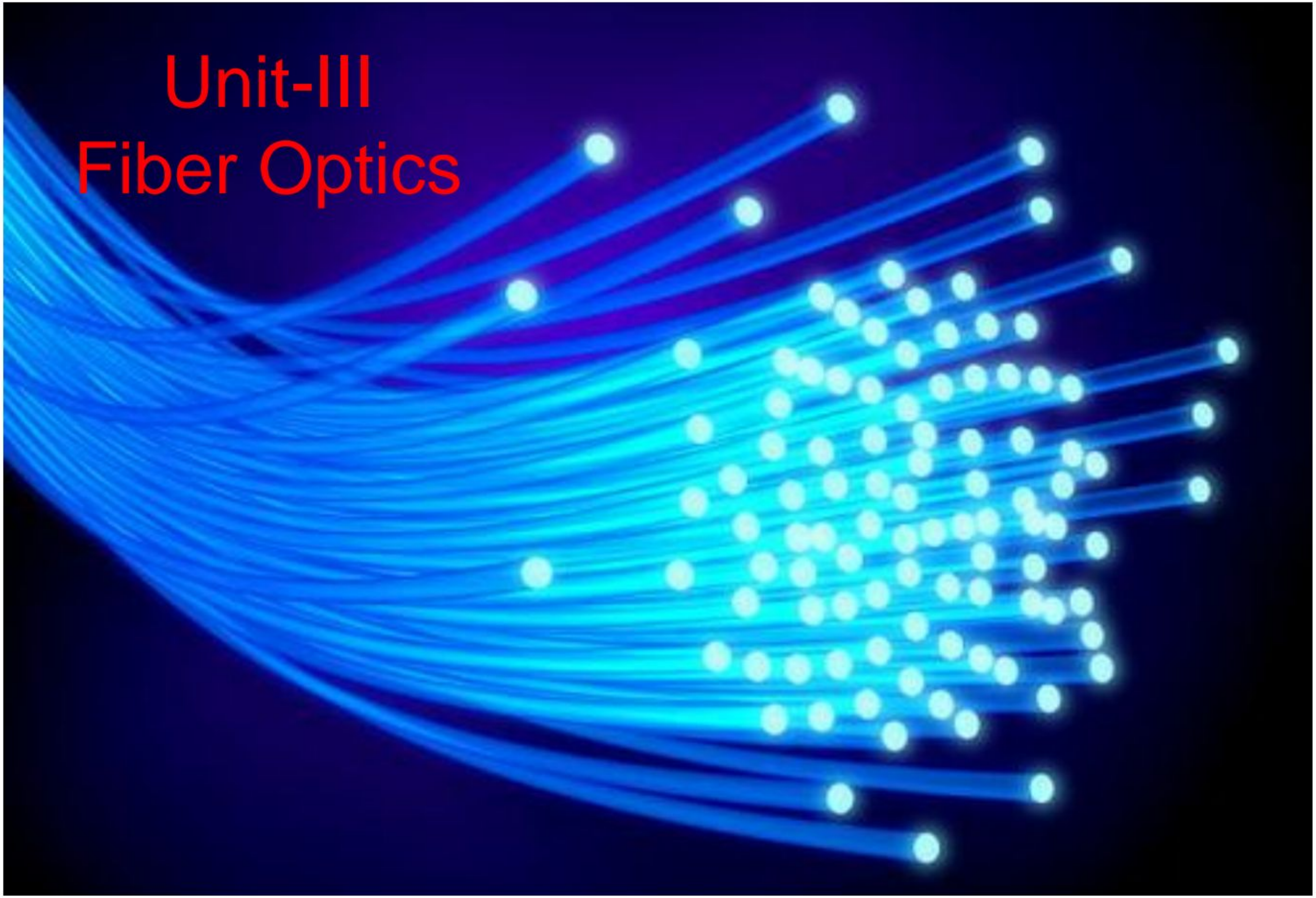

Unit-III
Fiber Optics

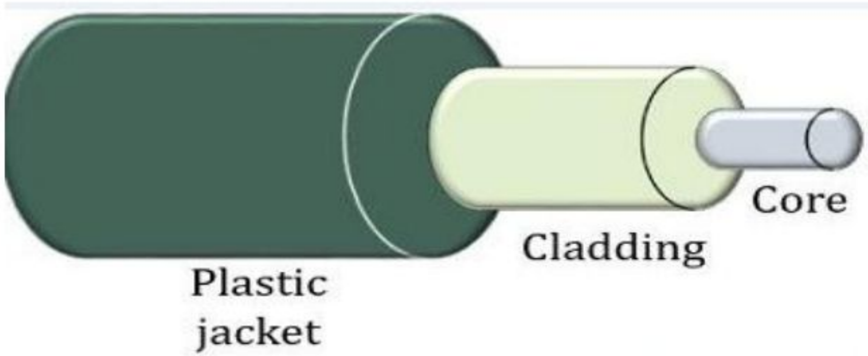
Introduction

- Fiber optics, or optical fiber, refers to the technology that transmits information as light pulses along a glass or plastic fiber.
- Fibers are used instead of metal wires because signals travel along them with less loss of signals
- The term was coined by Indian-American physicist Narinder Singh Kapany and called ae 'Father of Fiber Optics‘.
- The fibre optical cable uses the application of total internal reflection of light.
- Silica or multi-component glass are used for the fabrication of optical fibres.

Parts of Fiber Optics

Fiber Optic Cable consists of four parts.

- Core
- Cladding
- Jacket



Core. The core of a fiber cable is a cylinder of plastic that runs all along the fiber cable's length, and offers protection by cladding. The diameter of the core depends on the application used. Due to internal reflection, the light travelling within the core reflects from the core, the cladding boundary. The core cross section needs to be a circular one for most of the applications.

Cladding: Cladding is an outer optical material that protects the core. The main function of the cladding is that it reflects the light back into the core. When light enters through the core (dense material) into the cladding(less dense material), it changes its angle, and then reflects back to the core

JACKET: Fiber optic cable's jackets are available in different colors that can easily make us recognize the exact color of the cable we are dealing with. The color yellow clearly signifies a single mode cable, and orange color indicates multimode.

