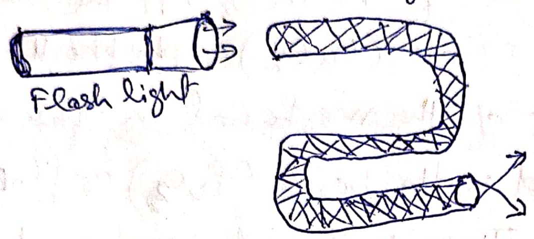
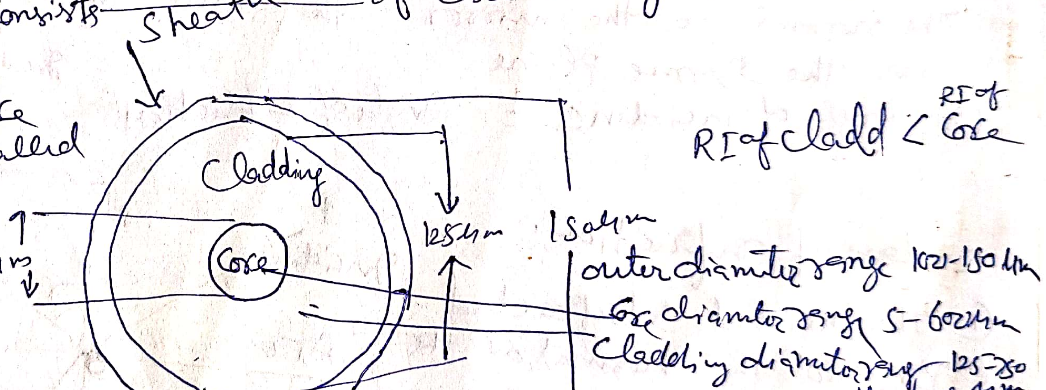
OPTICAL FIBER :→

Optical fibers are glass or plastic pipes which is thin as human hairs, that guide light waves through them.
optical fiber work on the principle of Total Internal Reflection (TIR).
when light enters into the optical fiber, it undergoes successive total internal reflections from side walls and travels down the length of the fiber along a Zig-Zag path.



when light travels from one end to the other end of the fiber, there is very small loss of light through the side walls.

→ optical fiber consists of essentially three regions.
→ Centre region is known as the Core
→ Middle region is called Cladding.
→ The outer region is a protective sheath.



RI of cladd < RI of Core

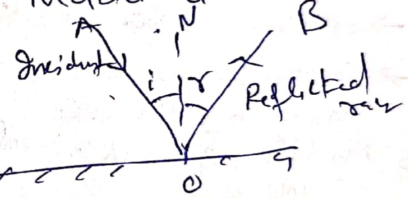
→ The refractive index of cladding is always lower than that of the Core. So cladding keeps the light waves with in the Core.
→ The cladding also provides some strength to the Core.
→ The outer protective sheath protects the cladding and Core from abrasions (friction), contamination and moisture.

Fabrication. Optical fibers are fabricated by glass or plastic. which are transparent to optical frequencies.
with these materials three major types of fiber are made -
(i) Plastic Core with plastic cladding.
(ii) Glass Core with plastic cladding
(iii) Glass Core with Glass Cladding.

→ In the Case of plastics, the Core can be polystyrene or polymethyl meta acrylate (PMMA), The cladding is generally silicon or teflon. The glass is made of Silica (SiO_2). It has refractive index of 1.458 at $\lambda = 8500 A^{\circ}$. Small amounts of Components such as boron, germanium or phosphorous is added to change the refractive index of the fiber. If the basic silica material is doped with germania (GeO_2) or phosphorous pentoxide (P_2O_5). The refractive index of the material in these cases. When pure silica is doped with boria (B_2O_3) or fluorine, its refractive index decreases. These materials are used for cladding when pure silica is used as Core material.

