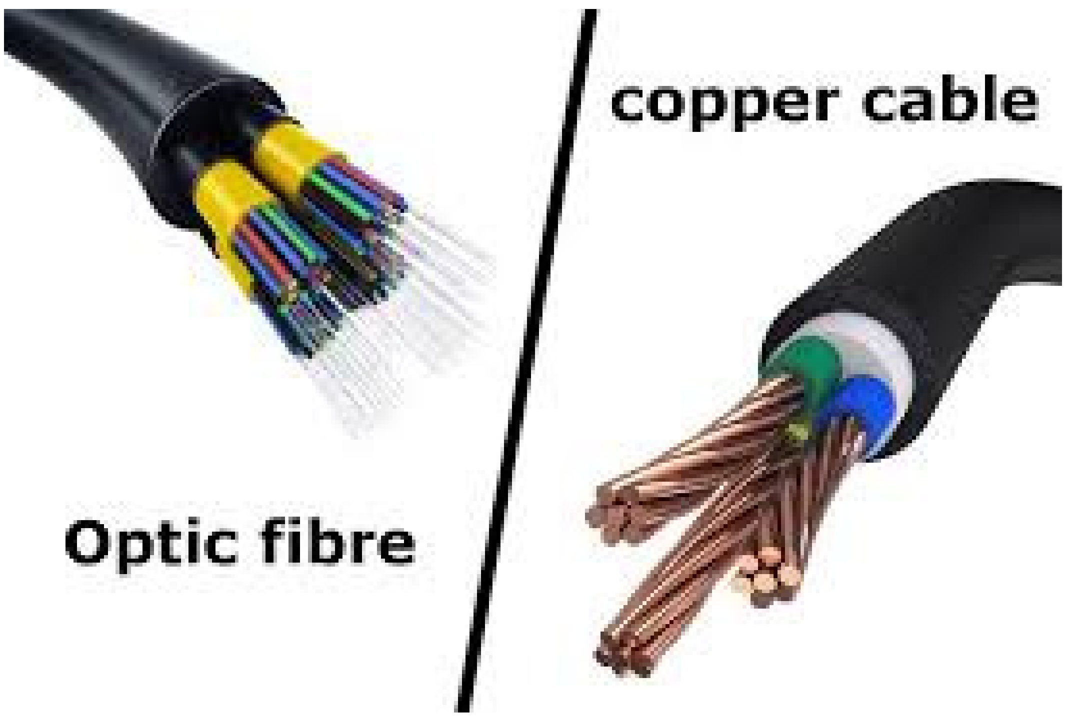
PHY109 UNIT III: Fiber optics

LECTURE 1



Continues Assessment (CA)

- CA1 : UNIT 1 and UNIT 2
- On 12th September 2018.. Next Wednesday
- 6 questions each carry 5 marks

FIBER OPTICS

We can't live without the **INTERNET**, and hence we can't live without **OPTICAL FIBER** and we didn't even know it☺

How many km of fiber optic cables are used in LPU for networking ??

Do You Know

Lovely Professional University has 70 Km of fibre optic cable throughout the campus which acts as a backbone for the network.

Understand fiber optics and why they are important- We will learn in this UNIT III

Historical Developments

- 1870 John Tyndall guided light through water air interface
- 1950Hopkins and Kanani realized transmission of images through optical fiber. It was Kanani coined the name Fiber Optics
- 1960 light transmitted through glass.. But that glass was lossy
- 1966 Kao and Hockham proposed information transmission over fiber
- 1970 Corning Glass developed low loss optical fiber transmission lines

FIBER OPTICS

"Fiber optics is a technology in which electrical signal is converted to optical signals and transmitted through fibers and reconverted back into electrical signals"

1977- Commercial communication system based on Optical fibers came into existence based on the proposed information transmission over glass fiber by Charles Kao (2009 Nobel Prize winner) and George Hockham.

- LASER diode and LED revolutionized the communication sector, which was dominated by Microwave and Radio waves as the carrier waves for sending information..
- Use of light as carrier wave improved the bandwidth considerably

UNIT III: Fiber optics

Syllabus

Fiber optics introduction, optical fiber as a dielectric wave guide, total internal reflection, acceptance angle, numerical aperture, relative refractive index, V-number, step index and graded index fibers, losses associated with optical fibers, application of optical fibers.

