Applications:

1. This type of laser is mostly used in optical applications
2. It is widely used in computers, especially on CD-ROMs.

2.1.16 Comparison Chart of different types of Lasers

S.No	Characteristics	Nd-YAG laser	He-Ne laser	CO_2 Laser	Semiconductor laser
1.	Type	Solid state laser	Gas laser	Molecular laser	Semiconductor laser
2	Active medium	Yttrium Aluminum garnet ($Y_3 Al_5 O_{12}$)	Mixture of He and Ne in the ratio of 10:1	Mixture of CO_2 ,N_2 and He gases	PN junction
3	Pumping method	Optical Pumping	Electrical pumping	Electrical Discharge method	Direct conversion
4	Optical resonator	Ends of the polished rods in silver	Pair of concave mirrors	Metallic mirror of gold or silicon coated with aluminum	End faces of the junction diode
5	Power output	2×10^4 watt	0.5- 50 mW	10kW	1 mW
6	Nature of power output	Pulsed	Continuous waveform	Continuous or pulsed	Pulsed or continuous wave form
7	Wavelength	1.06μm	6328 $\overset{0}{A}$	9.6μm and 10.6μm	8300- 8500 $\overset{0}{A}$

3.1.1 Introduction: FIBER OPTICS

The development of lasers and optical fiber has brought about a revolution in the field of communication systems. Experiments on the propagation of information – carrying light waves through an open atmosphere were conducted. The atmospheric conditions like rain, fog etc affected the efficiency of communication through light waves.

To have efficient communication systems, the information carried by light waves should need a guiding medium through which it can be transmitted safely.

This guiding mechanism is optical fiber. The communication through optical fiber is known as light wave communication or optical communication.

A light beam acting as a carrier wave is capable of carrying more information than that of radio waves and microwaves due to its larger bandwidth.

Currently in most part of the world, fiber optics is used to transmit voice, video and digital data signals using light waves from one place to other place.

3.1.2 Optical fiber:

The optical fiber is a wave guide.

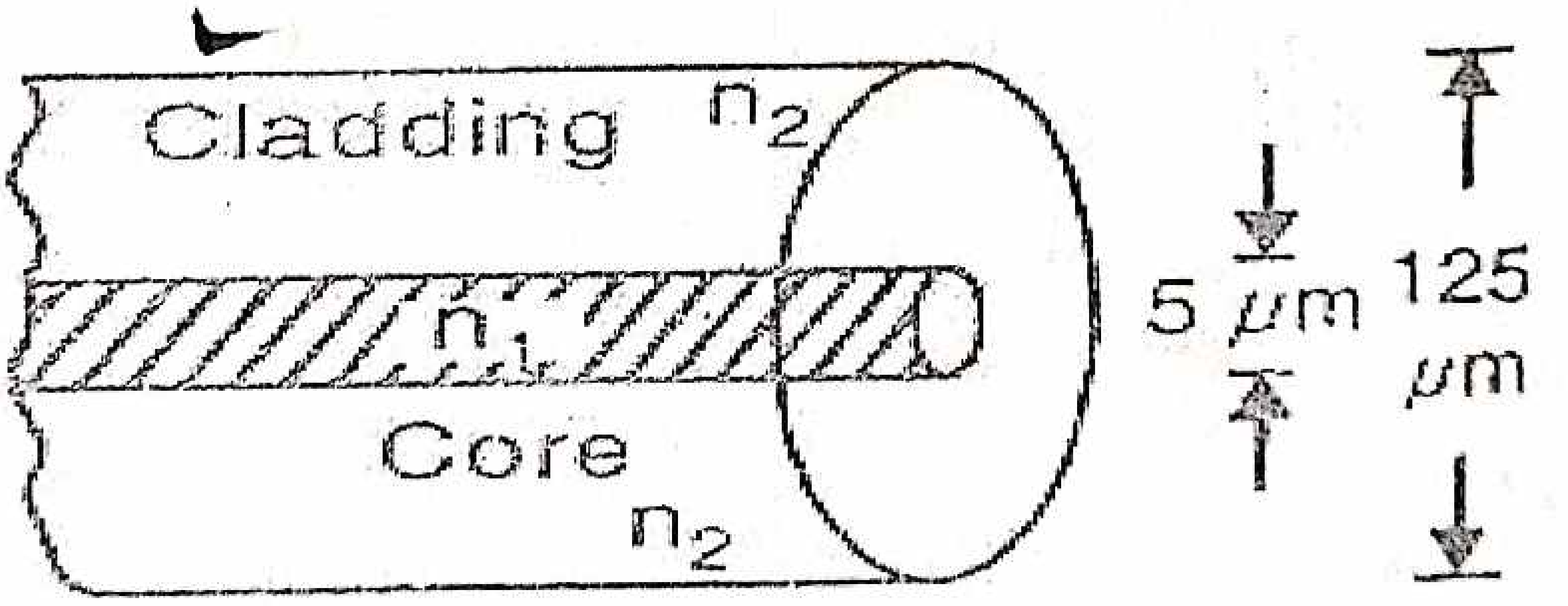
It is made up of transparent dielectrics (SiO_2), (glass or plastics).

3.2.1Fiber Construction:

It consists of an inner cylinder made of glass or plastic called core. The core has high refractive index n_1.

This core is surrounded by cylindrical shell of glass or plastic called cladding.

The cladding has low refractive index n_2. This cladding is covered by a jacket which is made of polyurethane. It protects the layer from moisture and abrasion. The light is transmitted through this fiber by total internal reflection. The fiber guides light waves to travel over longer distance without much loss of energy.

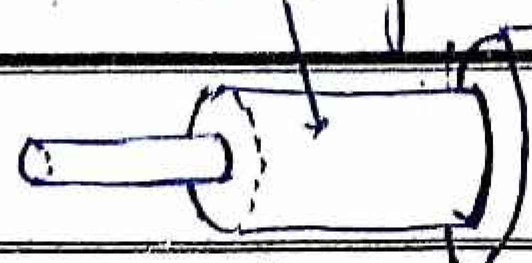


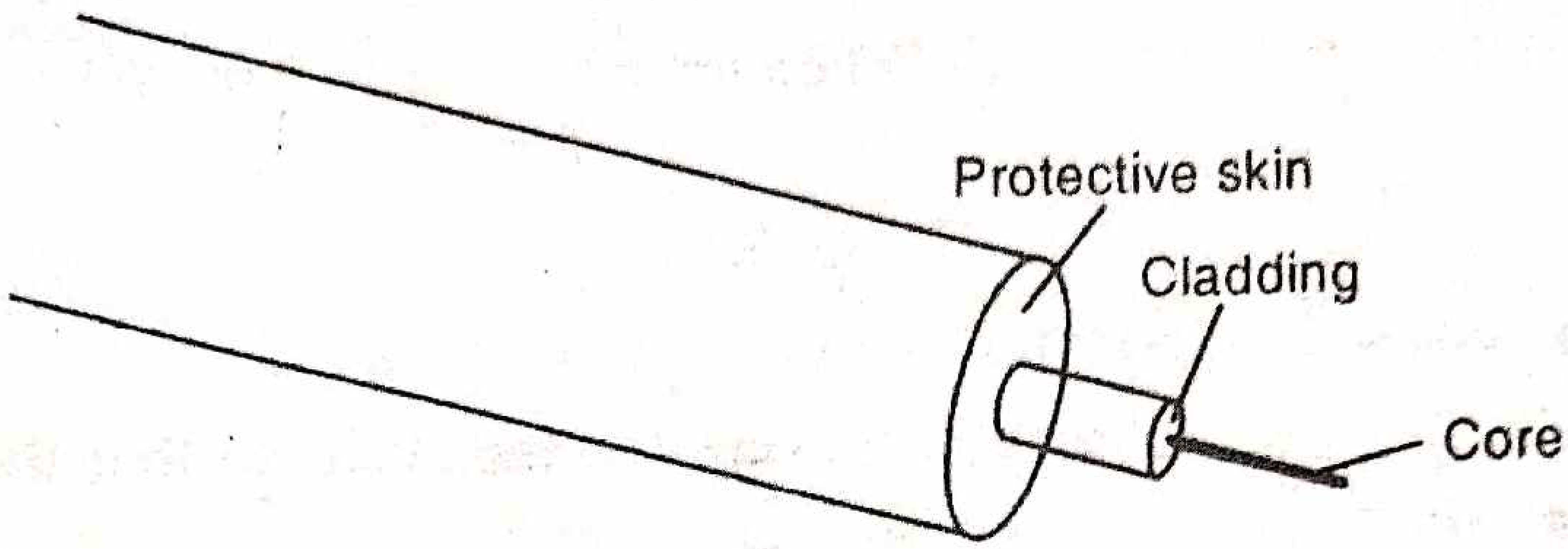
Core diameters range from 5 to 600μm while cladding diameters vary from 125 to 750μm.

Core transmits the light waves. The cladding keeps the light waves within the core by total internal reflection.

Refractive index:

The *refractive index or index of refraction* of a substance is a measure of the speed of light in that substance. It is expressed as a ratio of the speed of light in vacuum relative to that in the considered medium.

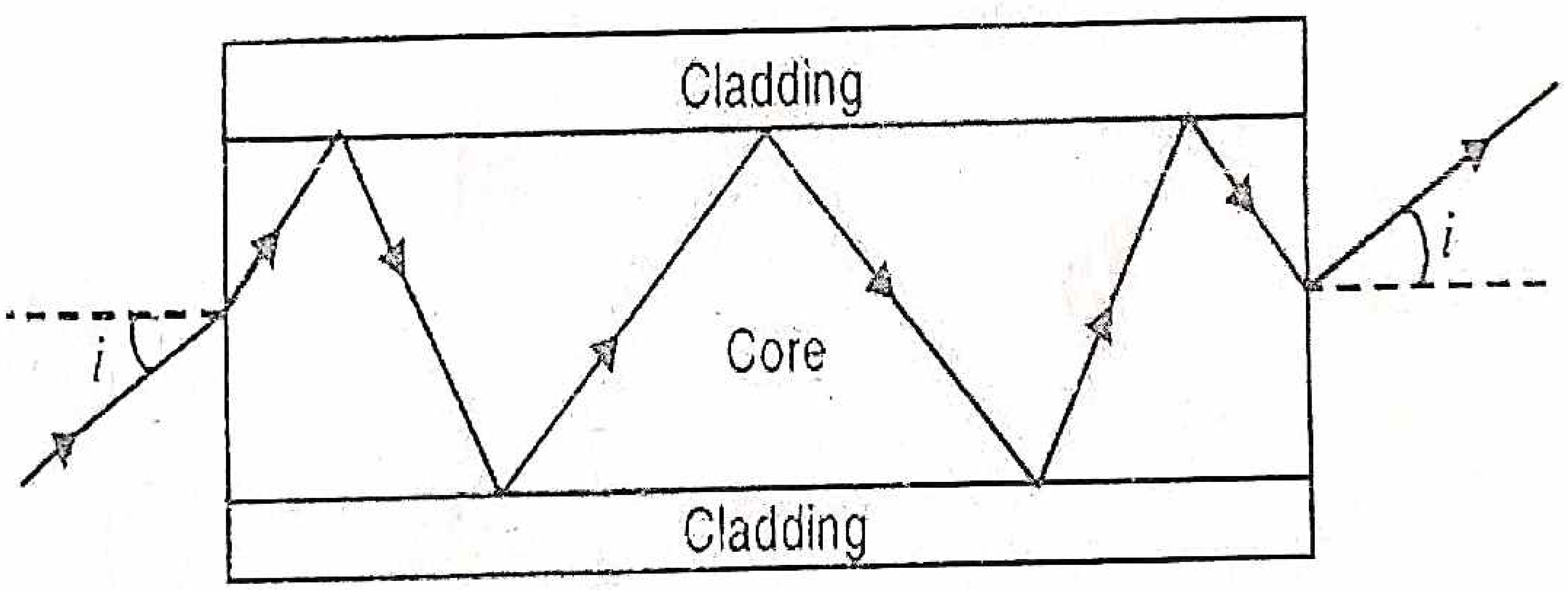




3.2.2 Principle of propagation of light in an optical fiber

The light launched inside the core at one end of the fiber propagates to the other end due to total internal reflection at the core and cladding interface.

