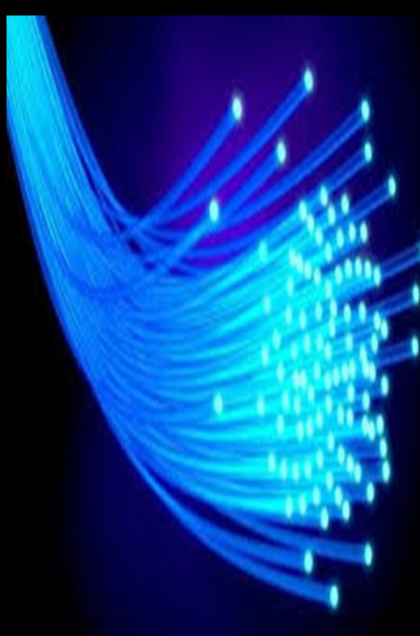
T.Y.B.Sc. SEM – VI

Subject: Physics

Paper- 603 (Spectroscopy & Applied physics)

Unit -5

FIBRE OPTICS



- INTRODUCTION
- CONSTRUCTION OF FIBRE OPTICS
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- Introduction :

Fibre optics deals with the light propagation through thin glass fibres. Fibre optics plays an important role in the field of communication to transmit voice, television and digital data signals from one place to another. The transmission of light along the thin cylindrical glass fibre by total internal reflection was first demonstrated by John Tyndall in 1870 and the application of this phenomenon in the field of communication is tried only from 1927. Today the applications of fibre optics are also extended to medical field in the form of endoscopes and to instrumentation engineering in the form of optical sensors.

1. The Basic principle of Optical Fibre Or Principle of Total Internal Reflection

https://youtu.be/CtQzlSFWwjY

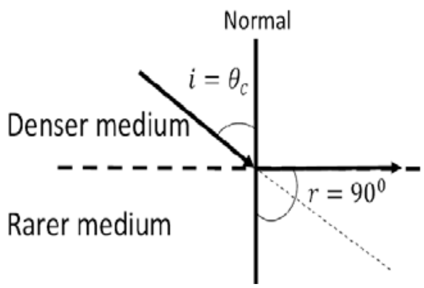
Principle:

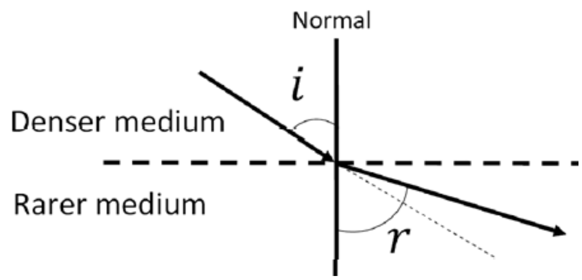
" The basic principle of optical fibre in the transmission of optical signal is total internal reflection."

- **Total internal reflection:**-

When the light ray travels from denser medium to rarer medium the refracted ray bends away from the normal. When the angle of incidence is greater than the critical angle, the refracted ray again reflects into the same medium. This phenomenon is called ***total internal reflection.***

The refracted ray bends towards the normal as the ray travels from rarer medium to denser medium. The refracted ray bends away from the normal as it travels from denser medium to rarer medium.

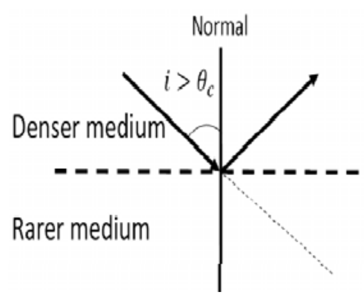




Let, a light ray traveling from denser medium (refractive index n_1) to rarer medium (refractive index n_2) with an angle of incidence i, then the angle of refraction r can be obtained by Snell's law.

