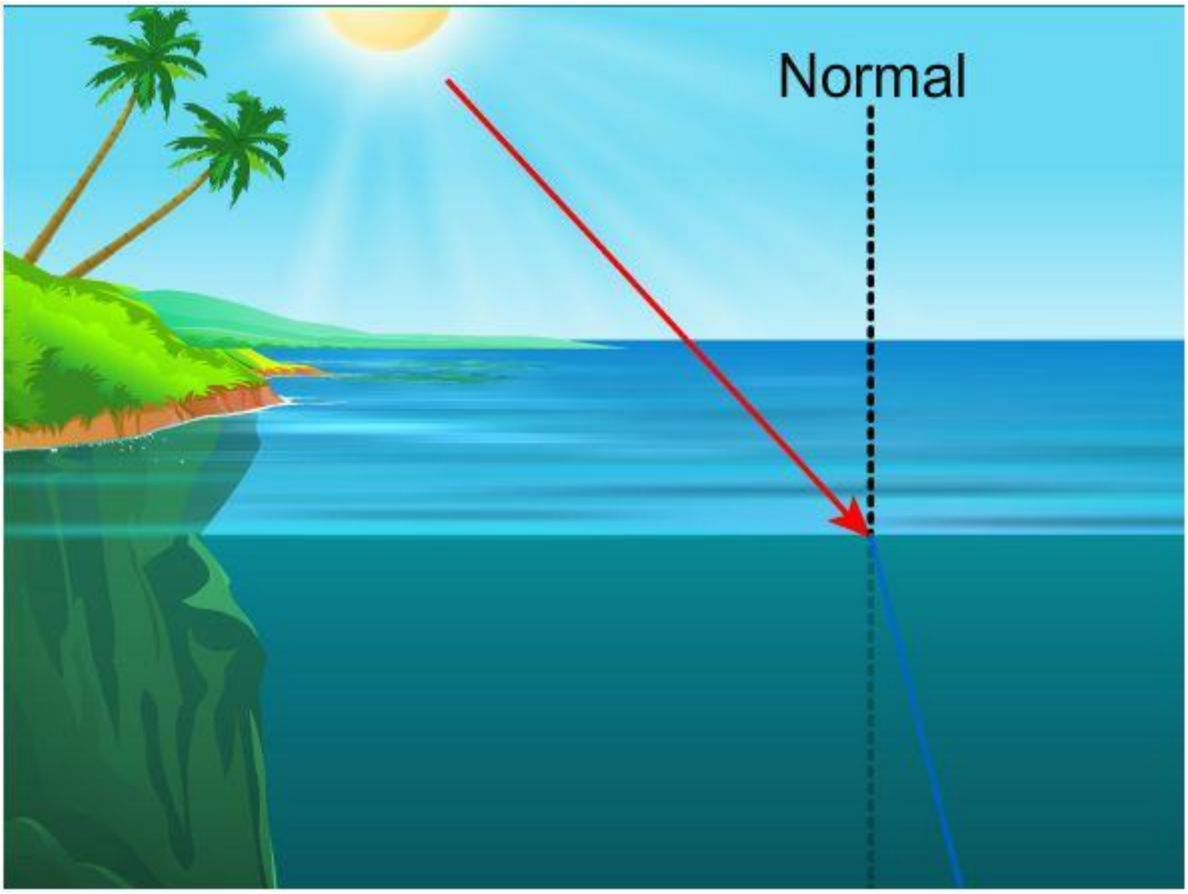
REFLECTION OF LIGHT

Refraction of light is the phenomenon due to which a ray of light deviates from its path, at the surface of separation of two media, when the ray of light is travelling from one optical medium.

Light bends while travelling from one medium to another as its velocity differs from one medium to another. The speed of light in optically rarer medium is larger compared to that in optically denser medium. Hence, while travelling from one medium to another, light bends and refraction occurs.