Core → Denser Medium
Cladding → Rarer Medium



Two Conditions

Total internal reflection at the fiber wall can occur only if two conditions are Satisfied:

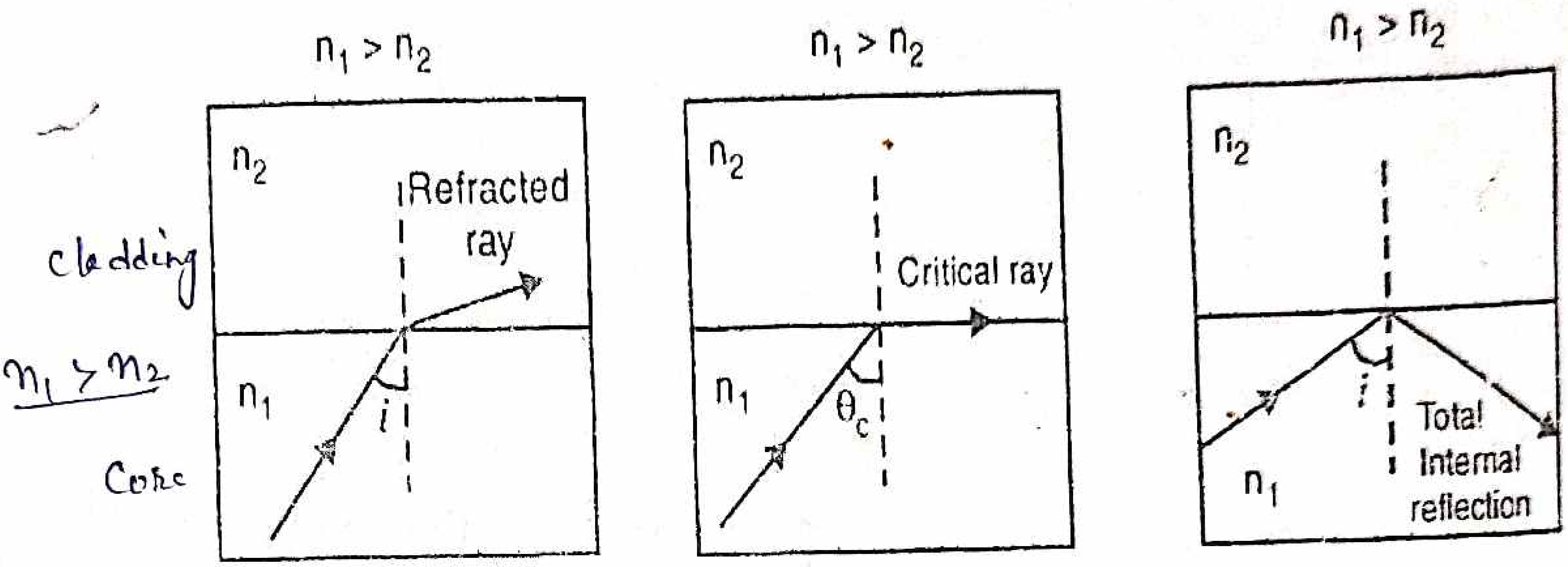
1. The refractive index of the core material n_1 must be higher than that of the cladding n_2 surrounding it.
2. At the core – cladding interface, the angle of incidence (between the ray and normal to the interface) must be greater than the critical angle defined as

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

The Light rays travel inside the core by the phenomenon of Total Internal Reflection (TIR). Since the core has higher internal refractive index (n_1) than that of Cladding (n_2) i.e $n_1 > n_2$. So when the light rays fall on the core-cladding interface (moves from denser to rarer medium, it returns back into the core. Because when light moves from denser to rarer medium with an incidence angle greater than the critical angle, it comes back into the same (denser) medium!!

Refraction of light:- Refraction ~~of light~~ is bending of the light as it passes from one transparent medium to another.

Let the light ray travel from core of refractive index n_1 to cladding of refractive index n_2 $n_1 > n_2$.



(a) When $i < \theta_c$ (b) When $i = \theta_c$ (c) When $i > \theta_c$

a) When $i < \theta_c$, it is refracted into rarer medium

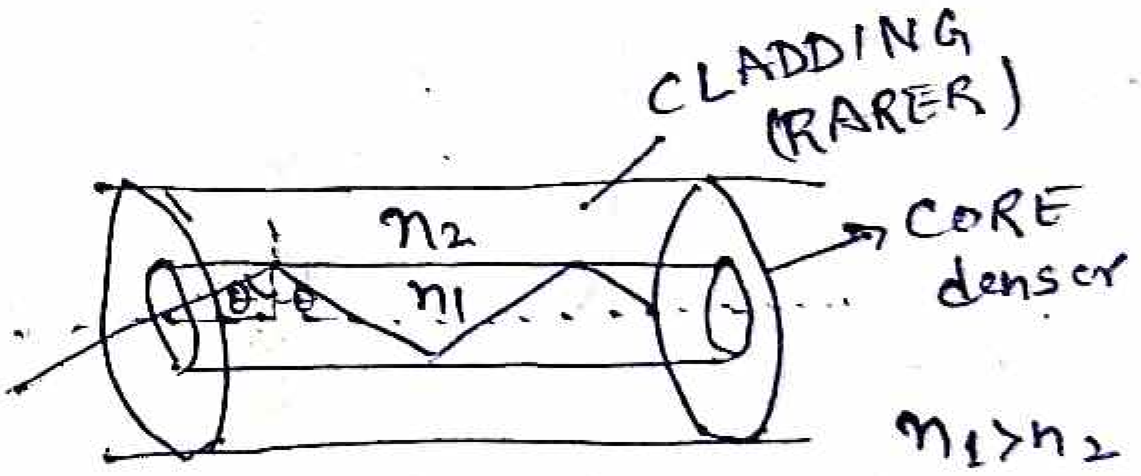
b) When $i = \theta_c$, it traverses along the interface so that angle of refraction is 90^0.

c) When $i > \theta_c$, it is totally reflected back into the denser medium itself.

When $i = \theta_c$, then by Snell's law,

$$n_1 \sin\theta_c = n_2 \sin 90^0$$

$$\therefore \sin\theta_c = \frac{n_2}{n_1}$$



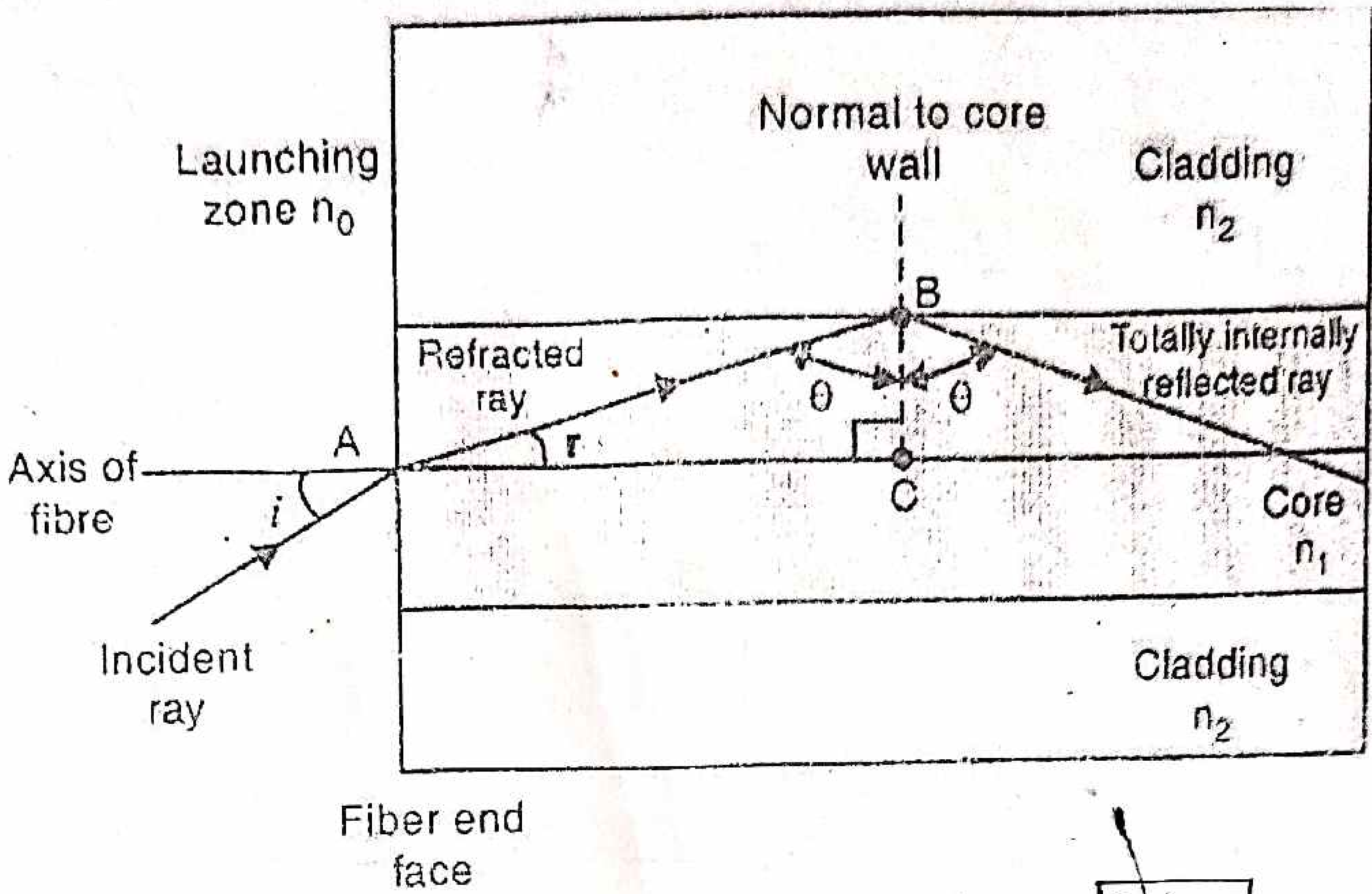
3.2.3 Propagation of light through fiber

Consider an optical fiber through which the light is being sent. The end at which light enters is called launching end. Let the refractive indices of the core and cladding be n_1 and n_2 respectively; $n_1 > n_2$. Let the refractive index of the medium from which the light is launched be n_0.