Applications of Optical Fiber

Medical industry:

Because of its extremely thin and flexible nature, it is used in various instruments to view internal body parts by inserting into hollow spaces in the body. It is used as lasers during surgeries, endoscopy, microscopy and biomedical research.

Communication and Networking

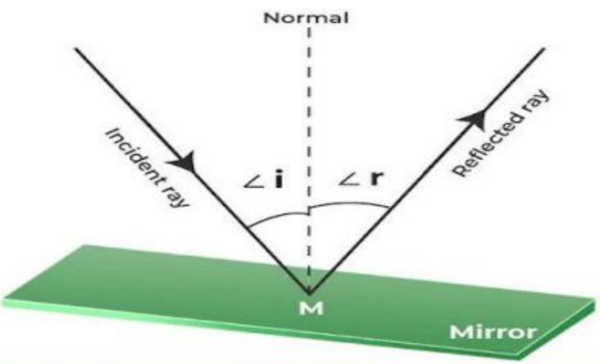
In the communication system, telecommunication has major uses of optical fibre cables for transmitting and receiving purposes. It is used in various networking fields and even increases the speed and accuracy of the transmission data. Compared to copper wires, fibre optics cables are lighter, more flexible and carry more data.

Broadcasting

These cables are used to transmit high-definition television signals which have greater bandwidth and speed. Optical Fibre is cheaper compared to the same quantity of copper wires. Broadcasting companies use optical fibres for wiring HDTV, CATV, video-on-demand and many applications.

Reflection of Light

Reflection of light is the process of bouncing back light rays when it strikes the smooth and shiny reflecting surface. It is due to the reflection of light we are able to see ourselves in the Plane mirror.



1. The angle of the reflected ray is equal to the angle of the incident ray, with respect to the normal to the surface that is to a line perpendicular to the surface at the point of contact.

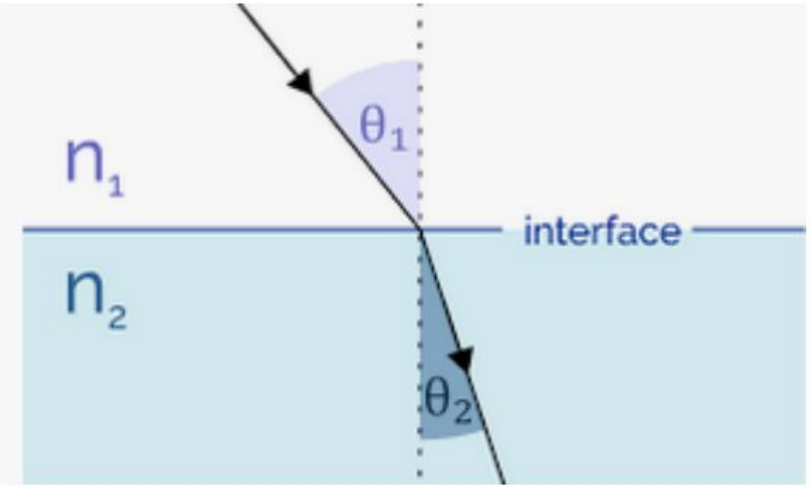
Incident angle = Reflected Angle

2. The reflected ray is always in the plane defined by the incident ray and the normal to the surface at the point of contact of the incident ray.