$$n_1 Sin\, i = n_2 Sin\, r$$

When the angle of incidence is increased angle of reflection also increases and for a particular angle of incidence $(i = \theta_C)$ the refracted ray travels along the interface of two mediums. This angle of incidence is known as ***critical angle (θ_C).***



$$n_1\, Sin\, \theta_C = n_2\, Sin\, 90$$

$$n_1\, Sin\, \theta_C = n_2 \Rightarrow Sin\, \theta_C = n_2/n_1$$

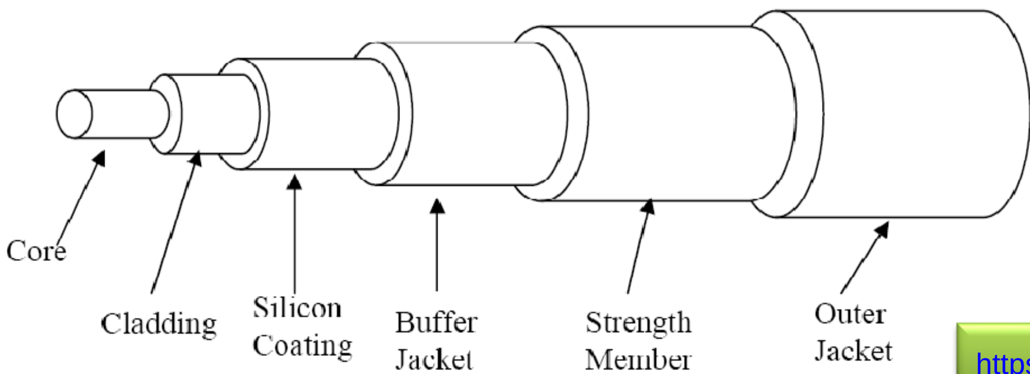
$$\theta_C = Sin^{-1}\left(\frac{n_2}{n_1}\right)$$

When the angle of incidence is greater than the critical angle $(i > \theta_C)$, the refracted ray again reflects into the same medium. This phenomenon is called total internal reflection

- When $(i < \theta_C)$, then the ray refracts into the secondary medium
- When $(i = \theta_C)$, then the ray travels along the interface
- When $(i > \theta_C)$, then the ray totally reflects back into the same medium

2. Construction of optical fibre:-

The optical fibre mainly consists the following six parts as shown in figure



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Core:

A typical glass fibre consists of a central core material. Generally core diameter is 50 μN. The core is surrounded by cladding. The core medium refractive is always greater than the cladding refractive index.

Cladding

Cladding refractive index is lesser than the cores refractive index. The over all diameter of cladding is 125 μN to 200 μN.

Silicon Coating

Silicon coating is provided between buffer jacket and cladding. It improves the quality of transmission of light.

Buffer Jacket

Silicon coating is surrounded by buffer jacket. Buffer jacket is made of plastic and protects the fibre cable from moisture.

Strength Member

Buffer jacket is surrounded by strength member. It provides strength to the fibre cable.

Outer Jacket

Finally the fibre cable is covered by polyurethane outer jacket. Because of this arrangement fibre cable will not be damaged during pulling, bending, stretching and rolling through the fibre cable is made up of glasses.

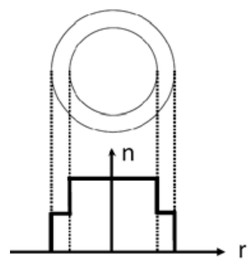
***Hint - કોર અને ક્લેડડીંગ નું કોટિંગ કરી બફર જેકેટ ને સ્ટ્રેન્થ આપો.

3. Classification of fibres:-

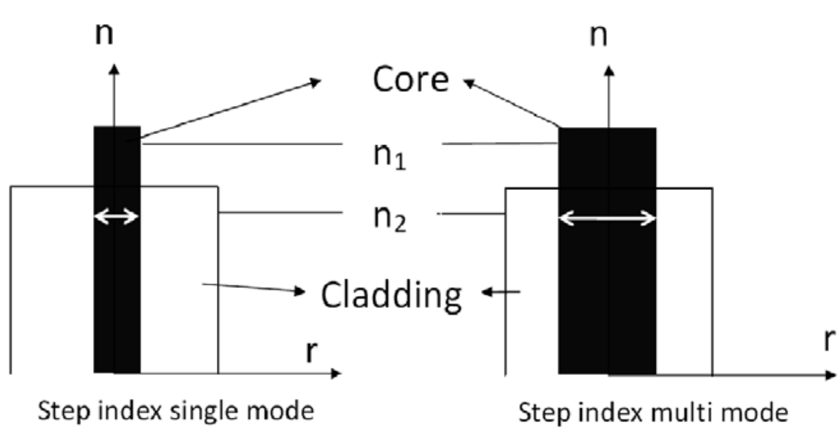
- Based on the refractive index of core medium, optical fibres are classified into two categories.
  i. Step index fibre
  ii. Graded index fibre
- Based on the number of modes of transmission, optical fibres are classified into two categories
  i. Single mode fibre
  ii. Multi-mode fibre
- Based on the material used, optical fibres are may broadly classified into four categories
  i. All glass fibres
  ii. All plastic fibres
  iii. Glass core with plastic cladding fibres
  iv. Polymer clad silica fibres.

