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Changing your Tomorrow

Refraction of light

XII- SCIENCE

SUBJECT : PHYSICS
CHAPTER NUMBER: 9
CHAPTER NAME : RAY OPTICS

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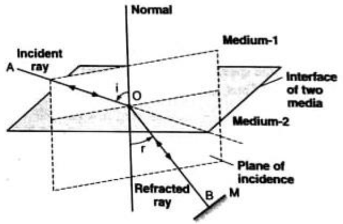
REFRACTION OF LIGHT

- **LAWS OF REFRACTION**
- ***The bending of a ray at the interface of two media is called refraction.***
- The bending or the change in direction of propagation of light occurs except when it strikes the interface normally, *i.e.*, when angle of incidence, i = 0^0
- **Law 1 :** ***The incident ray (AO), the normal to the interface at the point of incidence and the refracted ray (OB), all lie in the same plane.***
- **Law 2 :** ***The ratio of the sine of the angle of incidence to the sine of the angle of refraction is always a constant (a different constant for a different set of media).***

REFRACTION OF LIGHT

- **That is, sin i/sin r = constant = $^1\mu_2$ …(1)**
- Eqn. (1) is known as **Snell's law**. The constant $^1\mu_2$ is called the *refractive index of medium-2with respect to medium-1when a ray of light travels from medium-1 to medium-2.* In other words, $^1\mu_2$ is the refractive index of the medium in which the refracted ray lies w.r.t the medium in which the incident ray lies.



- According to the **principle of reversibility of light,** if the final path of a ray of light, which has suffered a number of reflections and refractions is reversed, the entire ray retraces its path. Thus if we place a mirror at *M* at an angle 90^0 to the refracted ray OB then BO will become the incident ray and OA will be the refracted ray. In such a case,
- Angle of incidence ='r' and angle of refraction ='i'
- Thus, sin r/sin i= $^2\mu_1$ **….(2)**
- From eqns. (1) and (2),
- **$^1\mu_2 = 1/\,^2\mu_1$ or $^2\mu_1 \times {}^1\mu_2 = 1$ ….(3)**

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Absolute Refractive Index

- Whenever light travels from one medium to another, its speed changes. The speed of light is maximum in vacuum and is given by $c=3x10^8$ m/s. The speed of light in another medium will be less than c, say equal to v. We define the refractive index of this medium to be
- μ = (speed of light in vacuum)/(speed of light in medium) = c/v ……(4)
- μ = **absolute** (or **standard**) **refractive Index**. Since v is less than c, μ is greater than 1. As the refractive index of air is almost unity (=1.00029), we can define the refractive index of a medium w.r.t. air instead of vacuum.
- **Note**
- Refractive index is a measure of speed of light in a transparent medium or technically a measure of the **optical density** of the material. For example, the speed of light in water is less than that in air, so water is said to be optically denser. Optical density in general correlates with mass density. However, in some cases, a material with greater optical density than another can have a lower mass density, *eg, mass density of turpentine oil is less than that of water but its optical density is higher.*
- Greater the refractive index of a material, the greater is the material's optical density and the smaller is the speed of light in that material (as v= c/ μ).

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Relative refractive index

- Suppose the speed of light in medium-1 is v_1, and that in medium-2 is v_2. Thus, the corresponding refractive indices μ_1 and μ_2 , are
- $\mu_1 = c/v_1$ and $\mu_2 = c/v_2$
- or $\mu_1 v_1 = \mu_2 v_2$
- or $\mu_2/\mu_1 = v_1/v_2 = {}^1\boldsymbol{\mu}_2$ ....(5)
- *The relative refractive index of medium-2 with respect to medium-1 (ie. ${}^1\mu_2$) Is equal to the ratio (μ_2/μ_1)of the absolute refractive indices μ_1 and μ_2 of the new media, I and 2.*
- From eqns. (1) and (5)
- $\sin i/\sin r = \mu_2/\mu_1$
- or $\mu_1 \sin i = \mu_2 \sin r$ .....(6)
- ***The product of the refractive index and the sine of the angle made by the ray with the normal at the point of incidence is constant for a given ray in both the media.***
- ***This is the general statement of Snell's law.***

