UNIT-I

Fiber Optics

Principle of optical fiber, construction of fiber, acceptance angle and acceptance cone, numerical aperture, types of optical fibers: step index and graded index fibers, attenuation in optical fibers, applications of optical fibers in medicine and sensors.

Principle of Optical Fiber

Optical Fiber

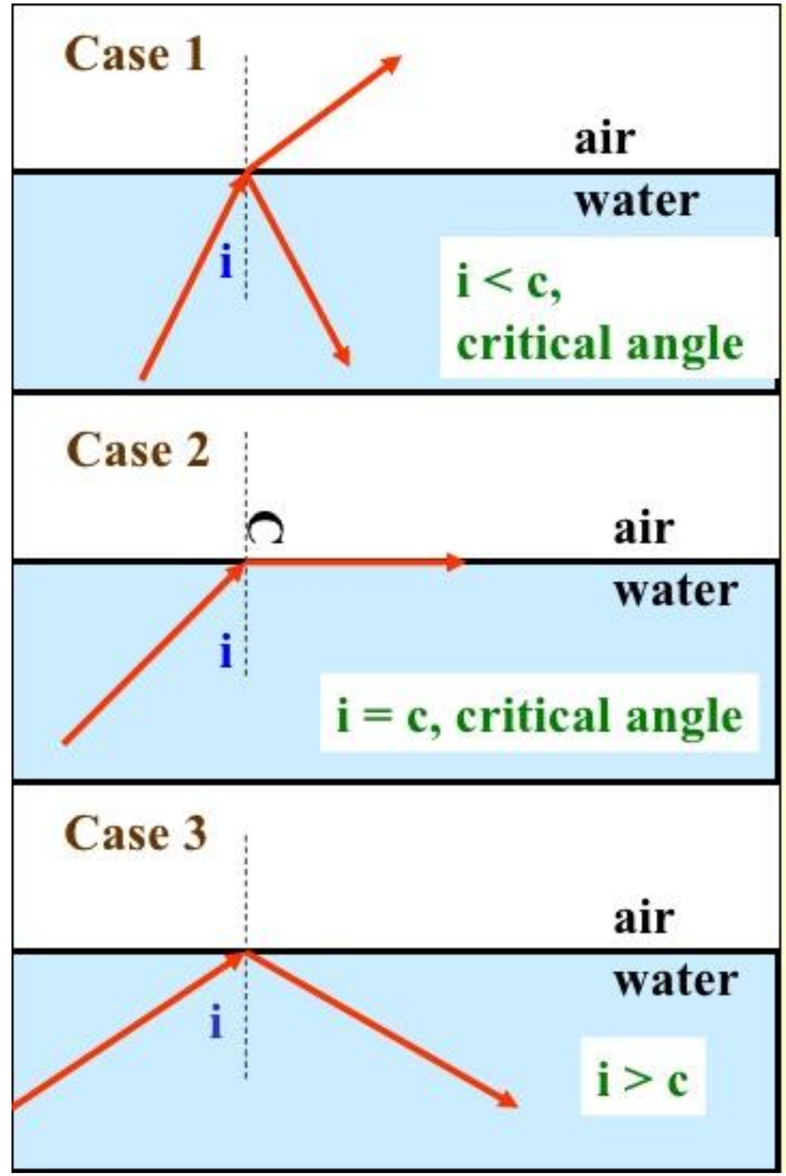
- An optical fiber (or fiber) is a glass or plastic fiber that carries light along its length.
- Principle of Optical fiber is Total Internal Reflection

Total Internal Reflection

The complete reflection of a light ray reaching an interface with a less dense medium when the angle of incidence exceeds the critical angle.

Total Internal Reflection

When light ray travelled from denser material to less dense material (say from water to air) and **if the angle of incidence i > c, the critical angle , all the light ray will reflected internally.** This is called total Internal Reflection (case 3)