So it is all about basics of Fiber Optics and its application..
Not a big business.. Very simple for us☺

Quick QUIZ

Quick Quiz Response on the 9/06/2018 Lecture

No	Question	Attempts	Right	Wrong
1	Which of the following is a unique property of laser?			
2	Which of the following is an example of optical pumping?			
3	The image produced by holography is			
4	Hologram contains the information about			
5	Hologram is the result of			

. Which of the following is a unique property of laser?

a) Directional
b) Speed
c) Coherence
d) Wavelength

Ans: C

Which of the following is an example of optical pumping?

a) Ruby laser
b) Helium-Neon laser
c) Semiconductor laser
d) Dye laser

Ans: A

The image produced by holography is

(a)One dimensional
(b)Two dimensional
(c)Three dimensional
(d)None of these

Ans: C

Hologram contains the information about

(a)Amplitude of the object
(b)Phase of the object
(c)Both amplitude and phase of the object

Ans: C

Hologram is the result of

(a)interference of object and reference beam
(b)polarization of the object and reference beam
(c)diffraction of the object and reference beam
(d)both (a) and (b)

Ans: A

Fiber optics

Lecture 1: ***Fiber optics introduction, optical fibers, Total internal reflection, acceptance angle, relative refractive index numerical aperture,***

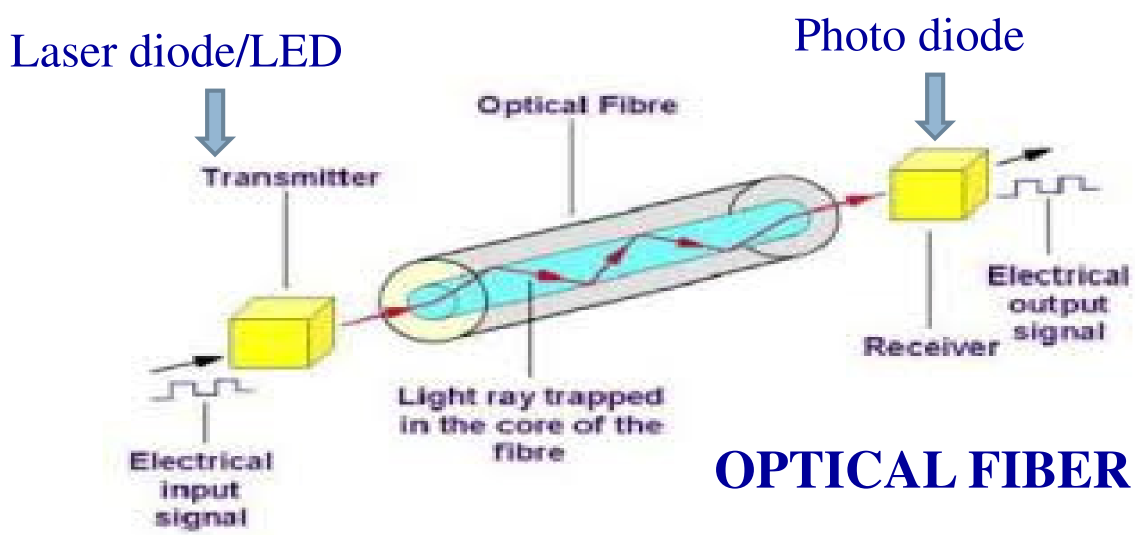
Lecture 2:***Classification of fibers, Step index and graded index fibers, V-number, optical fiber as a dielectric wave guide and modes of propagation;***

Learn fundamentals of optical fiber, the fundamental parameters of optical fibers and propagation of light through optical fiber, learned about the types of fibers

Lecture 3: ***Losses associated with optical fibers; Application of optical fibers;***

learn the reason for data loss. Learn about the applications,… endoscopy

Optical Fiber System

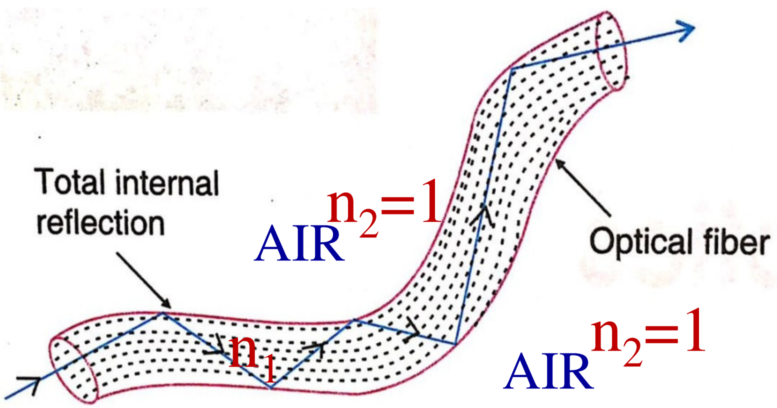


OPTICAL FIBER SYSTEM

"Fiber optics is a technology in which electrical signal is converted to optical signals and transmitted through fibers and reconverted back into electrical signals"

Optical Fiber

An **optical fiber** is a thin strand of **dielectric** material (glass or plastic) that can carry light from one end to the other,