Relationship between Refractive Index of a Material and the Wavelength of Light

- The speed of light waves may be different in different media but the frequency (ν) does not change (as it is characteristic of the source of light) when the wave propagates from one medium to another. This means that for the relation $\nu = c/\lambda$ to hold good, its wavelength must change. Suppose the wave motion of frequency ν, wavelength λ_1 and velocity v_1 passes from medium-1 to medium-2, where the corresponding quantities are ν, λ and v_2 . Let the refractive indices of the two media be μ_1 and μ_2 , and respectively. Thus,
- $v_1 = \nu\lambda_1$ and $v_2 = \nu \lambda_2$
- or $\lambda_2/ \lambda_1 = v_2/v_1 = (c/\mu_2)/(c/ \mu_1) = \mu_1/ \mu_2$
- or $\mu_1 \lambda_1 = \mu_2 \lambda_2$ ……(7)
- If the medium-1 is vacuum, then $\mu_1 = 1$ and $\lambda_1 = \lambda_0$ (say),
- Clearly, $1 \times \lambda_0 = \mu_2 \lambda_2$ or $\lambda_2 = \lambda_0/\mu_2$
- Or $\mu_2 = \lambda_0/ \lambda_2$
- In general,
- $\mu = \lambda_0/ \lambda$ ….(8)

Relationship between Refractive Index of a Material and the Wavelength of Light

- **Note:**
- Refractive index depends upon the wavelength; that is, μ varies with the colour of light, even though the variation is small. For example, the refractive indices of glass for red, green and violet light are 1.51, 1.52 and 1.53 respectively.
- Refractive index of medium-2 w.r.t. medium-1, i.e.
- ${}^{1}\mu_2 = \mu_2 / \mu_1 = v_1/v_2 = \lambda_1/ \lambda_2$ .....(9)

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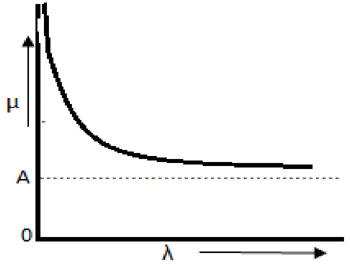
Dependence of refractive index of a medium on wave length

- Cauchy's formula gives the dependence of refractive index of a medium on wavelength . This is given as;

  $$\mu = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + ...$$

- It is some how also written as ; $\mu = A + \frac{B}{\lambda^2}$
- So if red , blue and green colour light enter normally into
- a glass slab at a time , then as $\lambda_{Red} > \lambda_{green} > \lambda_{blue}$
- $\Rightarrow \mu_{Red} < \mu_{green} < \mu_{blue}$ (By Cauchy's law)
- $\Rightarrow v_{Red} > v_{Green} > v_{Blue}$ (Since μ=c/v)
- $\Rightarrow t_{Red} < t_{Green} < t_{Blue}$ (Since t = d/v)
- So red colour emerges out earliest , then green and finally blue .



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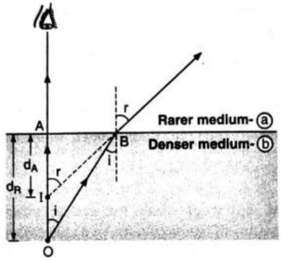
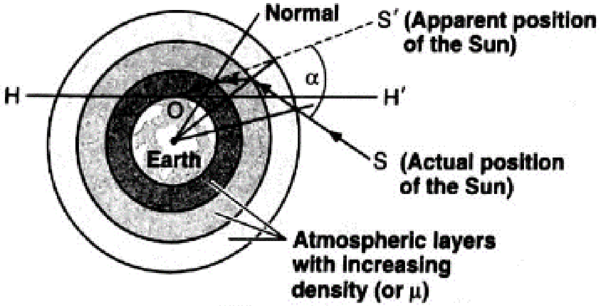
Relation between real depth and apparent depth

- Consider an object O in the denser medium.
- An incident ray OA goes undeviated into the rarer medium.
- Another ray of light OB bends away from the normal and appears to meet ray OA at I.
- I is the virtual image of the object O.
- O appears to be raised to the position I.
- OA = real depth
- IA = apparent depth
- ${}_{a}^{b}\mu = \frac{\sin i}{\sin r} = \frac{AB/OB}{AB/IB} = \frac{IB}{OB}$
- ${}_{b}^{a}\mu = \frac{1}{{}_{a}^{b}\mu} = \frac{OB}{IB}$
- For small angle of incidence OB≈OA and IB≈IA. Therefore, ${}_{b}^{a}\mu = \frac{OA}{IA} = \frac{real\ depth}{apparent\ depth}$
- **Note:** Displacement of the image $d_R - d_A = d_R\left(1 - \frac{d_A}{d_R}\right) = d_R\left(1 - \frac{1}{{}_{b}^{a}\mu}\right)$.