Let the light ray enter at an angle I to the axis of the fiber

→ Critical Angle :-

Critical Angle :- The angle of incidence beyond which ray of light passing through a denser medium to the surface of less denser medium are no longer refracted but totally reflected



The ray refracts at an angle r.

The ray strikes the core – cladding interface at an angle θ. If θ is greater than the critical angle θ_c, the ray undergoes total internal reflection at the interface.

Let us now find out up to what maximum value of i at A total internal reflection at B is possible.

In triangle ABC, $r = 90 - \theta$ ⟶ (1)

From Snell's law $\dfrac{\sin i}{\sin r} = \dfrac{n_1}{n_0}$ ⟶ (2)

$$\sin i = \frac{n_1}{n_0}\sin r = \frac{n_1}{n_0}\sin(90-\theta) = \frac{n_1}{n_0}\cos\theta$$

If θ is less than the critical angle θ_c, the ray will be lost by refraction. Therefore, limiting value for containing the beam inside the core by total internal reflection is θ_c. Let i_m me the maximum possible angle of incidence at the fiber end face A for which $\theta = \theta_c$.

$$\sin i_m = \frac{n_1}{n_0}\cos\theta_c \qquad \longrightarrow \qquad (3)$$

But $\sin\theta_c = \dfrac{n_2}{n_1}$

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

Numerical Aperture

$$\therefore \sin i_m = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

Or $$i_m = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right) \longrightarrow (4)$$

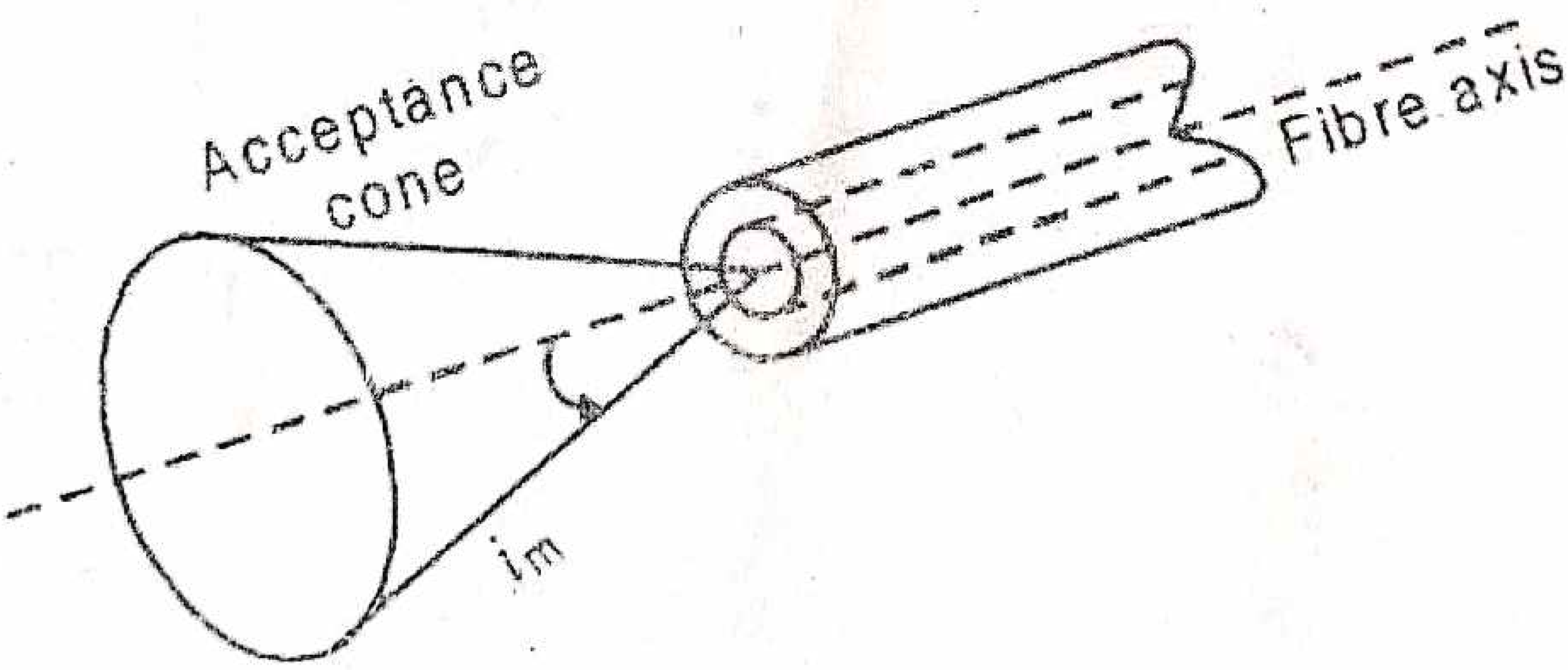
This angle i_m is called the acceptance angle of the fiber.

Definition: Acceptance angle is defined as the maximum angle that a light ray can have relative to the axis of the fiber and propagate down the fiber.

Or the maximum angle at or below which the light can suffer Total Internal Reflection is called acceptance angle.

Acceptance cone:

An optical fiber accepts only those rays which are incident within a cone having a semi angle i_m.



The light rays contained within the cone having a full angle $2i_m$ are accepted and transmitted along the fiber. Therefore, the cone is called the acceptance cone.

Light incident at an angle beyond i_m refracts through the cladding and the corresponding optical energy is lost. It is obvious that the larger the diameter of the core, the larger the acceptance angle.

Numerical Aperture:

Definition:

The numerical aperture (NA) is defined as the sine of the acceptance angle.

$$NA = \sin i_m$$

$$NA = \left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0} \right)$$

$n_0 = 1.0003$

$n_0 = 1$

Numerical aperture determines the light gathering ability of the fiber. It is a measure of amount of light that can be accepted by a fiber. NA depends only on the refractive indices of the core and cladding materials. A large NA implies that a fiber will accept large amount of light from the source.

Fractional Index change:

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

$$\Delta = \frac{n_1 - n_2}{n_1} = \frac{\text{Refractive index difference in core \& cladding}}{\text{Refractive index of core}}$$

Relation between NA and Δ

$$n_1 \Delta = n_1 - n_2$$

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

$$NA = \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

Substituting the value of $n_1 - n_2$ we have

$$NA = \sqrt{(n_1 + n_2)(n_1 \Delta)}$$

If $n_1 = n_2$, then $NA = \sqrt{2n_1^2 \Delta}$

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

$N.A. = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$

$n_0 = 1.0003$

$n_0 = 1$

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

$n_1 \Delta = n_1 - n_2$ — (1)

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

$N.A. = \sqrt{(n_1 - n_2)(n_1 + n_2)}$

$N.A. = \sqrt{n_1 \Delta (n_1 + n_2)}$

if $n_1 = n_2$

$N.A. = \sqrt{2 n_1^2 \Delta}$

$N.A. = n_1 \sqrt{2\Delta}$

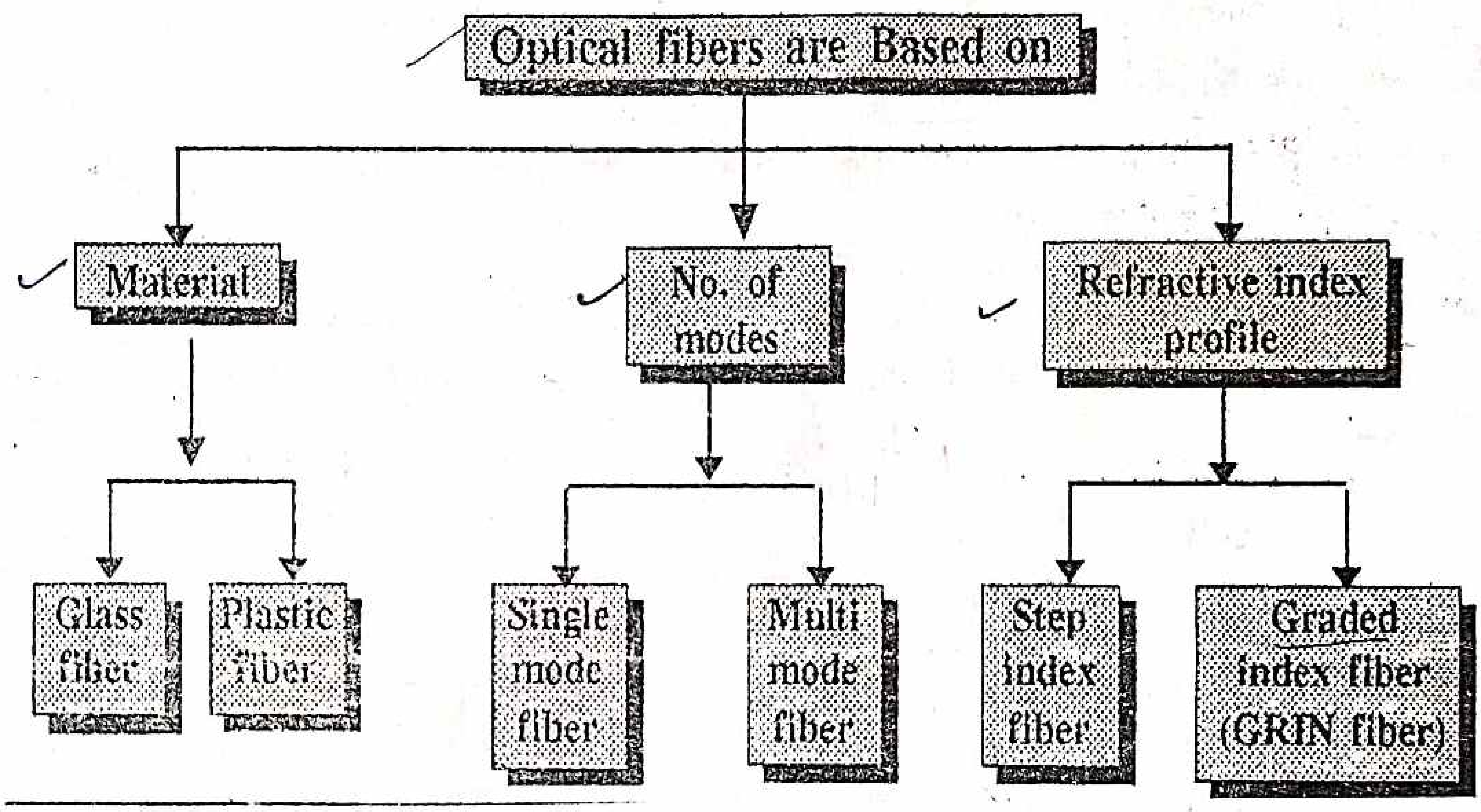
TYPES OF OPTICAL FIBERS

Optical fibers are classified into three major categories

i. The type of material used

ii. The number of modes

iii. The refractive index profile



Based on the type of the material used, they are classified into two types

1. Glass fiber:

Example:

Core: SiO_2 Cladding: SiO_2

Core: GeO_2- SiO_2 Cladding: SiO_2

2. Plastic fiber:

Example:

Core: polymethyl methacrylate : Cladding: Co- Polymer

Core: Polystyrene : Cladding: Methyl methacrylate

Based on the number of modes, they are classified as

1. Single mode fiber
2. Multimode fiber

Based on the refractive index profile, they are classified as

1. Step- index fiber
2. Graded index fiber

MODES OF PROPAGATION:

Light propagates as electromagnetic waves through an optical fiber. All waves, having ray directions above the critical angle will be trapped within the fiber due to total internal reflection. However, all such waves do not propagate through the fiber. Only certain ray directions are allowed to propagate. The allowed directions correspond to the modes of the fiber.

