CHAPTER 15

REFRACTION AT PLANE SURFACE

Refraction:-
↳ The phenomenon of bending of light ray on passing through one medium to another medium due to change in speed called refraction.

Rarer medium:-
↳ For a pair of medium, the medium in which the speed of light is comparatively larger is called rarer medium. For e.g.:- ray from glass to air.

Denser medium:-
↳ For a pair of medium, the medium in which the speed of light is comparatively smaller is called denser medium. For e.g.: ray from air to glass

Law of Refraction of Light:-
↳ The law of refraction of light are:-

[i] The incident ray, refracted ray & Normal at the point of incident lies in the same plane.

[ii] When light travels from rarer to denser medium it bends towards the normal and when light travels from denser to rarer medium it bends away from Normal.

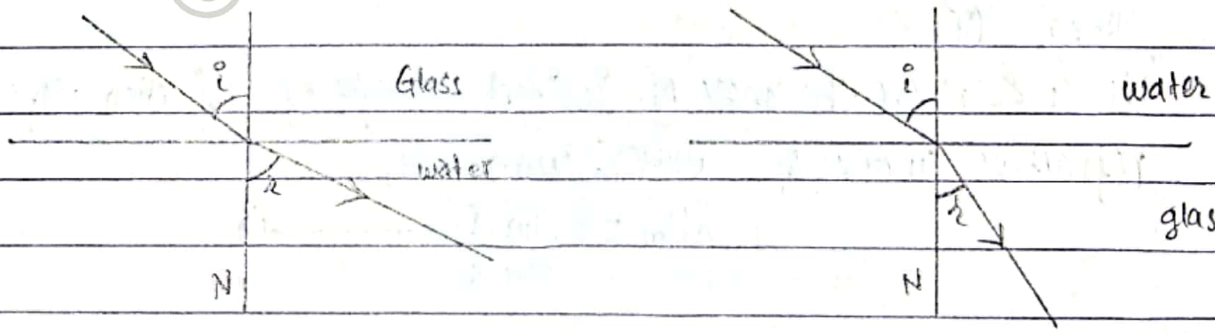

Fig:- refraction of light

[iii] For a given two medium, the ratio of sine of the angle of incidence to the sine of angle of refraction is constant, called **Refractive index** and denoted by 'μ'. Which is known as <u>Snell's law.</u>

Note> $_a\mu_b$ ⇒ Refractive index of medium 'b' w.r.t. medium 'a'.

OR, light travelling from medium 'a' to medium 'b'.

Refractive Index:-

↳ The refractive index in terms of Speed of light of a medium is defined as the ratio of speed of light in vaccum(c) to the speed of light in that medium (v).

i.e., $$\text{Refractive index} = \frac{\text{Velocity of light in vaccum}}{\text{Velocity of ligh in any medium}}$$

$$\mu = \frac{c}{v}$$

Where, $\boxed{c = 3 \times 10^8 \text{ m/s}}$

Principle of Reversibility of light:-

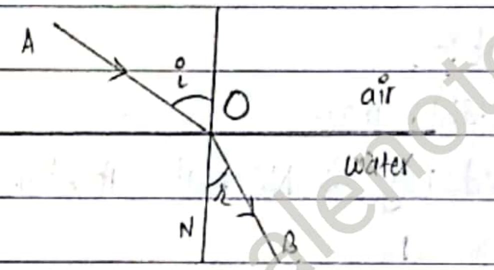

Fig:- Light refracted from air to water.

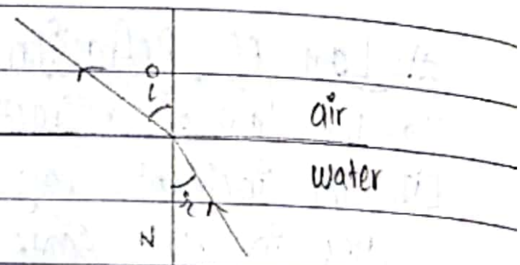

Fig:- Light Refracted from water to air

Let us consider a light ray 'AO' incident at point 'O' of the refracting medium of air and water. Then it beds towards normal and passes along 'OB'.

Let 'i' & 'r' are the angle of incident & angle of refraction respectively. Now, refractive index of water w.r.t. air,

$$_a\mu_w = \frac{\sin i}{\sin r} \text{ ——— (i)}$$

When, the light ray is made to incident on the water-air surface at angle 'r', Then, it get refracted along the previous direction of incident & angle of refraction is 'i'. Then, refractive index of air w.r.t. water,

$$_w\mu_a = \frac{\sin r}{\sin i} \text{ ——— (ii)}$$

Multiplying eq^n (i) & (ii)

$$\Rightarrow {}_a\mu_w \cdot {}_w\mu_a = \frac{\sin i}{\sin r} \times \frac{\sin r}{\sin r} = 1$$

$$\Rightarrow \boxed{{}_w\mu_a = \frac{1}{{}_a\mu_w}} \text{ ——— (iii)}$$

Real Depth and Apparent Depth:-

↳ When light ray travels from denser medium to rarer medium it bends away from the normal and the bottom of a pond seems to be rised as shown in figure below:-

Let us consider a point 'O' at the bottom of the pond from which a light ray 'OA' incident at angle 'i' and get refracted along 'AB' at angle of refraction 'r'. The point 'O' seems to be at point 'O'' on observing from point 'B'.