- **Step index fibre:-**

In step index fibres the refractive index of the core medium is uniform and undergoes an abrupt change at the interface of core and cladding as shown in figure.



The diameter of core is about 10micrometers in case of single mode fibre and 50 to 200 micrometers in multi-mode fibre.

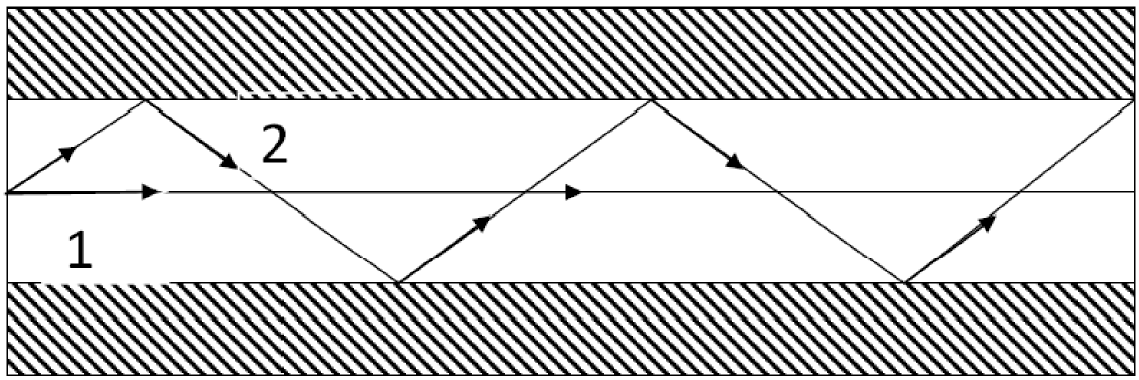


Attenuation is more for step index multi mode fibres but less in step index single mode fibres
Numerical aperture is more for step index multi mode fibres but it is less in step index single mode fibres

- **Transmission of signal in step index fibre**

The transmitted optical signal will cross the fibre axis during every reflection at the core cladding boundary. The shape of propagation of the optical signal is in zigzag manner.

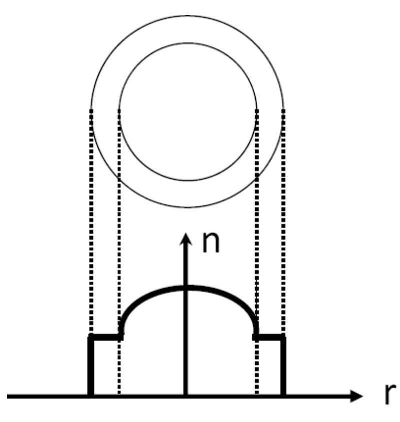
Generally the signal through the fibre is in digital form i.e. in the form of pulses representing 0s and 1s.



From figure the ray 1 follows shortest path (i.e. travels along the axis of fibre) and the ray 2 follows longer path than ray 1. Hence the two rays reach the received end at different times. Therefore, the pulsed signal received at other end gets broadened. This is called intermodal dispersion. This difficulty is over come in graded index fibres.

- **Graded index fibre**:-

In graded index fibres, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.