In simple terms, modes can be visualized as the possible number of paths of light in an optical fiber. The paths are all zigzag paths excepting the axial direction. Accordingly, light rays travelling through a fiber are classified as axial rays or zigzag rays. As a ray gets repeatedly reflected at the walls of the fiber, phase shift occurs. Waves travelling along the certain zigzag paths will be in phase and intensified. Waves travelling along certain other paths will be out of phase and diminish due to destructive interference. The light rays path along which the waves are in phase inside the fiber are called modes. The number of modes that a fiber will support depends upon the ratio of d/λ where d is the diameter of the core and λ is the wavelength of the wave being transmitted.

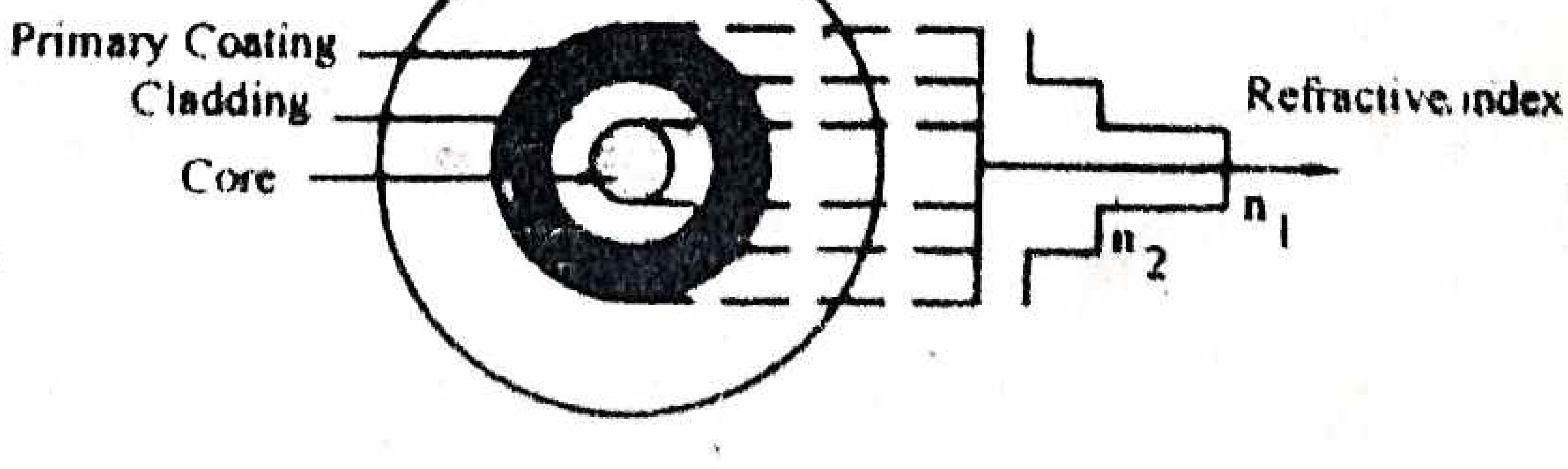
Modes are designated by an 'order' number 'm'. In a fiber of fixed thickness, the higher order modes propagate at smaller angles than the lower order modes.

Axial ray that travels along the axis of the fiber is called zero order rays.

SINGLE MODE FIBERS:

In general, the single mode fibers are step – index fibers. These types of fibers are made from doped silica. It has a very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers.

The cladding diameter must be very large compared to the core diameter. Thus in the case of single mode fiber, the optical loss is very much reduced. The structure of a single mode fiber as shown.



Structure:

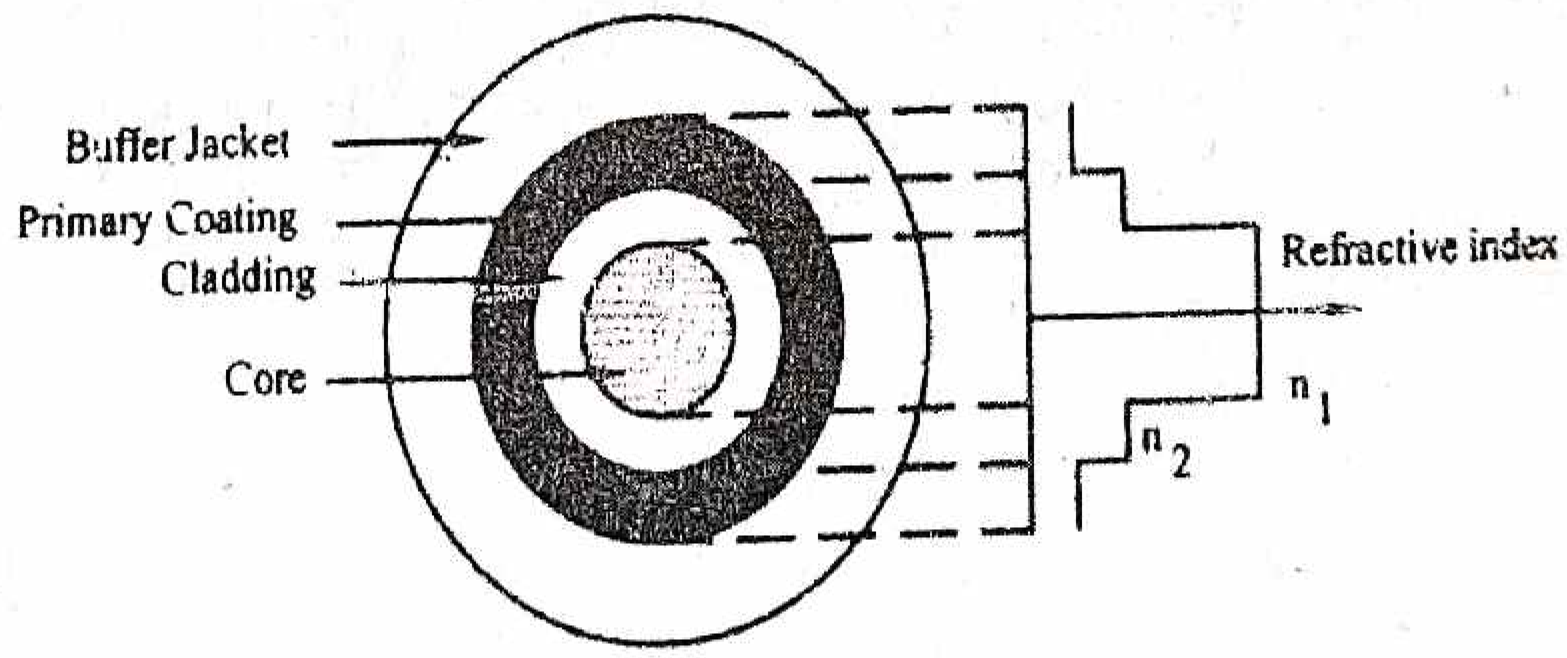
Core diameter	:	5-10μm
Cladding diameter	:	Generally around 125μm
Protective layer	:	250 to 1000μm
Numerical aperture	:	0.08 to 0.10
Band width	:	More than 50MHz km.

Application:

Because of high bandwidth, they are used in long haul communication systems.

MULTI- MODE FIBERS

The multi mode fibers are useful in manufacturing both for step – index and graded index fibers. The multi-mode fibers are made by multi-component glass compounds such as Glass – Clad Glass, Silica – Clad – Silica, doped silica etc. Here the core diameter is very large compared to single mode fibers, so that it can allow many modes to propagate through it and hence called as Multi mode fibers. The cladding diameter is also larger than the diameter of the single mode fibers. The structure of the multimode fiber is as shown in the figure.



Structure:

Core diameter	:	50-350μm
Cladding diameter	:	125μm - 500μm
Protective layer	:	250 to 1100μm
Numerical aperture	:	0.12 to 0.5
Band width	:	Less than 50MHz km.

The total number of modes possible for such an electromagnetic wave guide is

$$N = 4.9\left(\frac{d \times NA}{\lambda}\right)^2$$

Here d= core diameter

NA = numerical aperture

λ = Optical wavelength.

Application:

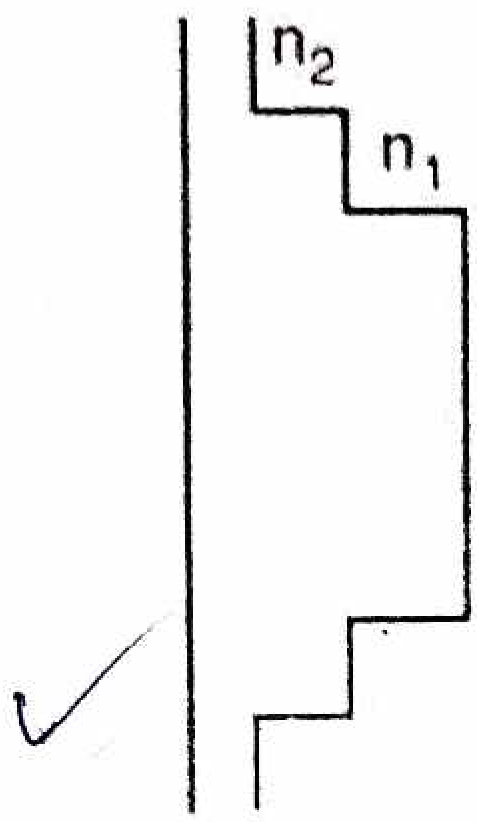
Because of its less band width it is very useful in short haul communication systems.