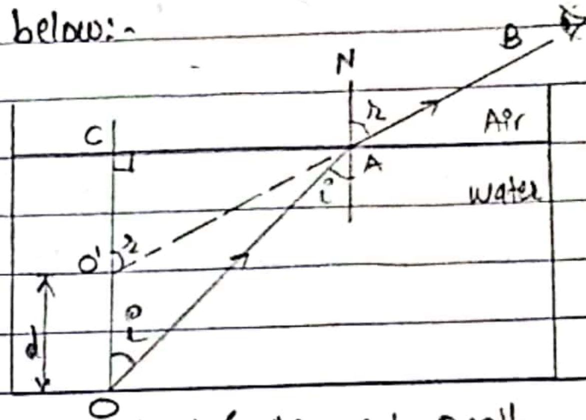

Fig:- Real & Apparent Depth

Here, CO = Real Depth, CO' = Apparent depth & $OO' = d$ = Apparent shift

Now, From figure,

$$OO' = CO - CO'$$

Apparent shift(d) = Real depth − Apparent depth ——— (i)

Now,

Refractive index of air w.r.t. water,

$$_w\mu_a = \frac{\sin i}{\sin r}$$

$$\Rightarrow {}_a\mu_w = \frac{\sin r}{\sin i} \text{ ——— (ii)}$$

From $\Delta CAO'$

$$\sin r = \frac{CA}{O'A}$$

Also, from ΔCAO

$$\sin i = \frac{CA}{OA}$$

Then, eq^n (ii) becomes,

$$_a\mu_w = \frac{CA}{O'A} \times \frac{OA}{CA} = \frac{OA}{O'A}$$

If A is very close to C

$OA \approx OC$ & $O'A \approx O'C$

$$\Rightarrow {}_a\mu_w = \frac{OC}{O'C}$$

$$\Rightarrow {}_a\mu_w = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$\Rightarrow \text{Apparent depth} = \frac{\text{Real depth}}{_a\mu_w}$$

If Real depth = t, Then,

$$\Rightarrow \text{Apparent depth} = \frac{t}{_a\mu_w} \text{ ——— (iii)}$$

Using eq^n (iii) in (i)

$$\Rightarrow d = t - \frac{t}{_a\mu_w}$$

$$\Rightarrow d = t\left[1 - \frac{1}{_a\mu_w}\right] \text{ ——— (iv)}$$

Which is required relation for Apparent shift.

Lateral shift(d):

↳ The perpendicular distance between the direction of incident ray and emergent ray is called the lateral shift.

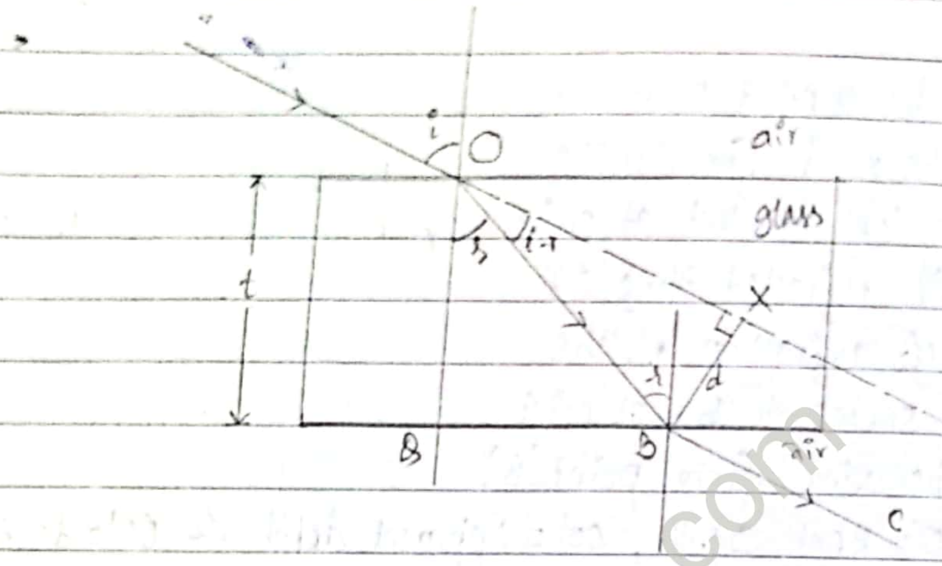

Fig:- Refraction through glass slab

↳ Let us consider a glass slab of thickness 't' where a ray of light incident on its upper face at angle of incidence 'i' along AO and gets refracted along OB inside the slab at angle of refraction 'r' and finally emerges out from the lower face along BC at angle of emergence 'e'. Also, Let $BX = d$ be the lateral shift.