Rules for Deviation of Light Rays During Refraction

- Light ray passing from rarer (air) to denser (water) medium bends towards the normal at the surface of separation of two media. This makes the angle of incidence i (angle between the incident ray and the normal at the point of incidence) larger than that of the angle of refraction r (angle between the normal and the refracted ray).
- Light ray passing from denser (water) to rarer (air) medium bends away from the normal. This makes the angle of incidence i (angle between the incident ray and the normal at the point of incidence) smaller than that of the angle of refraction (angle between the normal and the refracted ray).
- Light ray that strikes the surface of separation of the two media normally, does not deviate from its path.



Terms Related to Refraction of Light

- **Incident ray**: The ray which strikes the surface of separation of two optical media
- **Refracted ray**: The ray which travels in the second medium after deviation
- **Normal at the point of incidence**: A perpendicular drawn at the point where the incident ray strikes the surface of separation
- **Angle of incidence**: The angle which the incident ray makes with the normal at the point of incidence
- **Angle of refraction**: The angle which the refracted ray makes with the normal at the point of incidence

Effects of Refraction

- Fish in aquarium appear bigger than their original size due to refraction.
- When a pencil is dipped partially in a beaker of water, it appears to be bent and short.
- A coin kept at the bottom of a bowl appears to be raised.

Laws of Refraction

- The incident ray, the normal and the refracted ray, all lie in a plane.
- For a given pair of optical media, the ratio of the sine of the angle of incidence to the sine of angle of refraction is a constant, i.e., sin i / sin r = constant (Snell's Law).

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

Refractive Index
The extent to which a light ray bends depends in a medium depends on the refractive index of the medium. The ratio of velocity of light in vacuum to that in a medium, which is the absolute refractive index (m) of the medium, is the measure of the ability of light to bend in the given medium. Measuring speed of light is difficult. Hence, Snell's law helps to determine the refractive index. According to Snell's law, the refractive index is given by

n = sin i/sinr

Refraction of light is due to the fact that the speed of light is different in different media.

Example
The speed of light in air is 3×10^8 m/s, and in water it is 2.25×10^8 m/s. The extent of refraction can be found if we know an

optical property of the medium, called its refractive index.

The refractive index or absolute refractive index n of a medium is defined as the ratio of the speed of light in vacuum to its speed in the medium. It is a pure number and has no unit. Now, if c is the speed of light in vacuum and v the speed of light in a medium, then the refractive index of the medium is given by

$$n = c/v \qquad \text{------------- (1).}$$

Note that the speed of light in the medium, v, is inversely proportional to its refractive index N.

Example
The refractive index of water n_w = 1.33 and that of glass n_g = 1.52. Since the refractive index of glass, n_g, is more than that of water, n_w, the speed of light in glass, v_g, is less than the speed of light in water, v_w.