Atmospheric Refraction

- The refraction of light through the atmosphere is called atmospheric refraction.
- **(a) Advance Sunrise and Sunset:** The Sun is visible before actual sunrise and after actual sunset because of the atmospheric refraction. It occurs because as we go higher up from the Earth, the density and the refractive index of the air layers decrease. The rays of light from the Sun keep on bending towards the normal. When the Sun S is below the horizon HH', it appears to be at S' [Fig].



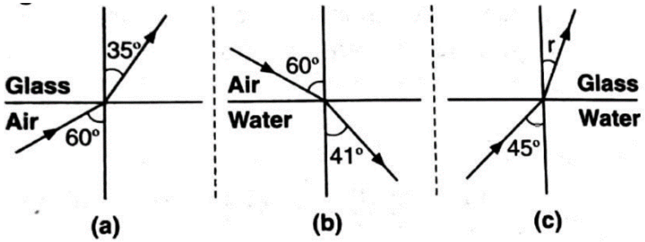
- The angle α through which the Sun or any other celestial body is apparently raised is called atmospheric refraction.

Atmospheric Refraction

- **(b) Flattened appearance of the Sun or the Moon at rising or setting:** The apparent raising due to refraction is greater for positions near the horizon. When the Sun or the Moon is nearer the horizon, the lower side along the vertical diameter appears to be raised more than the upper side while the two extremities along a horizontal diameter are raised to the same extent. Consequently, the vertical diameter appears to be shortened and so the disc of the Sun (or the moon) appears to be somewhat elliptical or flattened.
- **(c) Twinkling of Stars:** The refractive index of air varies periodically even at the same level. A star appears to twinkle as the rays of light from it are sometimes concentrated at a point and sometimes decrease inintensity. The planets being nearer, the amount of light received from them is greater and so the variation in brightness is not appreciable. Obviously, no twinkling is observed in case of planets.

Numericals

- **Question-1**: Fig. shows refraction of an incident ray in air at 60° with the normal to a glass-air and water-air interface respectively. Predict the angle of refraction of an incident ray in water at 45° with the normal to a water-glass interface.



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Solution

- In Fig. (a), as light travels from air to glass,
- ${}_{g}^{a}\mu = \frac{\sin 60^0}{\sin 35^0} = \frac{0.8660}{0.5736} = 1.51$
- In Fig. (b), as light travels from air to water
- ${}_{w}^{a}\mu = \frac{\sin 60^0}{\sin 41^0} = \frac{0.8660}{0.6551} = 1.32$
- In Fig. (c), as light travels from water to glass,
- ${}_{g}^{w}\mu = \frac{{}_{g}^{a}\mu}{{}_{w}^{a}\mu} = \frac{1.51}{1.32} = 1.144$
- $\frac{\sin i}{\sin r} = 1.144$
- $\sin r = \frac{\sin 45^0}{1.144}$
- $r = 38.2^0$

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Numericals

- **Question-2**: A tank is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to focus on the needle again?
- **Solution:** Refractive index, of water,
- ${}_{w}^{a}\mu = \frac{real\ depth}{apparent\ depth} = \frac{12.5}{9.5} = 1.33$
- Refractive index of Liquid
- ${}_{l}^{a}\mu = \frac{real\ depth}{apparent\ depth} = 1.63$
- Real Depth = 12.5 cm
- 1.63=(12.5/Apparent Depth)
- Apparent Depth = 7.7 cm
- The image of the needle moves up and microscope has to be moved up to keep the image in focus.
- Distance through which the microscope has to be moved up = 9.4cm-7.7cm=1.7cm

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