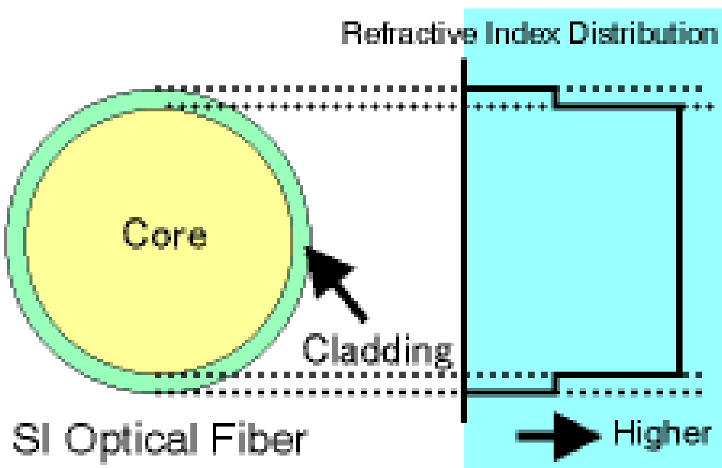


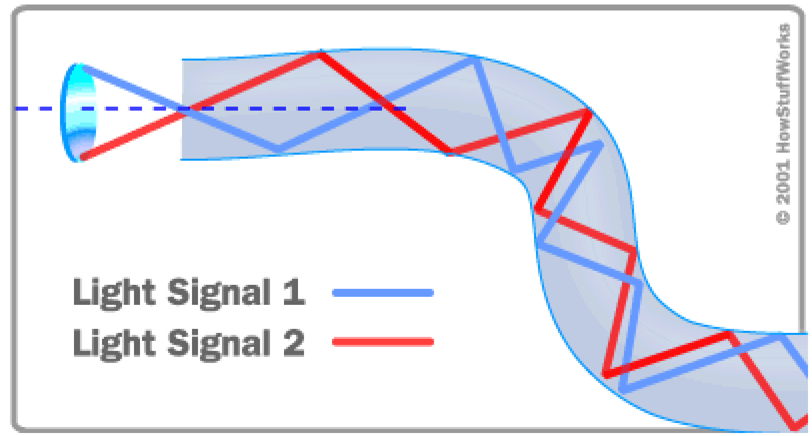
<u>In Optical fiber</u>

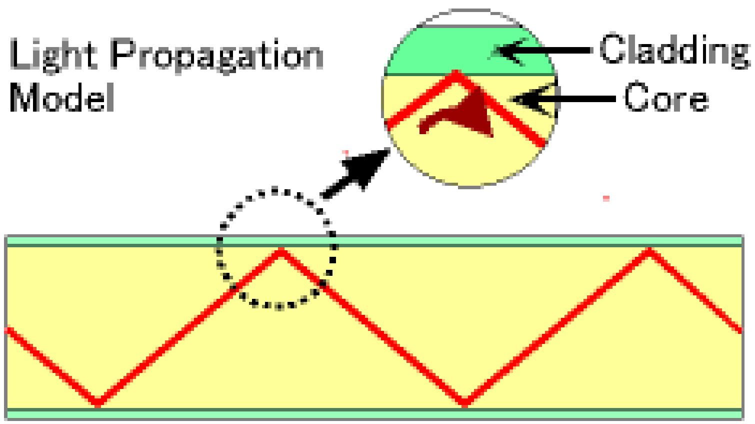
Denser material Is **Core**

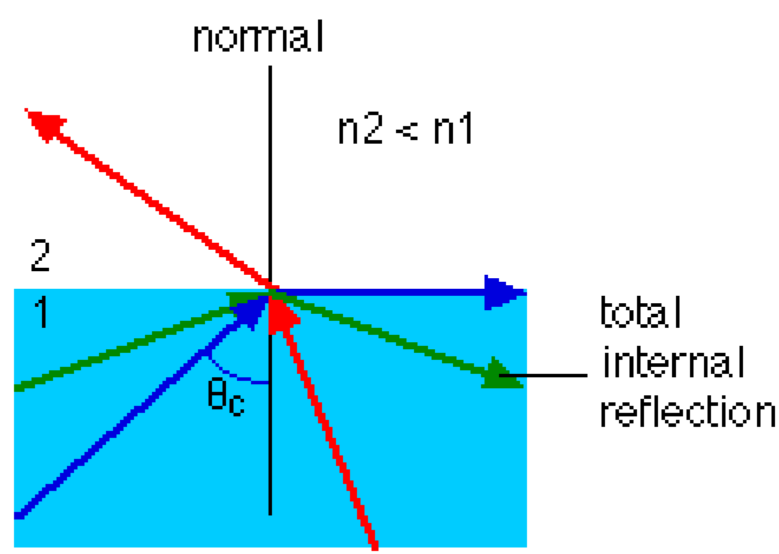
Less denser material is **Cladding**

How Does fiber optic transmit light



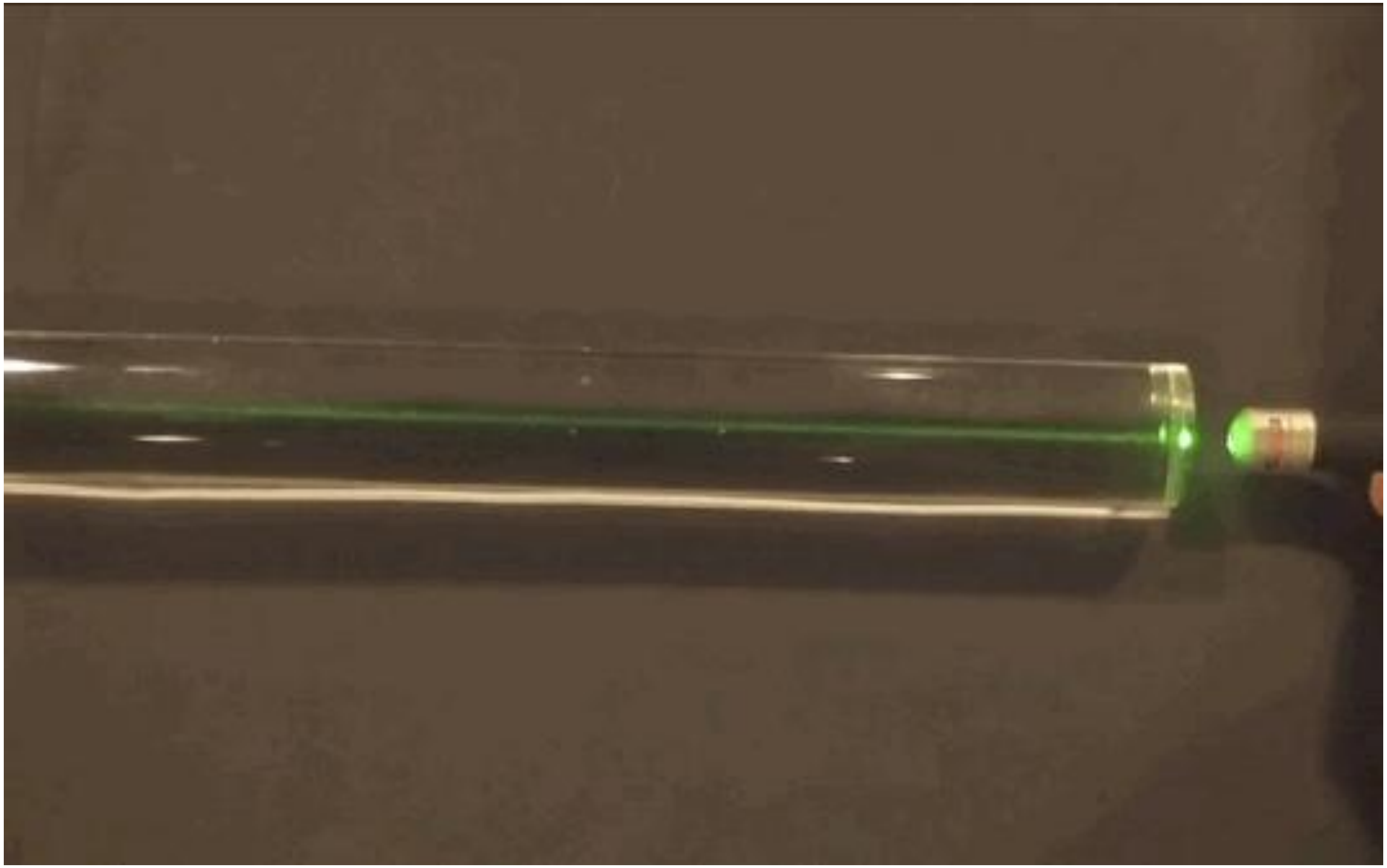






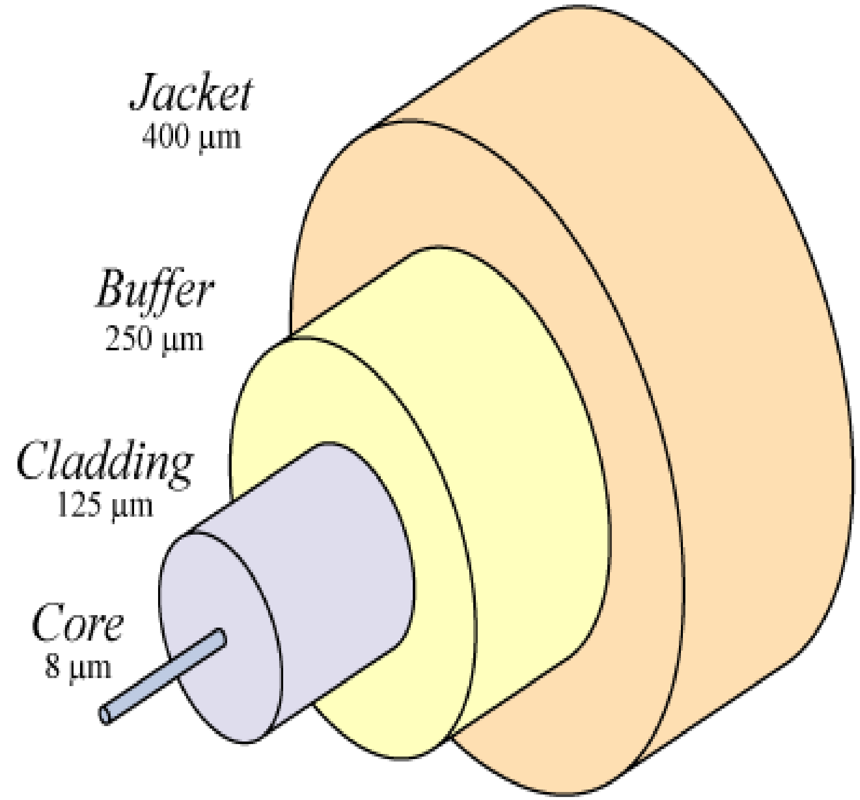
Total Internal Reflection in a light pipe