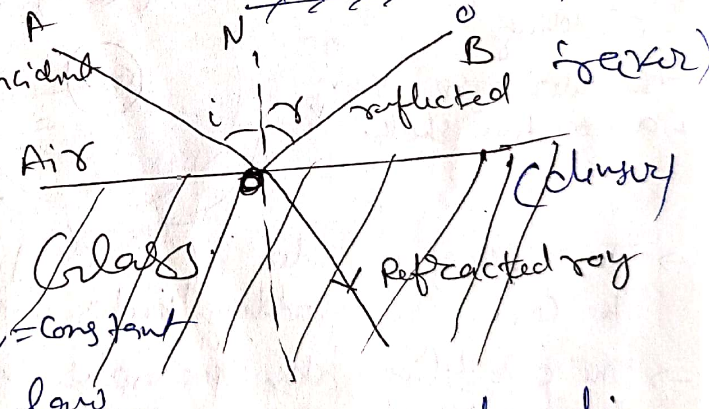
PROPAGATION MECHANISM –

1- **Basic laws of Optics** – Law of reflection: (a) Reflected ray, incident ray and The normal to the mirror at the point of incidence all lie in the same plane



(b) Angle of incidence = Angle of reflection

2- Law of refraction:



(1) The incident and refracted rays, and the normal at the point of incidence, all lie in the same plane

(2) for two given media, $\frac{\sin i}{\sin r}$ = Constant

This is also known as Snell's law.

The Constant is called refractive index of the second medium with respect to first and is denoted by

$$ {}_1n_2 = \frac{\sin i}{\sin r} $$

The medium, in which light is refracted, is called optically denser if its refractive index with respect to other is more than unity.

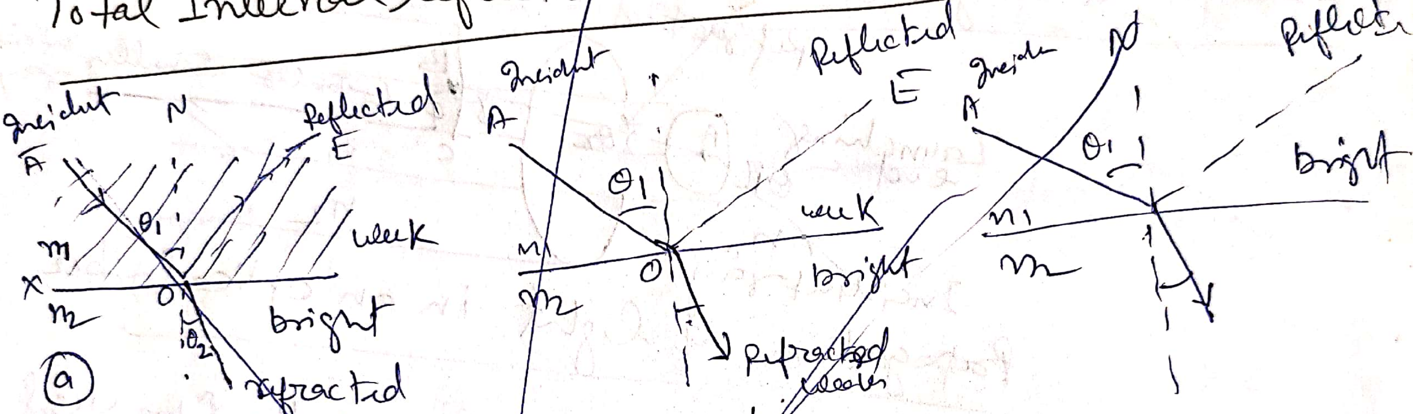
- if $n > 1$ then $i > r$ or (refracted ray will bend towards the normal.
- If the medium is rarer, its refractive index is less than unity. If $n < 1$ then $i < r$ or we say that in this Case refracted ray will go away from the normal.

→ Light is refracted because it has different velocities in different media. According to wave theory of light, the refractive index, ${}_1n_2$ for two given media 1 and 2 given by

$${}_1n_2 = \frac{\text{velocity of light in medium (1)}}{\text{velocity of light in medium (2)}}$$

or $$n = \frac{\text{velocity of light in vaccum}}{\text{velocity of light in medium}} = \frac{c}{v}$$

Total Internal reflection and critical Angle –



ⓐ most of the incident light energy is transmitted and a little is reflected

ⓑ when the angle of incidence (θ_i) in denser medium is increased, the angle of emergence (θ_r) is increased, at the same time, angle of incidence in the denser medium.