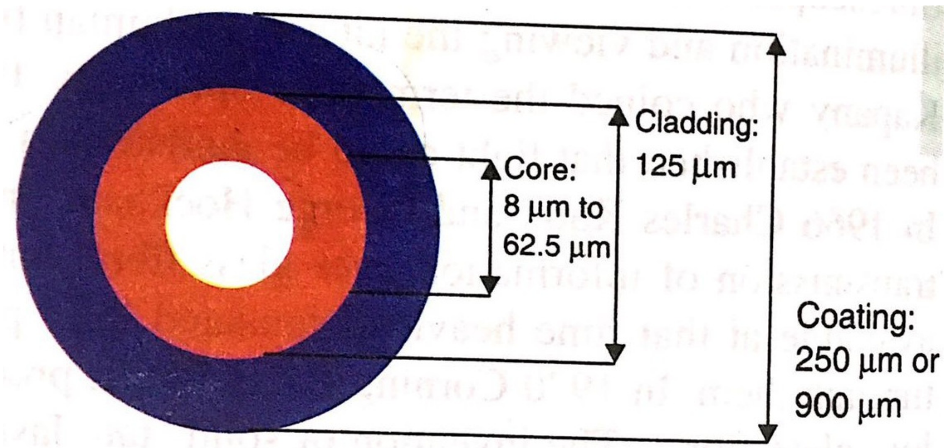
- Light undergoes total internal reflection ($n_1>n_2$)
- Zig-Zag path
- Launching /acceptance angle
- Small attenuation
- Will travel over the bends as well

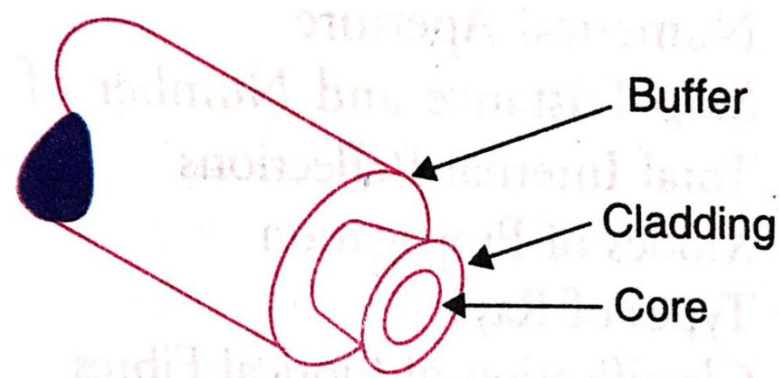
Thin strand of **dielectric** material we call fiber (*transmission of light*) *where as* if it is of **metal** we call it a wire (*transmission of electrical signal*)

Optical Fiber

Structure:

Human hair thickness ~ 100µm





1. Core - *Light guiding region*
2. Cladding- *confine the light to the core*
3. Buffer or Sheath - *protect the fiber from physical and environmental damage*

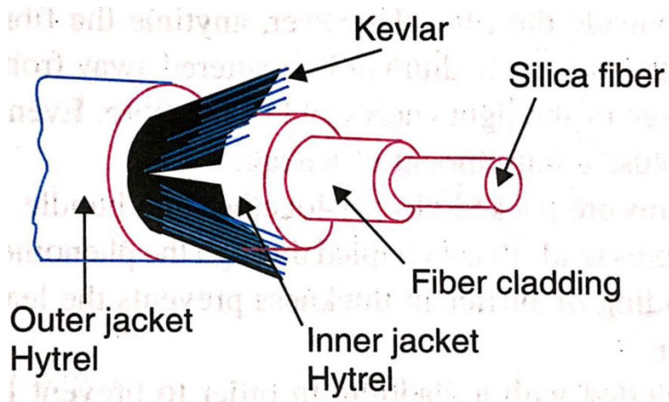
Functions of *'Cladding'* in Optical fiber

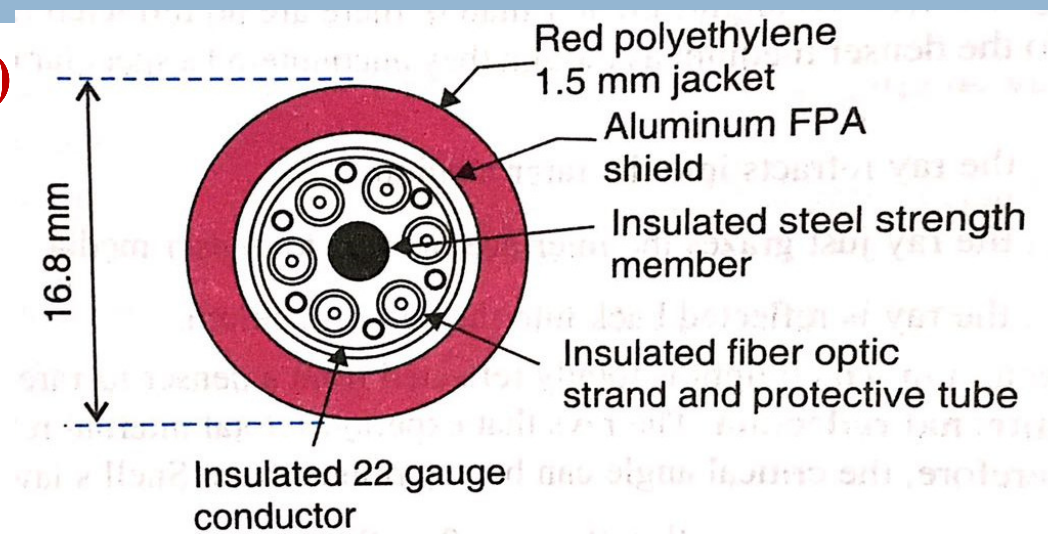
Why cladding is necessary?