How Fiber Works

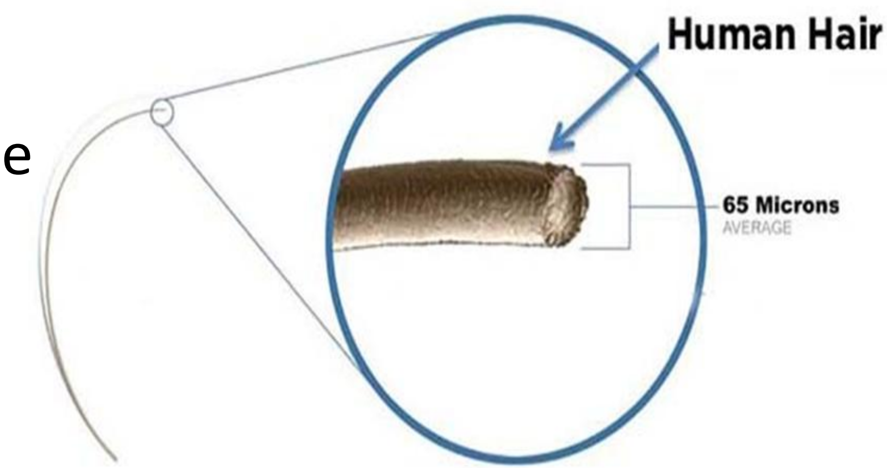


Optical Fiber Construction

- **Core**
  - Glass or plastic with a higher index of refraction than the cladding
  - Carries the signal
- **Cladding**
  - Glass or plastic with a lower index of refraction than the core
- **Buffer**
  - Protects the fiber from damage and moisture
- **Jacket**
  - Holds one or more fibers in a cable

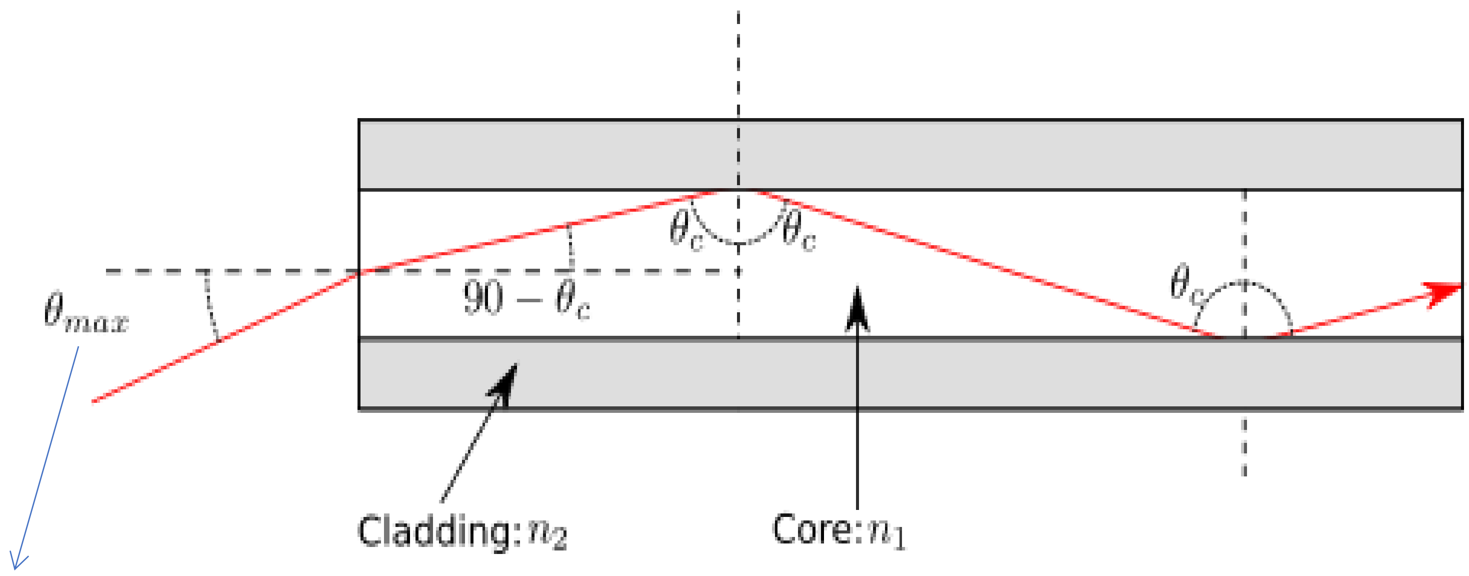


A glass optical fiber is about **twice the size of a human hair**.



ACCEPTANCE ANGLE

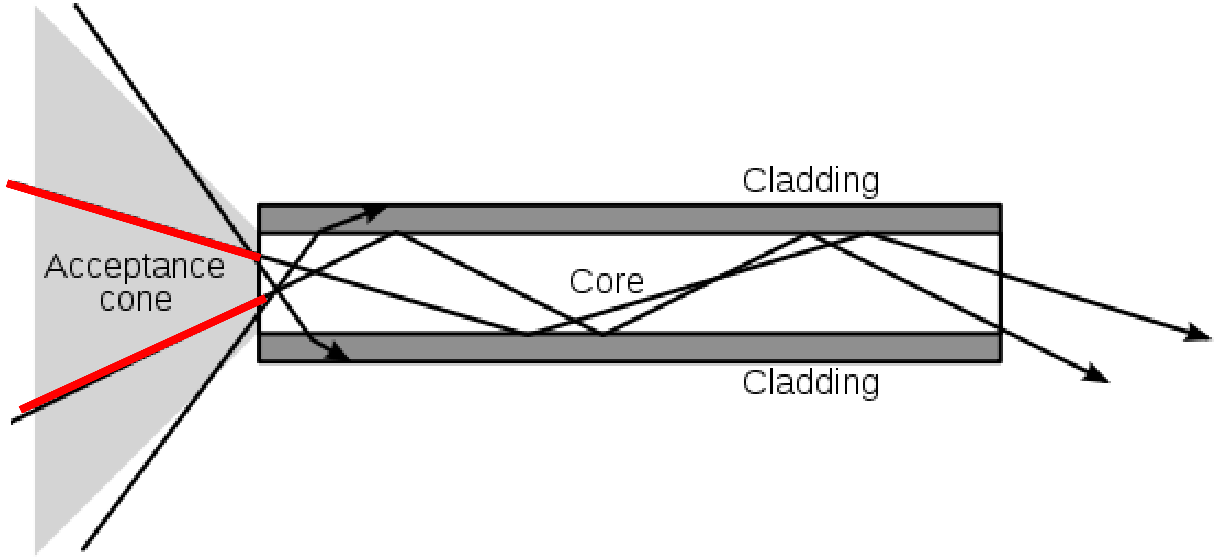
Acceptance angle is maximum angle at which a light ray enters into core and propagate through it in zigzag path