Example

Refraction of Light

Refraction is the bending of a wave when it passes from one medium to another. The bending is caused due to the differences in density between the two substances.



Laws of refraction state that:

1) The incident ray refracted ray, and the normal to the interface of two media at the point of incidence all lie on the same plane.

2) The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant. This is also known as Snell's law of refraction.

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Important formula

This is Snell's Law

Example

Refractive Index

The refractive index (or refraction index) of an optical medium is a dimensionless quantity that gives the indication of the light **bending ability of that medium.**

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

n = Refractive index

c = Speed of light = 3×10^8 m/s

v= velocity of light in medium

Reason of change of speed: The speed of light in a medium depends on the properties of the medium. In electromagnetic waves, the speed is dependent on the optical density of the medium. **An optical density is the tendency of the atoms in a material to restore the absorbed electromagnetic energy.** The more optically dense material is, the slower the speed of light. One such indicator of the optical density of a medium is the refractive index.

Refractive index for: air=1.0003; water=1.333; crown glass=1.517; and diamond, 2.417.

Numerical

Q1)What is the refractive index of the medium in which the speed of light is 1.5×10^8 m/s?

Sol: The refractive index of the medium can be calculated using the formula:

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

c = Speed of light = 3×10^8 m/s

$$n = 3 \times 10^8 \text{ m/s} / 1.5 \times 10^8 \text{ m/s} = 2$$

The refractive index of the medium is 2.

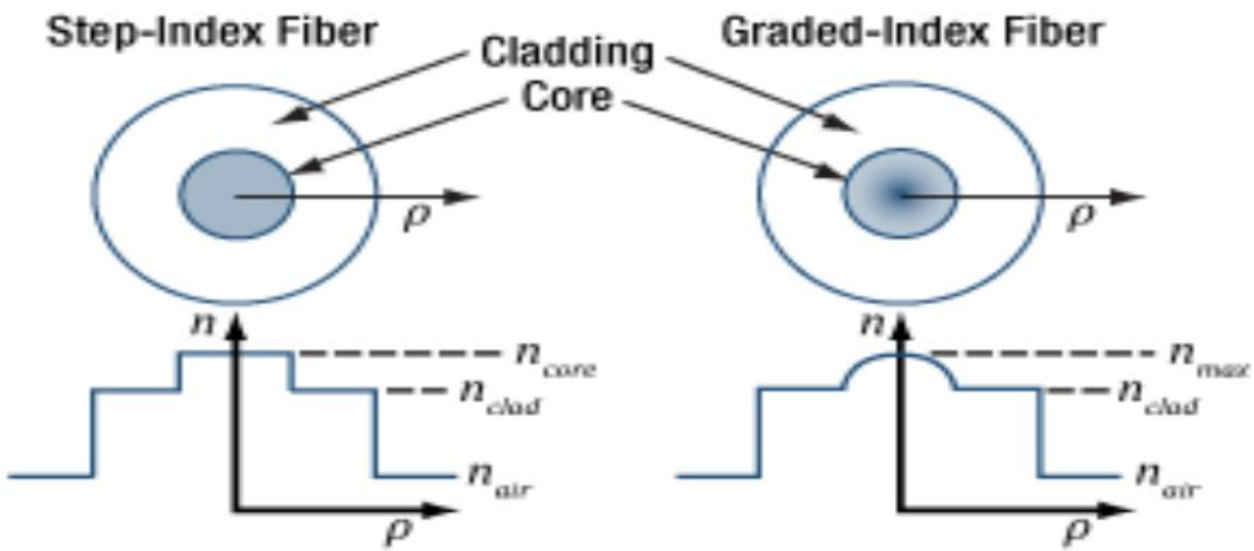
Q2) Refractive index of glass is 1.5. If the speed of light in vacuum is 3 X 10^8 m/s, find velocity of light in medium. **Ans: 2 X 10^8 m/s**

Types of Optical fibers

Depending on the refractive indices of optical fibers:

1) Step-index fiber : In these, the refractive index of the core is constant and undergoes an abrupt change at the interface with the cladding.