i. *To maintain the uniformity along the length of the fiber*
   a) *Make the diameter of the core remain constant and ensure same medium around the core*
ii. *To protect the outer surface of the core*
   a) *Ensure a scratch and dust free core surface along with immunity for environmental changes and physical damage (chipping).. Loss reduced*
   b) *Easier to add other protective layers over the fiber*
iii. *To reduce the cone of the light*
   a) *Ensure higher bit rate of transmission*
iv. *To confine light to the core*
   a) *Make sure the condition for total internal reflection always met along the length; maintain the signal strength*
   b) *Allows to pack the fibers in bundles by insulating it from other fibers in close proximity.*

OPTICAL FIBER CABLE

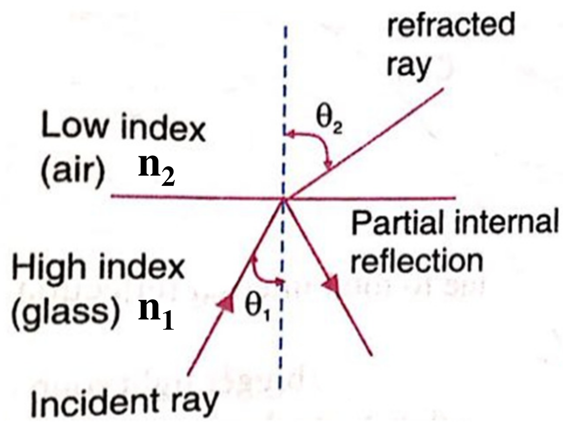
Single Fiber cable (side view)





Multi Fiber cable (cross section)

Total Internal Reflection



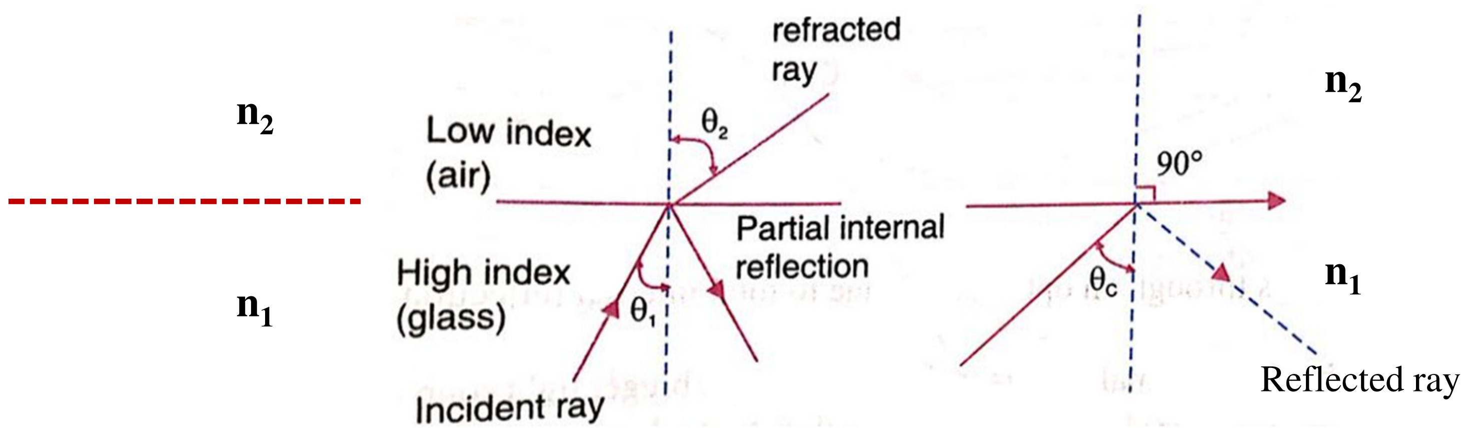
Rarer medium $n_2 < n_1$

Denser medium $n_1 > n_2$

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \quad \text{-------------------------------- Eq.1}$$

