

Refraction at plane Surface

- Refraction of light

When a light travels in a One medium it always follow a straight path but, when it moves from one medium to another, its path changes.

The phenomenon of bending of light

when it travels from one medium to another medium it is called refraction of light.

During refraction of light the velocity & wavelength of a light changes but frequency and energy of light remains constant.

- Refraction at plane surface

OA = Incident Ray

OB = Refracted Ray

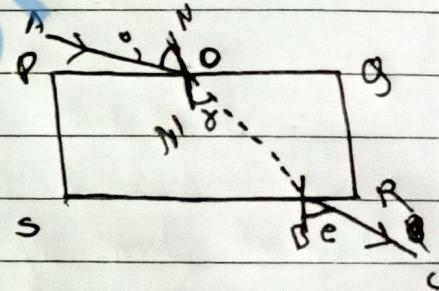
OC = Emergent Ray

NN' = Normal Ray

i° = Angle of incident

r° = Angle of reflection

e° = Angle of emergent



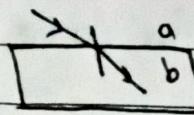
- Principle of law of reflection

(i) The Incident ray, reflected ray and normal ray at the point of incidence always lie on same plane.

II angle or when a ray of light passes through rarer to denser medium it bends towards the normal while the ray of light passing through denser medium to rarer, it bends away from normal.

III The ratio of Sin of the angle of incident to sin of angle of reflection is always constant called refractive index $M = \frac{\sin i}{\sin r}$

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



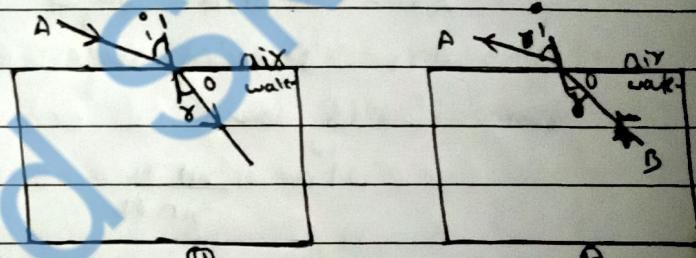
Refractive index of
b with a

⇒ The refractive index of a material is independent of angle of incidence and intensity of light but depends on nature of medium, temperature, wavelength of light.

Principle of Reversibility.

It states that "if the final path of the ray of light is reversed then ray of light trace (travel) the same path"

Suppose a ray of light AO is incident with the angle of incidence



① and got refracted with refracted with angle of reflection ② as shown in figure from Snell's law

$$\text{air } n_{\text{water}} = \frac{\sin i}{\sin r}$$

$$\text{air } n_w = \frac{\sin i}{\sin r} \quad \text{--- ①}$$

If the reflected ray OB is reversed to BO as shown in figure the ray of light retrace same initial path OA as before this is called principle of reversibility So, BO is now incident ray and with the angle of incidence ② & got refracted with angle of refraction i, From Snell's law

$$\text{water } n_{\text{air}} = \frac{\sin r}{\sin i} \quad \text{--- ②}$$

$$\text{air } n_w \times \text{air } n_a = \frac{\sin i}{\sin r} \times \frac{\sin r}{\sin i}$$

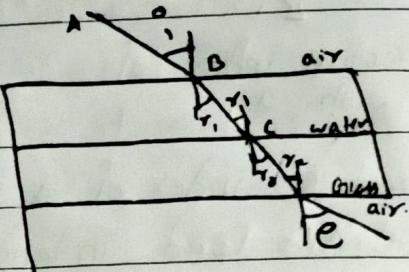
$$\text{air } n_w = \frac{1}{n_a}$$

refractive index for more than two medium

Suppose a ray of light AB incident on a surface of water from air.