Now, from ΔOQB,

$$\cos r = \frac{OQ}{OB} = \frac{t}{OB}$$

$$\Rightarrow OB = \frac{t}{\cos r} \quad \text{---(i)}$$

Also, from ΔOBX,

$$\sin(i-r) = \frac{BX}{OB} = \frac{d}{OB}$$

or, $d = OB \sin(i-r)$

or, $d = \frac{t}{\cos r} \sin(i-r)$ [Using (i)]

$$\Rightarrow \boxed{\text{Lateral shift}(d) = \frac{t}{\cos r} \sin(i-r)}$$

This is required expression.

When, $i = 90°$

Then,

$$BX = d = \frac{t \sin(90° - r)}{\cos r}$$

or, $d = \frac{t \cos r}{\cos r}$

$$\Rightarrow \boxed{d = t}$$

This shows that when light incident at angle of 90° then lateral shift is equal to the thickness of glass slab.

Total internal Reflection & Critical angle:-

★ Condition for total internal reflection:-

1) Object must be in denser medium.
2) Angle of incidence must be greater than the critical angle. i.e. $i > c$

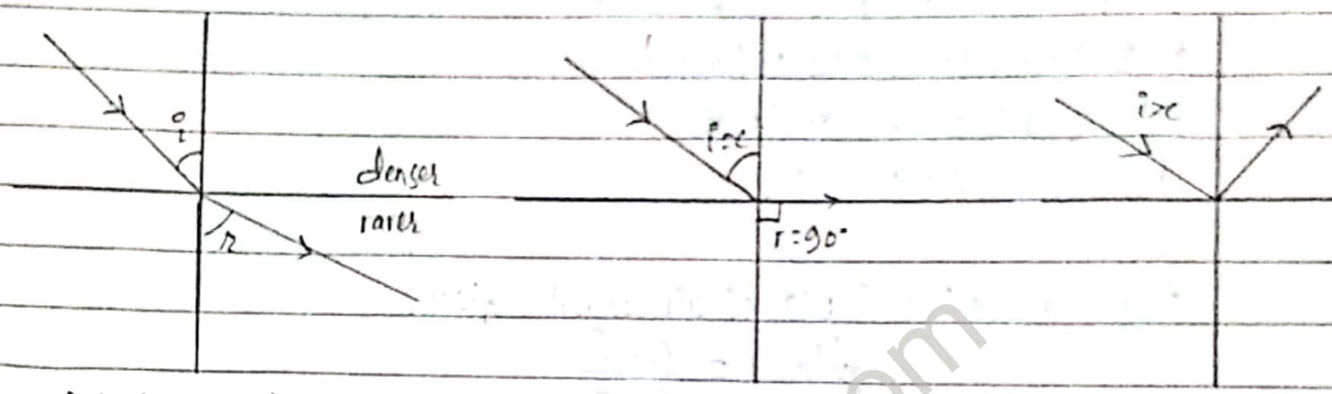

Fig:- Refraction of light from denser to rarer

Fig:- Critical angle

Fig: Total internal reflection.

↳ When light travels from denser medium to rarer medium it bends away from normal on increasing the angle of incidence the angle of refraction also increased and at a particular angle of incidence the angle of refraction becomes 90°. The angle of incidence in denser medium for which the angle of refraction in rarer medium is 90° is called critical angle 'c' of that medium. When the angle of incidence is further increased beyond the critical angle the ray of light returns the same medium, called total internal reflection.

Relation between 'μ' & 'c':-

Let us consider, Glass-air medium in which a light ray AB incident at point 'B' on glass with angle of incident $i=c$ and refracted along BC with angle of refraction $r=90°$.

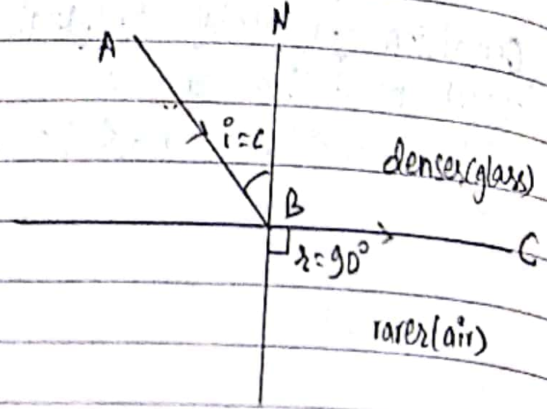

Fig:- Critical angle

Then, refractive index of air w.r.t. glass;

$${}_g\mu_a = \frac{\sin i}{\sin r}$$

$${}_g\mu_a = \frac{\sin c}{\sin 90°}$$

$$\Rightarrow {}_g\mu_a = \sin c \quad \text{——(i)}$$

Also, $${}_a\mu_g = \frac{1}{{}_g\mu_a}$$

$$\therefore \boxed{{}_a\mu_g = \frac{1}{\sin c}} \quad \text{——(ii)}$$

OR, $$\boxed{\mu = \frac{1}{\sin c}}$$

This is required relation between refractive index & critical angle.