Acceptance angle

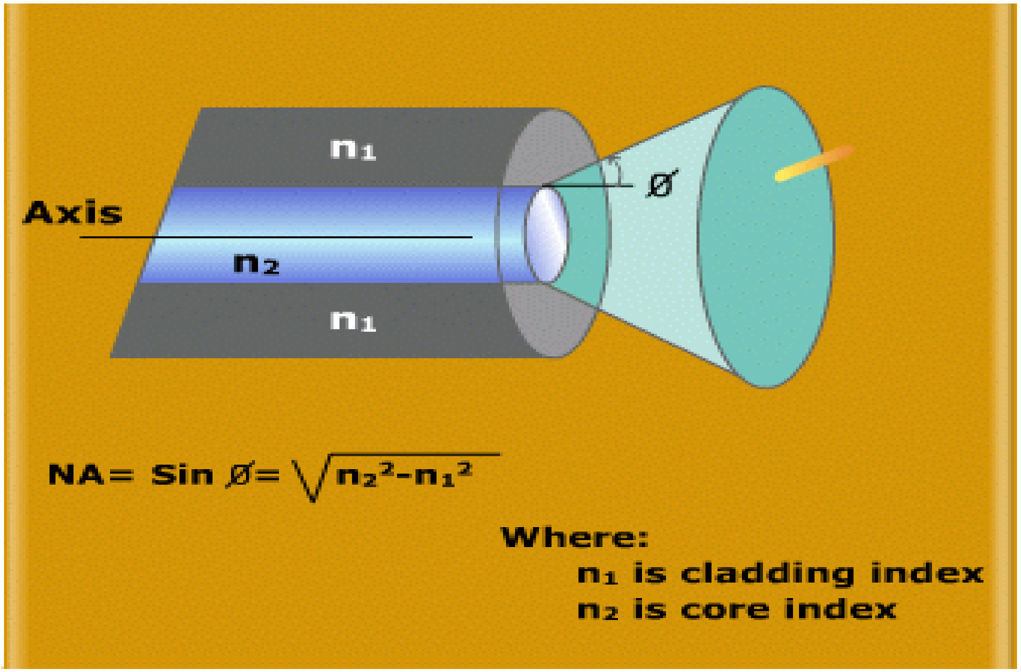
ACCEPTANCE CONE

- If all possible direction of acceptance angle are considered at same time we get a cone corresponding to surface known as **acceptance cone**



NUMERICAL APERTURE

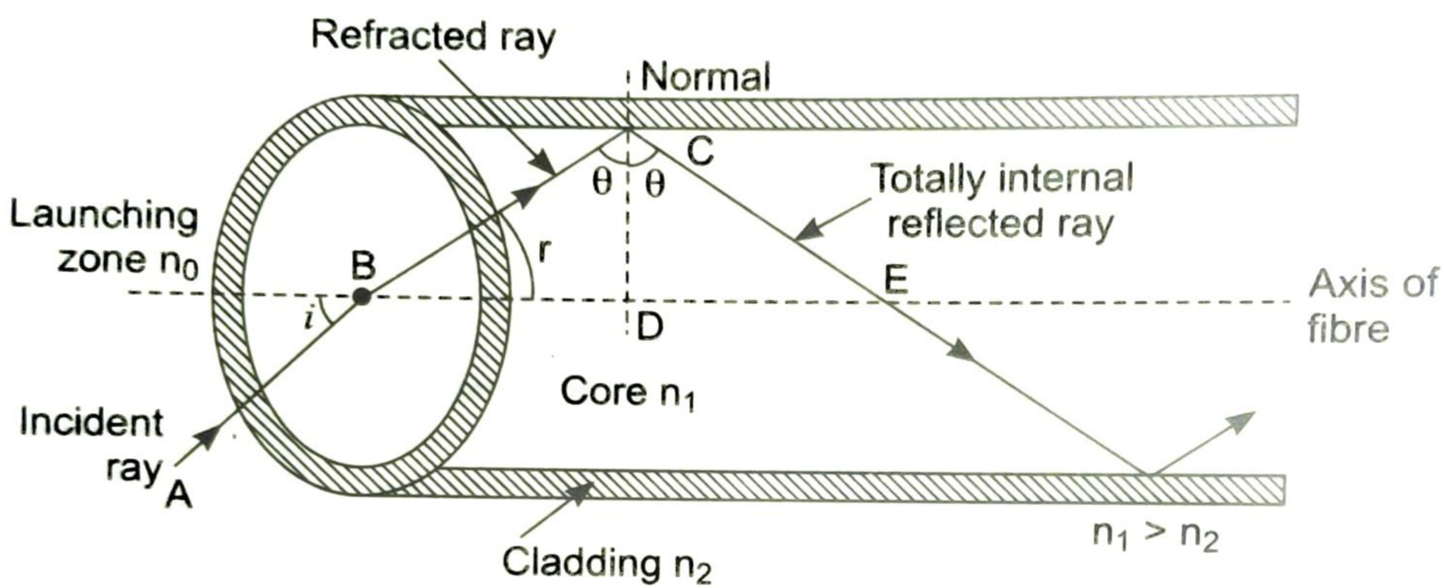
- It defines gathering capability of fiber mathematically expressed as sine of **acceptance angle**
- High Numerical Aperture increases dispersion hence low Numerical Aperture is desirable



Derivation

Acceptance angle and Numerical Aperture

1. Consider a cylindrical fibre wire which consists of an inner core of refractive index n_1 and an outer cladding of refractive index n_2 where $n_2 > n_1$.
2. Let n_0 be the refractive index of the medium from which the light enters the fibre.
3. End of the fibre is known as Launching End.
4. Let a ray of light enter the fibre at an angle i to the axis of fibre as shown in fig.1.
5. The ray refracts at an angle r and strikes the core- cladding interface at an angle θ. Let θ is greater θ_c. As long as the angle is greater than θ is greater than θ_c, the light will stay within the fibre.



The angle of incidence i for which $\theta \geq \theta_c$ (critical angle)

Applying snell's law of refraction at the point of entry of the ray AB into the core,

$$n_o \sin i = n_1 \sin r \qquad \rightarrow (1)$$

From triangle BCD, it is seen that

$$r = (90 - \theta) \quad or \ \sin r = (90 - \theta)$$

$$\sin r = \cos \theta \qquad \rightarrow (2)$$

Substituting the value of sin r from eq (2) in eq (1) we get

$$n_0 \sin i = n_1 \cos \theta$$

$$\sin i = \left(\frac{n_1}{n_0} \right) \cos \theta \qquad \rightarrow (3)$$

If i is increased beyond a limit, θ will drop below the critical value θ_c and the ray will escape from the side walls of the fibre.

$$sin\left(i_{max}\right)=\left(\frac{n_1}{n_o}\right)cos\ \theta_c \qquad \rightarrow (4)$$

We know that,

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

$$\cos\theta_c=\sqrt{1-\sin^2\theta_c}=\frac{\sqrt{\left(n_1^2-n_2^2\right)}}{n_1}$$

From eq (4), we have

$$sin\left(i_{max}\right)=\frac{n_1}{n_o}\times\frac{\sqrt{\left(n_1^2-n_2^2\right)}}{n_1}=\frac{\sqrt{\left(n_1^2-n_2^2\right)}}{n_o} \qquad \rightarrow (5)$$

$$n_o = 1(air\ medium) \qquad i_{max} = i_o$$

$$sin(i_o) = \sqrt{(n_1^2 - n_2^2)} \qquad \rightarrow (6)$$

i_o is called the acceptance angle of the fibre.

