JSR IAS ACADEMY

GENERAL SCIENCE
PHYSICS

LIGHT - 3

Refraction of light

The bending of light rays when they pass obliquely from one medium to another medium is called refraction of light.

Refraction of light at air – water interface

Put a straight pencil into a tank of water or beaker of water at an angle of 45° and look at it from one side and above. How does the pencil look now? The pencil appears to be bent at the surface of water.

Velocity of light is more in a rarer medium (low optical density) than in a denser medium (high optical density).

Refraction of light from a plane transparent surface

When a ray of light travels from optically rarer medium to optically denser medium, it bends towards the normal. (A)

When a ray of light travels from an optically denser medium to an optically rarer medium it bends away from the normal. (B)

A ray of light incident normally on a denser medium, goes without any deviation. (C)

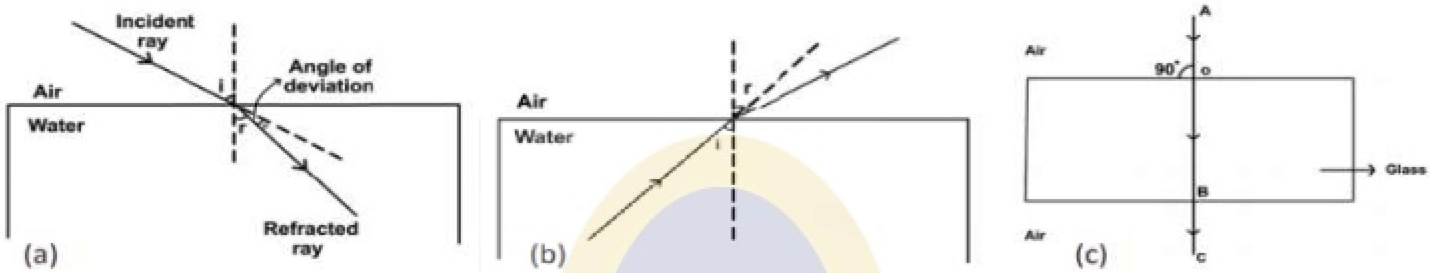


Figure 6.11 Refraction of light from a plane transparent surface

Refractive Index

- When the speed of light in a medium is more, the bending is less and when the speed of light is less, the bending is more.
- It is also known as the absolute refractive index and it is denoted by the Greek letter **'μ'** (pronounced as **'mew').**
- Refractive index is a ratio of two similar quantities (speed) and so, it has no unit.
- Since, the speed of light in any medium is less than its speed in air, refractive index of any transparent medium is always greater than 1.
- The speed of light in a medium is low if the refractive index of the medium is high and vice versa.

$$_1\mu_2 = \frac{\text{Absolute refractive index of the second medium}}{\text{Absolute refractive index of the first medium}}$$

$$_1\mu_2 = \frac{\frac{c}{V_2}}{\frac{c}{V_1}} \qquad \text{or} \qquad _1\mu_2 = \frac{V_1}{V_2}$$

SUBSTANCES	REFRACTIVE INDEX
Air	1.0
Water	1.33
Ether	1.36
Kerosene	1.41
Ordinary Glass	1.5
Quartz	1.56
Diamond	2.41

Speed of light in air is 3×10^8 m s^{-1} and the speed of light in a medium is 2×10^8 ms^{-1}. Find the refractive index of the medium with respect to air.

Solution:

$$\text{Refractive index } (\mu) = \frac{\text{Speed of light in air (c)}}{\text{Speed of light in the medium (v)}}$$

$$\mu = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

Snell's Law of Refraction

I) The incident ray, the refracted ray and the normal at the point of intersection, all lie in the same plane.

II) The ratio of the sine of the angle of incidence (i) to the sine of the angle of refraction (r) is equal to the refractive index of the medium, which is a constant.

$$\frac{\sin i}{\sin r} = \mu$$

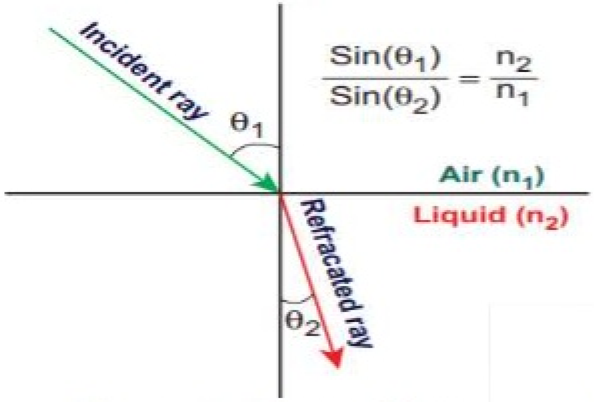


Figure 3.12 Snell's Law

This constant is called the refractive index of the second medium with respect to the first medium.

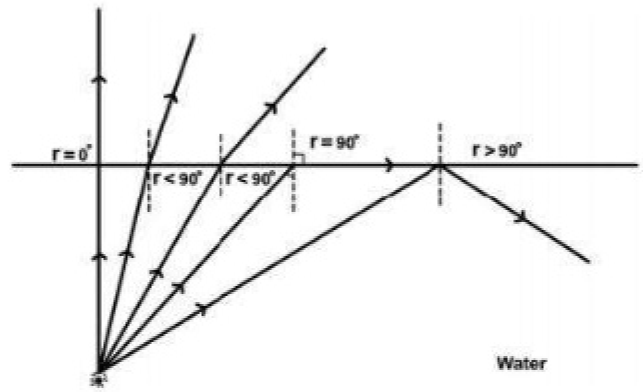
It is generally represented by the Greek letter, $_1\mu^2$ (mew).

REFRACTION OF A COMPOSITE LIGHT DISPERSION OF LIGHT

- If a source of light produces a light of single colour, it is known as a monochromatic source.
- On the other hand, a composite source of light produces a white light which contains light of different colours. Sun light is a composite light which consists of light of various colours or wavelengths.
- Another example for a composite source is a mercury vapour lamp.

Total Internal Reflection

- When light travels from denser medium into a rarer medium, it gets refracted away from the normal.
- While the angle of incidence in the denser medium increases the angle of refraction also increases and it reaches a maximum value of r = 90º for a particular value. Th is angle of incidence is called **critical angle**
- The angle of incidence at which the angle of refraction is 90º is called the critical angle
- When the angle of incidence exceeds the value of critical angle, the refracted ray is not possible. Since r > 90º the ray is totally reflected back to the same medium. This is called as total internal reflection



Conditions to achieve total internal reflection

1. Light must travel from denser medium to rarer medium. (Example: From water to air).
2. The angle of incidence inside the denser medium must be greater than that of the critical angle.

Total internal reflection in nature

Mirage:

- On hot summer days, patch of water may be on the road. This is an illusion.
- In summer, the air near the ground becomes hotter than the air at higher levels.
- Hotter air is less dense, and has smaller refractive index than the cooler air.
- Thus, a ray of light bends away from the normal and undergoes total internal reflection.

Total internal reflection is the main cause for the spectacular brilliance of **diamonds and twinkling of stars.**

Mirror equation

The expression relating the distance of the object (u), distance of the image (v) and the focal length (f) of a spherical mirror is called the mirror equation. It is given as

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

Linear magnifi cation(m)

Magnifi cation produced by a spherical mirror gives how many times the image of an object is magnified with respect to the object size.

$$m = \frac{h_i}{h_o}$$

It can be defined as the ratio of the height of the image (hi) to the height of the object (ho). The magnification can be related to object distance (u) and the image distance (v).

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

$$\therefore m = \frac{h_i}{h_o} = -\frac{v}{u}$$

Note:

- ❖ A negative sign in the value of magnification indicates that the image is real.
- ❖ A positive sign in the value of magnification indicates that the image is virtual.

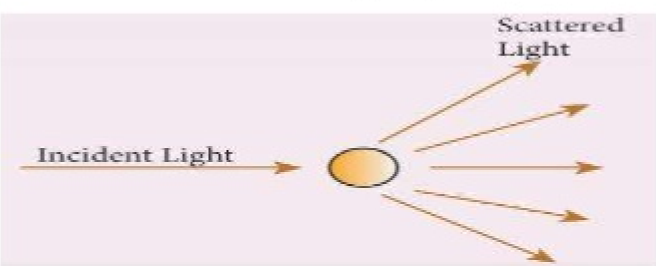
Speed of light

air, light travels with a speed of 3 × 108 m s-1

DO YOU KNOW? Some organisms can make their own light too? This ability is called bioluminescence. Worms, fish, squid, starfish and some other organisms that live in the dark sea habitat glow or flash light to scare off predators.

SCATTERING OF LIGHT

- ❖ When sunlight enters the Earth's atmosphere, the atoms and molecules of different gases present in the atmosphere refract the light in all possible directions. This is called as 'Scattering of light'.



Types of scattering

Based on initial and final energy of the light beam, scattering can be classified as, 1) Elastic scattering 2) Inelastic scattering

1) Elastic scattering

If the energy of the incident beam of light and the scattered beam of light are same, then it is called as 'elastic scattering'.

2) Inelastic scattering

If the energy of the incident beam of light and the scattered beam of light are not same, then it is called as 'inelastic scattering'.

The nature and size of the scatterer results in different types of scattering. They are

- ❖ Rayleigh scattering
- ❖ Mie scattering
- ❖ Tyndall scattering
- ❖ Raman scattering

Rayleigh scattering

- ❖ The scattering of sunlight by the atoms or molecules of the gases in the earth's atmosphere is known as Rayleigh scattering.
- ❖ Rayleigh's scattering law states that, "The amount of scattering of light is inversely proportional to the fourth power of its wavelength".

Amount of scattering 'S' ∝ $1/\lambda^4$

- ❖ According to this law, the shorter wavelength colours are scattered much more than the longer wavelength colours.
- ❖ When sunlight passes through the atmosphere, the blue colour (shorter wavelength) is scattered to a greater extent than the red colour (longer wavelength).
- ❖ This scattering causes the sky to appear in blue colour.
- ❖ At sunrise and sunset, the light rays from the Sun have to travel a larger distance in the atmosphere than at noon.
- ❖ Hence, most of the blue lights are scattered away and only the red light which gets least scattered reaches us. Therefore, the colour of the Sun is red at sunrise and sunset.

Mie scattering

- Mie scattering takes place when the diameter of the scatterer is similar to or larger than the wavelength of the incident light. It is also an elastic scattering.
- The amount of scattering is independent of wave length.
- Mie scattering is caused by pollen, dust, smoke, water droplets, and other particles in the lower portion of the atmosphere.
- Mie scattering is responsible for the white appearance of the clouds.
- When white light falls on the water drop, all the colours are equally scattered which together form the white light.

Tyndall Scattering

- When a beam of sunlight, enters into a dusty room through a window, then its path becomes visible to us.
- This is because, the tiny dust particles present in the air of the room scatter the beam of light. This is an example of Tyndall Scattering
- The scattering of light rays by the colloidal particles in the colloidal solution is called Tyndall Scattering or Tyndall Effect.

Raman scattering

- When a parallel beam of monochromatic (single coloured) light passes through a gas or liquid or transparent solid, a part of light rays are scattered.
- The scattered light contains some additional frequencies (or wavelengths) other than that of incident frequency (or wavelength). This is known as Raman scattering or Raman Effect.
- Raman Scattering is defined as "The interaction of light ray with the particles of pure liquids or transparent solids, which leads to a change in wavelength or frequency."
- The spectral lines having frequency equal to the incident ray frequency is called **'Rayleigh line'**
- the spectral lines which are having frequencies other than the incident ray frequency are called **'Raman lines'.**
- The lines having frequencies lower than the incident frequency is called **stokes lines**
- the lines having frequencies higher than the incident frequency are called **Antistokes lines.**