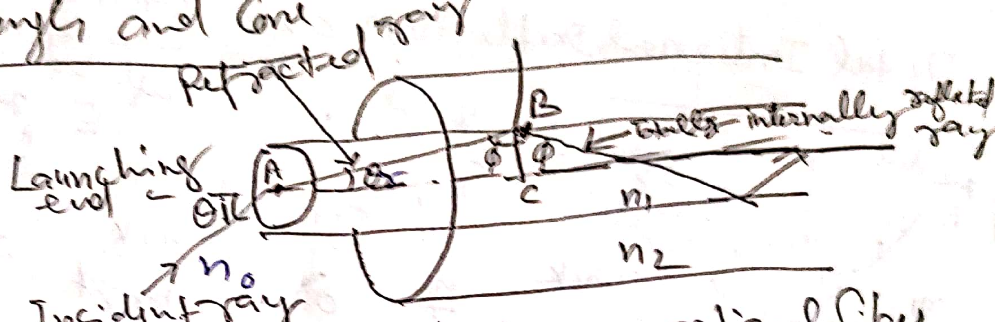
When the angle of refraction in rare medium is 90° a critical angle is reached at the point of incidence O. The angle of incidence in the denser medium are is accordingly known as the critical angle and denoted by θ_c.

In this position the R.I. of the rarer medium with respect to the denser medium $\frac{n_2}{n_1} = {}_1n_2 = \frac{\sin i}{\sin r} = \frac{\sin\theta_c}{\sin 90°} = \sin\theta_c$

Total internal reflection is keeps light inside an optical fiber. Without TIR we could not use optical fiber as a light guide over a long distance.

"When light travels from a medium with a higher refractive index to a medium with a lower refractive index and it strikes a boundary at more than the critical angle, all light will be reflected back to the incident medium" meaning it will not penetrate the second medium. This phenomenon is called total internal reflection (TIR).

Acceptance angle and Cone



Propagation of light in an optical fiber

Applying Snell's law to the launching face of the fiber we get

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0} \quad \text{— (1)}$$

Now largest value of θ_i occurs when $\phi = \theta_c$

From ΔABC we have, $\sin\theta_r = \sin(90^\circ - \phi) = \cos\phi$

from eq (1) we have

$$\sin\theta_i = \sin\theta_r \frac{n_1}{n_0} = \frac{n_1}{n_0}\cos\phi$$

When $\phi = \theta_c$, $\theta_i = \theta_{max}$

$$\sin\theta_{max} = \frac{n_1}{n_0}\cos\phi \quad \text{— (2)}$$

But $\sin\phi_c = \frac{n_2}{n_1}$ so $\cos\phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$ — (3)

Putting the $\cos\phi_c$ in eq (2)

$$\sin\theta_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \quad \text{— (4)}$$

if $(n_2^2 - n_1^2) \geq n_r^2$, then for all values of θ_i, TIR will occur.

→ Assuming $n_0 = 1$ the maximum value of θ_i for a ray to be guided is given by

$$\sin\theta_m = \sqrt{n_1^2 - n_2^2}$$

$$\theta_m = \sin^{-1}\sqrt{n_1^2 - n_2^2} \quad \text{— (5)}$$

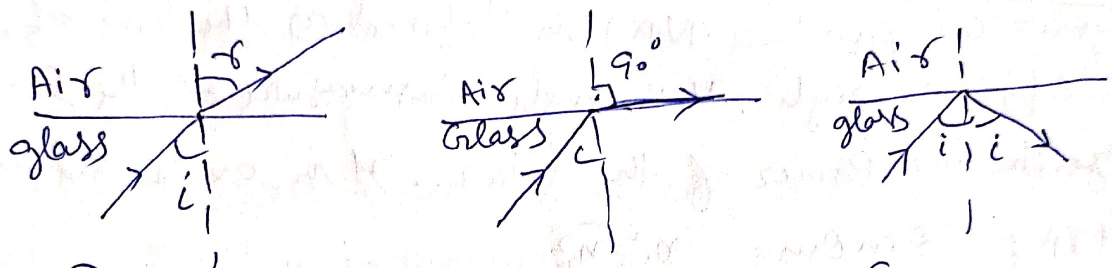
θ_m is called acceptance angle of the fiber.

"The maximum angle that a light ray can have relative to the axis of the fiber and propagate down the fiber."

"The light rays contained within the cone having a full angle $2\theta_m$ are accepted and transmitted along the fiber; this cone is therefore known as acceptance cone".

Critical angle and Total internal reflection

The Critical angle for two given media is the angle of incidence in the denser medium for which the angle of refraction in the rarer medium is 90°.
- Its value depend upon the nature of the two medium and the colour of light.
- For glass-air interface, the Critical angle for the visible mean light is about 42°.



(a) $i < c$ (b) $i = c$ (c) $i > c$

TIR.