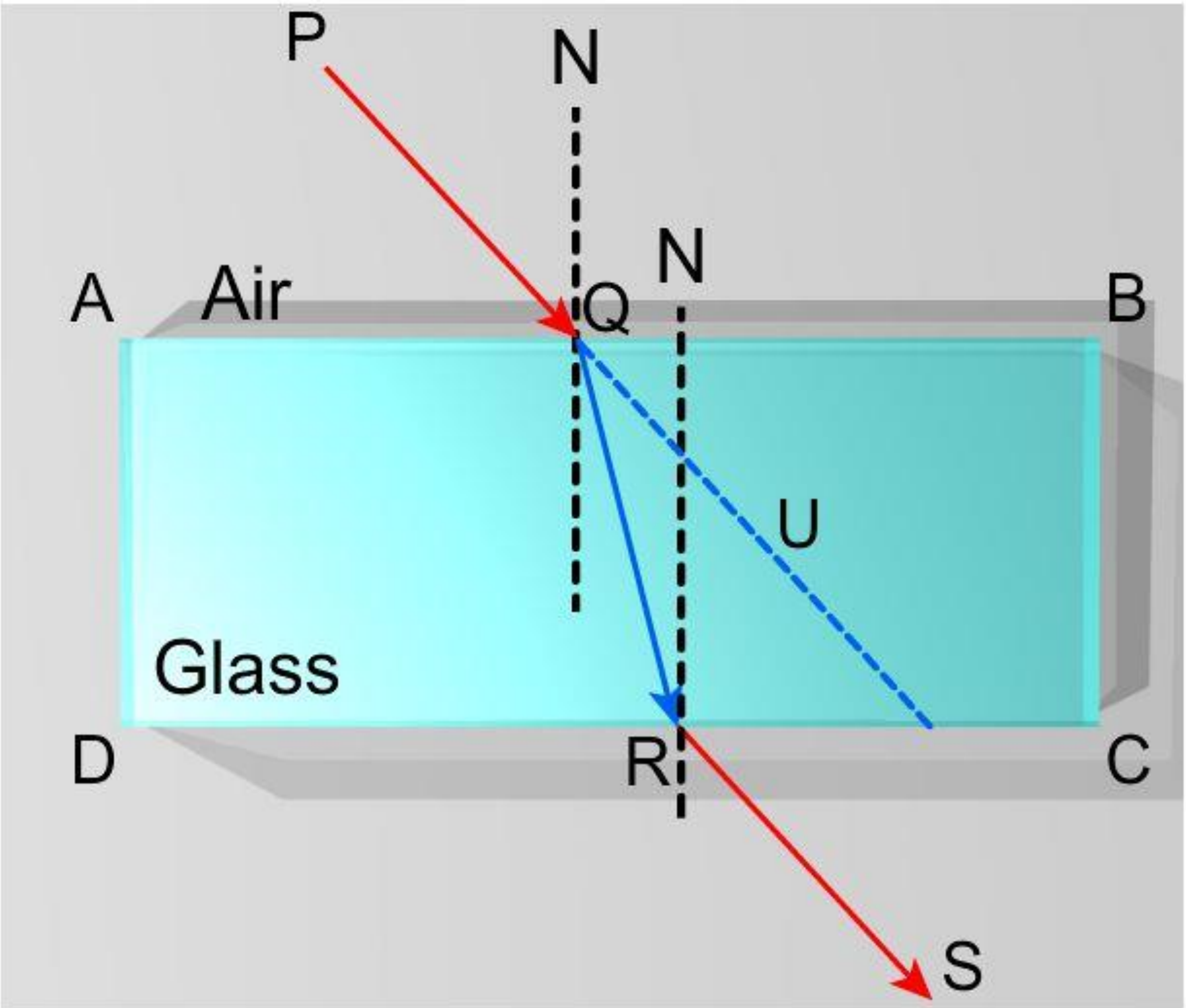
If the refractive index of a medium is greater than that of another, then the first medium is said to be optically denser than the second.

Example
glass is optically denser than water. It is important to note that the optical density of a medium is different from its mass density. The optical density of a medium is related to its refractive index and depends on the speed of light in it, whereas mass density is the mass per unit volume.

When light travels from a denser medium, like water, to a rarer medium, say air, its speed increases and it bends away from the normal. In such a case, the angle of incidence, i, will be less than the angle of refraction, r. On the other hand, if light travels from a rarer medium, like air, to a denser medium, say water, its speed decreases and it bends towards the normal. The angle of incidence, i, is greater than the angle of refraction, r. The relationship between the angle of incidence, i, and the angle of refraction, r, is explained by the laws of refraction.

Refraction of Light through A Rectangular Glass Slab

When a light ray, incident at an angle, passes through a glass slab, the emergent ray is shifted laterally. The lateral shift depends on the thickness and refractive index of the glass slab.



When a light ray bends from denser to rarer medium, it bends away from the normal. If the angle of incidence gradually increases, the angle of refraction too increases. At a particular angle of incidence in the denser medium, the refracted ray emerges along the surface. That particular angle is the critical angle. If the angle of incidence is greater than the critical angle, the ray undergoes total internal

reflection. It is due to this phenomenon that we
observe rainbows and mirages in deserts.

