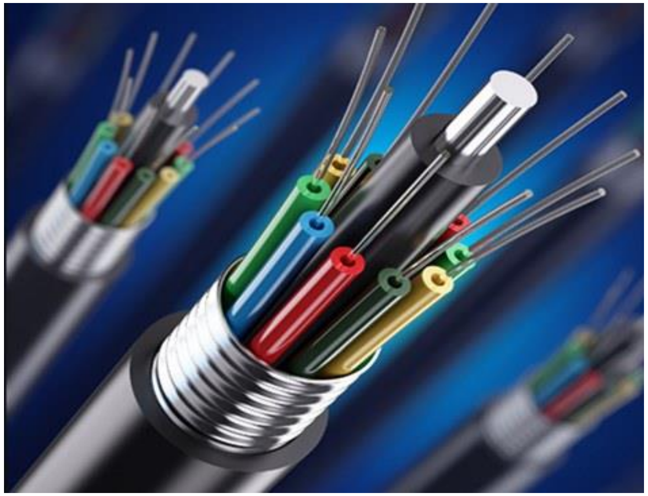
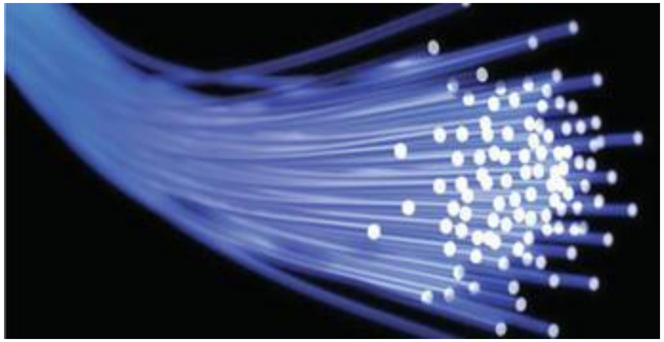
UNIT VI
OPTICAL FIBERS

Prof. Neha N Dorle

Contents





Optical Fibres

- A thin flexible transparent fiber made up of glass or plastic as thin as human hair which is designed to guide light waves along its length.

- It works on the principle of Total Internal Reflection.

- When the light enters the fibre, it suffers multiple total internal reflections from the side walls and travels zigzag path throughout the fibre.

- Some part of light may escape through side walls of the fibre but major portion comes out of the fibre through other end.

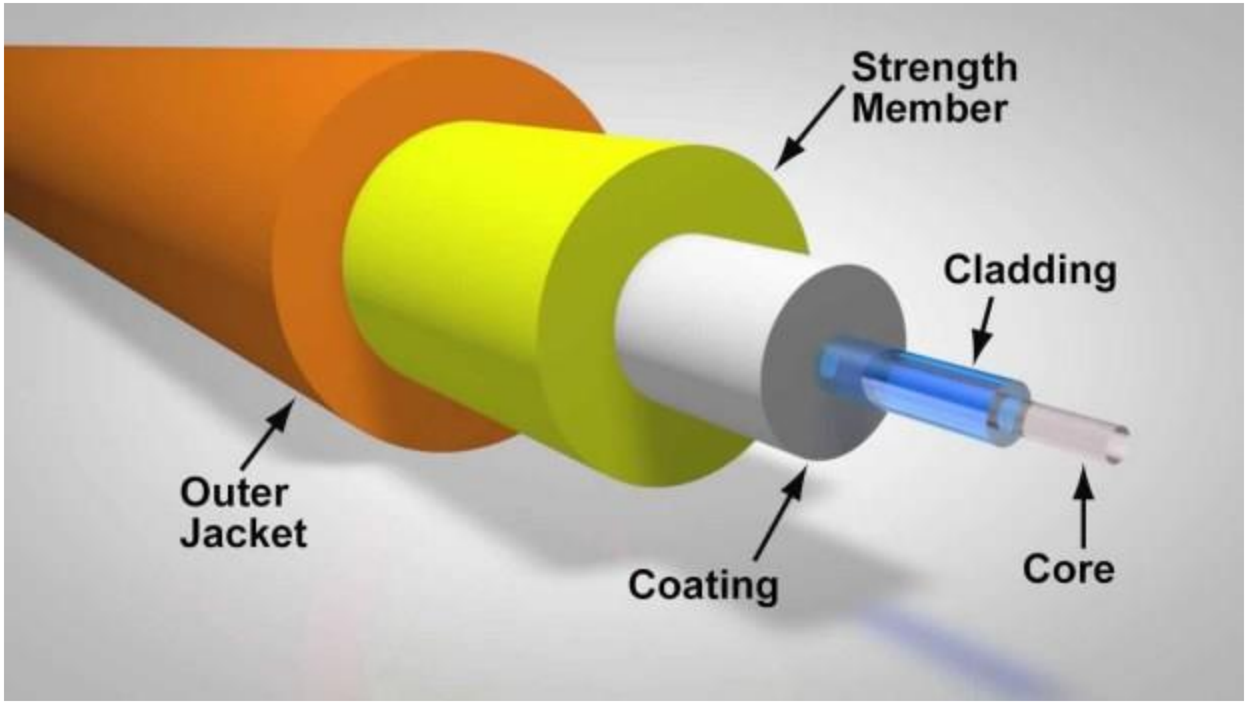
- The phenomenon was discovered in 1870.

- It has cylindrical shape.

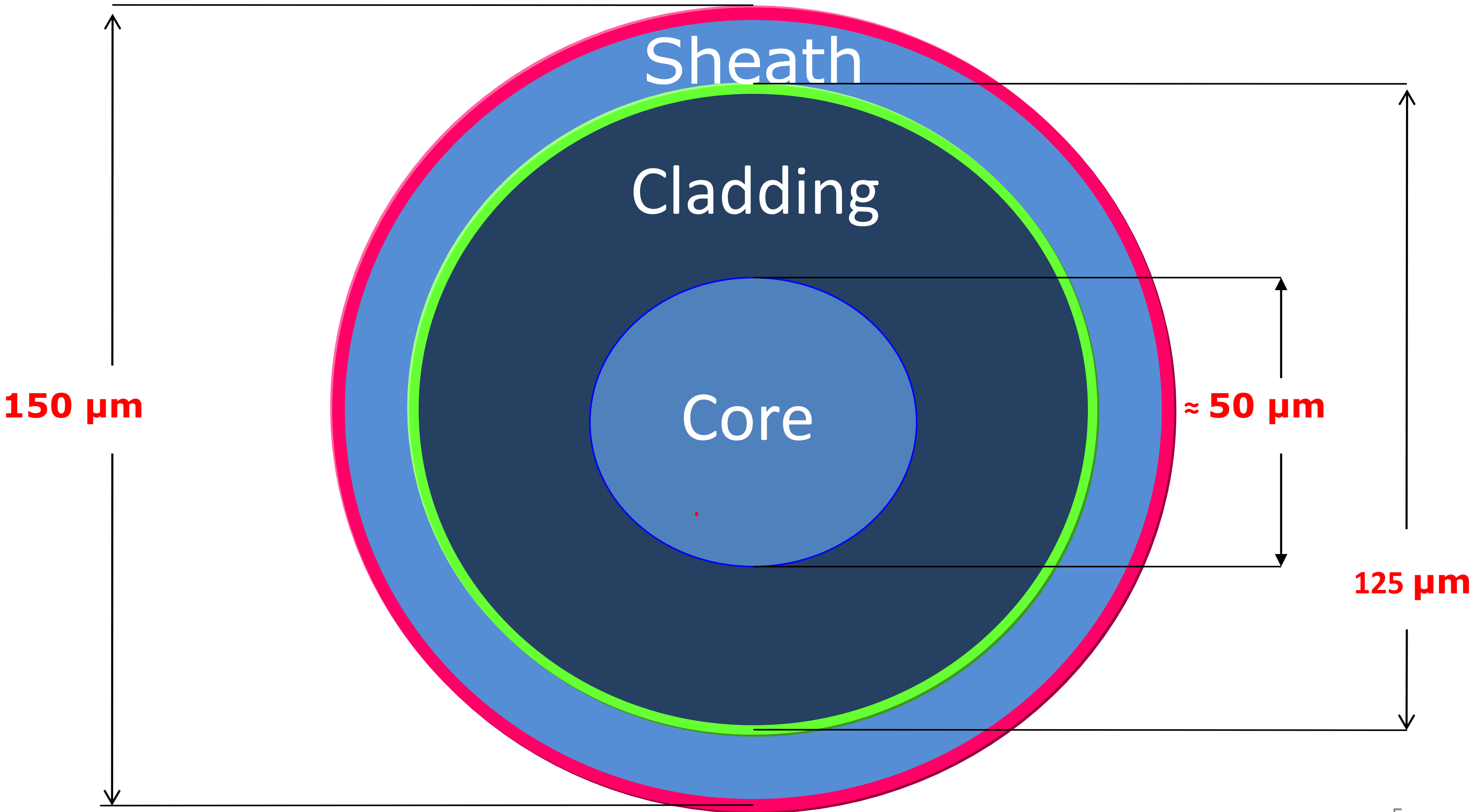
Structure of optical fibre

A typical optical fibre contains three different regions

1. **Core**
2. **Cladding**
3. **Sheath**



Structure of optical fibre



1. Core

- Core is a central region which has higher refractive index than that of cladding.
- The function of core is to collect as much light as possible from source.
- Light propagation medium.
- Conducts no electricity.