2) Graded-index fiber: The refractive index of the core varies in a radial manner from the center. The fiber is densest at the core and becomes rarer towards the edge of the core.



Types of optical fibers

Depending on the number of modes of propagation the optical fiber are classified in to two types

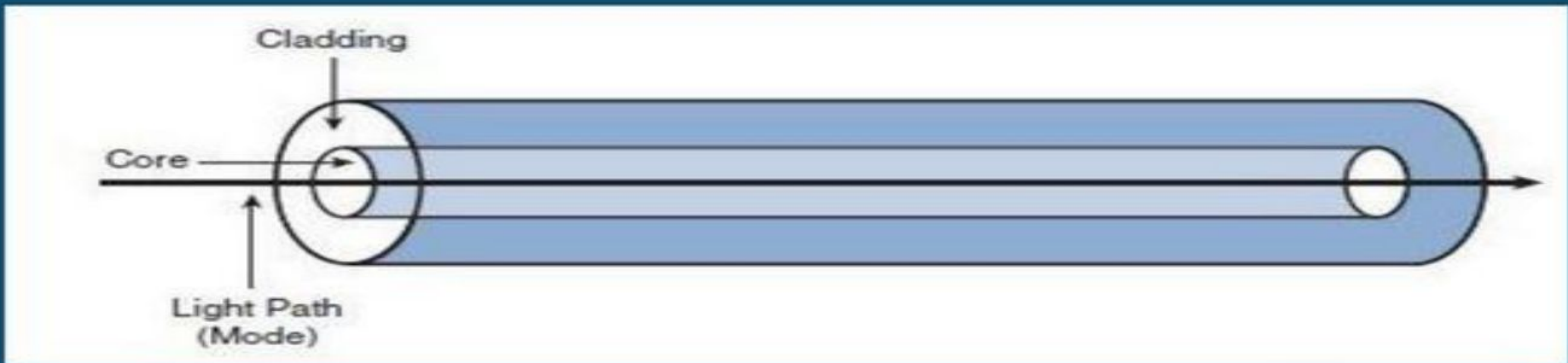
(i) single mode fiber

(ii) multimode fiber

Single mode fiber

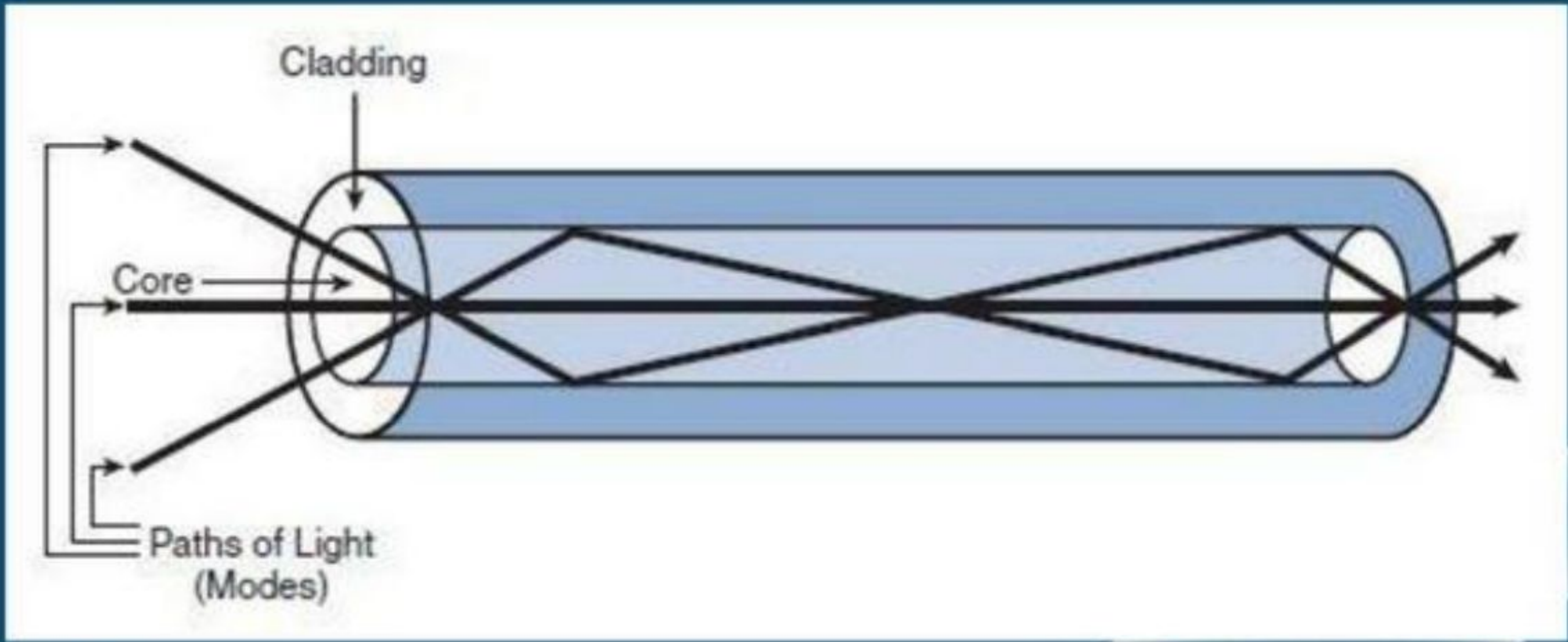
If only one mode is transmitted through an optical fiber, then the optical fiber is known as single mode fiber.