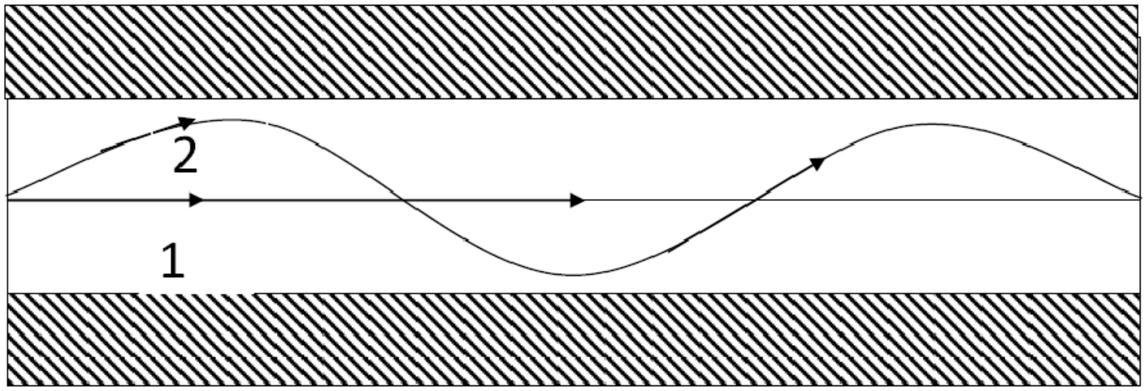
The diameter of the core is about 50 micrometers.

Attenuation is very less in graded index fibres

Numerical aperture is less in graded index fibres.

- **Transmission of signal in graded index fibre:-**

The shape of propagation of the optical signal appears in the helical or spiral manner.



As shown in figure, the ray 1 is traveling along the axis of the core and the other ray 2 traveling away from the axis undergoes refraction and bent. Since, ray 2 is traveling in the lesser refractive index medium, the two rays reach the other end simultaneously. Thus the problem of intermodal dispersion can be overcome by using graded index fibre.

- **Single mode optical fibre:-**

- In single mode optical fibres only one mode of propagation is possible.
- In case of single mode fibre the diameter of core is about 10micrometers
- The difference between the refractive indices of core and cladding is very small.
- In single mode fibres there is no dispersion, so these are more suitable for communication.
- The single mode optical fibres are costly, because the fabrication is difficult.
- The process of launching of light into single mode fibres is very difficult.
- The condition for single mode operation is

$$V = \frac{2\pi}{\lambda} a\, NA$$

$$V = \frac{2\pi}{\lambda} a\, n_1 \sqrt{2\Delta}$$

Where a is the radius of the core of the fibre,

n_1 is the refractive of the core,

NA is the numerical aperture and

λ is the wave length of light traveling through the fibre

- **Multi mode optical fibre:-**

➢ In multi-mode optical fibres many mummer of modes of propagation are possible.

➢ In case of in multi-mode fibre the diameter of core is 50 to 200 micrometers.

➢ The difference between the refractive indices of core and cladding is also large compared to the single mode fibres.

➢ Due to multi-mode transmission, the dispersion is large, so these fibres are not used for communication purposes.

➢ The multi-mode optical fibres are cheap than single mode fibres, because the fabrication is easy.

➢ The process of launching of light into single mode fibres is very easy.

➢ The condition for multi-mode propagation is

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

Where d the radius of the core of the fibre and NA is is the numerical aperture.

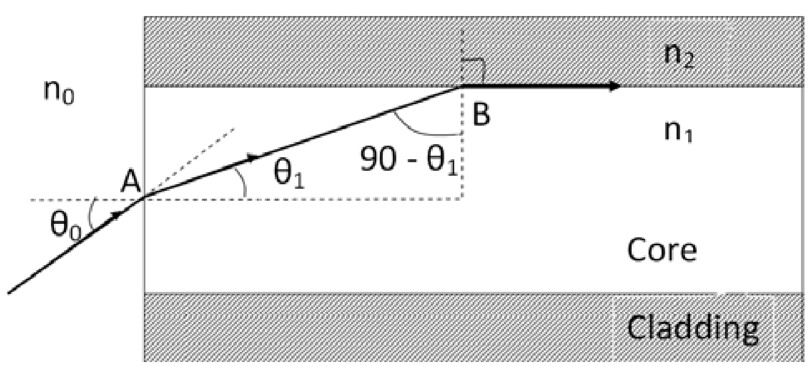
4. Acceptance angle:-

Definition:-

Acceptance angle is defined as the maximum angle of incidence at the interface of air medium and core medium for which the light ray enters into the core and travels along the interface of core and cladding.