When a ray of light passes from a denser to a rarer medium, some part of it gets refracted into the rarer medium such that it bends away from the normal. Some part of it gets reflected back into the denser medium. The light reflected back into the denser medium is said to be internally reflected.

In case of refraction from a denser to a rarer medium, the angle of refraction 'r' is greater than the angle of incidence 'i'. If the angle of incidence of the light ray is gradually increased, then at a certain angle of incidence, the angle of refraction in the rarer medium becomes 90^o.
The refracted light grazes the interface of the two media. This angle of incidence in the denser medium is called the critical angle, C, for the pair of media under consideration. This implies that when angle of incidence i = C, angle of refraction r = 90^o.
It means that the refractive index of the denser medium with respect to the rarer medium,
$n_{12} = 1/\sin C$.

Consider as an example light passing from glass of refractive index $n_1 = 1.5$ into air of refractive index $n_2 \approx 1$.
We can write $n_{12} = n_1/n_2 = 1/\sin C$. Here, $n_1 = 1.5$ and $n_2 = 1$.

By substituting and simplifying, we get the value of critical angle C as 42^o for the pair of glass and air.
If the angle of incidence is larger than the critical angle, then the incident light cannot refract to the rarer medium and is completely reflected back into the denser medium. This is known as "total internal reflection".

For total internal reflection, the conditions that must be satisfied are:

- Light must pass from a denser medium to a rarer medium.
- The angle of incidence in the denser medium must be greater than the critical angle for that pair of media.

Examples and Applications of Total Internal Reflection

Mirages

Mirages on a hot sunny day are caused by total internal reflection. An illusion of the presence of water on a hot summer day at a distance is known as a "mirage." On a hot summer day, the layer of air nearest to the surface of the earth is the hottest. As we move upwards from the ground, we come across layers of air with decreasing temperatures. Here, it is important to remember that the layer of air at a lower temperature has a greater refractive index than the one at a higher temperature. As a result, the refractive index of the different layers of air increases as we move upwards. Hence, the layers of hot air near the earth's surface are optically rarer than the layers of cold air a little above it. Therefore, rays from nearby objects propagating towards the earth's surface refract and bend away from the normal. At some point, the angle of incidence exceeds the critical angle and the rays undergo total internal reflection. The inverted image seen is actually a mirage.

Sparkling of A Diamond

Diamond has a high refractive index of 2.42, and the critical angle for the diamond-air interface is 24.4^{o}. A diamond is cut in such a way that most of the light rays entering it undergo total internal reflection many times before they exit. This gives diamonds their bright sparkle.

Appearance of Water Surface as A Mirror

Total internal reflection can also be observed while swimming. If you open your eyes just under the surface of the water, and if the water is calm, its surface appears mirror-like. The reason is that the critical angle for water is around 48º. Therefore, if rays of light travelling from water to air strike the water-air interface at an angle of more than 48º, they get totally internally reflected. Hence, the water surface looks like a mirror.

Silvery Appearance of A Test Tube in Water:

When an empty test tube is held at an angle in water and if you look at it from a side, it appears silvery shiny. This is because the critical angle for glass is 42º. When the rays of light travelling in water strike the glass-air interface at an angle greater than 42º, they get totally internally reflected and reach our eyes. These rays of light appear to come from the surface of the test tube and the test tube appears silvery.

Silvery Appearance of Air Bubbles in Water

The bubbles of air rising in a water tank appear silvery due to total internal reflection.
Optical fibres work on total internal reflection. An optical fibre is usually fabricated from glass or quartz, and consists of a core and cladding. The core is the inner-most layer and is surrounded by the cladding. The refractive index of the core material is a little higher than that of the cladding material. Hence, the core is a denser medium as compared to the cladding. When light is allowed to enter the core in such a way that the angle of incidence at the core–cladding interface is greater than the critical angle, it undergoes successive total internal reflections all along its path in the core. Since the loss of

energy is quite small in case of total internal reflection, light can be transmitted over long distances through an optical fibre with a minimum loss of energy. This is used to transmit light signals over long distances. Optical fibres are also used in endoscopy.

Total Internal Reflection in Totally Reflecting Prisms

These prisms can be used to deviate light through 90º or even 180º. They can also be used to provide erect images.
Prism Deviating Light through 90º: To deviate light through 90º, consider a prism, ABC, which has angles of 45º , 90º and 45º . The rays of light incident perpendicular to face AB of the prism pass without deviation and are incident on face AC of the prism at an angle of 45º to the normal N. Since the angle of incidence of the rays of light striking the glass-air interface is now greater than 42º , the critical angle for the glass-air interface, they get totally internally reflected and are deviated by 90º. The rays finally emerge through face BC.
Prism Deviating Light through 180º: When light is incident perpendicular to face AC of the prism, it passes without any deviation and is incident on face AB at an angle of 45º to the normal N_1. The light is now totally internally reflected and isnow incident on face BC at an angle of 45º to the normal. Here again, the light is totally internally reflected and finally emerges from face AC of the prism. Thus, the light deviates by 180º, and travels in exactly the opposite direction to that of its original direction.

Erecting Prism

Consider an object, say XY, placed in front of prism ABC. The rays of light from the object are incident on face AB of the prism and after refraction, are incident on face AC at an angle greater than 42º, which is the critical angle for the glass-air interface. They, therefore, get totally internally reflected towards face BC of the prism. Now they emerge from the prism such that they form an erect image of the object. It is important to note that there is no deviation in the path of the light, and hence, such prisms are also called no n-deviation prisms.

30-60-90 Prisms

When rays of light are incident perpendicular to face BC of the prism, they travel without deviation and are incident on face AC at an angle of 60º to the normal N_1. Since this is greater than the critical angle of 42º for the glass-air interface, they are totally internally reflected. They are now incident on side AB of the prism at an angle of 30º with the normal N_2, and finally emerge from side AB.

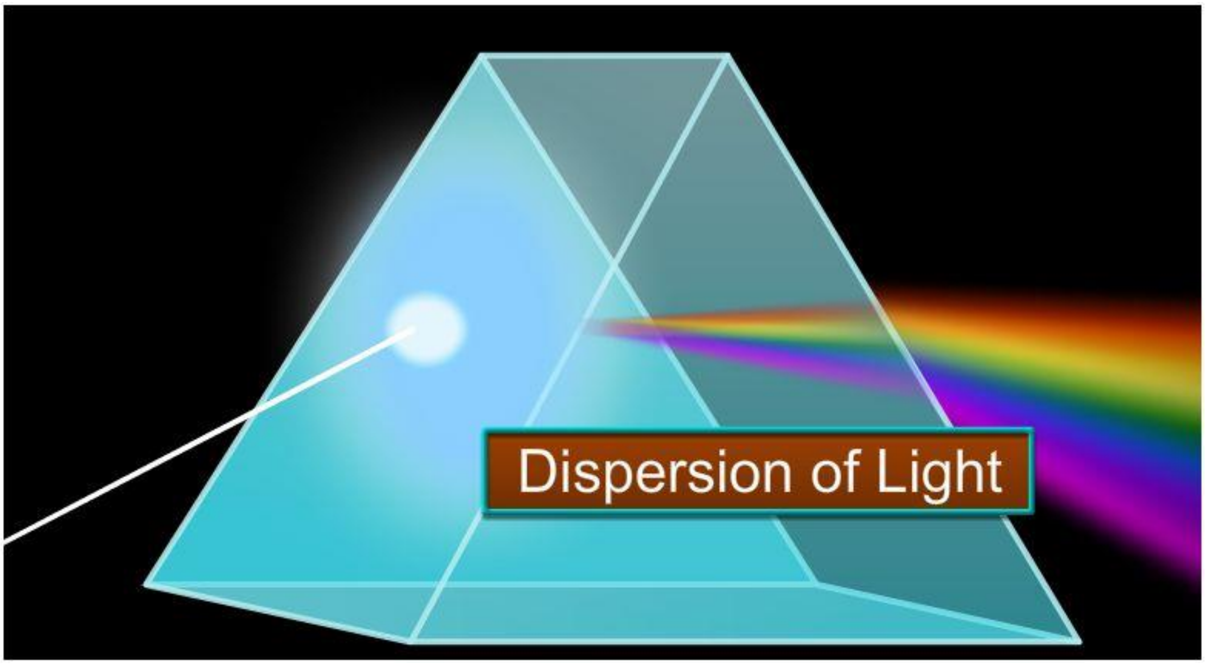
Here, it should be noted that total internal reflection depends on the path of the light entering the prism. The light can also simply emerge from the prism without any total internal reflection.

To know more about this, consider prism ABC and consider a ray of light incident perpendicular to face AB. This ray passes without any deviation into the glass and is incident on face AC at an angle of 30º to the normal N_1.

Since this angle of incidence is less than the critical angle of 42º of the glass-air interface, the light does not undergo any total internal reflection, just refracts through the face and emerges into the air.

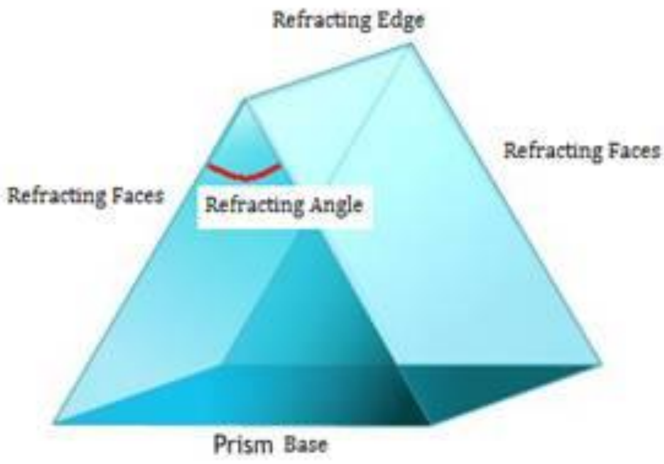
Dispersion

The phenomenon due to which a polychromatic light, like sunlight, splits into its component colours, when passed through a transparent medium like a glass prism, is called dispersion of light. Rainbow is the natural phenomenon in which dispersion takes place. The cause of dispersion is that sunlight consists of seven constituents (colours namely violet, indigo, blue, green, yellow, orange and red, popularly referred to as VIBGYOR) that have different refractive index with respect to a medium. The dispersion of white light occurs because colours of white light travel at different speeds through the glass prism. The wavelength of each colour is different and this causes the difference in velocity of the corresponding light when passing from one medium to another.