2. Cladding

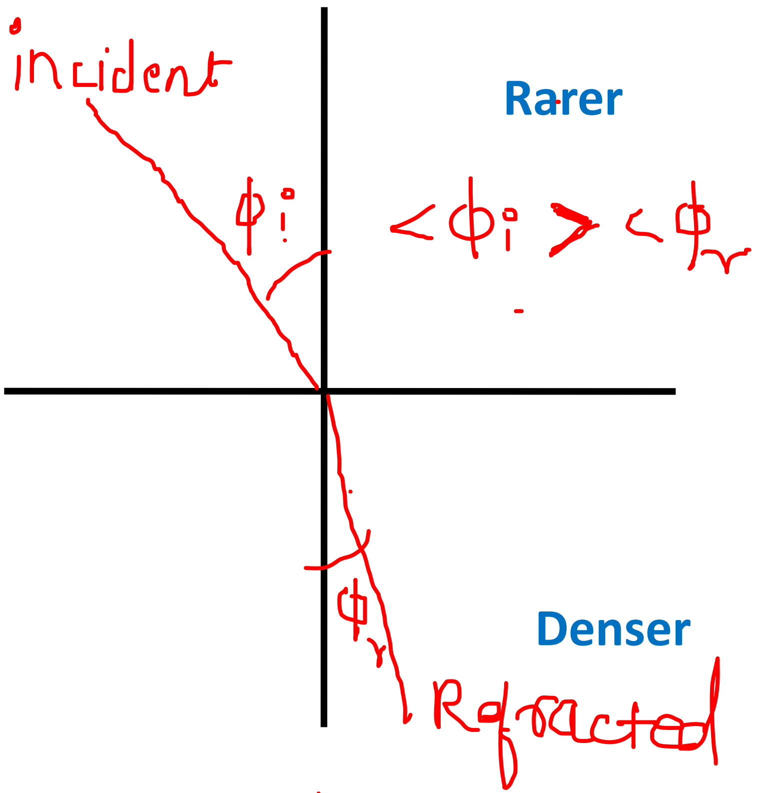
- Cladding surrounds the core and has refractive index less than that of core.
- Its function is to put the light in the zigzag path by the process of total internal reflection and confine the maximum light to the core.
- Made of glass or plastic i.e is made up of dielectric material.

3. Sheath

- Sheath is the outermost region which acts as a protective layer for optical fibre.
- It protects the core and cladding from harmful atmospheric effects, contamination.
- It imparts mechanical strength to the optical fibre.

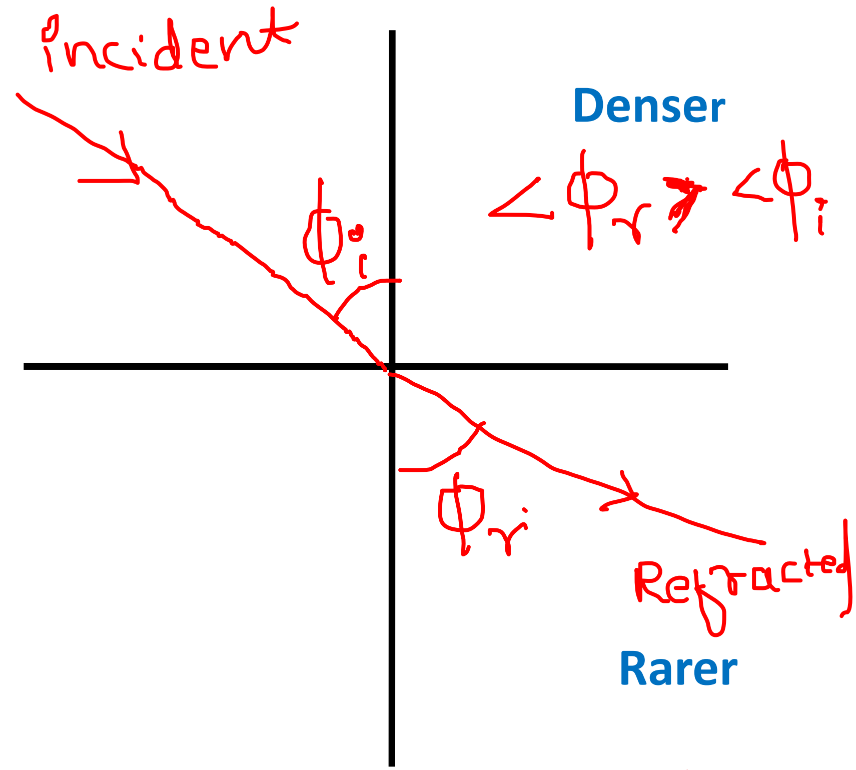
Refraction process

Rarer medium to Denser medium



→ Refracted ray Bend towards Normal

Denser medium to Rarer medium



→ Refracted ray move away

Total Internal Reflection (TIR)

- Optical fiber works on the principle of **Total Internal Reflection.**

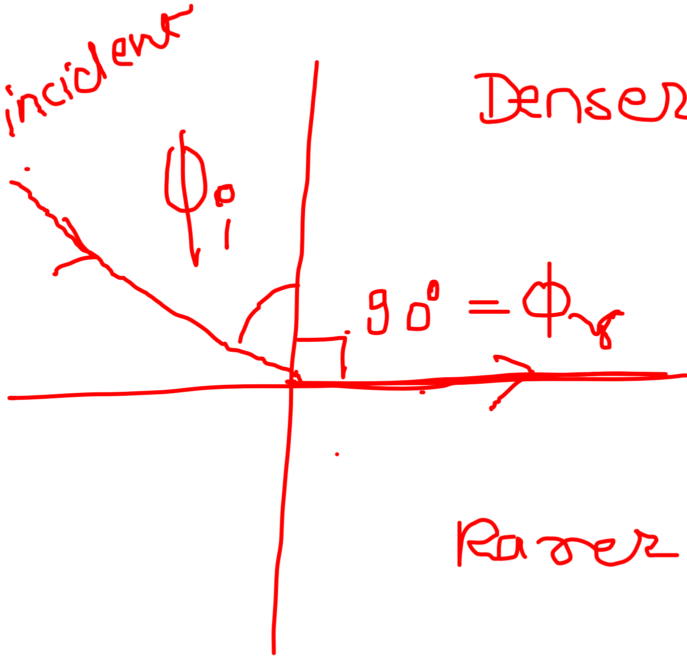
- TIR takes place when a ray of light strikes a medium boundary (core-cladding) at an angle larger than the critical angle with respect to the normal to the surface.

- It occurs only when light ray travels from Denser to Rarer medium.

- The angle of incidence at which refracted ray makes a 90 angle with a normal is know as critical angle Ɵc.

- Critical angle is a minimum value of angle of incidence at which total internal reflection occur.

Critical angle ϕ_c



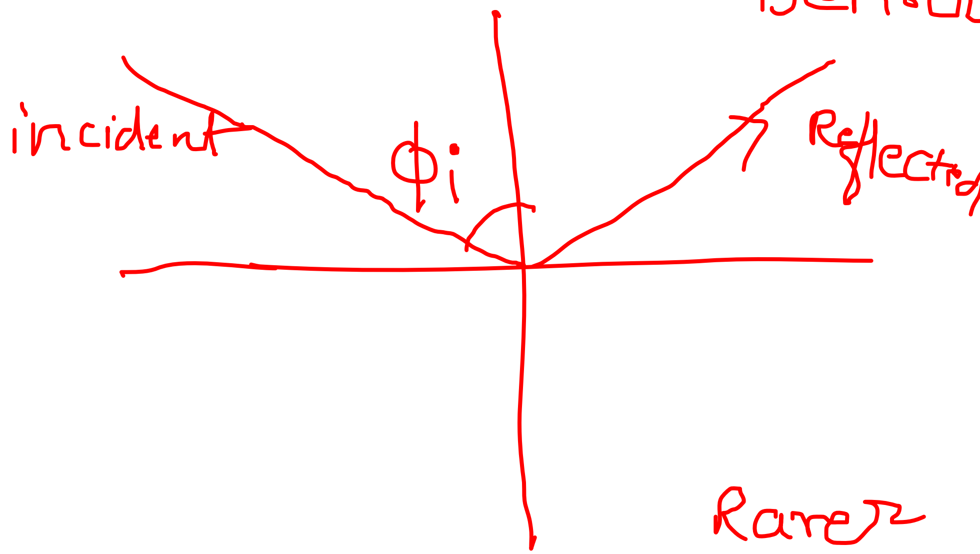
$\phi_i \rightarrow$ increases

$\phi_i = \phi_c \Rightarrow \phi_r = 90^\circ$

ϕ_c - critical angle

TIR

$\phi_i > \phi_c$



$\Rightarrow \phi_i \rightarrow$ increases

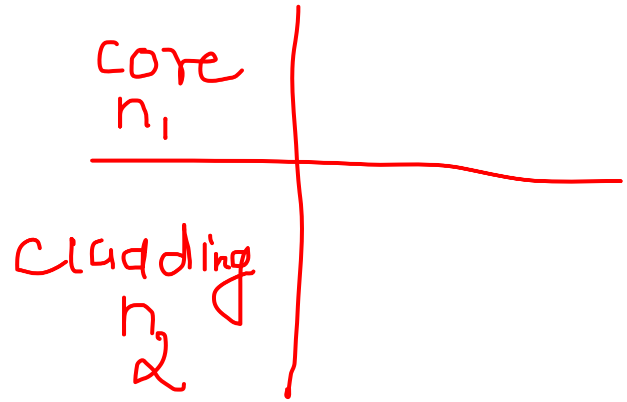
$\phi_i > \phi_c$

$\downarrow$

then TIR

Critical Angle ϕ_c

A/c to snell's law



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

$$\frac{\sin \phi_i}{\sin \phi_r} = \frac{n_2}{n_1}$$

put $\phi_i = \phi_c$ $\phi_r = 90^\circ$

$$\frac{\sin \phi_c}{\sin 90} = \frac{n_2}{n_1}$$

$\sin 90 = 1$

$$\frac{\sin \phi_c}{1} = \frac{n_2}{n_1}$$

$$\sin \phi_c = \frac{n_2}{n_1}$$

$$\phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Important points about TIR

1. To observe TIR , light should travel from denser to rarer medium.
2. TIR is observed when a particular angle of incidence θc is made with the normal.
3. i < θc then TIR does not occur.
4. i > θc then TIR not occur.

- Main function of an optical fiber is to collect as much light as possible from source and transmit it without much losses.

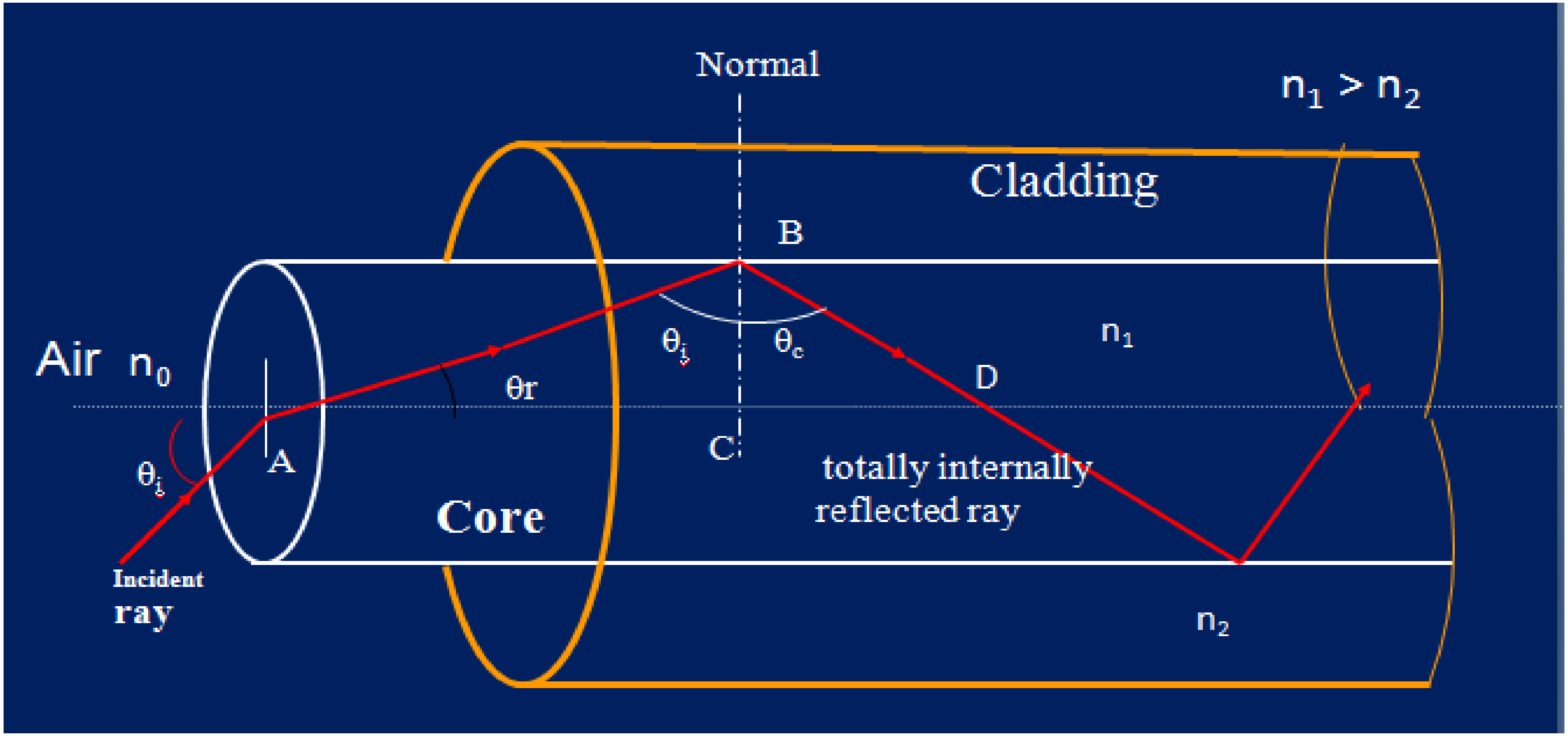
- Light collecting capacity of a fiber depends on two factors

1. Size of core
2. Numerical aperture (NA)

- Numerical aperture depends on

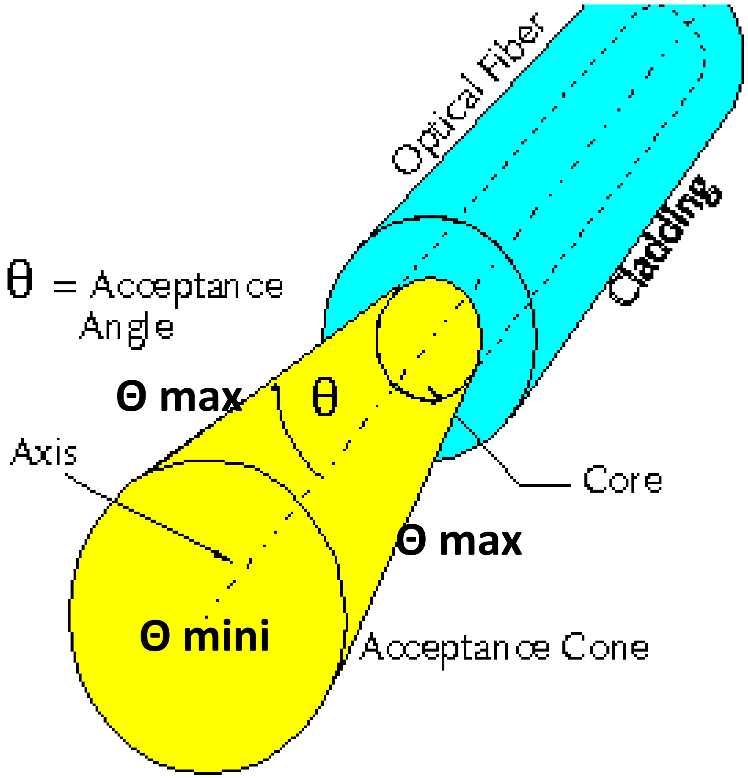
1. Acceptance angle
2. Fractional refractive index change

Expression for Acceptance Angle



Acceptance angle **-The maximum angle that a light ray can make with axis of fiber for its propagation by total internal reflection.θ**

Acceptance Cone



Acceptance cone:- It is twice of the acceptance angle i.e. $2\theta_0$.

- A cone enclosing all the allowed incident directions of light for the total internal reflection through the optical fiber.
- It is a cone with an apex at axis of fiber which encloses all the incident directions making an angle in range of **θ** maximum to **θ** minimum with the axis for the propagation of light by internal reflection.

Fractional Refractive Index Change (FRIC)

- Fractional refractive index change is the fractional difference between the refractive indices of the core and the cladding.
- It is ratio of difference of refractive index of core and cladding to the refractive index of core.

$$\Delta = \frac{n_1 - n_2}{n_1}$$

- FRIC is positive for TIR
- FRIC is of order of 0.01

Numerical Aperture (NA)

Numerical Aperture is defined as the sine of the acceptance angle.

$$NA = \sin\theta_0 = n_1\sqrt{2\Delta}$$

Important points NA

1. **NA determines the light collecting capacity of an optical fiber.**

2. **NA depends upon R.I of core and cladding.**

3. **NA value ranges from 0.13 to 0.50.**

4. **A large value of NA implies that a fiber will accepts large amount of light from the source.**

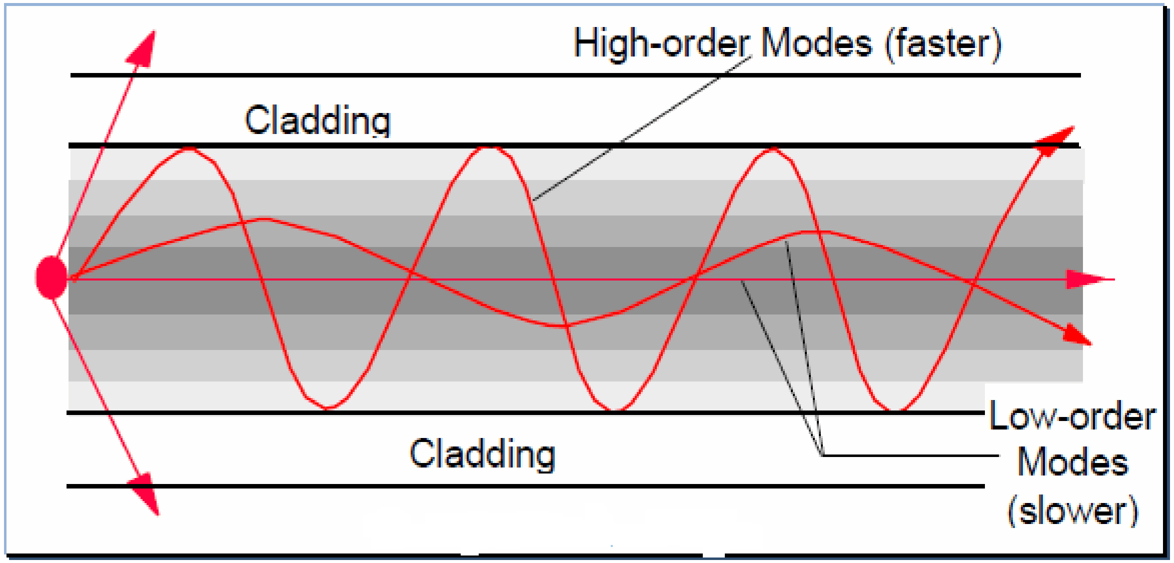
5. **More the difference in squares of R.I of core and cladding, more will be NA and large amount of light can be collected by fiber.**

Modes of propagation of light

- For the propagation of light by TIR through fibre, light ray essentially should lie in the acceptance cone.

- The light rays traveling through a fibre in two different paths

1. Along Axial path
2. Along Zigzag path



1. **Axial Rays –** rays travel along the axis and hence called as axial rays.

2. **Zigzag Rays** – rays travel along the zigzag path hence called as zigzag rays.

- **Modes -** Modes are the possible number of paths of light that propagates through optical fibre.

- Number of possible paths or modes are dependent upon the ratio d / λ.

- d = diameter of core
- λ = Wavelength of light

V Number

- **V Number – Normalized frequency parameter**

- The numbers of modes allowed in a given fibre are determined by a relationship between the wavelength of the light passing through the fibre, the core diameter and material of optical fibre. This relationship is know as V-number.

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

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

Where,
a = radius of core (microns)
NA= numerical aperture
d = diameter of core
λ = wavelength (microns)

For V < 2.405, the fibre can support only one mode.

For V > 2.405, the fibre can support many modes simultaneously.

Q.1 In an optical fiber, the core material has refrective index 1.43 and refractive index of clad material is 1.4. find the propagation angle.

ANS

Q.2 In an optical fiber, the core material has refractive index 1.6 and refractive index of clad material is 1.3. what is the value of critical angle and also calculate the value of angle of acceptance cone.

ANS

Q.3. Calculate the numerical aperture and acceptance angle of an optical fibre from the following data, R.I core =1.55 R.I cladding = 1.50

ANS

Q.4. What is the numerical aperture of an optical fibre cable with a clad index of 1.378 and core index of 1.546.

ANS

Q. 5. A fiber cable has an acceptance angle of 30 degree and a core index of refraction of 1.4. calculate the refractive index of the cladding.

ANS

Q.6. Calculate the angle of acceptance of a given optical fiber, if the refractive indices of core and cladding are 1.563 and 1.498 respectively.

ANS

Q 7. Calculate the fractional index change for a given optical fiber if the refractive indices of the core and cladding are 1.563 and 1.498 respectively.

ANS

Q.8. Calculate the refractive indices of the core and the cladding material of a fiber from the following data. NA = 0.22 AND FRIC = 0.012

ANS

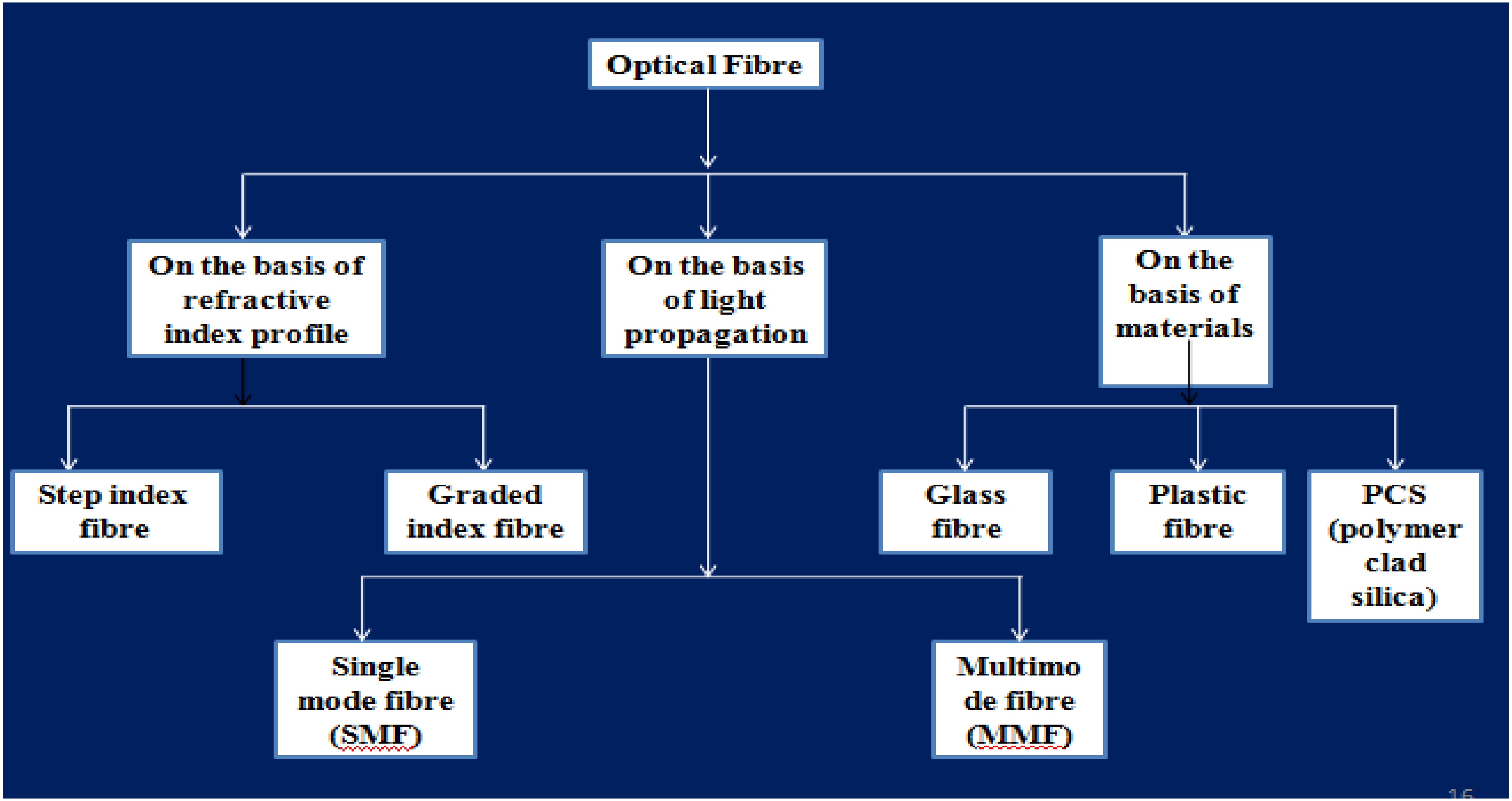
Q.9. Find the FRIC and NA for an optical fiber with refractive indices of core and cladding 1.5 and 1.49 respectively.

ANS

Classification of optical fibre

Optical fibre are classified on the basis of

1. **Material**
2. **Refractive index**
3. **Number of modes**



Classification on the basis of material use

Materials

1. Glass- Glass Fibre
2. Plastic -Plastic Fibre
3. Platic Clad Silica Fibre

1. Glass -Glass optical fibre –

- In this type of optical fibres, core is made up of glass and cladding is also made of glass.
- Refractive index of glass for cladding is always less than refractive index of glass for core.
- Very low losses.
- Useful for long distance communications.
- **Examples**

core	**cladding**
1. Silica - SiO_2	1.Borosilicate -$B_2O_3.SiO_2$
2. Lead glass	2.Borosilicate
3.$GeO_2.SiO_2$	3.SiO_2

2. Plastic - Plastic optical fibre -

- In this type of optical fibres, core is made up of plastic and cladding is also made of plastic.
- Refractive index of plastic for cladding is always less than refractive index of plastic for core.
- Material use for core is Perspex and polysterene and cladding made up of silicone resin.
- NA for this fibre is large i.e 0.6 aprox. Due to this light collecting capacity of these fibre is high.
- Low cost is main advantage and higher mechanical flexibility.
- They are temperature sensitive and losses are high at higher temperature.

- **Examples**

core - Perspex , polysterene

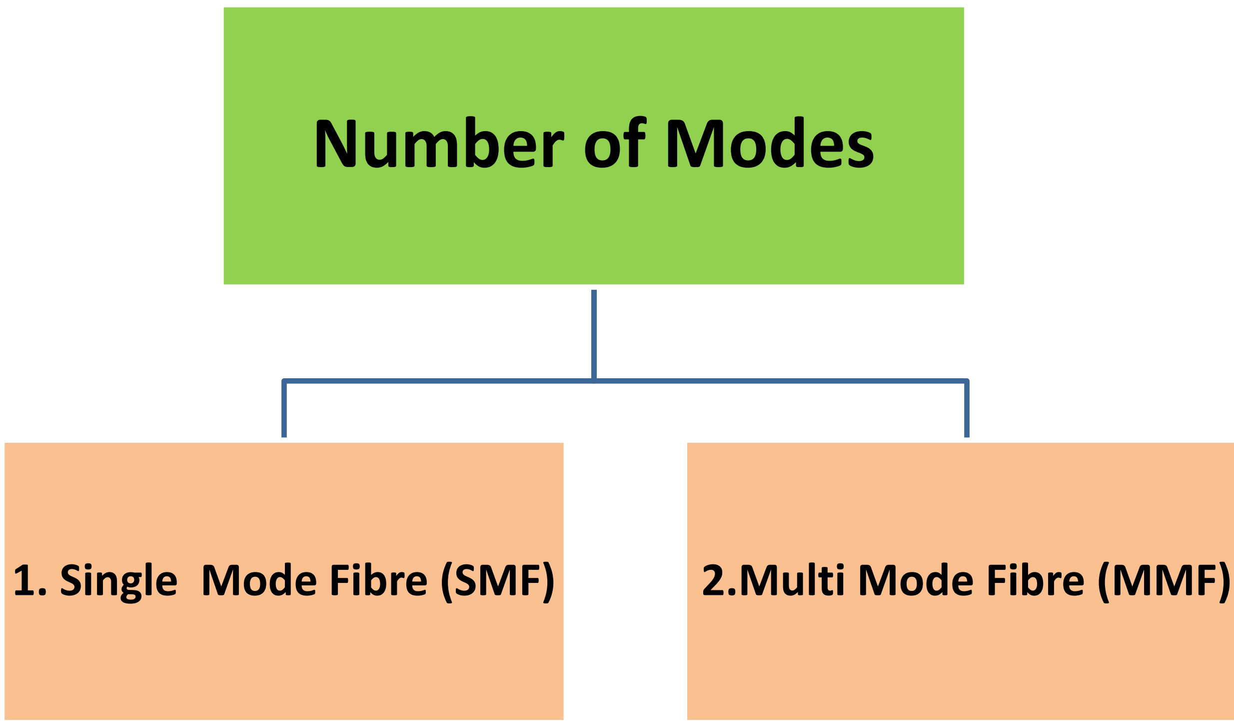
cladding - silicone resin.

3. Glass Plastic optical fibre or PCS Fibre –

- In this type of optical fibres, core is made up of silica glass and cladding is also made of plastic like silicone resin.
- PCS- Plastic Cold Silica.
- Refractive index of silicone resin for cladding is always less than refractive index of silica glass for core.
- High losses occur in this fibre.
- Use for short distance communications.
- They are inexpensive.
- Plastic cladding are used for step index fibres only.
- **Examples**

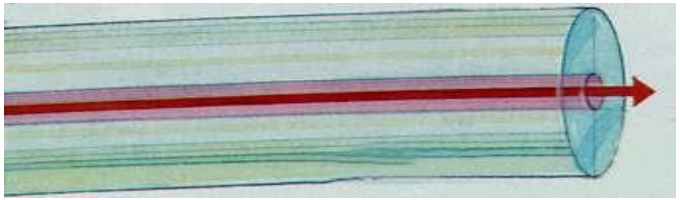
Silicone resin like ethylene propylene(teflon)

Classification on the basis of number of modes



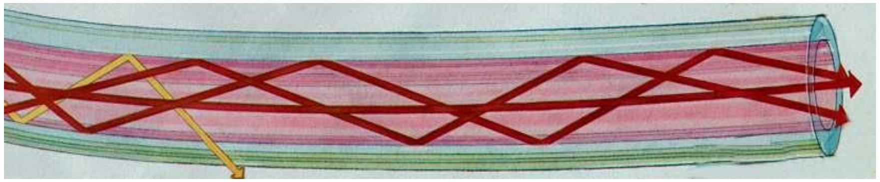
1. Single Mode fibre (SMF)

- It supports only single mode of propagation.
- Light travels along axis of fibre.
- It has small core diameter 4 micrometer, FRIC = 0.002 and small NA.
- due to small NA acceptance angle is also small.
- Index profile of SMF is a Step index.
- It only support one mode, intermodal dispersion does not exist.



2. Multi Mode fibre (MMF)

- It supports number of mode.
- Light travels along zigzag paths and many paths are permitted in this fibre.
- It has core diameter is larger.
- NA is larger 0.3 and hence acceptance angle is larger.
- Index profile of MMF is graded index fibre.
- It support number of mode due larger acceptance angle.



Classification on the basis of Refractive index profile

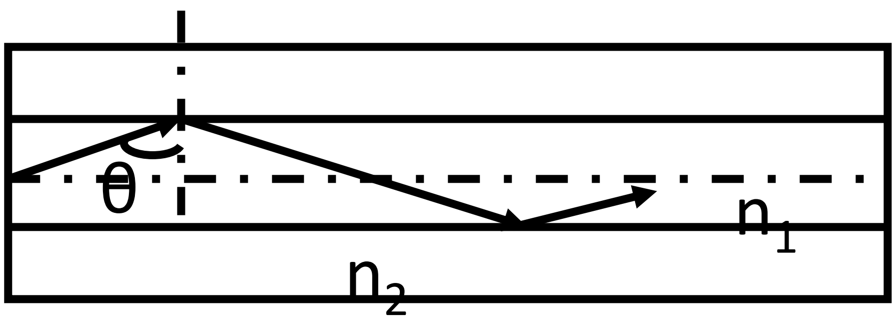
Refractive index profile

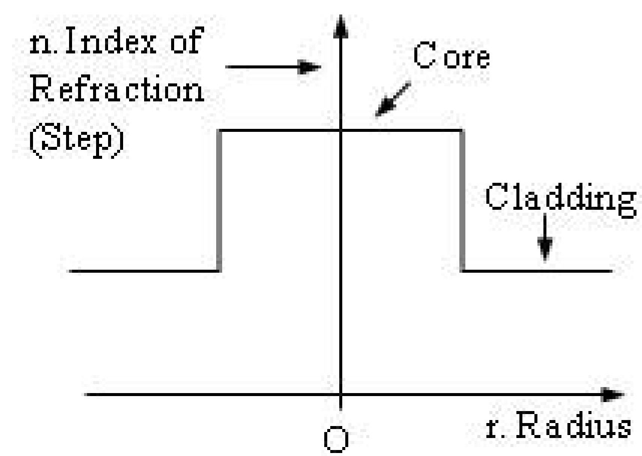
1. Step Index Fibre (S.I)

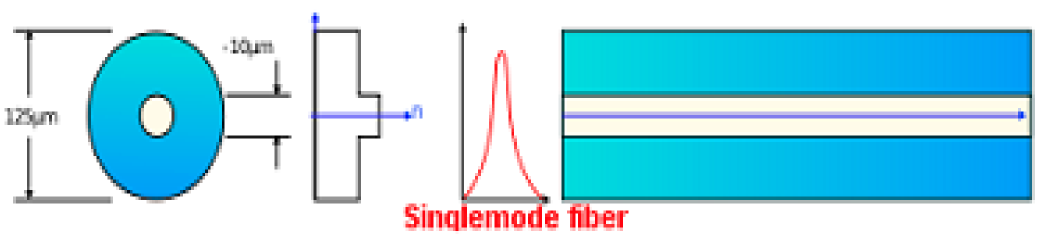
2.Graded index fibre (GRIN)

1. Step Index Fibre (S.I)

- Refractive index of core and refractive index of cladding are uniform.
- NA and acceptance angle are constant due to uniform R.I of core.
- Path of light rays through such fibres experiences sharp reflections at core cladding interface.
- R.I of core is grater than R.I cladding , it experiences an abrupt change in R.I at the boundary between core and cladding.

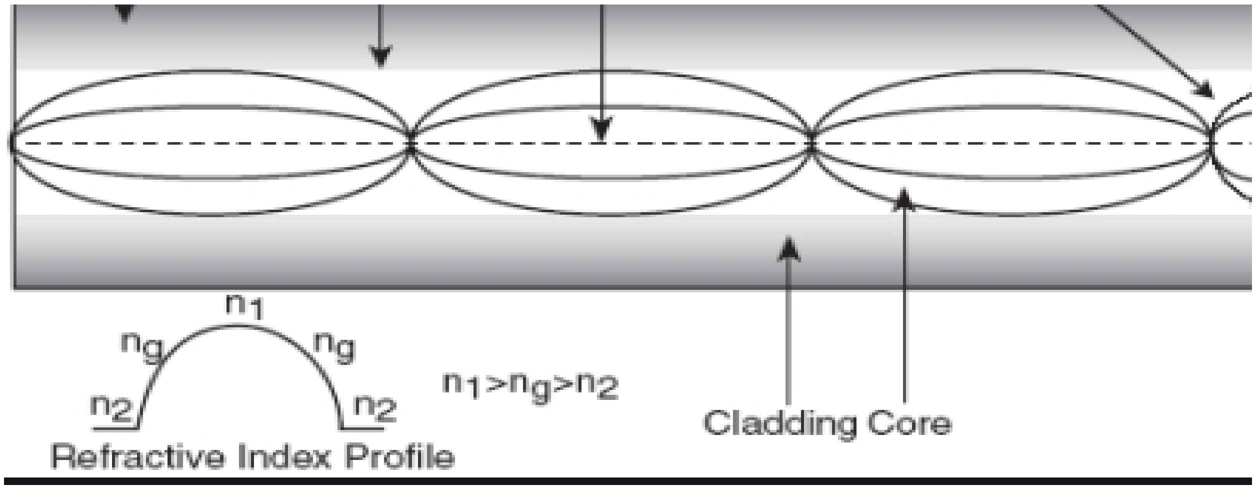


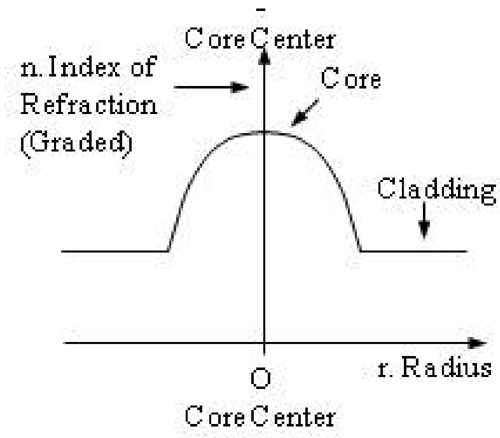




2.Graded Index Fibre (G.I.F)

- Refractive index of cladding is uniform and refractive index of core is not uniform.
- NA and acceptance angle are change due to non uniform R.I of core.
- Path of light rays through such fibres experiences blunt turns.
- R.I of core is non uniform and decreases gradually away from the axis. Thus light ray does not experience sudden change in R.I when it travels from core to cladding.





Sr. No.	Step index fiber	Graded index fiber
1	The refractive index n_1 of core to cladding changes abruptly to refractive index n_2 of cladding in one step	The refractive index n_1 of core gradually changes refractive index n_2 of cladding.
2	In step index fiber, core and cladding refractive indices materials are uniform.	In graded index fiber, core consists of layers of materials of refractive indices in decreasing order from axis of core to cladding while cladding is uniform.
3	The light ray moves along zigzag path crossing axis each time when it is internally reflected at core –cladding interface.	The light moves around the axis following a helical path and do not cross the axis.
4	Step index fiber supports single and multimode propagation of light.	Graded index fiber supports single and multimode propagation of light
5	The core diameter is about 10 μm for single mode and about 50 to 200 μm for multimode.	The core diameter is about 50 μm.

Sr. No.	**Single mode fiber**	**Multi mode fiber**
1	Light ray propagates as a single ray, through the fiber.	Light ray propagates following more than one path through the fiber.
2	The diameter of core is about 10μm	The diameter of core is about 50 to 200μm
3	Single mode fibers have a lower signal loss and a higher information capacity.	Multi mode fibers have a more single loss.
4	Single mode fibers typically must use laser source.	Multimode fibers can use LEDs.
5	Core to core coupling between two fibers is critical.	Core to core coupling between two fibers is not so critical
6	Single mode fiber is step index fiber only.	Multimode fibers may be step index or graded index fiber.

Fibre losses

- Light propagates through it and signal degradation is caused by

1. **Attenuation**
2. **Dispersion**

1. Attenuation

- Light propagates through the fibre, the intensity of light decreases over the length of fibre. This process know as attenuation.
- Attenuation represents the reduction in amplitude of signal.
- It is measured with respect to the distance travelled by light rays in optical cable.
- It Changes the shape of signal.
- It is also defined as a ratio of optical input power to output power over a length.
- Attenuation is denoted by α. It is expressed in decibel per kilometer (dB/Km).

$$\alpha_{dB/km} = \frac{10}{L} \log \frac{P_i}{P_o}$$

P_i input power

P_o output power

L = Length of optical fiber

- For Ideal optical Fibre, $\alpha = 0$ hence $P_i = P_o$
- Attenuation is wavelength dependent.

Causes of attenuation

The attenuation or losses occurring in fibre are due to,

1. **Absorption**
2. **Rayleigh Scattering**
3. **Geometrical effects**

1. Absorption

- The light intensity decreases due to its absorption by light carrying medium or impurities present in the fibre.
- There are two types of absorption

1.Intrinsic absorption –

Fibres are made up of glass. The pure glass has natural tendency to absorb light of specific wavelengths.it is inherent property of glass to absorb the light it called as intrinsic absorption.

2. Extrinsic absorption –

Impurities are present in the glass are major source of absorption in the fibre.

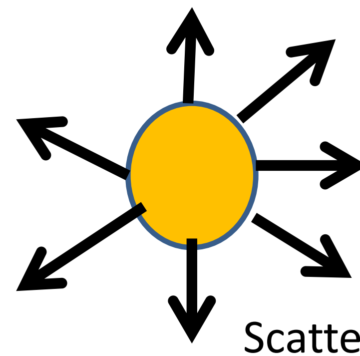
The presence of impurities such as hydroxyl ions (OH), Transition metals like copper, nickel, manganese, chromium.

- The losses due to intrinsic absorption are less as compared to other losses.

2. Rayliegh Scattering

- Scattering is due to non uniformities in optical fiber, a straight line path of the light rays get deviated in all directions.
- Rayliegh give relation between intensity of scattered light and the wavelength.
- It is given by,

$$I = \frac{K}{\lambda^4}$$



Where,

I = intensity of scattered light

λ = Wavelength of light

K = constant

- When light passes through glass optical fibre, it gets scattered from glass.
- Due to variation in density in optical fibre, the scattering of light takes place during transmission of light.
- For lower wavelengths intensity of transmitted light is less, because intensity is inversely proportional to wavelength.

3. Geometric Effect

- These are the losses occurring due to manufacturing defects in optical fibre.
- The irregularities may present in coating and cabling process.
- Due to this factor some part of light not show TIR hence light escapes out of fibre and intensity of light is decreases.

Optical Window

- It is a band of wavelengths at which attenuation is minimum is called as optical window.
- Optical signal having the wavelengths in this range travel through the fibre without much losses.
- Such windows are use for information transmission.

1. **Window I – lies between 800 μm to 900 μm**
2. **Window II – lies between 1300 nm to 1600 nm**

2. Dispersion

- Dispersion is basically the limiting factor.
- Due to dispersion, broadening of output signal takes place.
- It changes the shape of signal.
- In optical fibers, signals of different frequencies travel through different speeds and hence they reach at different times at the exit end. This results in overlapping of pulses and broadening of the pulse, due to which the information is lost.
- It is a process of distortion of an optical signal resulting into broadening of signal.
- Dispersion measured in Nano-second per kilometer (ns/km).
- There are 3 types of dispersion,

1. Material dispersion

2. Waveguide dispersion

3. Intermodal dispersion

1.Material dispersion

- Material dispersion depends on the refractive index of material used to manufacture the optical fibre.
- Light waves of different wavelengths travel at different speeds in a medium.
- The wave of short wavelength travel slower than long wavelength waves.
- It is very small for monochromatic light as spectral width is minimum.

2. Waveguide dispersion

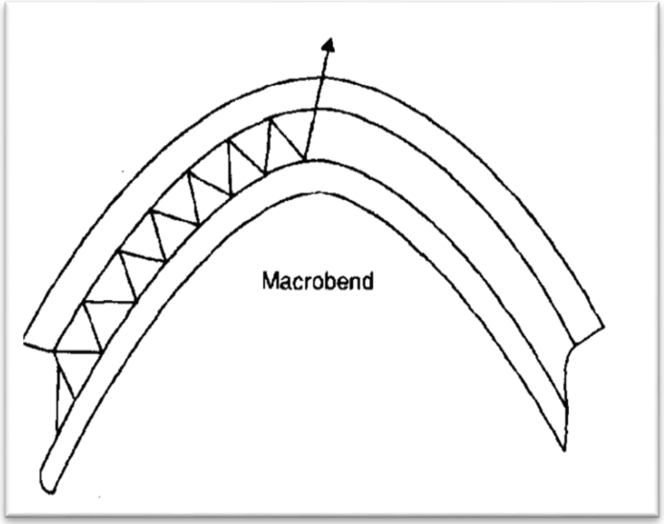
- When optical signals passing through the fibre, then optical fibre acting as waveguide.
- It arises due to relative size of the wave.
- The effective refractive index for any mode varies with wavelength due to which spreading of refractive signal takes place. This is known as waveguide dispersion.

3. Intermodal Dispersion

- It is arises due to different velocities of different modes travelling simultaneously through optical fiber.
- The modes of lower order travel faster than modes with higher order.
- As a result, the modes with higher velocity reach at the output end before modes with lower velocity. Which leads to broadening of signal takes place.

Bending

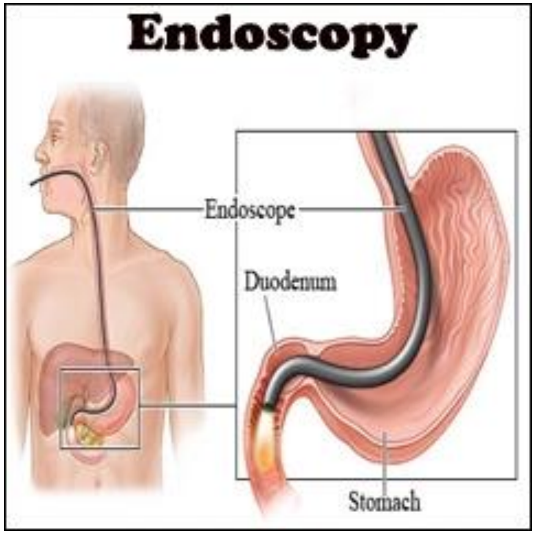
- It occurs when optical fibre undergoes or bend of finite radius of curvature. Light is lost at bends.
- A light travel into a fibre by TIR. At a bend , the angle between the normal and ray less than the critical angle, the ray is not reflected but is lost.
- Losses increase for fibre with increasing bends, because radius of curvature decreases.



Application of fiber optics

1.Medical Applications

Optical fibre technology is used in medical diagnostics as well as medical process.



- Endoscopy – optical fibre used to inspect internal organs for diagnostic.
- Laparoscopy – used to carry out minimum invasive surgery.
- Cardiology – used to evaporate plaque that blocked in artery.

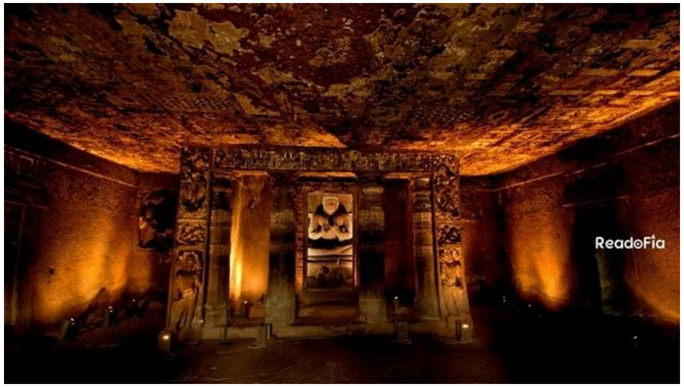
- Treatment of cancer – for treatment optical fibre technology is used. fibre illuminates the affected area of cancerous cells.

2.Monitoring civil structure

- Optical fibre technology use to monitor the health of flyovers, railway bridges and buildings.
- 24/7 monitoring is possible.
- It can monitor any defects in structure.
- Optical fibre sensors install in flyover to measure stain and stess.

3. Cold lighting

- Optical fibre is give only light so artwork in museum are not damaged or degraded.
- Ordinary light produce heat and light. Due to heat art work is degraded.



4. Military applications

- An aircraft, ships and tanks use optical fibre technology.
- Use of optical fibre in place of copper reduces weight and maintains communication.
- Sensors place on missile transmitter.
- Optical fiber technology used in guided missiles with the help of the sensors mounted on the missile. guidance System determines whether or not the missile is on course to reach the target.

5. Optical communications

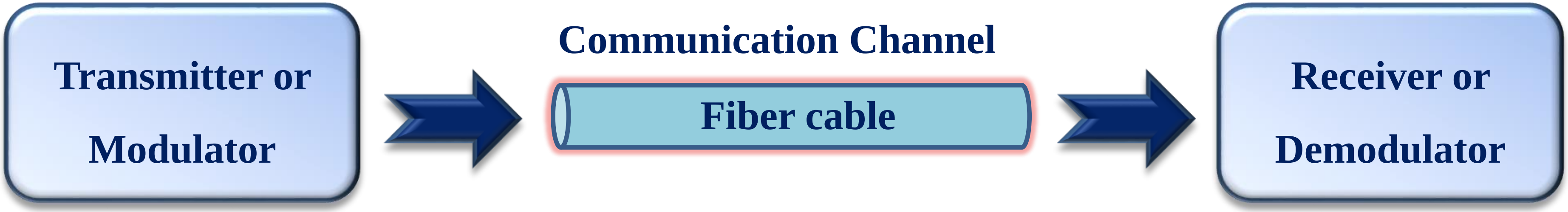
- A medium, such as a glass or plastic fiber, used for transmitting information from point to point at wavelengths of visible-light is called optical-fiber cable.
- In optical communication, light is used as carrier wave for transmitting audio and video signals.
- LEDs and lasers provide suitable light sources for optical communication.
- For Wi-Fi and broad band connection use the optical fibre cables.
- 5G data transfer is possible due optical fibre due to less loss.
- Today we are connected globally by using different social media apps and sites, internet, emails with help of fibre.

Advantages of Optical Fibre

- Large bandwidth
- Non hazardous
- Immunity to electromagnetic interference and radiofrequency interference
- Signal security
- Small size and weight
- Low transmission loss
- Ruggedness and flexibility
- Low cost

FIBER OPTIC COMMUNICATION SYSTEM

Any communication system consists of three major components.



1) ***Transmitter or Modulator:***

Linked with information source which converts electrical signal into light signal.

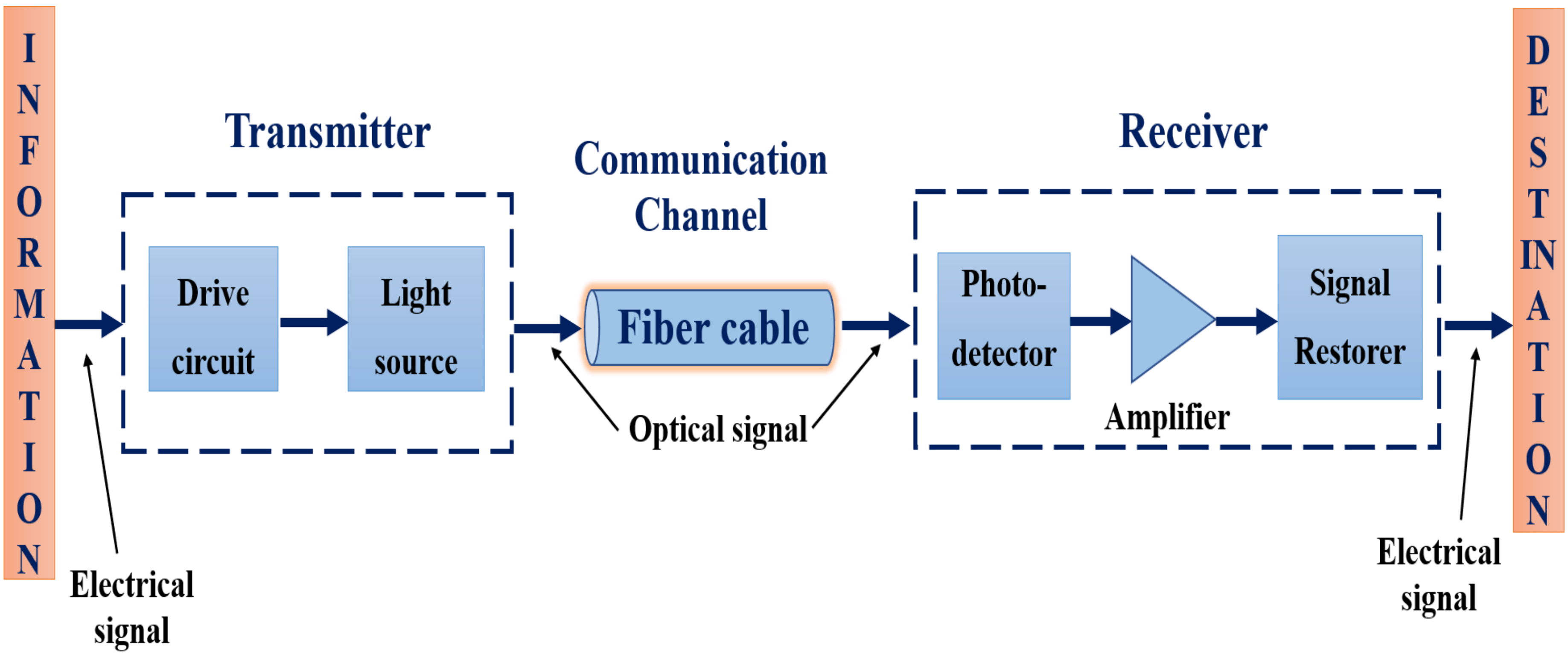
2) ***Communication Channel or Transmission medium:***

Transmits the optical signal through fiber cable.

3) ***Receiver or Demodulator:***

Receive the optical signals at other end of the fiber and converts it into electrical signals

Block Diagram for optical communication system

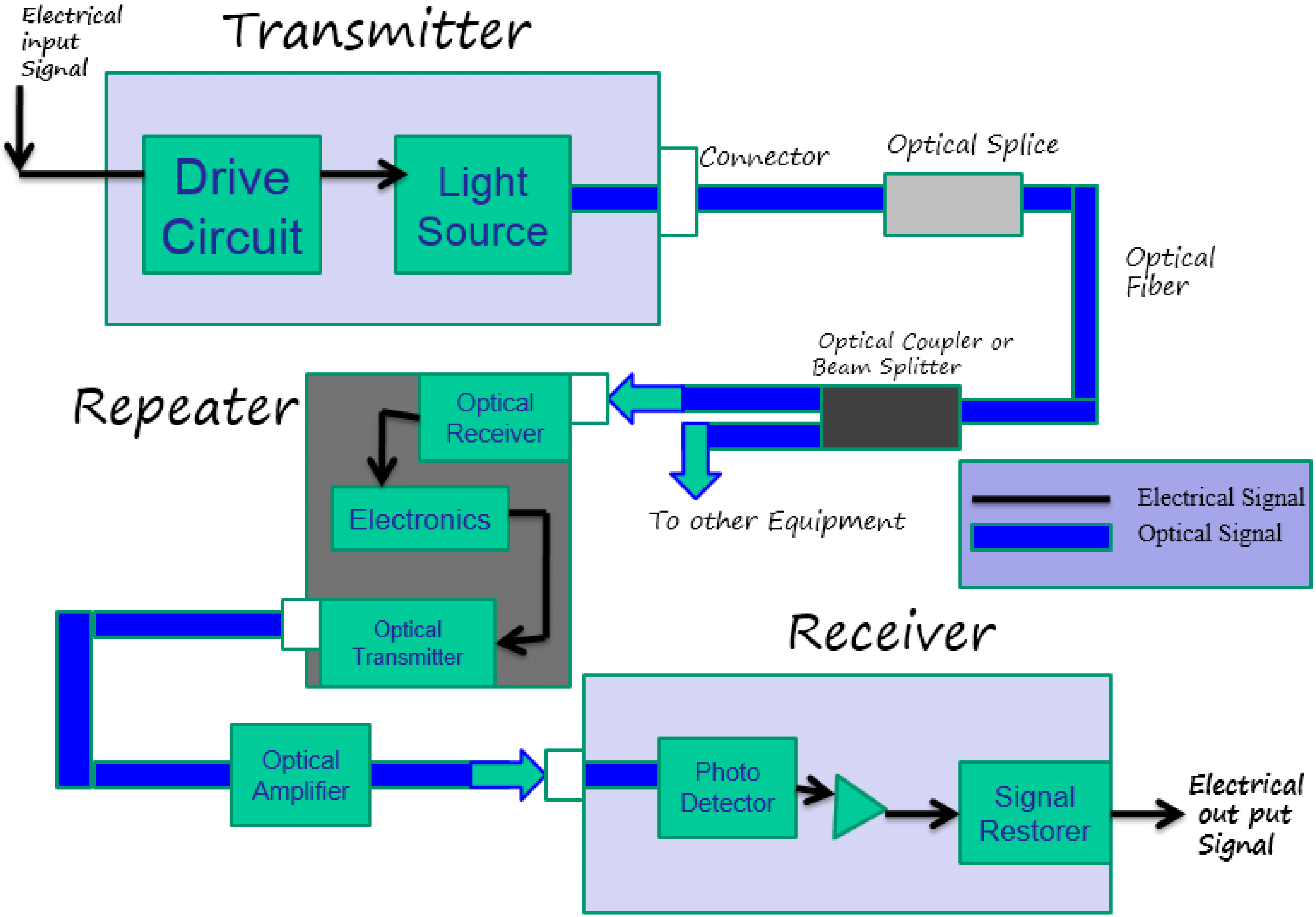


- Information or data is convert into electrical signal .
- Electrical signals from the source are given as input to the transmitter, which consists of drive circuit and light source inside it.
- Optical source like LED or LASERS.

- This optical signal is launched into optical fibre which is acting as a channel.
- Receiver receives the distorted optical signals.
- Receiver consists of 3 components

1. Photo detector
2. Amplifier
3. Signal restorer

- Photo detector of the receiver converts the optical signal into its equivalent electrical signals.
- Photo detectors like pin diode.
- Electrical signals are amplified in the amplifier.
- The signal restorer restores the signals to its original form by removing the distortion and attenuations.
- Original information is reached to destination.


Electrical input Signal
Transmitter
Drive Circuit
Light Source
Connector
Optical Splice
Optical Fiber
Optical Coupler or Beam Splitter
Repeater
Optical Receiver
Electronics
Optical Transmitter
To other Equipment
Electrical Signal
Optical Signal
Receiver
Optical Amplifier
Photo Detector
Signal Restorer
Electrical out put Signal

Q.1 A step index fibre is made with a core of refractive index 1.52. a diameter of 29 μm and fractional difference index of 0.0007. it is operated at a wavelength of 1.3 μm . Find the v number and number of modes that fiber will support.

2. A multimode step index fiber has a relative refractive index difference of 1.1%, and a core refractive index of 1.5. The number of modes propagating at a wavelength of 1.3 μm is 1100. Estimate the diameter of the fiber core.

3. What is attenuation in db/km, if 15% of the power fed at launching end of ½ km fibre is lost during propagation.