DIFFERENCES BETWEEN SINGLE AND MULTIMODE FIBER

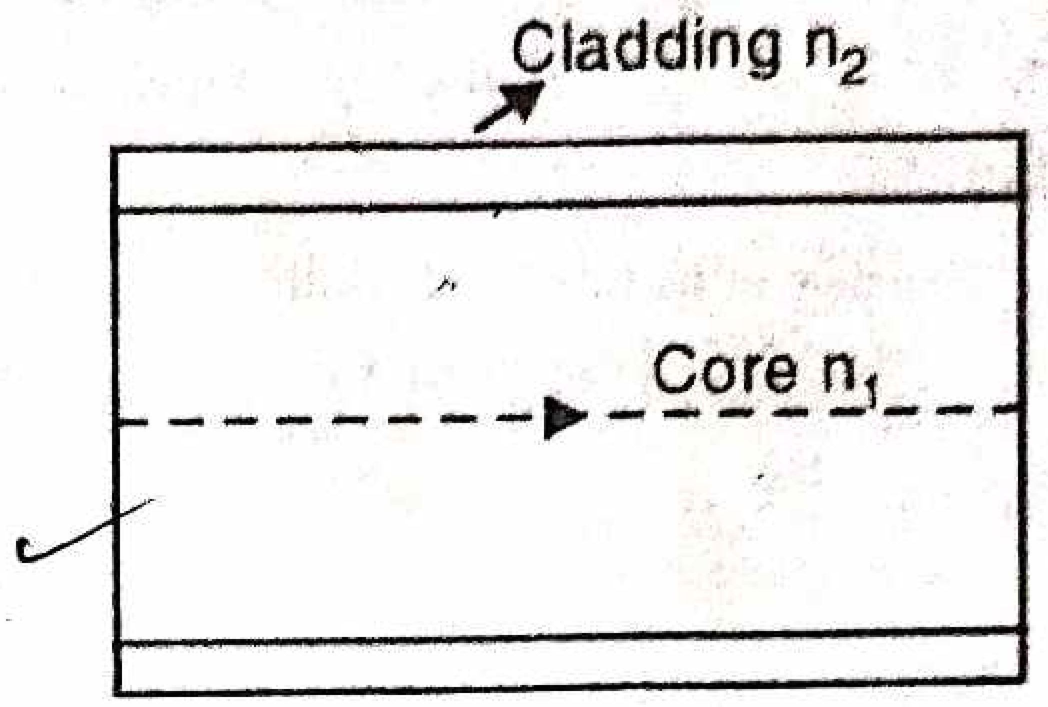
S.NO	SINGLE MODE FIBER	MULTIMODE FIBER
1.	In single mode fiber only one mode can propagate through the fiber	In multimode it allows a large number of paths or modes for the light rays travelling through it.
2.	It has smaller core diameter and the difference between the refractive index of the core and cladding is very small.	It has larger core diameter and refractive index difference is larger than the single mode fiber.
3.	**Advantages:** No dispersion(i.e. there is no degradation of signal during propagation)	**Disadvantages:** Dispersion is more due to degradation of signal owing to multimode.
4.	Since the information transmission capacity is inversely proportional to dispersion $\left(T \propto \frac{1}{D}\right)$ the fiber can carry information to longer distances.	Information can be carried to shorter distances only.
5.	**Disadvantages:** Launching of light and connecting of two fibers difficult.	**Advantages:** Launching of light and also connecting of two fibers is easy.
6.	Installation (fabrication) is difficult as it is more costly	Fabrication is easy and the installation cost is low.

3.1.5 SINGLE MODE STEP INDEX FIBER

A single mode step index fiber consists of a very thin core of uniform refractive index surrounded by a cladding of refractive index lower than that of core. The refractive index abruptly changes at the core cladding boundary. Light travels along a side path, i.e., along the axis only. So zero order modes is supported by Single Mode Fiber.



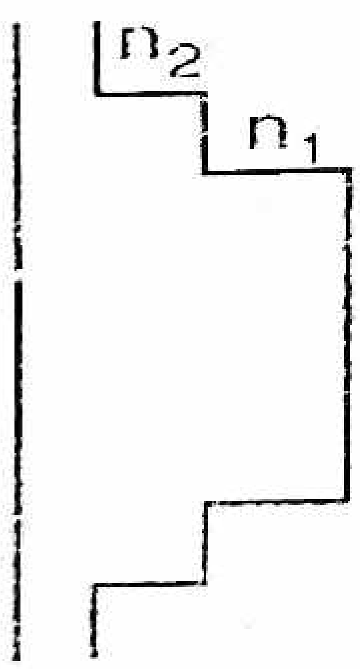
(a)



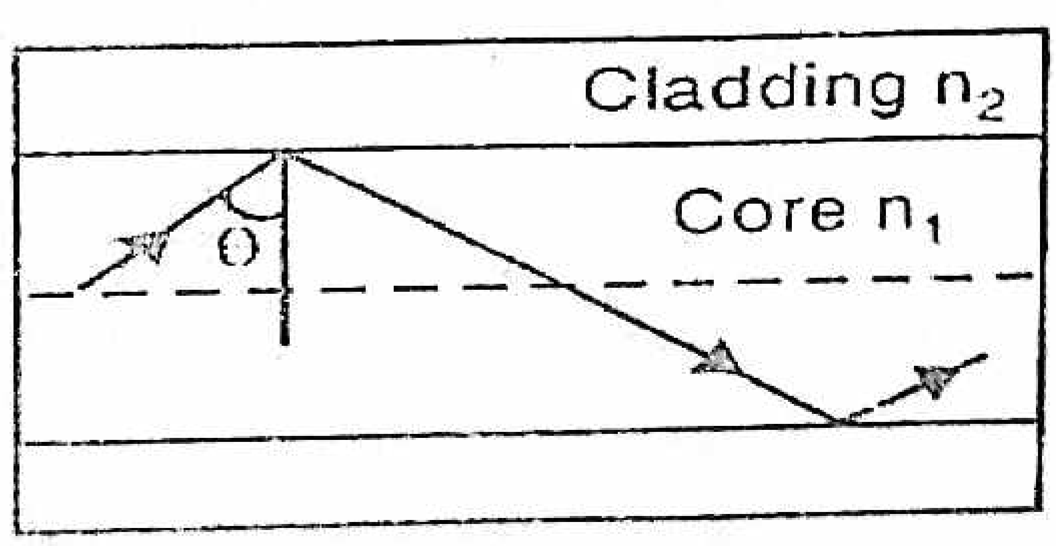
(b)

3.1.6 MULTIMODE STEP INDEX FIBER

A multimode step index fiber consists of a core of uniform refractive index surrounded by cladding of refractive index lower than that of the core. The refractive index abruptly changes at the core cladding boundary. The core is of large diameter. Light follows zigzag paths inside the fiber. Many such zigzag paths of propagation are permitted in Multi Mode Fiber. The Numerical Aperture of a Multi mode fiber is larger as the core diameter of the fiber is larger.



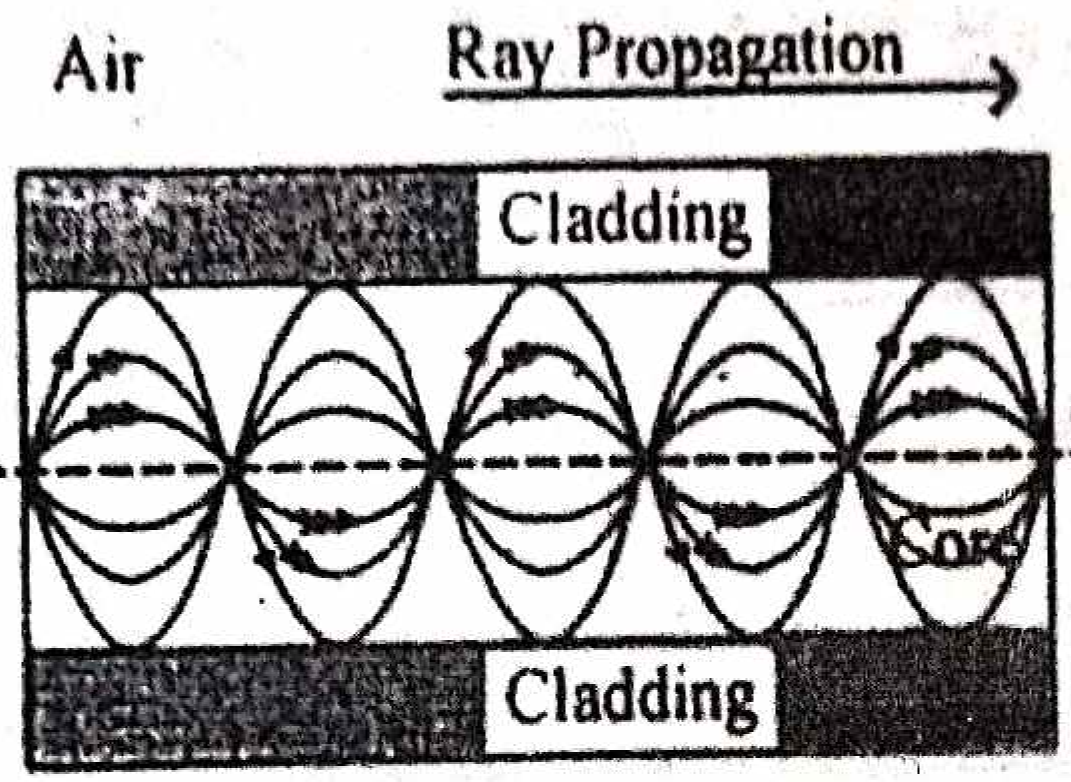
(a)

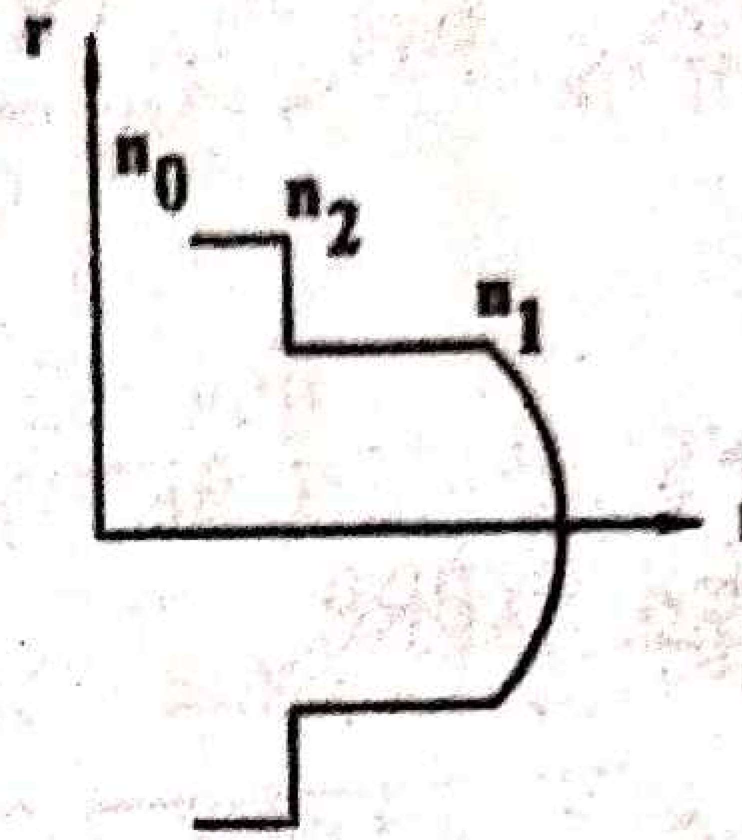


(b)

3.1.7 GRADED INDEX FIBER

GRIN fiber is one in which refractive index varies radially, decreasing continuously in a parabolic manner from the maximum value of n_1, at the center of the core to a constant value of n_2 at the core cladding interface.





In graded index fiber, light rays travel at different speeds in different parts of the fiber because the refractive index varies through out the fiber. Near the outer edge, the refractive index is lower. As a result, rays near the outer edge travel faster than the rays at the center of the core. Because of this, rays arrive at the end of the fiber at approximately the same time. In effect light rays arrive at the end of the fiber are continuously refocused as they travel down the fiber. All rays take the same amount of time in traversing the fiber. This leads to small pulse dispersion.

