glasses. This defect is called **Presbyopia.**

It arises due to the gradual weakening of the ciliary muscles and diminishing flexibility of the eye lens. Sometimes, a person may suffer from both myopia and hypermetropia.

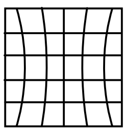
Such people often require bi-focal lenses. A common type of bi-focal lenses consists of both concave and convex lenses. The upper portion consists of a concave lens. It facilitates distant vision. The lower part is a convex lens. It facilitates near vision. These days, it is possible to correct the refractive defects with contact lenses or through surgical interventions.

4. Astigmation :

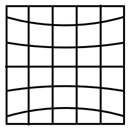
A person suffering from this defect cannot simultaneously focus on both horizontal and vertical lines of a wire gauze.



Normal Wire Gauge



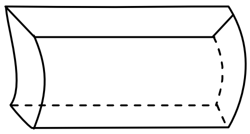
Wire gauge with
distorted vertical lines



Wire gauge with
distorted horizontal lines

This defect arises due to the fact that the cornea is not perfectly spherical

This defect can be corrected by using *cylindrical lens*



Cylindrical lens

✦ Solved Examples ✦

Ex.1 A person cannot see objects closer than 75 cm from the eye. Calculate the power of the corrected lens should he use.

Sol. Since the person cannot see objects lying closer than 75 cm, he suffers from hypermetropia. His near point has shifted from 25 cm to 75 cm. The focal length of the corrective lens can be calculated by considering u = –25 cm, v = – 75 cm, f = ?

Now, $\frac{1}{f} = \frac{1}{v} - \frac{1}{u} = \frac{1}{-75} - \frac{1}{-25}$

or $\frac{1}{f} = \frac{2}{75}$ or $f = \frac{75}{2}$ cm $= \frac{0.75}{2}$ m

$\therefore$ Power $= \frac{1}{f} = \frac{2}{0.75}$ D $= +\frac{8}{3}$ D = 2.66D

Ex.2 The far point of a myopic person is 80 cm in front of the eye. What is the nature and power of the lens required to enable him to see very distant objects distinctly?

Sol. Since the person suffers from myopia, concave lens of focal length 80 cm = –0.80 m should be used.

$\therefore \quad P = \frac{1}{-0.80} = -1.25D$

Ex.3 The far point of a person suffering from myopia is 2 m from the eye. Calculate the focal length and the power of the corrective lens.

Sol. The far point lies at 2 m. Therefore, a concave lens of focal length 2 m should be used so that the objects lying at infinity can be focused at the far point.

$\therefore$ For corrective lens, focal length, $f = -2$ m

$\therefore$ Power, $$P = \frac{1}{-2} = -0.5D$$

Ex.4 The near point of an elderly person lies at 50 cm from the eye. Calculate the focal length and power of the corrective lens.

Sol. The person suffers from hypermetropia. His near point lies at 50 cm. Therefore, a convex lens should be used for the correction of his vision. The focal length of the corrective lens is calculated by

$$\frac{1}{-25} - \frac{1}{-50} = \frac{1}{f}$$

or $$\frac{1}{f} = \frac{1}{50}$$

or $$f = 50 \text{ cm} = 0.5 \text{ m}$$

$\therefore$ Power of the corrective lens,

$$P = \frac{1}{f} = \frac{1}{0.5} = +2D$$

DISPERSION OF WHITE LIGHT BY A GLASS PRISM

When a ray of white light (sunlight) enters a glass prism (denser medium). It emerges out and broken into seven colours.

This phenomenon, due to which different components of a white light are separated is called (dispersion)

- **Explanation :** It is due to different refractive index of different components of white light.

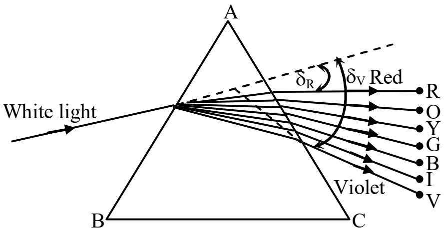
  White light has seven colours, namely, violet indigo, blue, green, yellow, orange and red (remembered by the word **VIBGYOR**). In air (strictly in vacuum) light waves of all colours have same velocity (3×10^8 m/s).

  But in a denser medium, their velocities become less and different. Red light waves, being longest in length, travel fastest and have maximum velocity. Violet light waves, being shortest in length, travel slowest and have minimum velocity in the denser medium.