Let n_0, n_1 and n_2 be the refractive indices of air, core and cladding media. Let a light ray OA is incident on the interface of air medium and core medium with an angle of incidence θ_0 then the light ray refracts into the core medium with an angle of refraction θ_1, and the refracted ray AB is again incidenting on the interface of core and cladding with an angle of incident $(90^0 - \theta_1)$.

If $(90^0 - \theta_1)$ is equal to the critical angle of core and cladding media then the ray travels along the interface of core and cladding along the path BC. If the angle of incident at the interface of air and core $\theta_1 < \theta_0$, then $(90^0 - \theta_1)$ will be greater than the critical angle. Therefore, the total internal reflection takes place.



According to Snell's law at point A

$$n_0 \sin\theta_0 = n_1 \sin\theta_1$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1$$

According to Snell's law at point B

$$n_1 \sin(90-\theta_1) = n_2 \sin 90$$

$$n_1 \cos\theta_1 = n_2$$

$$\cos\theta_1 = \frac{n_2}{n_1}$$

$$\sin\theta_1 = \sqrt{(1-\cos^2\theta_1)}$$

$$\sin\theta_1 = \sqrt{\left(1-\frac{{n_2}^2}{{n_1}^2}\right)} = \frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_1}$$

$$\sin\theta_0 = \frac{n_1}{n_0}\sin\theta_1 = \frac{n_1}{n_0}\frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_1} = \frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_0}$$

$$\sin\theta_0 = \frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_0}$$

$$\theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_0}\right)$$

$$\text{Acceptance angle } \theta_0 = \sin^{-1}\left(\frac{\sqrt{({n_1}^2-{n_2}^2)}}{n_0}\right)$$

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5. <u>Numerical aperture</u>:-

<u>Definition: -</u>

"Numerical aperture is defined as the light gathering capacity of an optical fibre and it is directly proportional to the acceptance angle."

$$NA = Sin\left(Sin^{-1}\left(\frac{\sqrt{(n_1^2-n_2^2)}}{n_0}\right)\right)$$

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

If the refractive index of the air medium is equal to unity then

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

Fractional change in refractive index

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

$$n_1\Delta = (n_1-n_2)$$

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

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

$$NA = \sqrt{n_1\Delta 2n_1} \qquad \because n_1 \approx n_2\ ; \quad n_1+n_2 = 2n_1$$