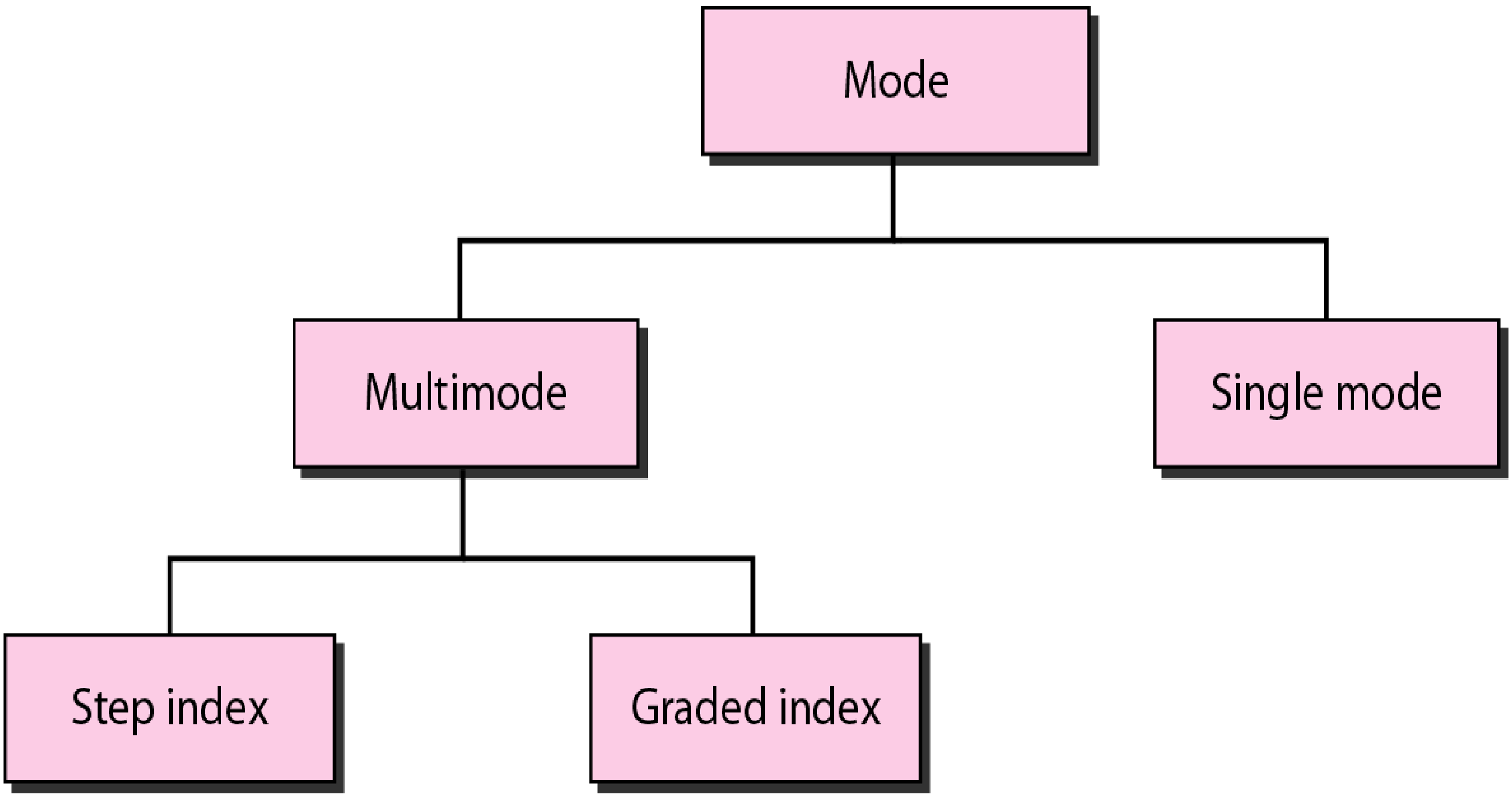
$$i_o = sin^{-1}\sqrt{(n_1^2 - n_2^2)} \qquad \rightarrow (7)$$

- The acceptance angle is defined as a maximum angle that a light ray can have relative to the axis of the fibre so that it may propagate drawing the fibre.
- It also may be defined as the maximum angle from the fibre axis at which light may enter the fibre so that it will propagate in the core by total internal reflection.
- Numerical Aperture
- It determines the light gathering ability of the fibre. So, it is a measure of the amount of light that can be accepted by the fibre. This is also defined as the sine of acceptance angle.

$$\text{NA} = sin\ i_o$$

$$NA = \sqrt{(n_1^2 - n_2^2)} \qquad \rightarrow (8)$$

OPTICAL FIBER TRANSMISSION MODES/ TYPES OF FIBERS



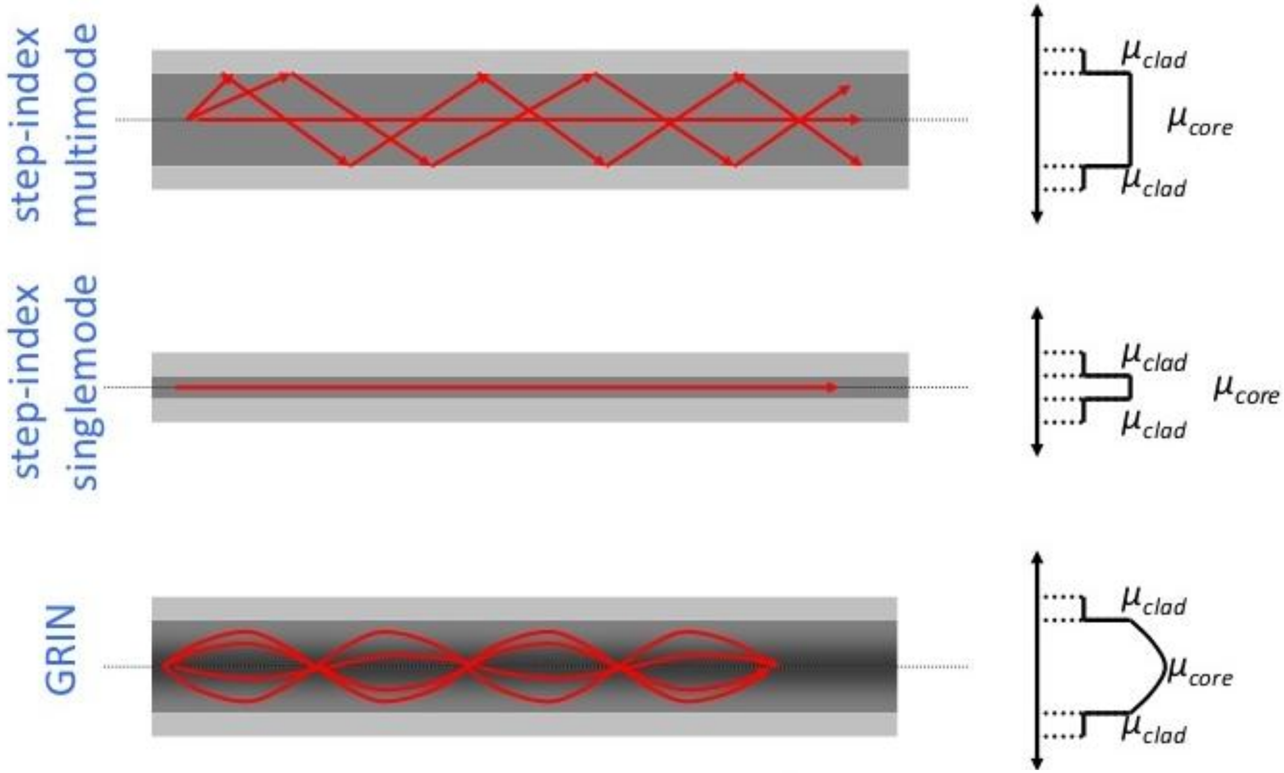
TYPES OF FIBERS (contd.)