When a ray of light incident on the interface from a denser medium, the refracted ray bend away from the normal in the rarer medium. In that case the angle of incidence and refraction are related to refractive indices n_1 (denser medium) and n_2 (rarer medium) **through Snell's law**

Total Internal Reflection

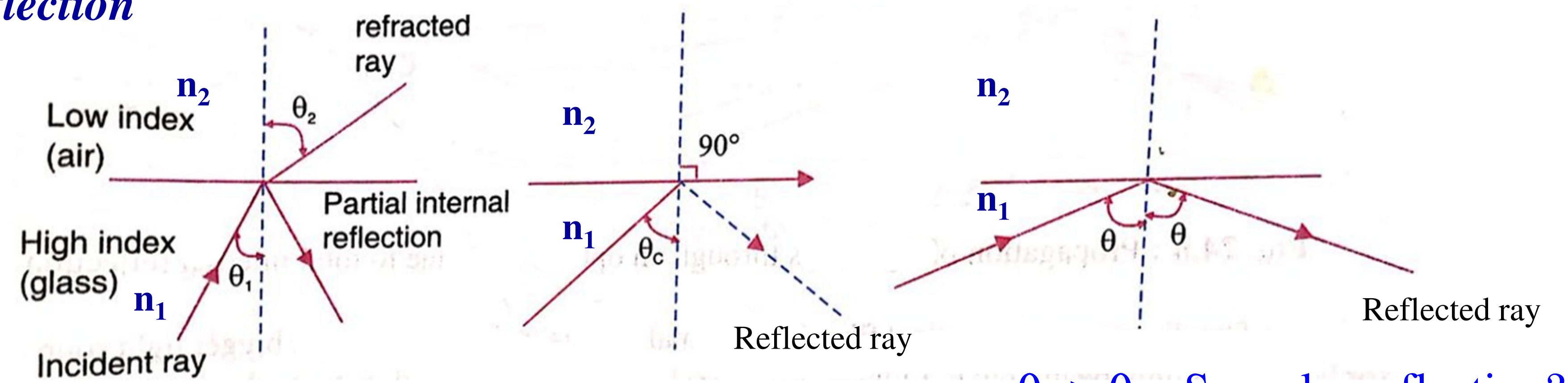


According to Eq.1, as incident angle (θ_1) increases refracted angle (θ_2) also increases

- ✓ Means refracted ray move more and more away from the normal
- ✓ When θ_1 becomes θ_c , (critical angle)refracted ray just glide the interface θ_2 =90°

Total Internal Reflection

In the third case, when incident angle $\theta_1 > \theta_c$ there is no refracted ray into rarer medium. The ray is reflected back to denser medium as if it encountered ***specular reflection***



$\theta_1 > \theta_c$; Specular reflection?

To summarize

i. $\theta_1 < \theta_{c\,,}$ Ray of light refract to rarer medium

ii. $\theta_1 = \theta_{c.}$ Ray of light grazes the interface of rare-denser medium

iii. $\theta_1 > \theta_{c,}$ Ray of light totally reflect back into denser medium

Total Internal Reflection

The phenomena in which light is totally reflected back to denser medium at the denser-rarer boundary is known as TOTAL INTERNAL REFLECTION.

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \quad \text{-------------------------------- Eq.1}$$

Critical angle can be obtained from Eq.1

$\theta_1 = \theta_c$; **$\theta_2 = 90°$**

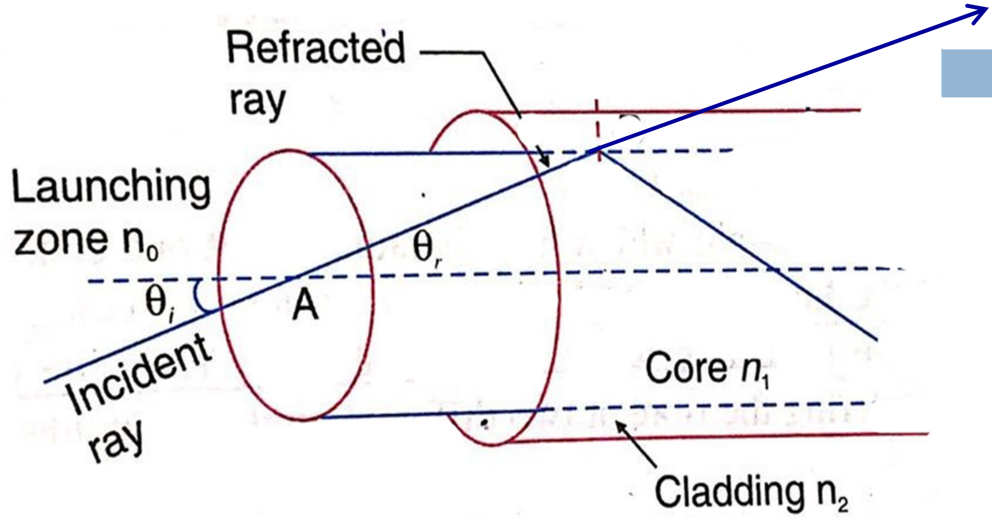
$$\sin\theta_c = \frac{n_2}{n_1} \quad \text{------------------ Eq.1a}$$