  The refractive index (μ)of a medium for a wave is given by the relation.

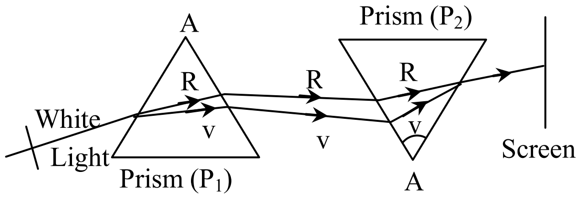
$$\mu = \frac{\text{Velocity of Wave in air (or vacuum)}}{\text{Velocity of wave in the medium}} = \frac{c}{v}$$

As μ is maximum for violet so it bends maximum



Dispersion of white light by a glass prism

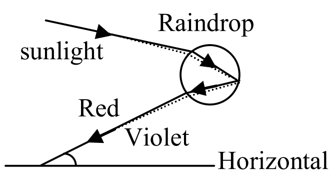
When this dispersed white light is made to fall on a white screen, we get a seven coloured band or light. This coloured band is called spectrum.



REFRACTION IN NATURE

(A) FORMATION OF RAINBOW

A rainbow is a natural spectrum appearing in the sky after a rain shower. It is caused by dispersion of sunlight by tiny water droplets, present in the atmosphere. A rainbow is always formed in a direction opposite to that of the Sun. The water droplets act like small prisms. They refract and disperse the incident sunlight, then reflect it internally, and finally refract it again when it comes out of the raindrop. Due to the dispersion of light and internal reflection, different colours reach the observer's eye.



(B) ATMOSPHERIC REFRACTION

We can observe the apparent random wavering or flickering of objects seen through a turbulent stream of hot air rising above a fire or a radiator. The air just above the fire becomes hotter than the air further up. The hotter air is lighter (less dense) than the cooler air above it, and has a refractive index slightly less than that of the cooler air. Since the physical conditions of the refracting medium (air) are not stationary, the apparent position of the object, as seen through the hot air, fluctuates. This wavering is thus an effect of atmospheric refraction (refraction of light by the earth's atmosphere) on a small scale in our local environment. The twinkling of stars is a similar phenomenon on a much larger scale.

(a) Twinkling of stars :

The twinkling of a star is due to atmospheric refraction of starlight. The starlight, on entering the earth's atmosphere, undergoes refraction continuously before it reaches the earth. The atmospheric refraction occurs in a medium of gradually changing refractive index.

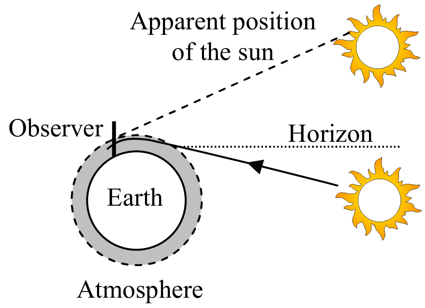
Since the stars are very distant, they approximate point-sized sources of light. As the path of rays of light coming from the star goes on varying slightly, the apparent position of the star fluctuates and the amount of starlight entering the eye flickers – the star sometimes appears brighter, and at some other time, fainter, which is the twinkling effect.

(b) Why don't the planets twinkle?

The planets are much closer to the earth, and are thus seen as extended sources. If we consider a planet as a collection of a large number of point-sized sources of light, the total variation in the amount of light entering our eye from all the individual point-sized sources will average out to zero, thereby nullifying the twinkling effect.

(C) ADVANCE SUNRISE AND DELAYED SUNSET :

Advance sunrise and delayed sunset The Sun is visible to us about 2 minutes before the actual sunrise, and about 2 minutes after the actual sunset because of atmospheric refraction. By actual sunrise, we mean the actual crossing of the horizon by the Sun. figure shows the actual and apparent positions of the Sun with respect to the horizon. The time difference between actual sunset and the apparent sunset is about 2 minutes. The apparent flattening of the Sun's disc at sunrise and sunset is also due to the same phenomenon.



Atmospheric refraction at sunrise and sunset

SCATTERING OF LIGHT

The interplay of light with objects around us gives rise to several spectacular phenomena in nature. The blue colour of the sky, colour of water in deep sea, the reddening of the sun at sunrise and the sunset are some of the wonderful phenomena we are familiar with. The path of a beam of light passing through a true solution is not visible. However, its path becomes visible through a colloidal solution where the size of the particles is relatively larger.