- **Multimode step-index fiber**
  - the reflective walls of fiber move light pulses to receiver

- **Multimode graded-index fiber**
  - acts to refract light toward center of fiber by variations in density

- **Single mode fiber**
  - the light is guided down center of an extremely narrow core

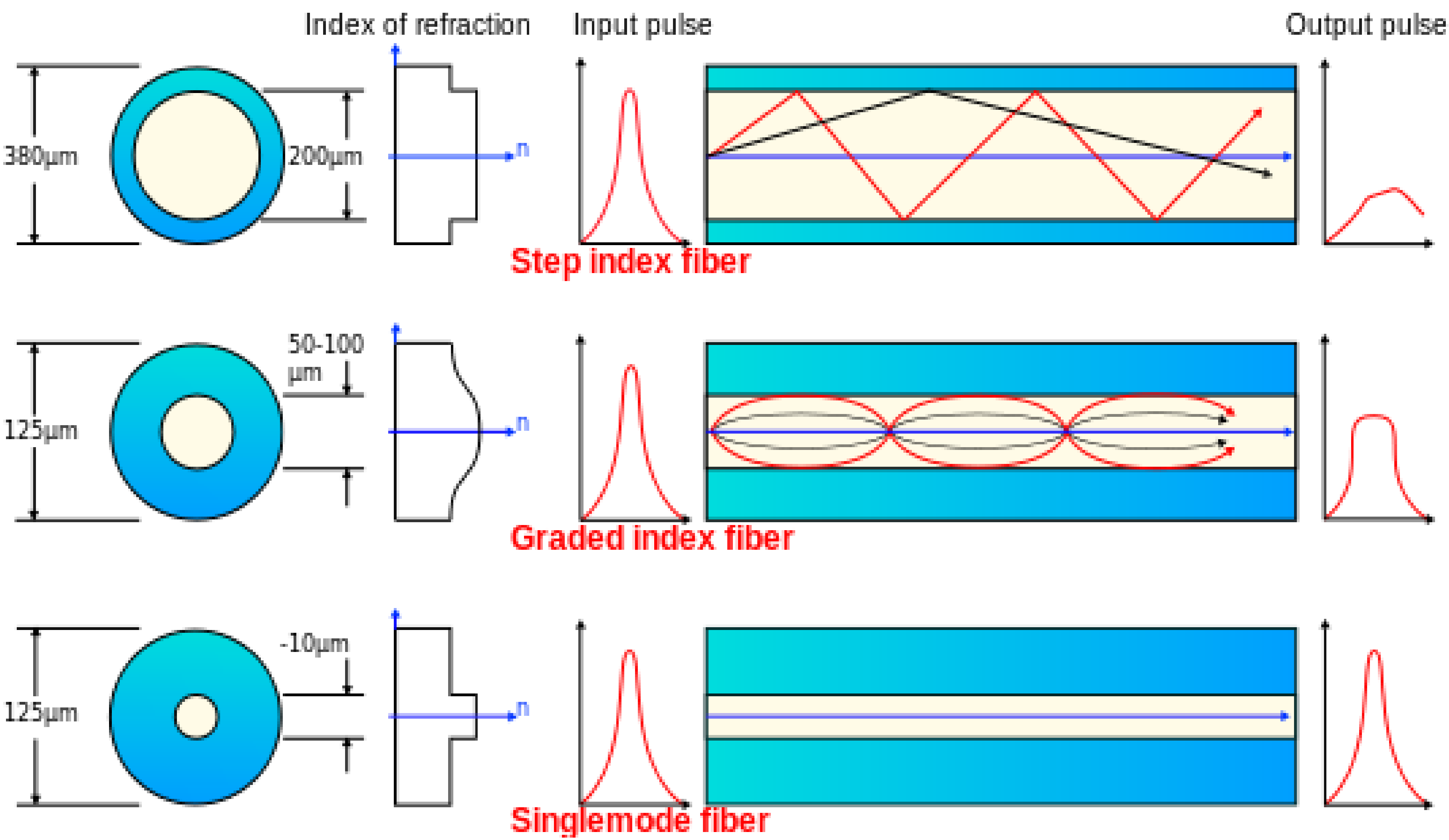
TYPES OF FIBERS (contd.)



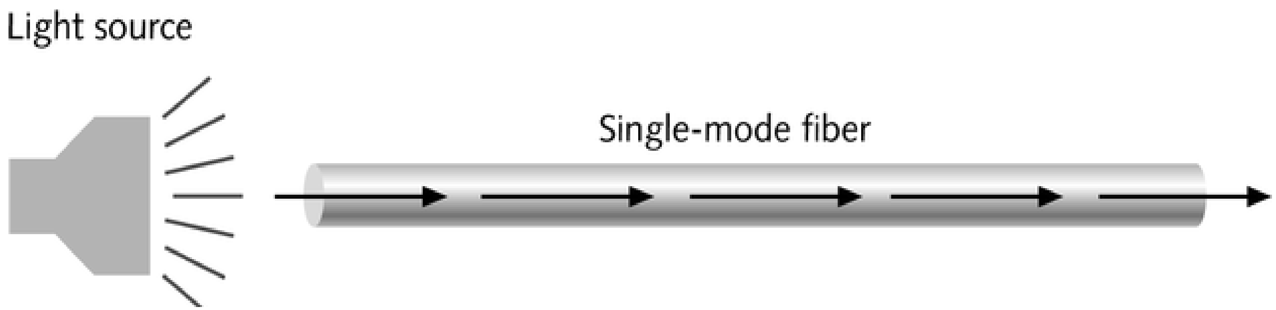
Comparison

Multimode 50/125 μm | **Multimode 62.5/125 μm** | **Single-mode 9/125 μm**

TYPES OF FIBERS (contd.)



SINGLE MODE FIBER



Carries light pulses along single path

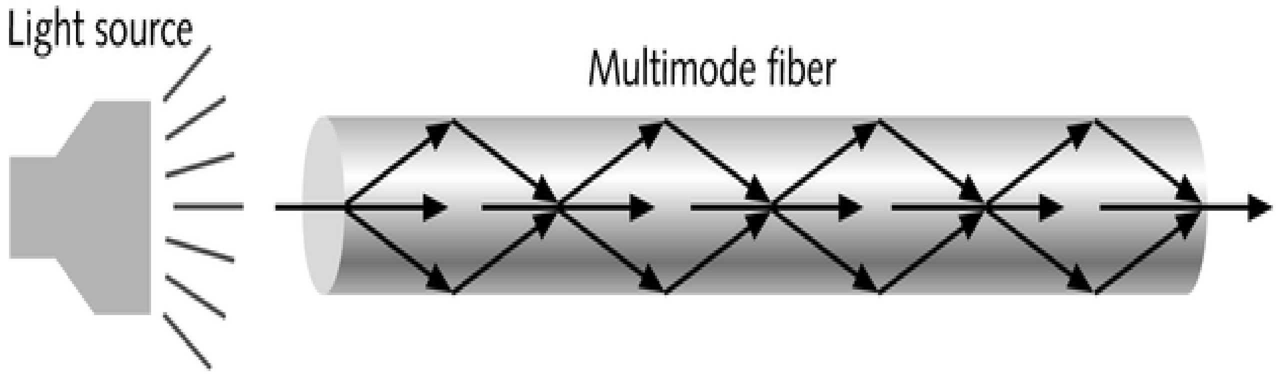
Advantages:

- Minimum dispersion: all rays take same path, same time to travel down the cable. A pulse can be reproduced at the receiver very accurately.
- Less attenuation, can run over longer distance without repeaters.
- Larger bandwidth and higher information rate

Disadvantages:

- Difficult to couple light in and out of the tiny core
- Highly directive light source (laser) is required
- Interfacing modules are more expensive

MULTIMODE FIBER



Many pulses of light generated by LED travel at different angles

- **Multimode step-index Fibers**:
  - inexpensive
  - easy to couple light into Fiber
  - result in higher signal distortion
  - lower TX rate
- **Multimode graded-index Fiber**:
  - intermediate between the other two types of Fibers

Attenuation in optical Fiber

- **When light travels along the fibre, there is a loss of optical power, which is called attenuation.**