The pulse dispersion is given by $\Delta\tau = \tau_{max} - \tau_{min} = \frac{n_2 L}{2c}\Delta^2$

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

For a parabolic index fiber, the pulse dispersion is reduced by a factor of about 200 in comparison to step index fiber. It is because of this reason that first and second generation optical communication systems used near parabolic index fibers.

3.7.1 PROPAGATION OF LIGHT IN GRIN FIBER

Let n_a, n_b, n_c, n_d etc be the refractive index of different layers in graded index fiber with $n_a > n_b > n_c > n_d$ etc. then the propagation of light through the graded index fiber is as shown in the figure.

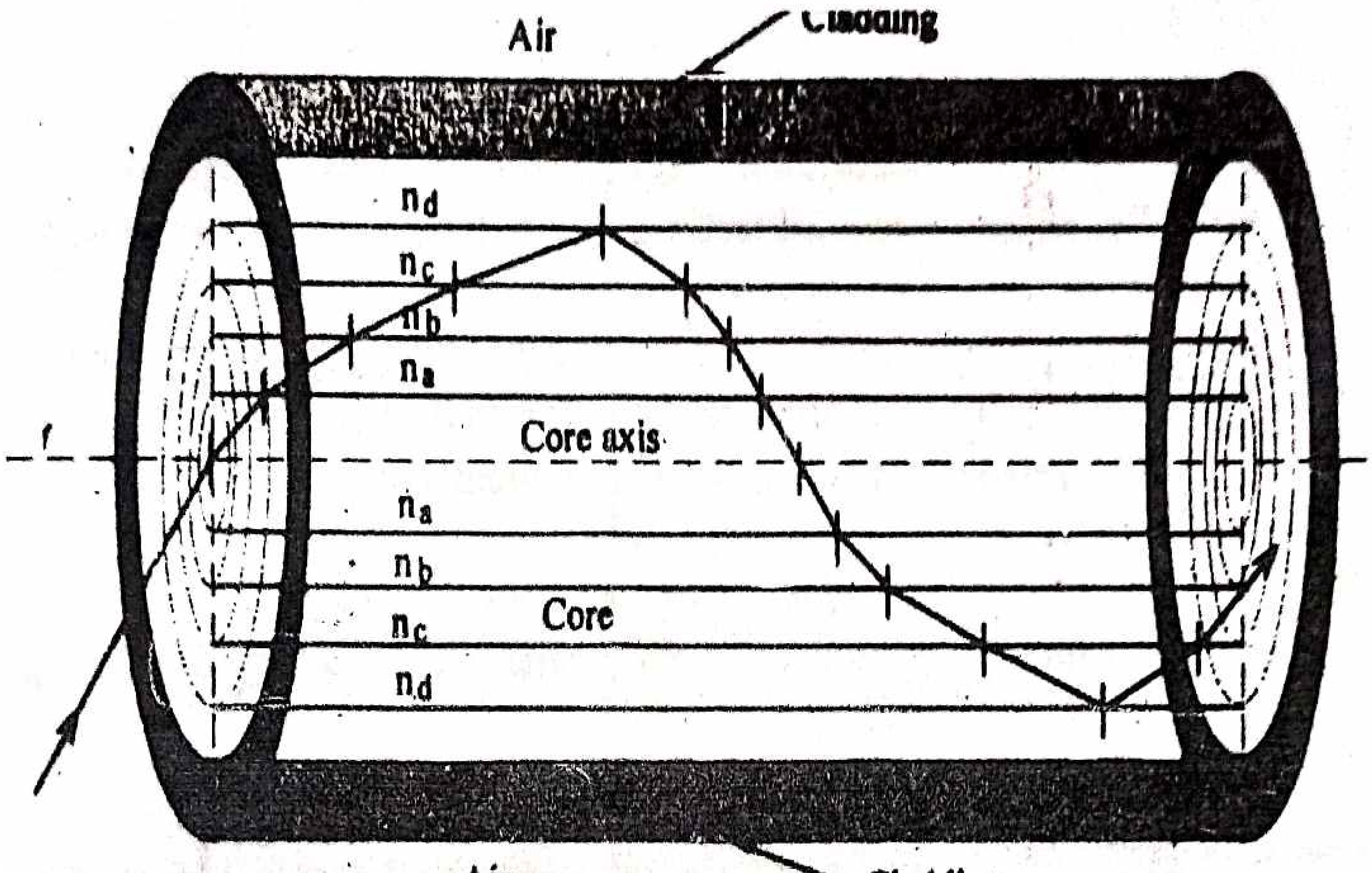


Fig. 3.15

Here, since $n_a > n_b$ the ray gets refracted. Similarly since $n_b > n_c$, the ray gets refracted and so on. In a similar manner, due to decrease in refractive index the ray gets gradually curved towards the upward direction and at one place , where in it satisfies the condition for total internal reflection,($\phi > \phi_c$) it is totally internally reflected .

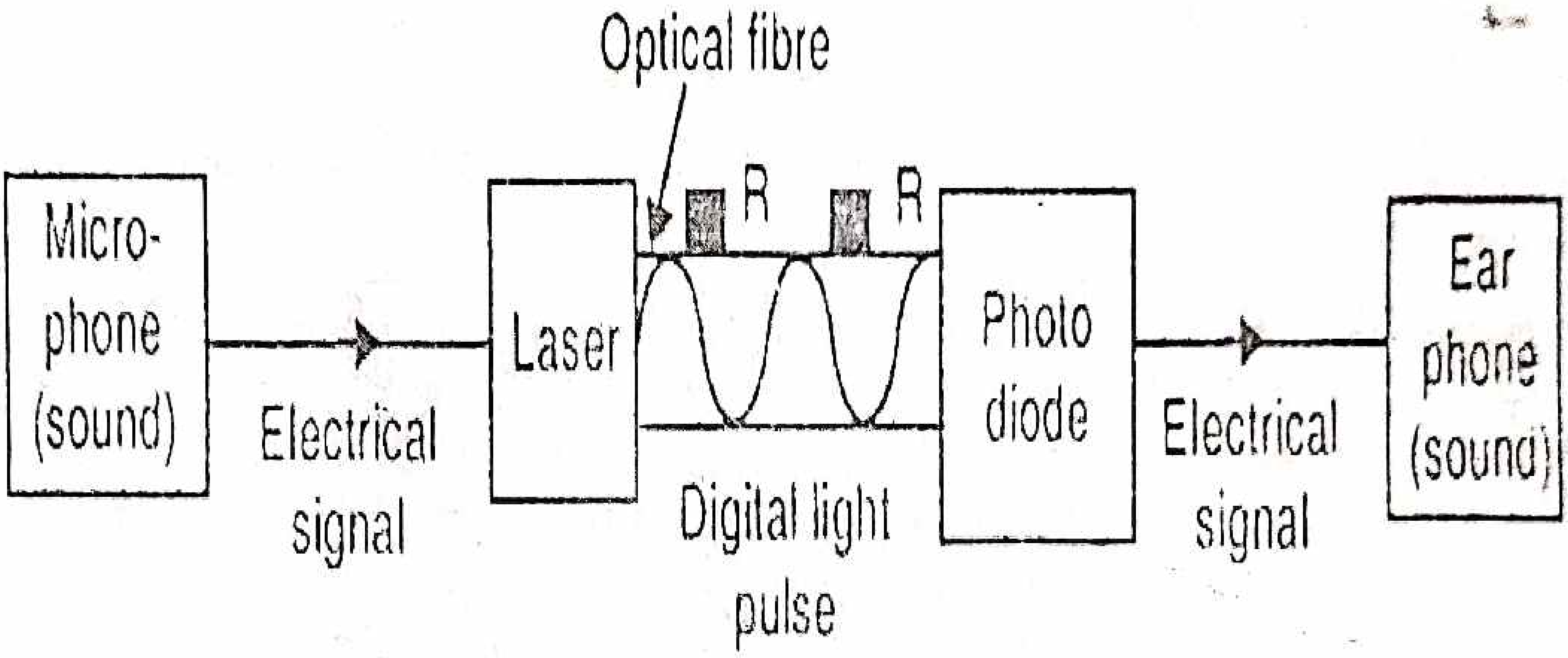
The reflected rays travels back towards the core axis and without crossing the fiber axis, it is refracted towards downwards direction and again gets totally internally reflected and passes towards upward direction. In this manner the ray propagates inside the fiber in a helical or spiral manner

3.8 Difference between Step Index fiber and Graded Index fiber

S. NO	STEP INDEX FIBER	GRADED INDEX FIBER
1.	The refractive index of the core is uniform throughout and undergoes on abrupt change at the core cladding boundary	The refractive index of the core is made to vary gradually such that it is maximum at the center of the core.
2.	The diameter of the core is about 50-200μm in the case of multimode fiber and 10μm in the case of single mode fiber	The diameter of the core is about 50μm in the case of multimode fiber
3.	The path of light propagation is *zig- zag* in manner	The path of light is ***helical*** in manner
3.	***Attenuation is more*** for multimode step index fiber but for single mode it is very less. *Explanation:* When a ray travels through the longer distances there will be some difference in reflected angles. Hence high angle rays arrive later than low angle rays causing dispersion resulting in distorted output.	*Attenuation is less.* *Explanation:* Here the light rays travel with different velocity inn different paths because of their variation in their refractive indices. At the outer edge it travels faster than near the center. But almost all the rays reach the exit at the same time due to helical path. Thus, there is no dispersion.
4.	This fiber has ***lower bandwidth***	This fiber has ***higher bandwidth***
5.	The light ray propagation is in the form of meridional rays and it passes through the fiber axis.	The light propagation is in the form of skew rays and it will not cross fiber axis.
6.	**No of modes of Propagation:** $N_{step} = 4.9\left(\frac{d \times NA}{\lambda}\right)^2 = \frac{V^2}{2}$ Where d= diameter of the fiber core λ= wavelength NA = Numerical Aperture V- V-number is less than or equal to 2.405 for single mode fibers and greater than 2.405 for multimode fibers.	**No of modes of Propagation:** $N_{Graded} = \frac{4.9\left(\frac{d \times NA}{\lambda}\right)^2}{2} = \frac{v^2}{4}$ Or $N_{graded} = \frac{N_{step}}{2}$

3.1.9 OPTICAL FIBER AS AN OPTICAL WAVEGUIDE

Optical fibers are used as dielectric waveguides for electromagnetic signals of optical frequencies. Figure shows the block diagram of transmission of sound along the optical fiber and conversion again to sound at the other end.



i. Sound is first converted into electrical signal by a microphone.
ii. The electrical signals modulate the intensity of light from laser.
iii. Then the information is carried along the fiber in a digital form.
Boosters or repeaters are placed at a distance of about 50km of cable to make up the signal loses occurring due to scattering and absorption.
iv. At the receiving place, a photodiode converts the digital light pulses into corresponding electrical signals.
v. The electrical signals are then converted into sound by an earphone (receiver)
Time division multiplexing system is used to transmit many thousands of telephone cells through a single optical fiber with the use of digital pulses.