Here, $\angle i$ = incident angle

$\angle r_1$ = reflected angle



From Snell's law

$$\mu_{\text{water}} = \frac{\sin i}{\sin r_1}$$

while passing from water to glass

$\angle r_1$ = Incident angle made by BC

$\angle r_2$ = Reflected angle made along normal

From Snell's law

$$\mu_{\text{glass}} = \frac{\sin r_2}{\sin r_3}$$

while passing from glass to air

$\angle r_3$ = Reflected incident angle made by incidence ray

$\angle e$ = angle of emergence

From Snell's law

$$\mu_{\text{air}} = \frac{\sin r_3}{\sin e}$$

now,

$$\mu_{\text{water}} \times \mu_{\text{glass}} \times \mu_{\text{air}} = \frac{\sin i}{\sin r_1} \times \frac{\sin r_2}{\sin r_3} \times \frac{\sin r_3}{\sin e}$$

$$\mu_{\text{water}} \times \mu_{\text{glass}} \times \mu_{\text{air}} = \frac{\sin i}{\sin e}$$

$$\mu_{\text{water}} \times \mu_{\text{glass}} \times \mu_{\text{air}} = 1$$

$$\mu_{\text{glass}} = \frac{1}{\mu_{\text{water}} \times \mu_{\text{air}}}$$

$$\mu_{\text{glass}} = \frac{\mu_{\text{air}}}{\mu_{\text{water}}}$$

Lateral Shift

The ray of light incident on the glass slab, the emergent ray will be parallel to the incident ray. the perpendicular distance between the direction of incident ray with the emergent ray is called lateral shift.

n_b

let us consider a glass slab

PORS with the thickness (d) as shown

in figure suppose a ray of light AB is incident with the angle of incidence (i)

and refracted along the path BC with the angle of refraction (r) and ultimately

it emerges by the path CD which is parallel to direction of incident ray AB. now,

let us draw a perpendicular from C to O which is lateral shift given by the glass slab.

In $\triangle BOC$

$$\angle CBO = i - r$$

$$\sin(i-r) = \frac{CO}{BC} = \frac{d}{BC} \therefore$$

In $\triangle BNC$

$$\cos r = \frac{BN}{BC}$$

$$BC \cos r = \pm \frac{BN}{\cos r}$$

$$\therefore BC \sin(i-r) \cdot d \therefore \text{Substituting the value of } BC \text{ in eqn (1)}$$

$$d = \pm \frac{\sin(i-r)}{\cos r}$$

which is the required expression for lateral shift due to a glass slab. if we plot graph between lateral shift and angle of incidence, we get the :-

Special case :-

when $i = 90^\circ$

$$d = \pm \frac{\sin(90^\circ - r)}{\cos r} = \pm \frac{\cos r}{\cos r} = \pm 1$$

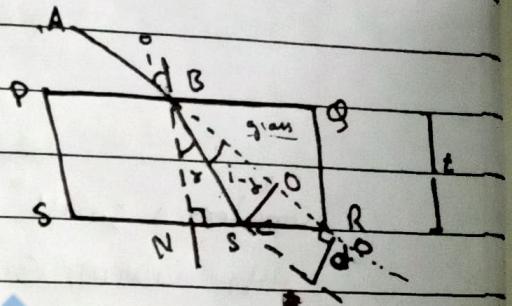
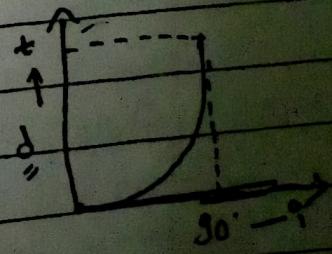


Fig: lateral shift



Real depth or Apparent depth

Consider a small object O at a bottom of a beaker with water. Suppose a light ray OP passes perpendicularly on the surface of water MN and ray $O'P$ bends at P and passes along PQ . Here, the two refracted rays AB and PQ appear to come from a same point O' .