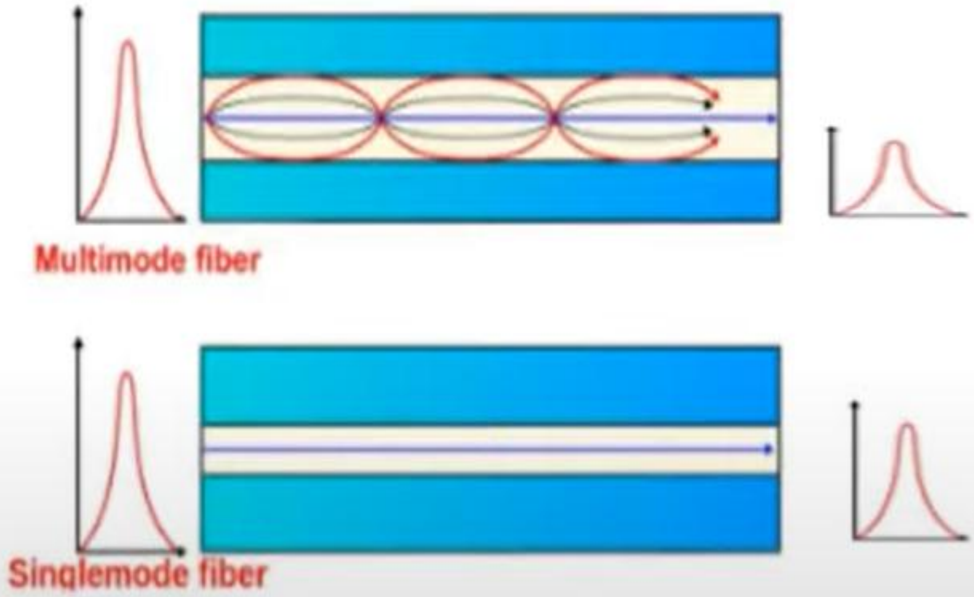
Definition:

Attenuation: Ratio of optical input power (P_i) to the optical output power (P_o)

Optical Input power: The power transmitted into the fibre from an optical source

Optical output power: The power received at the fibre end

Attenuation is the reduction in power of the light signal as it is transmitted.



Fiber Attenuation Cont……..

This relation defines the signal attenuation or absorption coefficient in terms of length L of the fibre:

$$\boxed{\alpha = \frac{10}{L}\log_{10}\frac{P_i}{P_0}}$$

Length **L** of the fibre is expressed in **kilometers**
Here, the unit of Attenuation is decibels/kilometer i.e. **dB/km.**

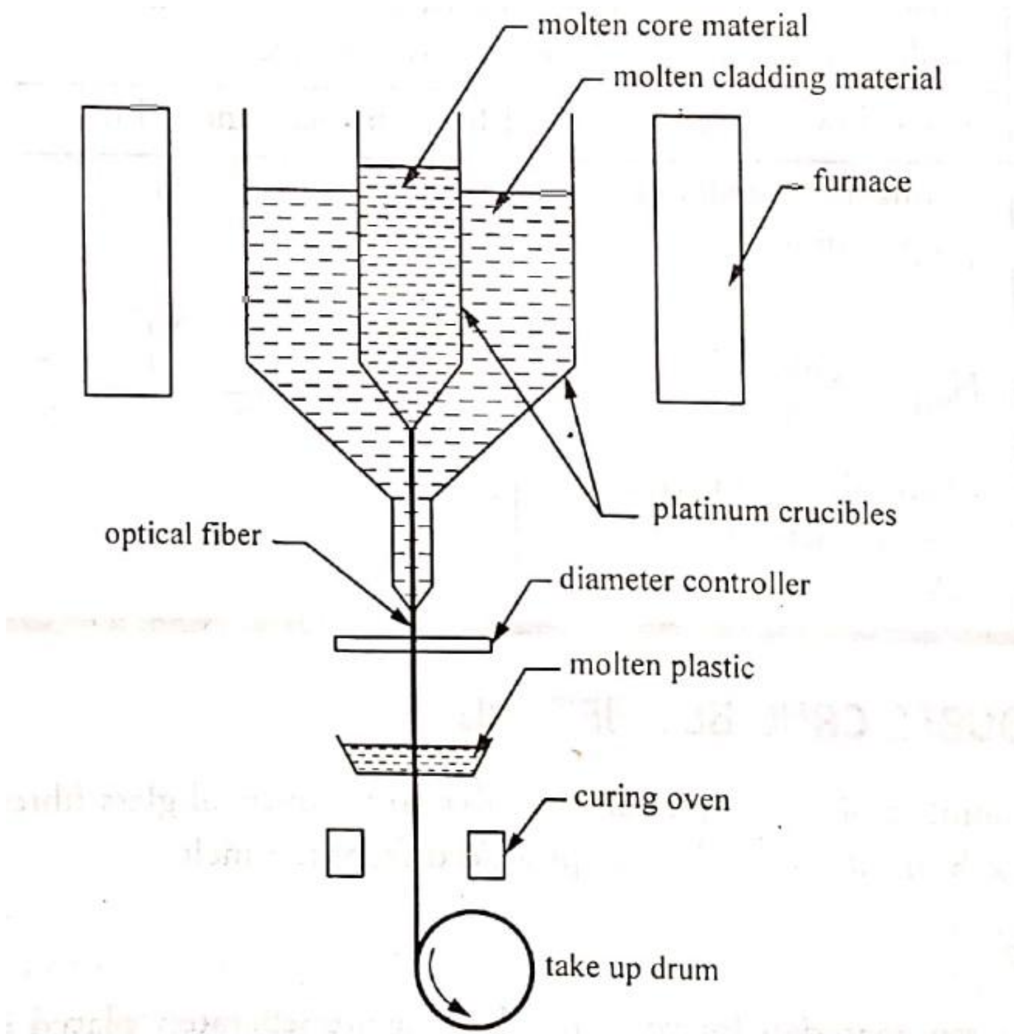
The main causes of attenuation in optical fibre are:

(a)Absorption
(b)Scattering
(c)Bending losses

Each mechanism of loss is influenced by the properties of fibre Material and fibre structure.

Double Crucible Method

A method of fabricating an Optical Wave guide by melting the core and clad glasses in two suitably joined concentric crucibles and then drawing a fiber from the combined melted glass.



1. Highly purified glass powders of various refractive indices are fed into the inner crucible for the core in the outer crucible for cladding.