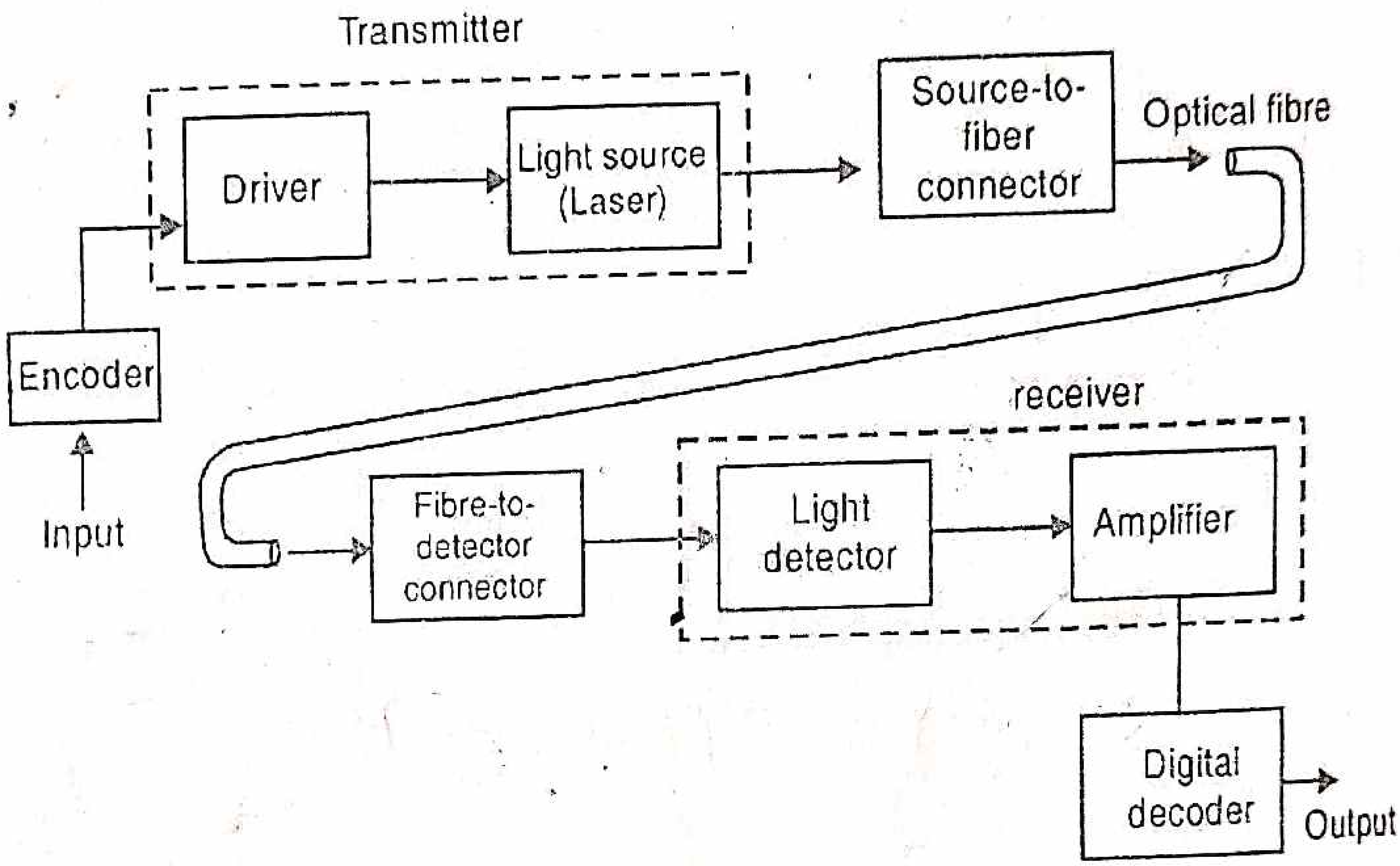
3.1.10 THE FIBER OPTIC COMMUNICATION SYSTEM

Figure shows the schematic diagram of a fiber optic communication system. The major components of an optical fiber communication system are

i. The optical transmitter
ii. The optical fiber
iii. The optical receiver

PRINCIPLE:

Basically, a fiber optic system converts an electrical signal to an infrared light signal. This signal is transmitted through an optical fiber. At the end of the optical fiber, it is reconverted into an electric signal



Working:

1. Encoder encodes the information in the binary sequence zeros and ones.

   a. Encoder is an electric circuit where in the information is encoded into binary sequences of zeros and one. In the light wave transmitter each 'one' corresponds to an electrical pulse and 'zero' corresponds to an absence of a pulse. These electrical pulses are used to turn a light source on and off very rapidly. The driver converts the incoming electrical signal into a form that will operate with the light source.

2. These electrical pulses are used to turn a light source on and off rapidly.

3. The optical fiber acts as a wave guide and transmits the optical pulses towards the receiver, by the principle of total internal reflection.

4. The light detector receives the optical pulses and converts them into electrical pulses. These signals are amplified by the amplifier.

5. The amplified signals are decoded by the decoder.

ADVANTAGES:

1. Extremely wide bandwidth.

   a. Optical frequencies are very large (10^{15} Hz) as compared to radio frequencies (10^{6}Hz) and microwave frequencies (10^{10} Hz). The rate at which information can be transmitted is directly related to signal frequency. Therefore, a transmission system that operates at the frequency of light can theoretically transmit information at a higher rate than systems that operate at radio frequencies or microwave frequencies.

2. Lack of cross talk between parallel fibers.

   a. There is virtually no signal leakage from fibers. Hence, cross-talks between neighboring fibers are almost absent. This is quite frequent in conventional metallic system

3. Immunity to inductive interference

   a. Since optical fibers are not metallic, they do not pick up electromagnetic waves. The result is noise free transmission i.e., fiber optic cables are immune to interference caused by lighting or other electromagnetic equipment

4. Smaller diameter and light weight cable

   a. Optical fibers, because of their light weight and flexibility, can be handled more easily than copper cables.

5. Signal security

   a. The transmitted signal through the fibers does not radiate. Further the signal cannot be tapped from a fiber in an easy manner. Therefore, optical fiber communication provides a hundred percent signal security hence this system is highly suited to secure communications in defence communication networks.

6. Economical & Low loss per unit length.

Attenuation: Loss of optical power.

The attenuation of an optical fiber is expressed by the attenuation coefficient, which is defined as, the loss of the fiber per unit length in dB/km. The attenuation of the optical fiber is a result of two factors absorption & scattering

Optical Fibre Losses

Attenuation in Optical Fibres

- Attenuation limits the optical power which can reach the receiver, limiting the operating span of a system.
- Once the power of an optical pulse is reduced to a point where the receiver is unable to detect the pulse, an error occurs.
- **Attenuation** is mainly a result of:
- **Light Absorption**
- **Scattering of light**
- **Bending losses**
- **Attenuation** is defined as the ratio of optical input power (P_i) to the optical output power (P_o).
- The following equation defines signal attenuation as a unit of length :

Attenuation $$\alpha(dB/km) = -\frac{10}{L} Log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- **Types of Attenuation**

Absorption Loss:

- Caused by the fiber itself or by impurities in the fiber, such as water and metals.

Scattering Loss:

- Intrinsic loss mechanism caused by the interaction of photons with the glass itself.

Bending loss:

- Loss induced by physical stress on the fiber.

1. Material Absorption Losses

- Material absorption is caused by absorption of photons within the fiber.
- – When a material is illuminated, photons can make the valence electrons of an atom transition to higher energy levels
- – Photon is destroyed, and the radiant energy is transformed into electric potential energy. This energy can then
- • Be re-emitted (scattering)
- • Frees the electron (photoelectric effects) (not in fibers)
- • Dissipated to the rest of the material (transformed into heat)
- In an optical fiber Material Absorption is the optical power that is effectively converted to heat dissipation within the fiber.
- • Two types of absorption exist:
- – **Intrinsic Absorption**, caused by interaction with one or more of the components of the glass.
- – **Extrinsic Absorption**, caused by impurities within the glass.

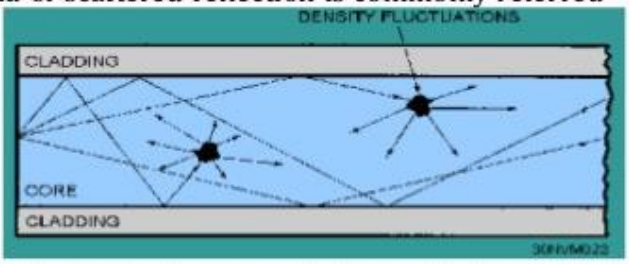
- **Intrinsic Absorption** is caused by basic fiber material properties. If an optical fiber is absolutely pure, with no imperfections or impurities, ten all absorption will be intrinsic. Intrinsic absorption in the ultraviolet region is caused by electronic absorption bands. **Intrinsic Absorption** occurs when a light particle (photon) interacts with an electron and excites it to a higher energy level.
- **Extrinsic Absorption** is caused by impurities caused by impurities introduced into the fiber material. The metal impurities such as iron, nickel and chromium are introduced into the fiber during fabrication. **Extrinsic Absorption** is caused by the **electronic transition** of these metal ions from one energy level to another energy level.

2. Scattering Losses

- **Light scattering** is a form of scattering in which light in the form of propagating energy is scattered.
- Light scattering can be thought of as the deflection of a ray from a straight path, for example by irregularities in the propagation medium, particles, or in the interface between two media.
- Deviations from the law of reflection due to irregularities on a surface are also usually considered to be a form of scattering.
- When these irregularities are considered to be random and dense enough that their individual effects average out, this kind of scattered reflection is commonly referred to as diffuse reflection.

Linear Scattering may be of two types

- **Rayleigh Scattering**
- **Mie Scattering**

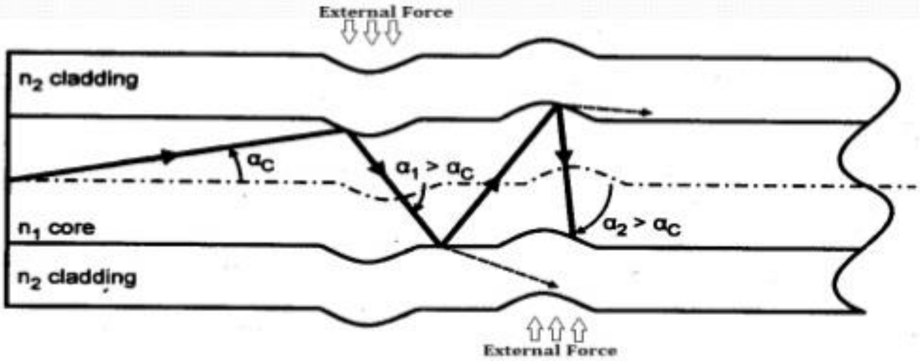


3. Fibre Bending losses

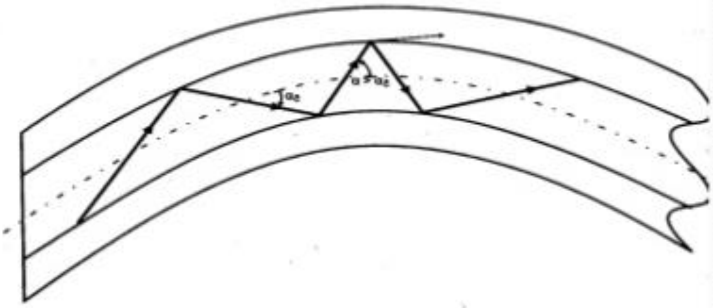
Bending loss is classified according to the bend radius of curvature :

1. **Microbend Loss** 2. **Macrobend Loss**

- **Microbend Loss** are caused by small discontinuities or imperfections in the fiber. Uneven coating applications and improper cabling procedure increases micro bend loss. External forces are also a source of micro bends.