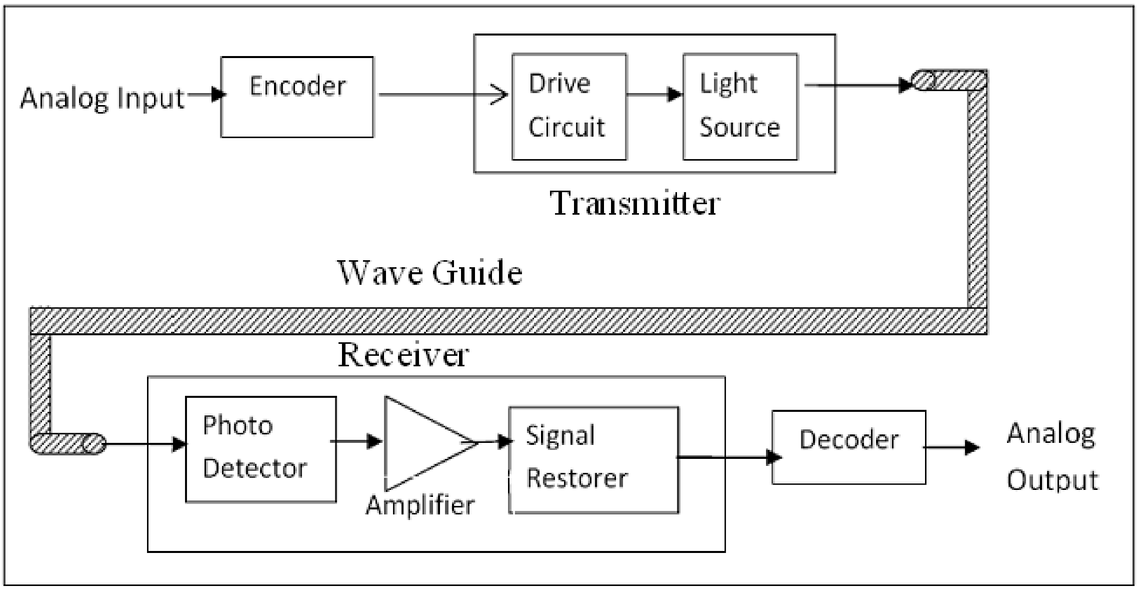
$$NA = n_1\sqrt{2\Delta}$$

The above equation gives a relationship between numerical aperture and fractional change in relative refractive index.

6. Optical fibre communication system:-

An optical fibre communication system mainly consists of the following parts as shown in figure.

1. **Encoder**
2. **Transmitter**
3. **Wave guide**.
4. **Receiver.**
5. **Decoder**



1. **Encoder**

Encoder is an electronic system that converts the analog information like voice, figures, objects etc., into binary data.

2. **Transmitter**

It contain two parts, they are drive circuit and light source. Drive circuit supplies the electric signals to the light source from the encoder in the required form. The light source converts the electrical signals into optical form.
With the help of specially made connector optical signals will be injected into wave guide from the transmitter.

3. **Wave guide**.

It is an optical fibre which carriers information in the form of optical signals over distances with the help of repeaters. With the help of specially made connector optical signals will be received by the receiver from the wave guide.

4. **Receiver.**

It consists of three parts; they are photo detector, amplifier and signal restorer. The photo detector converts the optical signal into the equivalent electric signals and supply to hem to amplifier. The amplifier amplifies the electric signals as they become weak during the long journey through the wave guide over longer distance. The signal restorer deeps the electric signals in a sequential form and supplies to the decoder in the suitable way.

5. **Decoder**

It converts electric signals into the analog information.

7. Differences between step index fibres and graded index fibres:-

Step index fibre	Graded index fibre
1. In step index fibres the refractive index of the core medium is uniform through and undergoes an abrupt change at the interface of core and cladding.	1. In graded index fibres, the refractive index of the core medium is varying in the parabolic manner such that the maximum refractive index is present at the center of the core.
2. The diameter of core is about 10micrometers in case of single mode fibre and 50 to 200 micrometers in multi mode fibre.	2. The diameter of the core is about 50 micro meters.
3. The transmitted optical signal will cross the fibre axis during every reflection at the core cladding boundary.	3. The transmitted optical signal will never cross the fibre axis at any time.
4. The shape of propagation of the optical signal is in zigzag manner.	4. The shape of propagation of the optical signal appears in the helical or spiral manner
5. Attenuation is more for multi-mode step index fibres but Attenuation is less in single mode step index fibres	5. Attenuation is very less in graded index fibres
6. Numerical aperture is more for multi mode step index fibres but it is less in single mode step index fibres	6. Numerical aperture is less in graded index fibres

- **Differences between single mode and multi-mode fibres:-**

Single mode fibre	Multi-mode fibre
1. In single mode optical fibres only one mode of propagation is possible	1. In multi-mode optical fibres many mummer of modes of propagation are possible.
2. In case of single mode fibre the diameter of core is about 10 micrometers	2. Case of in multi-mode fibre the diameter of core is 50 to 200 micrometers.
3. The difference between the refractive indices of core and cladding is very small.	3. The difference between the refractive indices of core and cladding is also large compared to the single mode fibres.
4. In single mode fibres there is no dispersion, so these are more suitable for communication.	4. Due to multi-mode transmission, the dispersion is large, so these fibres are not used for communication purposes.
5. The process of launching of light into single mode fibres is very difficult	**5.** The process of launching of light into single mode fibres is very easy.
6. The condition for single mode operation is $V = \frac{2\pi}{\lambda} a\, NA$	6. The condition for multi-mode propagation is $N = 4.9\left(\frac{d \bullet NA}{\pi}\right)^2$
7. Fabrication is very difficult and the fibre is costly.	7. Fabrication is very easy and the fibre is cheaper.