Later we use ϕ for θ

If the rarer medium is air n_2=1

$$\sin\theta_c = \frac{1}{n_1} \quad \text{or} \quad \theta_c = \sin^{-1}\left(\frac{1}{n_1}\right) \quad \text{------------------ Eq.2}$$

Acceptance Angle



Case 1: Refraction at A

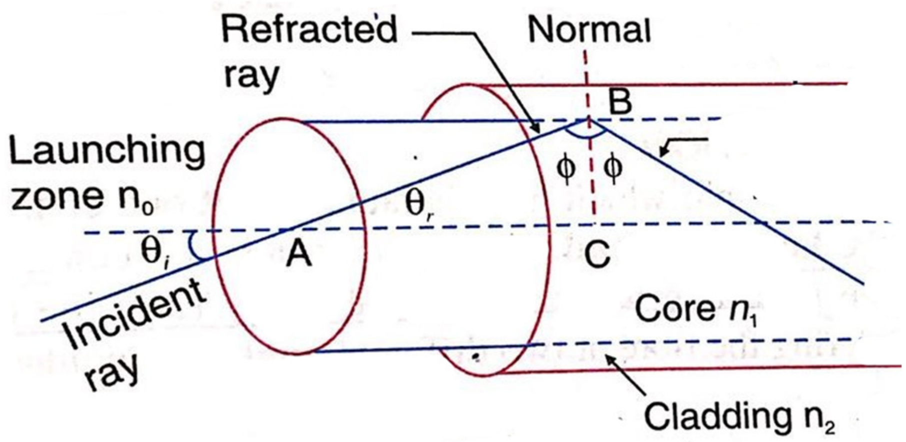
Incident ray from launching medium having the refractive index n_0 → refracted into the core having refractive index n_1 , according to the Snell's law…

$$n_1 \sin\theta_r = n_0 \sin\theta_i \qquad \text{------------------ Eq.3}$$

Acceptance Angle

Case 2: Refracted ray incident on interface

Refracted ray in the core (n_1) now incident on the core-cladding interface at an angle (ϕ),



From the triangle ABC

$\theta_r = 90 - \phi$ -------- Eq.4

substitute Eq.4 Eq.3

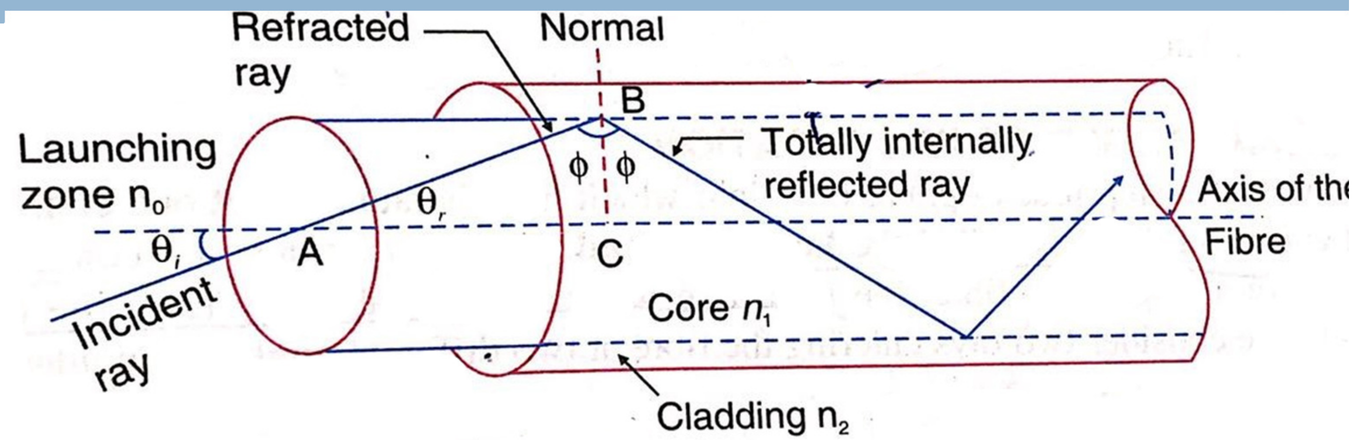
$$n_1 \sin(90 - \phi) = n_0 \sin\theta_i$$

$$n_1 \cos\phi = n_0 \sin\theta_i$$

$$\mathrm{Sin}\theta_i = \frac{n_1}{n_0}\cos\phi$$ -------- Eq.5

Acceptance Angle

Case3: Total internal reflection at B



When $\phi=\phi_c$ total internal reflection occurs at B, that set the maximum allowable launching angle, θ_{imax} , equation 5 changes to

$$\text{Sin}\ \theta_{imax} = \frac{n_1}{n_0}\cos\phi_c \qquad \text{-------- Eq.6}$$

But from Eq.1a

$$\sin\phi_c = \frac{n_2}{n_1} \qquad \text{-------- Eq.7}$$

Acceptance Angle

$\cos^2\phi_c + \sin^2\phi_c = 1$ substitute for $\sin^2\phi_c$ from Eq.7

$$\cos^2\phi_c + \left(\frac{n_2}{n_1}\right)^2 = 1$$

$$\cos^2\phi_c = \frac{n_1^2 - n_2^2}{n_1^2}$$ Or $$\cos\phi_c = \frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$ -------- Eq.8

substitute Eq.8 in Eq.6

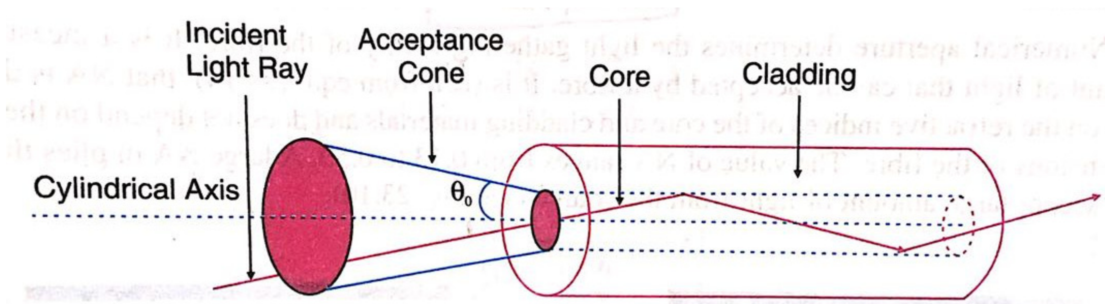
$$\mathrm{Sin}\ \theta_{imax} = \frac{n_1}{n_0}\frac{\sqrt{n_1^2 - n_2^2}}{n_1}$$ For launching from air $n_0=1$

$$\mathrm{Sin}\ \theta_{imax} = \sqrt{n_1^2 - n_2^2}$$ $$\theta_{imax} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$ -------- Eq.9

θ_{imax} is the acceptance angle of the fiber.

Acceptance Cone

We know in 2D, θ_{imax} is the acceptance angle- and is with axis of the fiber



If you consider 3D, instead of angle it is the **cone (solid angle)**, and hence called **acceptance cone.**

- Larger the θ_{imax} easier to launch light into the fiber
- Incident at an more than θ_{imax} refract through the cladding and lost

Relative Refractive Index

The fractional difference between the refractive indices of the core and the cladding *is relative refractive index or the fractional refractive index difference*

$$\Delta = \frac{n_1 - n_2}{n_1} \qquad \text{-------- Eq.10}$$

- Δ is always positive because $n_1 > n_2$.
- Typically value of Δ is the order of 0.01
- For effective light transmission through the fiber, $\Delta \ll 1$.

Numerical aperture

Light gathering ability of the fiber depends on the numerical aperture , NA and is defined as the sine of the acceptance angle θ_{imax}

$$NA = sin\theta_{imax}$$

$$\theta_{imax} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

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

-------- Eq.11

NA is also related to the relative refractive index Δ

$$NA = n_1\sqrt{2\Delta}$$

How? We will see now!