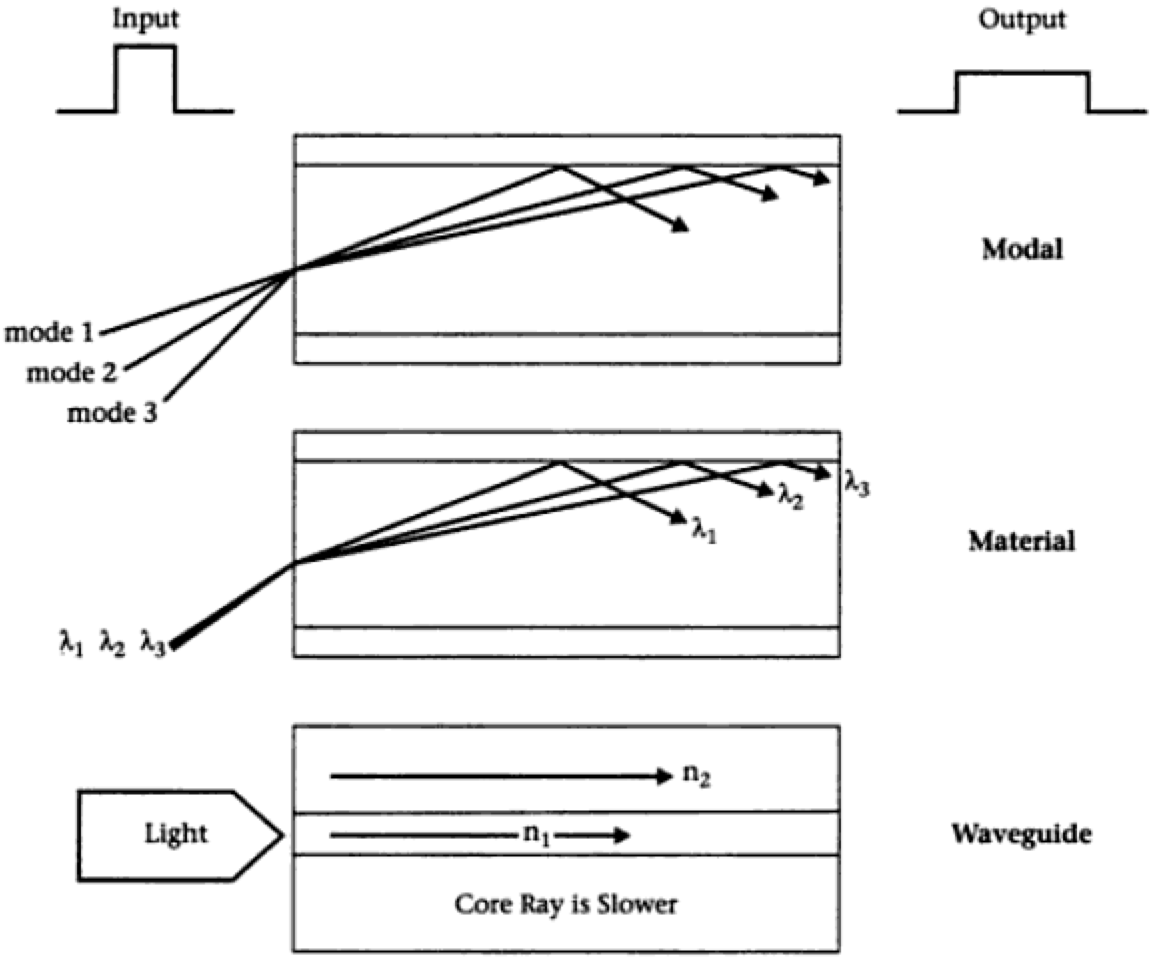


- **Macrobend Losses** are observed when a fiber bend's radius of curvature is large compared to the fiber diameter. These bends are a great source of loss when the radius of curvature is less than several centimeters.



OPTICAL FIBER DISPERSION

Dispersion is the spreading out of a light pulse in time as it propagates down the fiber. Dispersion in optical fiber includes model dispersion, material dispersion and waveguide dispersion. Each type is discussed in detail below.



MODEL DISPERSION IN MULTIMODE FIBERS

Inter model Dispersion

Multimode fibers can guide many different light modes since they have much larger core size. This is shown as the 1st illustration in the picture above. Each mode enters the fiber at a different angle and thus travels at different paths in the fiber.

Since each mode ray travels a different distance as it propagates, the ray arrive at different times at the fiber output. So the light pulse spreads out in time which can cause signal overlapping so seriously that you cannot distinguish them any more.

Model dispersion is not a problem in single mode fibers since there is only one mode that can travel in the fiber.

MATERIAL DISPERSION (Intra Model Dispersion)

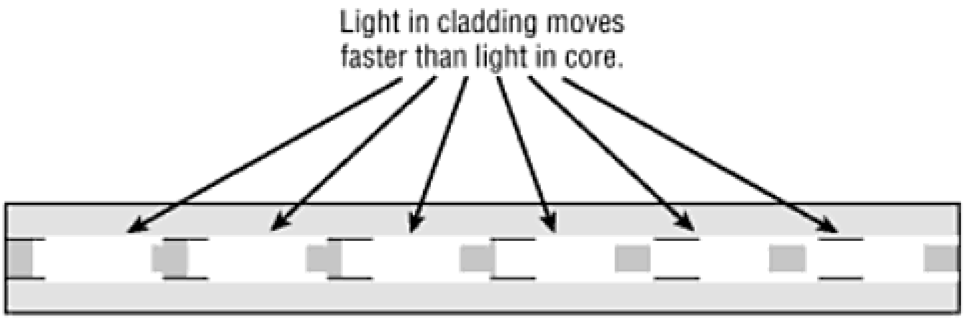
Material dispersion is the result of the finite linewidth of the light source and the dependence of refractive index of the material on wavelength. It is shown as the 2nd illustration in the first picture.

Material dispersion is a type of chromatic dispersion. Chromatic dispersion is the pulse spreading that arises because the velocity of light through a fiber depends on its wavelength.

WAVEGUIDE DISPERSION

Waveguide dispersion is only important in single mode fibers. It is caused by the fact that some light travels in the fiber cladding compared to most light travels in the fiber core. It is shown as the 3rd illustration in the first picture.

Since fiber cladding has lower refractive index than fiber core, light ray that travels in the cladding travels faster than that in the core. Waveguide dispersion is also a type of chromatic dispersion. It is a function of fiber core size, V-number, wavelength and light source linewidth.



While the difference in refractive indices of single mode fiber core and cladding are minuscule, they can still become a factor over greater distances.

Chromatic dispersion is a phenomenon that is an important factor in fiber optic communications. It is the result of the different colors, or wavelengths, in a light beam arriving at their destination at slightly different times

APPLICATIONS OF FIBER OPTICS

As the popularity of optical fibers continue to grow, so does their applications and practical uses. Fiber optic cables became more and more popular in a variety of industries and applications.

Communications / Data Storage

Since fiber optics are resistant to electronic noise, fiber optics has made significant advances in the field of communications. The use of light as its source of data transmission has improved the sound quality in voice communications. It is also being used for transmitting and receiving purposes.

Military

Optical systems offer more security than traditional metal-based systems. The magnetic interference allows the leak of information in the coaxial cables. Fiber optics is not sensitive to electrical interference; therefore fiber optics is suitable for military application and communications, where signal quality and security of data transmission are important.

The increased interest of the military in this technology caused the development of stronger fibers, tactical cables and high quality components. It was also applied in more varied areas such as hydrophones for seismic and SONAR, aircrafts, submarines and other underwater applications.

Medical

Fiber optic are used as light guides, imaging tools and as lasers for surgeries. Another popular use of fiber-optic cable is in an endoscope, which is a diagnostic instrument that enables users to see through small holes in the body. Medical endoscopes are used for minimally invasive exploratory or surgical procedures. Fiber optics is also used in bronchoscopes and laparoscopes.

All versions of endoscopes look like a long thin tube, with a lens or camera at one end through which light is emitted from the bundle of optical fibers banded together inside the enclosure.

Mechanical or Industrial

Industrial endoscopes also called a borescope or fiberscope, enables the user to observe areas that are difficult to reach or see under normal circumstances, such as jet engine interiors, inspecting mechanical welds in pipes and engines, inspecting space shuttles and rockets. Inspection of sewer lines and pipes.

Networking

Fiber optic is used to connect servers and users in a variety of network settings. It increases the speed, quality and accuracy of data transmission. Computer and Internet technology has improved due to the enhanced transmission of digital signals through optical fibers.

Industrial/Commercial

Fiber optics are used for imaging in areas which are difficult to reach. It is also used in wiring where electromagnetic interference is an problem. It gets used often as sensory devices to make temperature, pressure and other measurements as well as in the wiring of motorcars and in industrial settings.

Spectroscopy

Optical fiber bundles are used to transmit light from a spectrometer to a substance which cannot be placed inside the spectrometer itself, in order to analyse its composition. A spectrometer analyses substances by bouncing light off of and through them. By using optical fibers, a spectrometer can be used to study objects that are too large to fit inside, or gasses, or reactions which occur in pressure vessels

Broadcast/CATV/Cable Television

Broadcast or cable companies use fiber optic cables for wiring CATV, HDTV, internet, video and other applications.

Usage of fiber-optic cables in the cable-television industry began in 1976 and quickly spread because of the superiority of fiber optic cable over traditional coaxial cable. Fiber optic systems became less expensive and capable of transmitting clearer signals further away from the source signal. It also reduced signal losses and decreased the number of amplifiers required for each customer. Fiber optic cable allows cable providers to offer better service, because only one optical line is needed for every ± 500 households.

<u>Lighting and Imaging</u>

Fiber optic cables are used for lighting and imaging and as sensors to measure and monitor a vast range of variables. It is also used in research, development and testing in the medical, technological and industrial fields.

Fiber optics are used as light guides in medical and other applications where bright light needs to shine on a target without a clear line-of-sight path. In some buildings, optical fibers are used to route sunlight from the roof to other parts of the building. Optical fiber illumination is also used for decorative applications, including signs, art and artificial Christmas trees.

<u>Conclusion</u>

With the introduction of highly transparent fiber-optic cable in the 1970s, very high-frequency laser signals now carry phenomenal loads of telephone conversations and data across the country and around the world.

From surgical procedures to worldwide communication via the internet, fiber optic has revolutionised our world. Fiber optics has made important contributions to the medical field, especially with regards to surgery. One of the most useful characteristics of optical fibers is their ability to enter the minute passageways and hard-to-reach areas of the human body. But perhaps the greatest contribution of the 20th century is the combination of fiber optics and electronics to transformed telecommunications.