The depth O . The depth AO is real depth

(i) the object and depth AO is apparent depth

In $\triangle OAD$

$$\frac{\sin i}{\sin r} = \frac{AP}{OP} \quad \text{--- (i)}$$

$$\text{In } \triangle OAP : \frac{\sin i}{\sin r} = \frac{AP}{OP} \quad \text{--- (ii)}$$

Dividing eqn (i) & (ii)

$$\frac{\sin i}{\sin r} = \frac{AP}{OP} \times \frac{OP}{AP} = \frac{OP}{AP}$$

Since the value of i and r is very small then $i \approx r$ and $OP \approx OA$,

$$\text{or } \frac{\sin i}{\sin r} = \frac{OA}{OP} \quad \text{--- (iii)}$$

Since, light passes from the denser medium to the rarer medium

$$\frac{1}{n_{r/r}} = \frac{\sin i}{\sin r} \quad \text{and hence, } n_{r/r} = \frac{\sin r}{\sin i} \quad \text{--- (iv)}$$

Equating eqn III & IV

$$\Delta P_w = \frac{GA}{l}$$

$$\text{or } \Delta P_w = \frac{\text{Real depth}}{\text{Apparent depth}}$$

Find that is the apparent position of an object below rectangular block of glass 6cm thick if a layer of water 4cm thick is on the top of glass.

Given, refractive index of glass = $\frac{3}{2}$ ΔP_w
refractive index of water = $\frac{4}{3}$ ΔP_w

For glass (apparent shift)

$$d_1 = l_1 \left(1 - \frac{1}{\Delta P_w}\right)$$

$$= 6 \left(1 - \frac{2}{3}\right) = 2 \text{ cm}$$

For water (apparent shift)

$$d_2 = l_2 \left(1 - \frac{1}{\Delta P_w}\right)$$

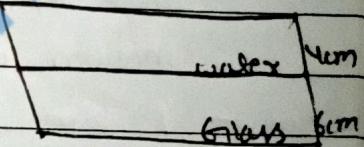
$$= 4 \left(1 - \frac{3}{4}\right)$$

$$= 1$$

Then total shift $- d$ is given by

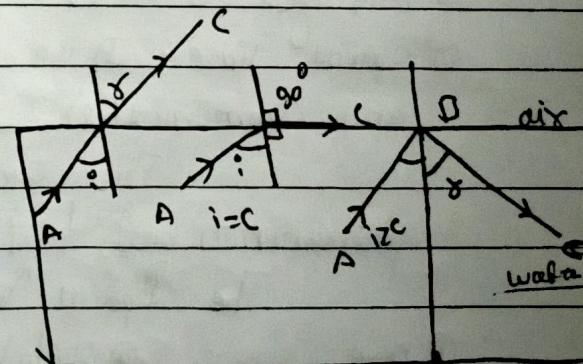
$$d_1 + d_2$$

$$\therefore d = 3 \text{ cm}$$



Total Internal reflection

When a ray of light passes from denser medium to rarer medium, it bends away from normal, thus an Incident ray AB passes from water to air and bends away from normal in the direction of DC.



As we increase the angle of incidence there is a point where for a given angle of incidence, the angle of refraction is exactly 90°. This condition is called Critical Condition. The critical angle is defined as angle of incidence for which the angle of refraction is 90°.

Given a ray of light passes from denser to rarer medium at an angle of incidence of 45°, then the angle of refraction will be 60°.

For a critical condition,
 $i = c$. & $r = 90^\circ$

then,

$$n_1^M n_2 = \frac{\sin r}{\sin i}$$

$$\therefore n_1^M n_2 = \frac{\sin r}{\sin i}$$

$$n_1^M n_2 = \frac{\sin 90^\circ}{\sin c} = n_1^M n_2 = \frac{1}{\sin c}$$

If we increase the angle of incidence greater than critical angle then the refracted ray of light returns to same medium which is known as total internal reflection.

Condition for total internal reflection

- ① The ray of light must be travelling from denser medium to rarer medium
- ② The angle of incidence must be greater than critical angle

Some application of total internal reflection

① Mirage

② Optical fibre:- It is a device which is used to transmit light and communication signal through total internal reflection.

The working of optical fibre is based on the phenomenon of total internal reflection

The optical fibre consists of two parts

① Core ② Cladding ③ Coating

① Core:- The central cylindrical core is made up of high quality glass of refractive index of $n_1 = 1$ and has diameter about 10 to 100 micrometer.

② Cladding:- The core is surrounded by a glass of refractive index n_2 ($n_2 < n_1$) in typical optical fibre the refractive index of core is greater than cladding