Numerical aperture

Numerical aperture can also be expressed in terms of relative refractive , Δ

$$(NA)^2 = n_1^2 - n_2^2 = (n_1 - n_2)(n_1 + n_2)$$

Multiply and divide with $2n_1$

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

Approximating $(n_1+n_2)/2 \sim n_1$ and eq.10

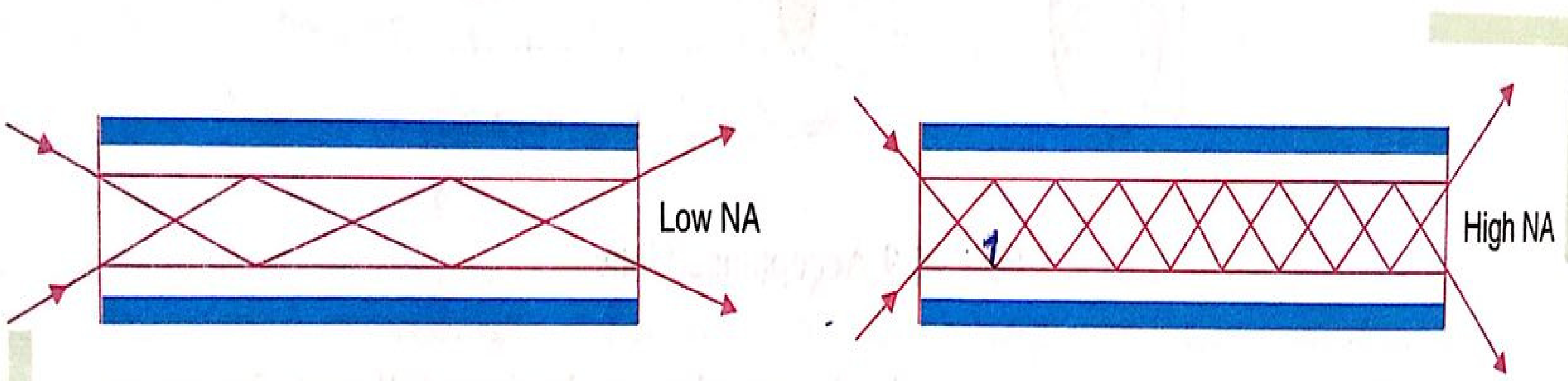
$$= 2\, n_1^2 \Delta$$

That is $$NA = n_1 \sqrt{2\Delta}$$

- Depends only on the refractive indices of the core and cladding.
- Independent of the dimension of the fiber

Numerical aperture

- Measure of the light gathering ability of the fiber
- Depends only on the refractive indices of the core and cladding.
- Independent of the dimension of the fiber
- Typical values are in the range 0.13 to 0.50



High NA means fiber accept large amount of light from the source and propagate it

Quick Quiz

What is the principle of fiber optical communication?

a) Frequency modulation

b) Population inversion

c) Total internal reflection

d) Doppler Effect

What is the other name for maximum external incident angle?

a)Optical angle

b)Total internal reflection angle

c)Refraction angle

d) Wave guide acceptance angle

A Fiber optic telephone transmission can handle more than thousands of voice channels. True or false?

(a) True
(b) False

Fiber optics

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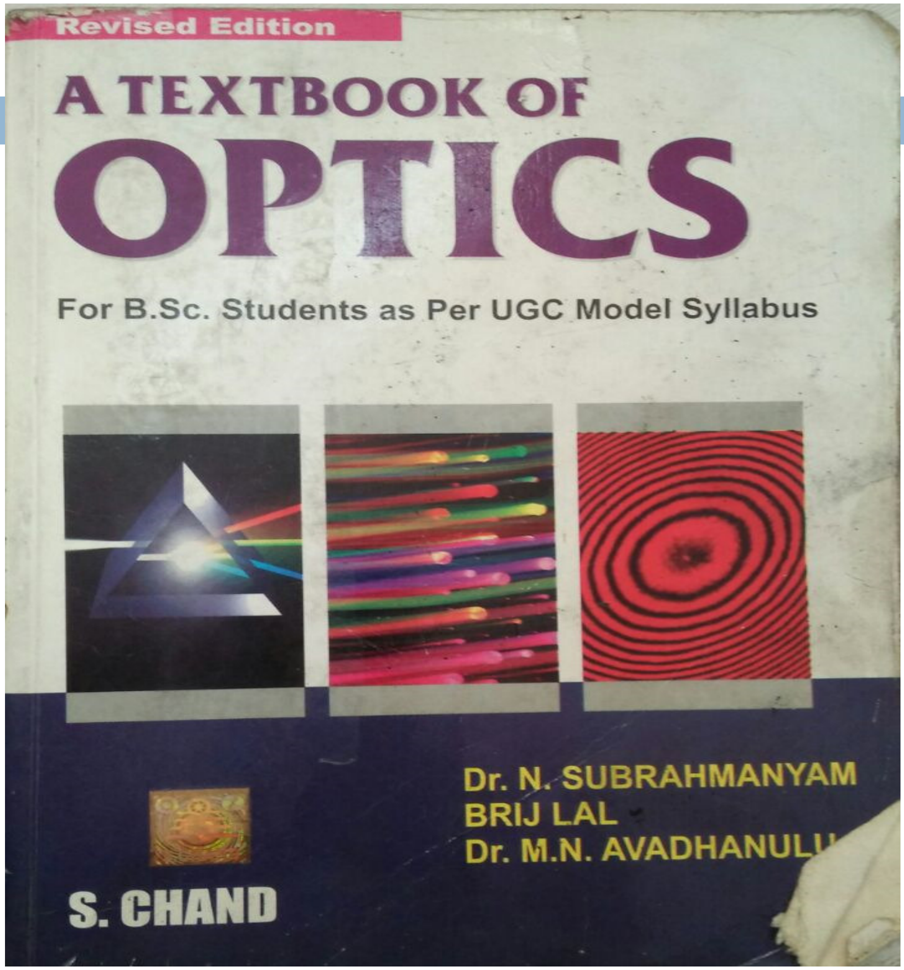
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