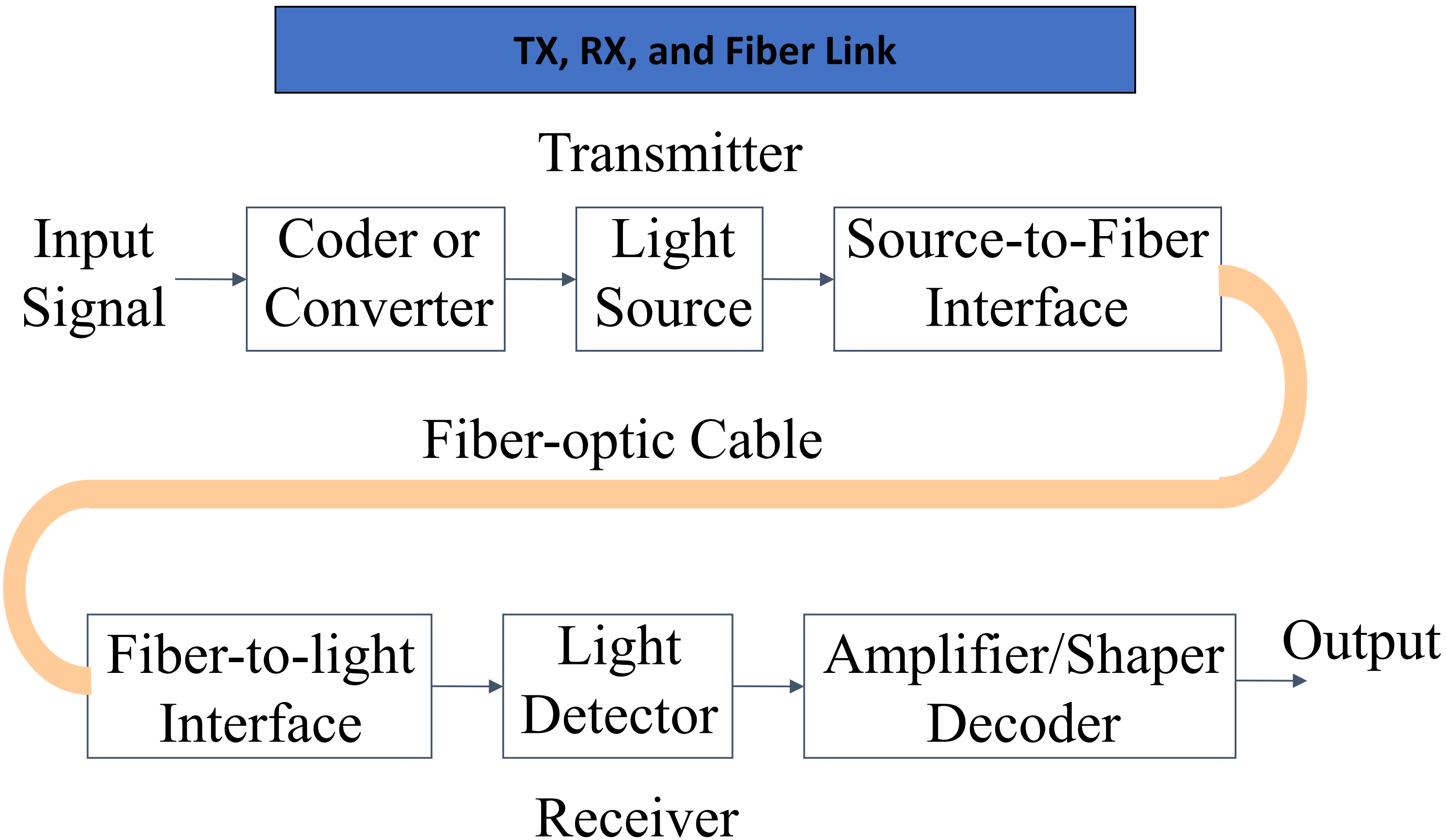
2. The electric furnace is switched on and the materials are heated to very high temperature.

3. The material goes to molten state and the material starts squeezing through the orifice of the crucible.

4. Now the core material will start diffusing into cladding material to form an optical fiber.

5. The fiber is drawn through the bottom surface of the crucible and dopant such as thallium with high rate of diffusion in silica is used to maintain the difference in refractive index.

FIBER OPTIC COMMUNICATION



Optical Fiber Architecture – Components

- **Light source:**

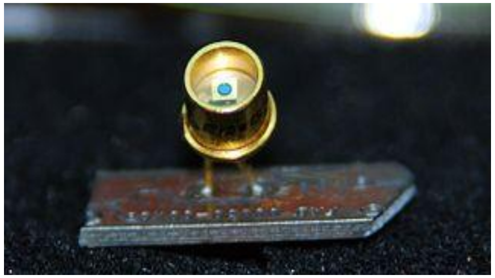
  Amount of light emitted is proportional to the drive current

  Two common types:

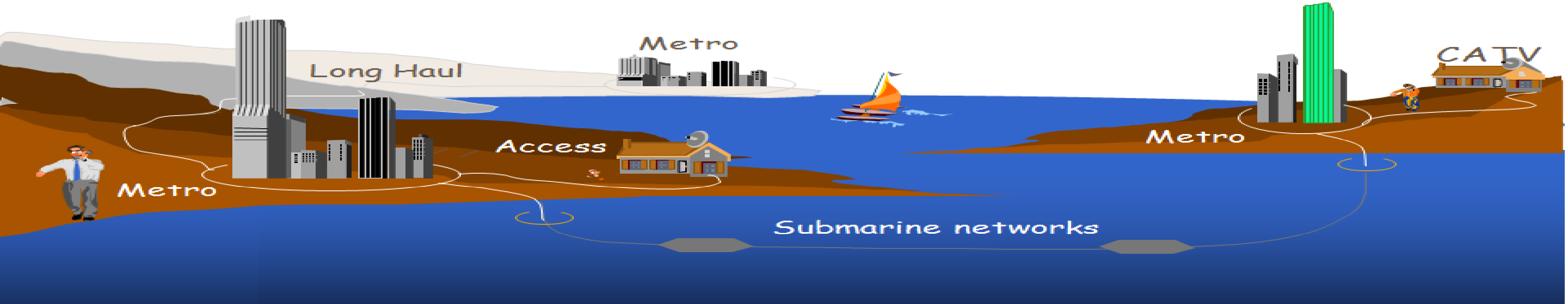
  - LED (Light Emitting Diode)
  - ILD (Injection Laser Diode)

- **Source–to-fiber-coupler (similar to a lens):**

A mechanical interface to couple the light emitted by the source into the optical fiber



- **Light detector:**
  - PIN (p-type-intrinsic-n-type)
  - APD (avalanche photo diode)
  - Both convert light energy into current



Applications of optical fibers

- Optical fibers are used as sensors
- These are used in Endoscopy
- These are used in communication system
- For decorative peaces in home needs.
- These are used in defense areas for the sake of high security.
- These are used in electrical engineering
- No hazards of short circuits as in case of metals.
- Can be used safely in explosive environment.
- No need of additional equipment to protect against grounding and voltage problems.
- Nominal installation cost.
- Using a pair of copper wires only 48 independent speech signals can be sent simultaneously whereas using an optical fiber 15000 independent speeches can be sent simultaneously.

Numerical Problems

Activity 1: The refractive indices for core and cladding for a step index fibre are 1.52 and 1.41 respectively
Caculate (1) Critical angle (2) Numerical Aperture
(3) The maximum incidence angle

Hints: Given Here $=\mu_1 = \mu_{core} = 1.52$, and $\mu_2 = \mu_{clad} = 1.41$

Critical angle $\theta_c = \sin^{-1} (\mu_{2/} \mu_1)$ **Ans = 68.06^0**

Numerical Aperture $\boxed{\sqrt{\mu_1^{\,2} - \mu_2^{\,2}}}$ **Ans = 0.568**

Maximum incidence angle $(\theta_0)=$ $\boxed{\sin^{-1}\left(\sqrt{\mu_1^{\,2} - \mu_2^{\,2}}\right)}$

Ans $\theta_0 = 34.6^0$

Numerical Problems

Activity 2: A light ray enters from air to a fibre. The refractive Index of air is 1.0. The fibre has refractive index of core is equal to 1.5 and that of cladding is 1.48. Find the critical Angle, the fractional refractive index, the acceptance angle anc Numerical aperture.

Hints: Given Here $= \mu_0 = \mu_{air} = 1.0$; $\mu_1 = \mu_{core} = 1.5$, and $\mu_2 = \mu_{clad} = 1.48$

Critical angle $\theta_c = \sin^{-1}(\mu_{2/}\ \mu_1)$ **Ans: $\theta_c = 80.63^0$**

Fractional Refractive index $\dfrac{\mu_1 - \mu_2}{\mu_1}$ **= 1.33% of light**

Ans = 0.568

Numerical Aperture $\sqrt{\mu_1^2 - \mu_2^2}$

Acceptance angle $(\theta_0) = \sin^{-1}\left(\sqrt{\mu_1^2 - \mu_2^2}\right)$ **Ans $\theta_0 = 14.13^0$**