- its core diameter is small in the order of a few times the wavelength of light
- It is designed to have small refractive index difference between the and cladding.



Multimode fiber

- If more than one mode is transmitted through an optical fiber, then the optical fiber is known as multimode fiber.



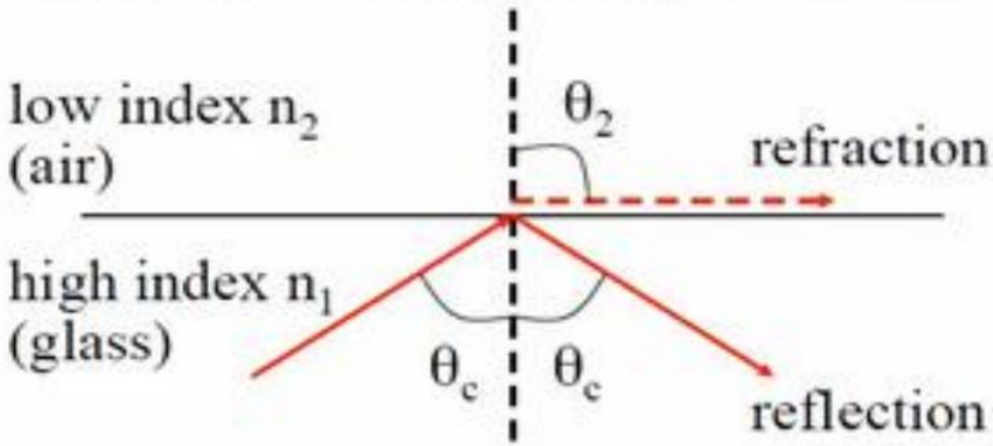
- The large core radii of multimode fiber makes it easier to launch light in to the fiber.
- It can support a number of modes.

Total Internal Reflection (TIR)

- Total Internal Reflection (TIR) is basically a phenomenon where light rays travel from a more optically denser medium to a less optically denser medium and gets reflected back into the more optically denser medium.
- TIR is only possible if the incident angle is greater than critical angle

Critical Angle (θ_c)

- The angle at which total internal reflection occurs is called the critical angle of incidence.
- At any angle of incidence (θ_1) greater than the critical angle, light is totally reflected back to the glass medium.
- For $n_1 > n_2$, the angle of refraction θ_2 is always greater than the angle of incidence θ_1.
- When the angle of refraction θ_2 is 90^o the refracted ray emerges parallel to the interface between the media.



The critical angle is determined by using Snell's Law. The critical angle is given by : $n_1 Sin\theta_c = n_2 Sin\, 90^O$

$$\boxed{\sin\theta_c = n_2 / n_1} \quad (Sin\, 90^O = 1)$$

$$\boxed{\theta_c = \sin^{-1}(n_2/n_1)}$$

Numerical

Q1. An optical fibre made up the glass with refractive index n_1 = 1.5 which is surrounded by another glass of refractive index n_2. Find the refractive index n_2 of the cladding such that the critical angle between the two cladding is 80°.