(a) Tyndall effect

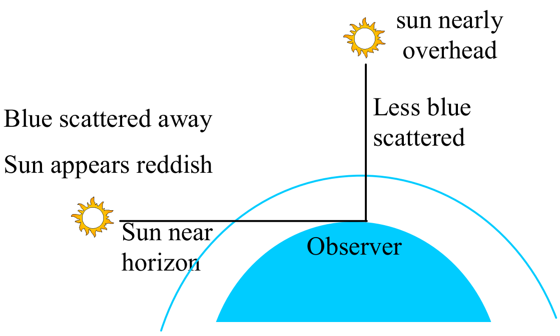
The earth's atmosphere is a heterogeneous mixture of minute particles. These particles include smoke, tiny water droplets, suspended particles of dust and molecules of air. When a beam of light strikes such fine particles, the path of the beam becomes visible. The light reaches us, after being reflected diffusely by these particles. The phenomenon of scattering of light by the colloidal particles gives rise to **Tyndall effect**. This phenomenon is seen when a fine beam of sunlight enters a smoke-filled room through a small hole. Thus, scattering of light makes the particles visible. Tyndall effect can also be observed when sunlight passes through a canopy of a dense forest. Here, tiny water droplets in the mist scatter light. The colour of the scattered light depends on the size of the scattering particles. Very fine particles scatter mainly blue light while particles of larger size scatter light of longer wavelengths. If the size of the scattering particles is large enough, then, the scattered light may even appear white.

(b) Why is the colour of the clear sky blue :

The molecules of air and other fine particles in the atmosphere have size smaller than the wavelength of visible light. These are more effective in scattering light of shorter wavelengths at the blue end than light of longer wavelengths at the red end. The red light has a wavelength about 1.8 times greater than 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 eyes. If the earth had no atmosphere, there would not have been any scattering. Then, the sky would have looked dark. The sky appears dark to passengers flying at very high altitudes, as scattering is not prominent at such heights. You might have observed that 'danger' signal lights are red in colour. Do you know why? The red is least scattered by fog or smoke. Therefore, it can be seen in the same colour at a distance.

(c) Colour of the sun at sunrise and sunset

The sky and the Sun at sunset or sunrise appears red. Near the horizon, most of the blue light and shorter wavelengths are scattered away by the particles. Therefore, the light that reaches our eyes is of longer wavelengths. This gives rise to the reddish appearance of the Sun.



◈ MIRAGE OR INFERIOR MIRAGE

◆ **Definition :** It is an optical illusion, seen in deserts at summer noon, due to which an inverted image of a distant tree is seen formed in hot sand below it, as if formed in water. Actually there is no water anywhere.

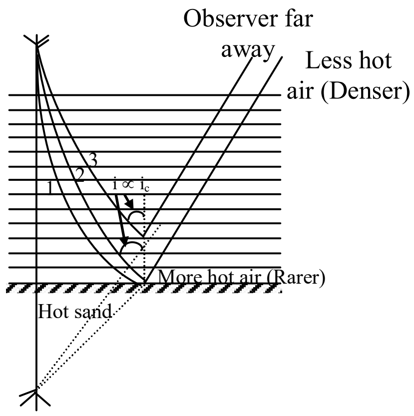


Fig. Mirage in hot desert–Inverted image of tree in hot sand

◆ **Explanation :** It is due to total internal reflection. At summer noon, in desert, sand becomes hot. The air in its contact becomes very hot and hence rarer. As we move up, air becomes less and less hot, hence less and less rarer. The air can be divided into layers of different optical density (fig.).

For rays (like number 1 ray), incident at small angle at upper most layer, the angle of incidence on lowest layer may not be more than critical angle. These rays are all absorbed by sand.

The ray no. 2 starting from tree top and making a bigger angle since beginning, reaches the lowest layer at bigger angle. The angle of incidence may become just more than the critical angle. The ray is totally reflected upward and outward. All rays on the right of ray no. 2 will start with still bigger angle and will have angle of incidence becoming more than critical angle from upper and upper layers. They are also totally reflected.

◈ LOOMING OR SUPERIOR MIRAGE

◆ **Definition :** It is an optical illusion, seen, at sea–shore in winter evening, due to which an image of a ship is seen formed in air in sea–sky. The actual ship is nowhere visible.

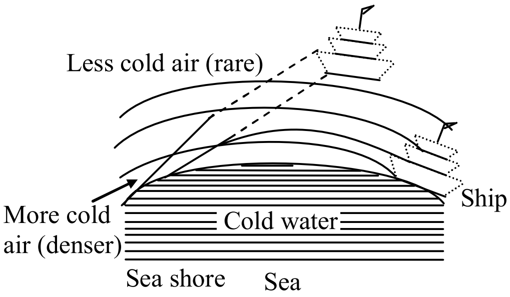


Fig. Looming at cold sea–shore

- **Explanation :** It is due to total internal reflection. In cold evening, over sea–bed sea water becomes too cold. Air layer in its contact is cold and denser. As we go up, air layers become less and less colder and hence rarer. (Fig.)

  Rays from invisible ship going upward go from denser to rarer air layers. They are totally reflected downwards and received by an observer at sea–shore. The observer sees an image (virtual) of the ship hanging in the sky.

IMPORTANT POINTS TO BE REMEMBER

- **Cornea :** A transparent spherical membrane which refracts light into the eye is called cornea.
- **Iris :** A dark muscular diaphragm that controls the size of the pupil is called iris.
- **Pupil :** A small circular opening in the centre of the iris is called pupil. Pupil appears black because no light if reflected from it.
- **Eye lens :** A converging lens made of a transparent jelly-like proteinaceous material behind the pupil is called the eye lens.
- **Retina :** The inside surface of the real (back) part of the eye ball where the light which enters the eye is focussed is called retina. The surface of the retina consists of about 125 million light-sensitive receptors. These receptors are called **rods** and **cones**. The rods are sensitive to the intensity of light, while cones are sensitive to the colour of light.
- **Colour blindness :** It is a defect of the eye due to which person is not able to distinguish between certain colours. Colour blindness is a genetic disorder.
- **Near point :** The nearest point up to which an eye can see clearly is called its near point
- **Far point :** The farthest point up to which an eye can see clearly is called its far point. For a normal eye, the far point is at infinity.
- **Least distance of distinct vision :** The minimum distance up to which an eye can see clearly is called the least distance of distinct vision.
  For a normal eye of an adult, the least distance of distinct vision is 25 cm.
- **Accommodation power of the eye :** The property due to which the eye lens is able to change its focal length is called accommodation of the eye. When the eye is focussed on any distant object, the ciliary muscle is most tense (strained).
- **Myopia (shortsightedness) :** The defect on eye due to which eye is not able to see the distant objects clearly though it can see the nearby objects clearly is called myopia or shortsightedness.
  Myopia is caused by a decrease in the focal length of the eye lens. It can be corrected by using spectacles made from concave lenses of suitable focal length.
- **Hypermetropia (Longsightedness) :** The defect of the eye due to which eyes is not able to see clearly the nearby objects through it can see the distant objects clearly is called hypermetropia or longsightedness. Hypermetropia (long-sightedness) is caused by an increase in the focal length of the eye lens. It can be corrected by using spectacles made from convex lenses of suitable focal lengths.
- **Astigmatism :** The defect of the eye due to which the rays of light coming from the horizontal and vertical planes of an object do

not come to focus at the same point is called astigmatism. Astigmatism occurs when the cornea or the eye lens or both are not perfectly spherical. This can be corrected by using cylindrical lenses.

- **Dispersion of white light :** The process of splitting white light into its seven constituent colours is called dispersion of white light. The band of seven colours is called spectrum of visible light.

  Rainbows are formed due to the dispersion of white light by small droplets of water hanging in the air after the rain.
- **Rainbow :** Rainbow is a band of seven colours across the sky produced due to the dispersion of white light by small raindrops hanging in the air after the rain.
- **Atmospheric refraction :** The optical density of our atmosphere decreases with altitude. Thus a ray of light entering any layer of the atmosphere suffers refraction as it travels through the other layers. This is called atmospheric refraction. Many interesting natural phenomena occur due to atmospheric refraction.
- **Scattering of light :** The earth's atmosphere consists of gases, and many different kinds of particulate matter. When light falls on such particles, it get scattered in all direction. Smaller particles scatter blue light to a larger extent than the red light.

  Larger particles scatter light of longer wavelengths, such as orange/red. In the case of very larger particles, the scattered light appears white.