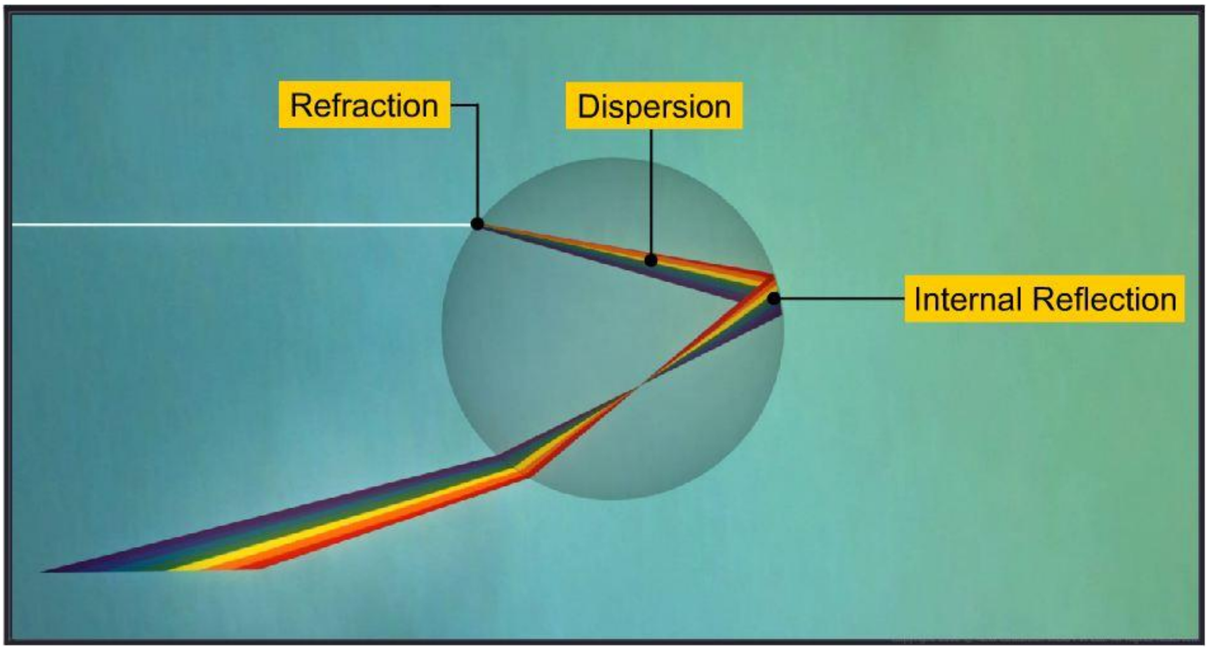
This phenomenon can be observed in a lab environment using a triangular glass prism. A prism is a solid structure having three rectangular and two triangular surfaces. Any two rectangular faces are the refracting surfaces and the third one is the base. The angle between the refracting surfaces is the angle of the prism or refracting angle. The edge formed by the two refracting surfaces is the refracting edge. When a light ray enters one refracting surface of the prism, it bends towards the normal and when it emerges out of the other refracting surface it bends away from the normal. The angle between the incident ray and the emergent ray is the angle of deviation.

The band of colours obtained on the screen, when a polychromatic light splits into component colours is called a spectrum.



Rainbow Formation

The formation of a rainbow involves a series of physical phenomena - reflection, refraction, dispersion and total internal reflection. The occurrence of each of these is due to the interaction of light with air and water and the boundaries between them.   As light enters the raindrop, it is refracted (the path of the light is bent to a different angle), and some of the light is reflected by the internal, curved, mirror-like surface of the raindrop, and finally is refracted back out the raindrop toward the observer. Conditions necessary to observe a rainbow: (1) The Sun should be behind us. (2) It should have rained and the Sun should be present.



Scattering of Light

Scattering of light means to throw light in various random directions. Light is scattered when it falls on various types of suspended particles in its path. Depending on the size of particles, the scattering can be of white sunlight or of the component colours of sunlight. The sky appears blue during a clear cloudless day because the molecules in the air scatter blue light from the sun more than they scatter red light. During sunrise and sunset, the sky appears red and orange because the blue light has been scattered out and away from the line of sight.

Tyndall Effect

The scattering of light by particles in its path is known as Tyndall effect. Tyndall discovered that when white light consisting of seven colours is passed through a clear liquid having small suspended particles in it, then the blue colour of sun light having shorter wavelength is scattered much more than the red colour having longer wavelength.

When a beam of sunlight enters a dusty room through a hole, then its path becomes visible to us. This is because the tiny dust particles present in the air in the room scatter the beam of sunlight all around the room. When this scattered light enters our eyes, we can see the beam of light. Tyndall effect can also be observed when sunlight passes through the canopy of dense forest. Here tiny droplets of water in the mist scatter sunlight.

Clouds are White

Clouds are white because their water droplets or ice crystals are large enough to scatter the light of the seven wavelengths the component colours of white light (i.e red, orange, yellow, green, blue, indigo, and violet), which combine to produce white light.