Sol

Critical angle, θ(c) = 80°

Refractive index, n1 = 1.5

Refractive index n2 = ?

Using the below formula, we can calculate n_2:

$$Sin\theta_c = \frac{n_2}{n_1}$$

$$n_2 = n_1 Sin\theta_c$$

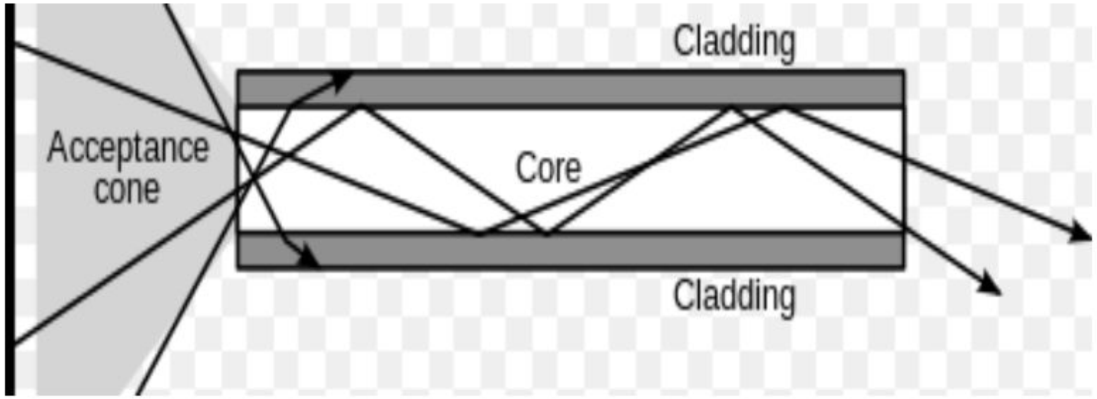
n2=1.5 Sin 80°

Sin 80°= 0.9848

n2=1.48 Ans

Optical Fiber as a Dielectric Wave Guide

- Waveguides are employed in various applications for propagating electromagnetic energy in a desired direction in space from one point to another.



- The circular dielectric waveguide or fiber optic has an internal core that has a higher index of refraction than the cladding. At a certain diameter there is an angle that is less than the critical angle so there is total internal reflection.

Example

Acceptance angle

- It is defined as the **maximum angle** of a ray (against the fiber axis) hitting the fiber core which allows the incident light to be guided/TIR by the core.
- it is essentially determined by the refractive index contrast between core and cladding of the fiber, assuming that the incident beam comes from air or vacuum:

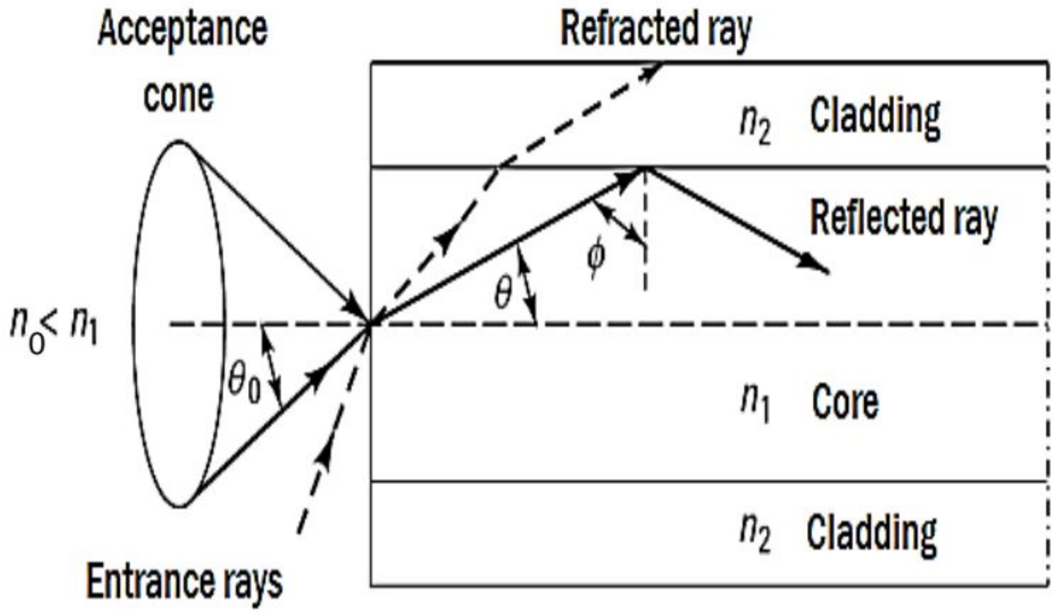
$$\sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n0}$$

If the fiber is place in air then n0=1

$$\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

$$\theta_0 = \sin^{-1}\sqrt{n_1^2 - n_2^2}$$

This is the acceptance angle



Numerical Aperture (N.A.)

- The numerical aperture (NA) of an optical system is a measure for its angular acceptance for incoming light.
- The numerical aperture of an optical system is defined as the product of the refractive index **of the medium** from which the light input is received and the sine of the maximum ray angle against the axis,

Numerical Aperture if the cable is placed in air (n0=1)

$$NA = \sin\theta_0$$

Relative/Fractional Index Charge (Δ)

It is the ratio of refractive index difference in core and cladding to the refractive index of core.

$$\Delta = \frac{n1 - n2}{n1}$$

V-Number/Normalized Frequency

V – number determines how many modes a fiber can support, It is given by,

$$V = \frac{\pi d}{\lambda} NA$$

where d is the diameter of the core, λ is the wavelength of light used and NA is the numerical aperture of the fibre.

$$V = \frac{\pi d}{\lambda}\sqrt{n_1^2 - n_2^2}$$

If V ≤ 2.405, then the fibre is single mode fibre (SMF)

If V > 2.405, then the fibre is multimode fibre (MMF)

Number of Modes traveling in Fibre

For Step Index Fibre:

$$N = \frac{V^2}{2}$$

For Graded Index Fibre:

$$N = \frac{V^2}{4}$$

Numerical

To Find:

1) Core radius (a)

2) Numerical aperture (N.A)

3)acceptance angle (Θ_a)

Given:

λ =820nm

n_1=1.482

n_2=1.474

V = 2.405 (single mode step index)

Solution: - N.A = $\sqrt{n_1^2 - n_2^2} = \sqrt{1.482^2 - 1.474^2}$ - N.A= 0.153

$$\boxed{Numerical\ \ aperture\ \ (N.A) = 0.153}$$

- $V = \frac{2\pi a(N.A)}{\lambda}$
- $2.405 = \frac{2\pi * a * 0.153}{820 * 10^{-9}}$
- a = 2.051µm

$$\boxed{Core\ \ radius\ \ (a) = 2.051\mu m}$$

Core radius (a) = 2.051µm

- N.A = sin Θ_a

0.153=sin Θ_a

Θ_a = 8.8°

$$\boxed{Acceptance\ \ angle\ \ (\Theta_a) = 8.8^\circ}$$

Find the V number of an optical fibre having numerical aperture 0.25 and core diameter 20 m, if its operating wavelength is 1.55 micrometer.

Numerical Aperture (N.A.) = 0.25
core diameter = 20 μm
wavelength = 1.55 μm

Formula:

$$V\ number = \frac{\pi d}{\lambda} \times\ N.A.$$

$$V\ number = \frac{3.142 \times 20}{1.55} \times 0.25$$

$$\therefore V\ number = 10.135$$

Optical Fiber Loss and Attenuation

- The attenuation of an optical fiber measures the amount of light lost between input and output. Total attenuation is the sum of all losses.
- Optical losses of a fiber are usually expressed in ***decibels per kilometer (dB/km)***. The expression is called the ***fiber's attenuation***
- It decides the number of repeaters required between transmitter and receiver

$$\text{Attenuation} = \frac{10}{L}\log_{10}\frac{P(z)}{P(0)} \quad (In\ db/km)$$

L=Length of optical fiber

P(z)=Optical power at a position z

P(0)= Optical power at origin.

Losses in Optical Fiber

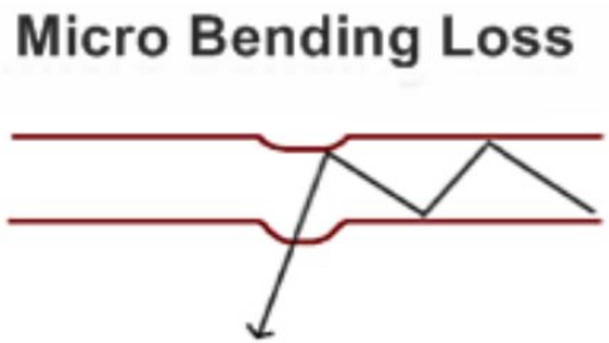
1) Absorption loss:

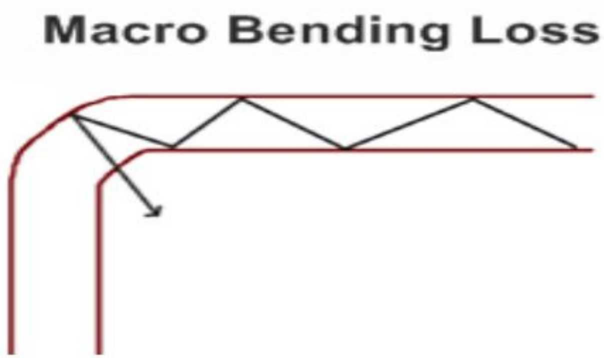
Due to the presence of impurities in the fiber cable some of the residues still remain resulting in the absorption. The composition of the fiber and its fabrication of fiber results in absorption loss. There is dissipation of optical power in the fiber cable. There are two types of absorption loss

a. **Intrinsic absorption:** When the light signal interacts with the components of the glass, an electron or metal ions, the light power is absorbed by the impurities

b. **Extrinsic absorption.** Fiber optic splicing is another type of loss in optical fiber. By joining two optical fibers end-to-end, splicing aims to ensure that the light passing through it is almost as strong as the virgin fiber itself.

2) Due to Bending: Bending is the common problem that can cause optical fiber losses generated by improper fiber optic handling. There are two basic types. One is micro bending, and the other one is macro bending (shown in the picture below). Macro bending refers to a large bend in the fiber (with more than a 2mm radius).

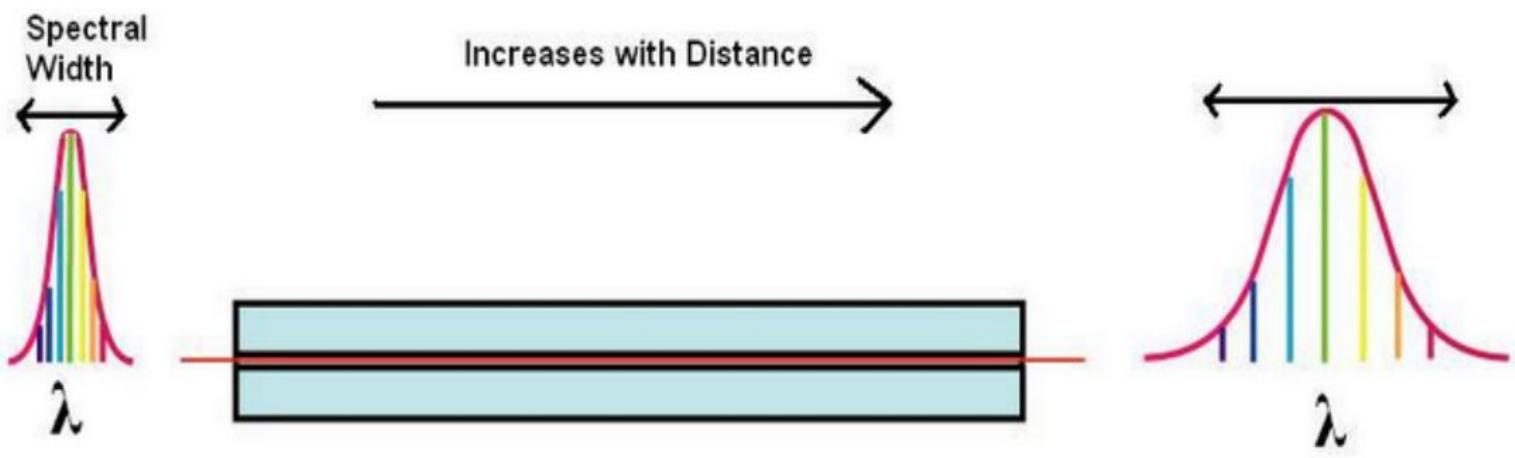




3) Dispersion loss: Spreading of signal as it propagates along the fiber is called dispersion and such medium is called dispersive medium

a) Intermodal Dispersion (For multimode fiber): It arises due to the mode having different value of group velocity at a single frequency.

b) Intramodal/chromatic Dispersion (For Single mode): This is due to core material which is a function of wavelength. If the laser used to transmit the signal was a perfect single frequency then it would have an extremely high bandwidth.



Intramodal/chromatic Dispersion

Thank you….