When a ray of light travelling from a denser medium to a rarer medium, is incident at the interface of the two medium at an angle greater than the critical angle for the two media, ray is totally reflected back into the denser medium.
- So there are two Conditions to be fullfilled for total internal reflection to occur -
(i) The ray of incident on the interface of two media should travel in the denser medium.
(ii) The angle of inciding should be greater than the critical angle for two media.

→ 1 is represented as rare medium and 2 is denser medium

then $_2n_1 = \frac{\sin c}{\sin 90°} = \sin c$ $[\because \sin 90° = 1]$

or $_1n_2 = \frac{1}{\sin c} = \frac{\text{velocity of light in air}}{\text{velocity of light in air}} = \text{ang.}$

Fractional Refractive Index change -

This parameter is defined as the ratio of the difference between the refractive indices of the core and the cladding to the refractive index of core. It is denoted by Δ and expressed as

$$\Delta = \frac{n_1 - n_2}{n_1} \quad (6)$$

Numerical Aperture -

Numerical Aperture (NA) is defined as the sine of the acceptance angle. This angle is a measure of the light gathering power of the fiber. It is expressed as—

$$NA = \sin\theta_m = \sqrt{n_1^2 - n_2^2}$$

$$NA = \sqrt{n_1^2 - n_2^2} = n_1\sqrt{2\Delta} \quad (7)$$

Note

$$n_1^2 - n_2^2 = (n_1 + n_2)(n_1 - n_2) = \left(\frac{n_1 + n_2}{2}\right)\left(\frac{n_1 - n_2}{n_1}\right) n_1$$

Let $\frac{n_1 + n_2}{2} = n_1$ so $n_1^2 - n_2^2 = 2 n_1^2 \Delta$

(06)

① Calculate the numerical aperture and hence the acceptance angle for an optical fiber given that refractive indices of the core and cladding are 1.45 and 1.40 respectively.

→ Numerical aperture (NA) = $\sqrt{n_1^2 - n_2^2}$

given $n_1 = 1.45$, $n_2 = 1.40$

so $NA = \sqrt{(1.45)^2 - (1.40)^2} = \sqrt{.1425} = .3775$

Acceptance angle →

$\theta_m = \sin^{-1}[\sqrt{n_1^2 - n_2^2}] = \sin^{-1}(NA) = \sin^{-1}(.3775)$

$= 22.18°$

② A glass clad fiber is made with core glass of refractive index 1.5 and the cladding is doped to give a fractional index difference of .0005.

Find – (a) The cladding index
(b) The critical internal reflection angle
(c) The external critical acceptance angle
(d) The numerical aperture.

→ given. $n_1 = 1.5$ and $\Delta = .0005$

(a) if n_2 is R.I. of cladding.

$\Delta = \frac{n_1 - n_2}{n_1} \Rightarrow .0005 = \frac{1.5 - n_2}{1.5}$

$n_2 = 1.5 - 1.5 \times .0005 = 1.49925$

(b) Let ϕ_c is the critical internal reflection angle

$\sin\phi_c = \frac{n_2}{n_1} \Rightarrow \theta_c = \sin^{-1}\left[\frac{n_2}{n_1}\right] = \sin^{-1}\left[\frac{1.49925}{1.5}\right]$

$= \sin^{-1}(.9995)$

$= 88.20$

(c) Let θ_m be the external critical acceptance angle

$$\sin\theta_m = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \quad \text{where } n_0 = 1$$

$$\theta_m = \sin^{-1}\left[\sqrt{n_1^2 - n_2^2}\right] = \sin^{-1}\sqrt{\left[(1.5)^2 - (1.49925)^2\right]}$$

$$= \sin^{-1}(.0474) = 2.72^0$$

(d) Numerical Aperture

$$NA = n_1\sqrt{2\Delta} = 1.5\sqrt{2 \times .0005} = .0474$$

(3) An optical fiber is made of glass with a refractive index of 1.55 and is clad with another glass with a refractive index of 1.51, Launching takes place from air.

(a) What numerical aperture does the fiber have?

(b) what is acceptance angle?

(a) fractional index difference or normalised difference between the indices is

$$\Delta = \frac{n_1 - n_2}{n_1} = \frac{1.55 - 1.51}{1.55} = 0.0258$$

Numerical aperture (NA) $= n_1\sqrt{2\Delta} = 1.55\sqrt{2 \times .0258}$

$= .352$

(b) The acceptance angle is

$$\theta_m = \sin^{-1}(NA) = \sin^{-1}(0.352)$$

$= 20.6$