- **Advantages of fibre optic communication:-**

The optical fibre communication has more advantages than convectional communication.

- Enormous bandwidth
- low transmission loss
- electric isolation
- signal security
- small size and less weight
- low cost
- immunity cross talk

1. **Enormous bandwidth**

The information carrying capacity of a transmission system is directly proportional to the frequency of the transmitted signals. In the coaxial cable (or convectional communication system) transmission the bandwidth range is up to around500MHZ. only. Where as in optical fibre communication, the bandwidth range is large as 10^5 GHZ.

2. **Low transmission loss:-**

The transmission loss is very low in optical fibres (i.e. $0.2\ dB/Km$) than compare with the convectional communication system. Hence for long distance communication fibres are preferred.

3. **Electric isolation**

Since fibre optic materials are insulators, they do not exhibit earth and interface problems. Hence communicate through fibre even in electrically danger environment.

4. **Signal security**

The transmitted signal through the fibre does not radiate, unlike the copper cables, a transmitted signal cannot be drawn from fibre without tampering it. Thus the optical fibre communication provides 100% signal security.

5. **Small size and less weight**

The size of the fibre ranges from $10\mu m$ to $50\mu m$, which is very small. The space occupied by the fibre cable is negligibly small compared to convectional electrical cables. Optical fibres are light in weight.

6. **Low cost**

Since optical fibres made up of silica which is available in abundance, optical fibres are less expensive.

7. **Immunity cross talk**

Since the optical fibres are dielectric wave guides, they are free from any electromagnetic interference and radio frequency interference. Since optical interference among different fibres is not possible, cross talk is negligible even many fibres are cabled together.

10. Applications of optical fibres

1. Optical fibres are extensively used in communication system.
2. Optical fibres are in exchange of information between different computers
3. Optical fibres are used for exchange of information in cable televisions, space vehicles, submarines etc.
4. Optical fibres are used in industry in security alarm systems, process control and industrial auto machine.
5. Optical fibres are used in pressure sensors in biomedical and engine control.
6. Optical fibres are used in medicine, in the fabrication in endoscopy for the visualization of internal parts of the human body.
7. Sensing applications of optical fibres are

   Displacement sensor

   Fluid level detector

   Liquid level sensor

   Temperature and pressure sensor

   Chemical sensors
8. Medical applications of optical fibres are

   Gastroscope

   Orthoscope

   Couldoscope

   Peritonescope

   Fibrescope

- **NUMERICALS**

1. In an optical fibre the core material has refractive index 1.43 and refractive index of clad material is 1.4 find the propagation angle. **[Ans : 11.8°]**

2. In an optical fibre, the core material has refractive index 1.6 and refractive index of clad material is 1.3 . What is the value of critical angle? Also calculate the value of angle acceptance cone. **[Ans : 54.3°, 60.5°]**

3. Calculate the numerical aperture and acceptance angle of an optical fibre from the following data;

   Refractive index of core – 1.55 and refractive index of cladding – 1.50

   [Ans: NA = 0.391, θ_0= 23.02°]

4. What is the NA of an optical fibre cable with a clad index of 1.378 and a core index of 1.546 ?

   [Ans : 0.70]

5. A fibre Cable has an acceptance angle of 30 and a core index of refraction of 1.4 calculates the refractive index of the cladding. **[Ans : n_2 = 1.308]**

6. Calculate the fractional index change for a given optical fibre if the refractive indices of the core and the cladding are 1.563 and 1.498 respecitvely. **[Ans : θ_0= 26.49°]**

7. Calculate the fractional index change for a given optical fibre if the refractive indices of the core and the cladding are 1.563 and 1.498 respectively. **[Ans : 0.0415]**

8. Calculate the refractive indices of the core and cladding material of a fibre from the following data: NA = 0.22 and Δ = 0.012. **[Ans : n_1 = 1.42 , n_2 = 1.403]**

9. Find the fractional refractive index and numerical aperture for an optical fibre with refractive indices of core and cladding as 1.5 and1.49 respectively.

   [Ans : NA = 0.174 and Δ = 0.0067

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For solution: