Chapter-8*

Fibre Optics

8.1. Introduction

Fibre optics is a branch of physics which discusses on the **transmission of light through a transparent glass or plastic fibre** based on the **principle of total internal reflection**.

Here, light is used to transmit the information from one place to other. Instead of using an electrical signal travelling over a cable or electromagnetic waves travelling through space, the information is inserted on a light beam and transmitted through a cylinder of transparent dielectric medium, called optical fibre.

8.2. Optical Fibre and its Construction

An optical fibre is a very thin and flexible cylindrical thread of transparent plastic or glass medium to guide visible and infrared light over a long distance. It is widely used in the field of communication and transmission of optical signal from one place to the other by the principle of total internal reflection.

8.2.1. Construction

It consists of three sections : **(i)** the core **(ii)** the cladding and **(iii)** the jacket.

- **Core** It is the innermost part and is made of glass or plastic.
- **Cladding** The core is surrounded by a layer of material (glass or plastic) having lower refractive index than the material of the core. This layer is called cladding which helps to keep the light within the core using the principle of total internal reflection.
- **Jacket** The outer section which covers the cladding is known as jacket. The jacket is made of plastic or polymer. It protects the optical fibre from moisture, mechanical shocks and other environmental hazards (*viz.* pollution and radiation etc.)

8.2.2. Dimension of Fibre

The diameter of the core is usually in the order of 5 μm to about 50 μm.

* *This chapter is not included in W.B.U.T. syllabus.*

The diameters of the cladding and the jacket are about 125 μm and 250 μm respectively.

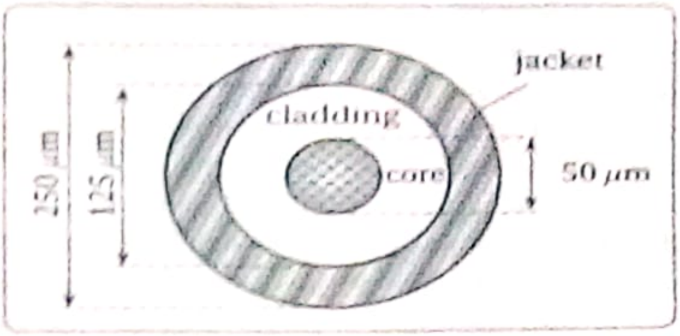

Fig. 1 ▷ Cross-sectional view of an optical fibre

8.3. Advantages of Fibres over Wires or Cables

The main advantages of optical fibres are :

1. Optical fibres are **lighter in weight and occupy less space** (*i.e.* smaller size) than copper wires or coaxial cables or bundle of twisted pair cables.
2. Optical fibres systems are **more economical** than that of an equivalent wire cable systems in the long run.
3. The transmission speed of sending information is very fast in optical fibres in comparison to co-axial cables or wires.
4. In optical fibres, the electrical noise does not interfere with propagated light signals. So, **the cross talking can be avoided.** Hence, the transmission is more secure.
5. **The attenuation in a fibre is markedly lower** than that of coaxial cable or twisted pair.
6. **The bandwidth of the fibre is higher** than that of coaxial cable or wire.
7. The raw material for production of optical fibre is available in plenty.
8. **Optical fibre has longer life than the copper wire** as the fibre are not effected **by environmental** hazards (*viz.* pollution and radiation etc.)
9. Modern electrical communication such as telegraphy, telephone and radio communication used radio waves and microwaves to carry information through copper wires and co-axial cables. The information carrying capacity of these wires is highly restricted. Whereas fibre optics communication systems have a tremendus capacity to carry information. The capacity of carrying information is near about thousand times greater than that of electronic communication systems.

Ankur ray

8.4. Working Principle of Optical Fibre

The central part of an optical fibre consists of a very fine glass core of refractive index n_1 and this is coated with a glass cladding of refractive index n_2 provided $n_1 > n_2$ (Fig. 2).

optical fibre [Fig. 4] So, rays near the outer edge travel faster than rays in the centre of the core. Because of this, all the rays arrive at the end of the fibre at approximately the same time. As a result, light rays are continuously refocussed within the core as they travel down the fibre. This reduces signal distortion. The refractive index of the cladding is uniform.

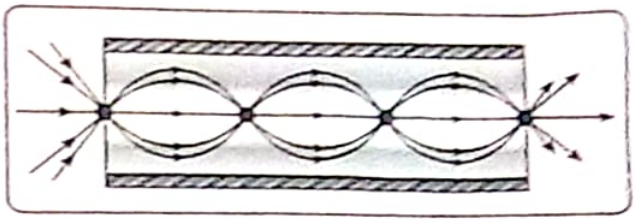

Fig. 4 ▷ Graded-index optical fibre

8.6. Numerical Aperture and Acceptance Angle

Consider a ray of light OX incidents on the entrance aperture of the fibre at an angle 'α' with the axis of the fibre and is refracted along XY at an angle β with the axis [Fig. 5]. Let n, n_1 and n_2 be the refractive indices of the outside medium, core and the material of the cladding respectively.

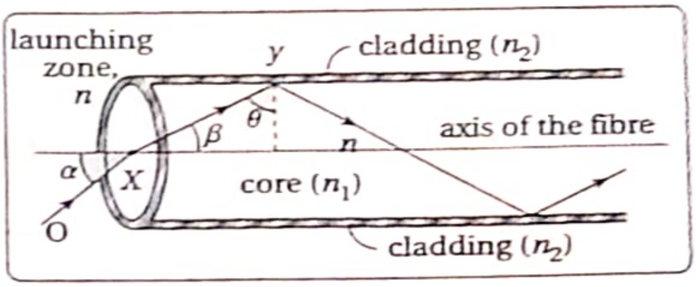

Fig. 5 ▷ Schematic diagram for calculation of numerical aperture of optical fibre

Let θ be the angle of incidence at the core and cladding interface. If α decreases, β also decreases and so $\theta(=90^\circ-\beta)$ increases. So when α decreases sufficiently, θ exceeds the critical angle (θ_C) of the core-cladding interface and the ray XY is totally reflected at point Y.

Acceptance angle **The maximum angle of incidence at the entrance aperture of the fibre for which the light ray is totally reflected at the core-cladding interface and propagates through the fibre is called the acceptance angle (θ_A).**

Now, when $\alpha = \theta_A$, $\beta = 90^\circ - \theta_C$ as $\theta = \theta_C$.

Now applying Snell's law at the point X, we get

$$n\sin\theta_A = n_1\sin\beta \quad \text{or,} \quad n\sin\theta_A = n_1\sin(90^\circ-\theta_C)$$

$$\text{or,} \quad n\sin\theta_A = n_1\cos\theta_C \quad \text{or,} \quad \sin\theta_A = \frac{n_1}{n}\cos\theta_C \qquad \cdots(8.1)$$

Again, when $\theta = \theta_C$, the incident ray at Y grazes the interface after refraction. Applying Snell's law at the point Y, we have,

$$n_1\sin\theta_C = n_2\sin 90^\circ \quad \text{or,} \quad \boxed{\sin\theta_C = \frac{n_2}{n_1}} \qquad \cdots(8.2)$$

$$\text{or,} \quad \cos\theta_C = \sqrt{1-\frac{n_2^2}{n_1^2}} \qquad \cdots(8.3)$$

Here, n_1 = r.i. of core = 1.54 , n_2 = r.i. of cladding = 1.50

n = r.i. of air = 1

$\therefore \quad NA = \sqrt{(1.54)^2 - (1.50)^2} = 0.3487 \simeq 0.35$

$\therefore$ Acceptance angle $\theta = \sin^{-1}\dfrac{\sqrt{n_1^2 - n_2^2}}{n}$

$= \sin^{-1}(0.35) \simeq 20.48°$

Problem 2

An optical fibre is made by glass core of refractive index 1.55 and the cladding of refractive index 1.50 with a core diameter of 40 μm. Calculate I the critical angle of the fibre, II the number of reflections per metre suffered by the guided ray at the core-cladding interface within the optical fibre, III fractional refractive index difference.

Solution

I If θ_C is the critical angle, $\sin\theta_C = \dfrac{n_2}{n_1} = \dfrac{1.50}{1.55} = .9677 \simeq 0.97$

or, $\theta_C = \sin^{-1}(0.97) = 75.9°$

II From the figure, if the axial distance traversed by the ray between two consecutive reflection is x (say), then

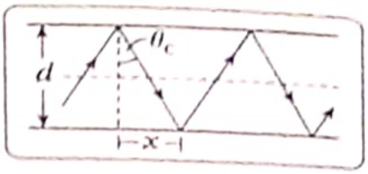

Fig. 6

$x = d\tan\theta_C = 40\tan 75.9\ \mu m$

$= 159.246\ \mu m$

$\simeq 159.25\ \mu m$

So, The number of reflections per metre is

$$\frac{1\text{ m}}{x} = \frac{1\text{ m}}{159.25 \times 10^{-6}\text{ m}} \simeq 6279$$

III Δ = fractional index difference $= \dfrac{n_1 - n_2}{n_1} = \dfrac{1.55 - 1.50}{1.55} = 0.032$

8.7. Attenuation : Loss of Energy in the Fibre (or Transmission Losses in Fibre)

In general, the fibre material and its structure are not perfect and have minute irregularities, impurities and microbendings. As a result, **when an optical signal propagates through a fibre, the signal will get progressively attenuated** (*i.e.* reduced). So, there is an energy loss of optical signal with distance during its propagation.

The losses can occur due to the following aspects—

1. macrobending and microbending of optical fibre cable

When light enters at one end of the fibre, it travels from the denser medium (*i.e.* core) towards the rarer medium (*i.e.* cladding). When it incidents at the core-cladding interface at an angle greater than the critical angle of the fibre material *w.r.t* cladding, the ray of light undergoes total internal reflection. It suffers of total internal reflection repeatedly until the angle of incidence remains greater than the critical angle. Hence, the light wave is propagated along the fibre by the repeated internal reflections until it emerges out from the other end of the fibre without losing any energy, even if the fibre is bent.

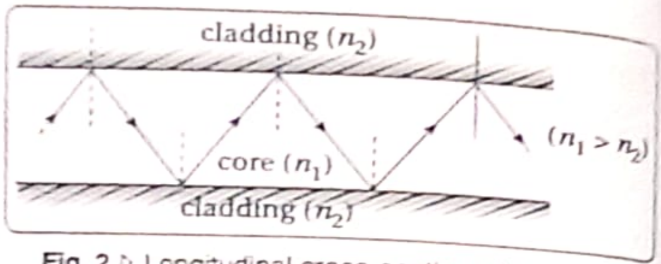

Fig. 2 ▷ Longitudinal cross-section of fibre and propagation of light wave along the fibre

The ability of the light gathering of fibre depends on

(i) the core size and (ii) numerical apperature.

8.5. Classification of Optical Fibre

Depending on their modes of propagation optical fibre is classified into two types. These are— (i) Step-index optical fibre and (ii) Graded-index optical fibre

① Step-index optical fibre

It has a core and a cladding of uniform refractive index n_1 and n_2 respectively provided $n_1 > n_2$. It has a very small core diameter which is of the same order as the wavelength of the light wave propagator. It is called step-index optical fibre as there is a **sudden change of refractive index** at the junction of the core-cladding interface in a single step to permit total internal reflection (Fig. 3).

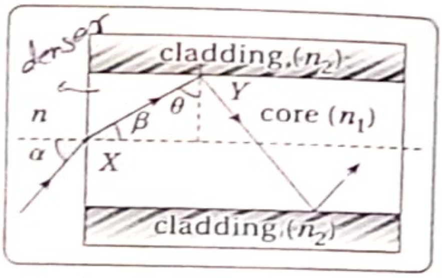

Fig. 3 ▷ Step-index optical fibre

The single mode step-index fibre is by far the best for long distance communication. Because the pulse repetition can be high and maximum amount of information can be send. But the use of very thin core creates mechanical difficulties in manufacturing and handling the fibre. Hence, this type of fibre is very expensive. It is used in under sea-level transmission where the expenditure is justified.

② Graded-index optical fibre

It is a multimode[1] fibre with a large core diameter. This core has non-uniform refractive index. The refractive index of the core is a function of radial distance from the fibre axis (*i.e.* r.i. decreases gradually from the centre towards the core-cladding interface) and so the fibre is called graded-index

[1] A mode is a path of light rays along which the light waves travel down in phase through the core of the optical fibre. Usually modes are represented by order number m.

optical fibre [Fig. 4] So, rays near the outer edge travel faster than rays in the centre of the core. Because of this, all the rays arrive at the end of the fibre at approximately the same time. As a result, light rays are continuously refocussed within the core as they travel down the fibre. This reduces signal distortion. The refractive index of the cladding is uniform.

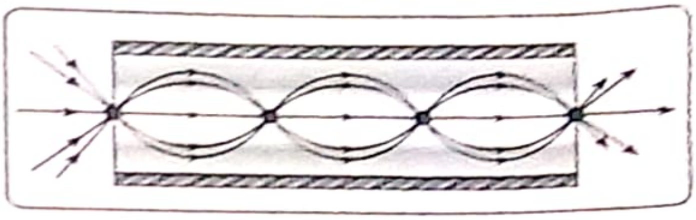

Fig. 4 ▷ Graded-index optical fibre

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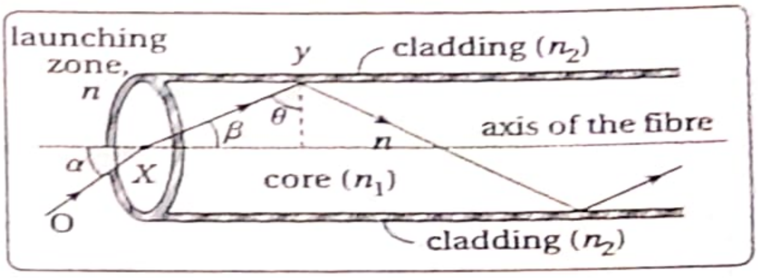


Fig. 5 ▷ Schematic diagram for calculation of numerical aperture of optical fibre

Let θ be the angle of incidence at the core and cladding interface. If α decreases, β also decreases and so $\theta(=90^\circ-\beta)$ increases. So when α decreases sufficiently, θ exceeds the critical angle (θ_C) of the core-cladding interface and the ray XY is totally reflected at point Y.

- **Acceptance angle** **The maximum angle of incidence at the entrance aperture of the fibre for which the light ray is totally reflected at the core-cladding interface and propagates through the fibre is called the acceptance angle (θ_A).**

Now, when $\alpha = \theta_A$, $\beta = 90^\circ - \theta_C$ as $\theta = \theta_C$.

Now applying Snell's law at the point X, we get

$$n\sin\theta_A = n_1\sin\beta \qquad \text{or,} \quad n\sin\theta_A = n_1\sin(90^\circ-\theta_C)$$

$$\text{or,} \quad n\sin\theta_A = n_1\cos\theta_C \qquad \text{or,} \quad \sin\theta_A = \frac{n_1}{n}\cos\theta_C \qquad \cdots(8.1)$$

Again, when $\theta = \theta_C$, the incident ray at Y grazes the interface after refraction. Applying Snell's law at the point Y, we have,

$$n_1\sin\theta_C = n_2\sin 90^\circ \qquad \text{or,} \quad \boxed{\sin\theta_C = \frac{n_2}{n_1}} \qquad \cdots(8.2)$$

$$\text{or,} \quad \cos\theta_C = \sqrt{1-\frac{n_2^2}{n_1^2}} \qquad \cdots(8.3)$$

Hence, from equation (8.1), we get

$$\sin\theta_A = \frac{n_1}{n}\sqrt{1-\frac{n_2^2}{n_1^2}} \quad \text{or,} \quad \sin\theta_A = \frac{\sqrt{n_1^2-n_2^2}}{n} \quad \cdots(8.4)$$

or, $$n\sin\theta_A = \sqrt{n_1^2-n_2^2} \quad \cdots(8.5)$$

From the equation (8.4), we get the acceptance angle

$$\boxed{\theta_A = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n}\right)} \quad \cdots(8.6)$$

Numerical aperture It is defined as the sine of the acceptance angle of the optical fibre and measures the light gathering or accepting power of the fibre. Thus it is represented by

$$\boxed{NA(=\sin\theta_A) = \frac{\sqrt{n_1^2-n_2^2}}{n}} \quad \text{[for air medium r.i. } n = 1\text{]} \quad \cdots(8.7)$$

Special Note :

The fractional refractive index changes in the core-cladding interface:

For air r.i. $n = 1$. So, we get from equation (8.7), the numerical apperture

$$NA = \sqrt{n_1^2-n_2^2} \quad \cdots(1)$$

Usually, $(n_1 - n_2)$ is not large

$$\therefore \quad n_1^2-n_2^2 = (n_1+n_2)(n_1-n_2) \simeq 2n_1 \cdot \delta n, \text{ where } \delta n = n_1 - n_2$$

Thus we have from equation (1),

$$NA = \sqrt{2n_1 \cdot \delta n} = n_1\sqrt{\frac{2\delta n}{n_1}}$$

$$\boxed{NA = n_1\sqrt{2\Delta}} \quad \text{where } \Delta = \frac{\delta n}{n_1} = \frac{n_1-n_2}{n_1} \quad [\text{for } n = 1]$$

This equation measures the fractional refractive index change of the core-cladding interface. It is typically of the order of 0.01.

Problem 1

Compute the numerical aperture and the acceptance angle of an optical fibre having refractive indices 1.54 (core) and 1.50 (cladding). Surrounding medium is air.

[Question Bank WBUT]

Solution Numerical aperture $NA = \sin\theta_A = \dfrac{\sqrt{n_1^2-n_2^2}}{n}$

Here, n_1 = r.i. of core = 1.54, n_2 = r.i. of cladding = 1.50

n = r.i. of air = 1

$\therefore$ $NA = \sqrt{(1.54)^2 - (1.50)^2} = 0.3487 \simeq 0.35$

$\therefore$ Acceptance angle $\theta = \sin^{-1}\dfrac{\sqrt{n_1^2 - n_2^2}}{n}$

$= \sin^{-1}(0.35) \simeq 20.48°$

Problem 2

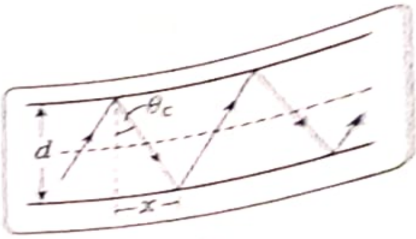
An optical fibre is made by glass core of refractive index 1.55 and the cladding of refractive index 1.50 with a core diameter of 40 μm. Calculate (i) the critical angle of the fibre, (ii) the number of reflections per metre suffered by the guided ray at the core-cladding interface within the optical fibre, (iii) fractional refractive index difference.

Solution

(i) If θ_C is the critical angle, $\sin\theta_C = \dfrac{n_2}{n_1} = \dfrac{1.50}{1.55} = .9677 \simeq 0.97$

or, $\theta_C = \sin^{-1}(0.97) = 75.9°$

(ii) From the figure, if the axial distance traversed by the ray between two consecutive reflection is x (say), then



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So, The number of reflections per metre is

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(iii) Δ = fractional index difference $= \dfrac{n_1 - n_2}{n_1} = \dfrac{1.55 - 1.50}{1.55} = 0.032$

8.7. Attenuation : Loss of Energy in the Fibre (or Transmission Losses in Fibre)

In general, the fibre material and its structure are not perfect and have minute irregularities, impurities and microbendings. As a result, when an optical signal propagates through a fibre, the signal will get progressively attenuated (*i.e.* reduced). So, there is an energy loss of optical signal with distance during its propagation.

The losses can occur due to the following aspects—

(1) macrobending and microbending of optical fibre cable

② absorption and scattering in the fibre itself

③ fibre to fibre joints—axial displacement of fibres.

The optical power at a distance L *i.e.* (at the receiving end) in optical fibr[e is] related by

$$P_L = P_0 e^{-\alpha L} \quad \cdots(8.[8])$$

where P_0 is the power of the optical signal launched at input of a fibre and α is [the] attenuation (or loss) coefficient in decibel per unit length. In practice, the unit [of] measurement of attenuation or reduction is **decibel /kilometer** ($\text{dB} \cdot \text{km}^{-1}$).

Hence, **the attenuation (reduction) of signal is defined as the logarithmic ra[tio] of the optical power at the input of a fibre to the optical power at a distance L in th[e] fibre per its unit length.**

It is generally expressed as

$$\boxed{\alpha\,(\text{loss}) = \frac{10}{L}\log_{10}\left(\frac{P_0}{P_L}\right)} \quad \cdots(8.9)$$

$$\therefore \quad P_L = P_0 \cdot 10^{-\frac{\alpha L}{10}} \quad \cdots(8.10)$$

If $P_L = P_0$, attenuation is zero.

Problem 1

A 10 km optical fibre is formed by joining optical fibres of 1 km each with connectors that give attenuation of 0.75 dB each. This optical fibre of length 10 km has also an attenuation of $1.8\ \text{dB} \cdot \text{km}^{-1}$. What will be the minimum optical power must be launched on the fibre to maintain a mean optical power level of $0.2\ \mu W$ at the detector?

Solution Here, the attenuation (*i.e.* fibre loss) or the optical fibre $= 1.8\ \text{dB} \cdot \text{km}^{-1}$

So, the loss for 10 km optical fibre

= Fibre loss (i.e. attenuation) × length of optical fibre

$= 1.8\ \text{dB} \cdot \text{km}^{-1} \times 10\ \text{km} = 18\ \text{dB}$

Again the connector loss/ km $= 0.75\ \text{dB} \cdot \text{km}^{-1}$

Since this 10 km optical fibre is formed by connecting optical fibres of 1 km each the total loss for 10 km optical fibre due to connectors $= 0.75 \times 10 = 7.5\ \text{dB}$.

$\therefore$ Total loss of optical signal $(\alpha L) = (7.5 + 18)\ \text{dB} = 25.5\ \text{dB}$

Now the optical power at the receiving end *i.e.* at detector $P_L = 0.2\ \mu W$

Now using the relation, $\alpha L = 10\log_{10}\frac{P_0}{P_L}$ [P_0 = optical power at the launching position]

we get, $25.5 = 10\log_{10}\frac{P_0}{0.2}$ or, $\log_{10}\frac{P_0}{0.2} = 2.55$

or, $\frac{P_0}{0.2} = 10^{2.55}$ or, $P_0 = 70.962\ \mu W$

Problem 2

The attenuation of an optical fibre is 2.6 dB · km^{-1}. If the power of optical signal at launching end is 0.6 mW, find the power level after 5 km.

Solution In this problem, the attenuation or reduction $\alpha = 2.6$ dB · km^{-1}

P_0 = power at launching end = 0.6 mW.

L = Length of the cable = 5 km

Let P_L be the power at the receiving end

So, the attenuation of the signal $\alpha = \frac{10}{L}\log_{10}\frac{P_0}{P_L}$

or, $$10\log_{10}\frac{0.6}{P_L} = 2.6 \times 5 = 13 \text{ dB}$$

or, $$\log_{10}\frac{0.6}{P_L} = \frac{13}{10} = 1.3 \quad \text{or,} \quad P_L = 0.03007 \text{ mW}$$

8.8. Uses of Optical Fibre

① **Communication** Due to the large bandwidth, good electrical isolation and no cross-talking optical fibre is widely used in the field of optical communication and is capable of handling a large number of channels.

② **Medical use** It is extensively used in medical investigations. Optical fibres are used in endoscopic instrument by which doctors can visually examine the inside of the human body like as stomach, intestine etc. It is also applied in bloodless surgery and laser opthalmoscope for retinal welding.

③ It is extensively used in security alarm system and process control.

④ Optical fibre sensors have been used to measure temperature and pressure.

⑤ It is used for transmission of digital data such as that generated by computers.

Exercise

Multiple Choice Questions

1. Optical fibre works on—

Ⓐ principle of total internal reflection

Ⓑ reflection

Ⓒ polarisation

Ans. Ⓐ

2. In optical fibre, the transmission medium is—

Ⓐ radiowaves Ⓑ electrical signal Ⓒ light **Ans.**

3. In optical fibre the refractive index of core in comparison to that of cladding is—

Ⓐ smaller Ⓑ greater Ⓒ equal **Ans.**

4. The attenuation in optical fibre than that in co-axial cable or wire is—

Ⓐ greater Ⓑ lower Ⓒ none **Ans.**

5. The bandwidth of optical fibre than that of co-axial cable or wire is—

Ⓐ lower Ⓑ higher Ⓒ equal **Ans.**

6. The life time of optical fibre is greater than that of copper wire as it—

Ⓐ can not be effected by environmental hazards

Ⓑ can be effected by environmental hazards

Ⓒ none **Ans.** Ⓐ

7. The total internal reflection process may be seen at core-cladding interface as—

Ⓐ the refractive index of core is greater than that of cladding

Ⓑ the refractive index of core is less than that of cladding

Ⓒ none **Ans.** Ⓐ

8. In step-index optical fibre, the refractive index of core—

Ⓐ changes suddenly at the core-cladding interface

Ⓑ changes gradually throughout the core surface

Ⓒ none **Ans.** Ⓐ

9. In graded-index optical fibre, the refractive index of core is—

Ⓐ decreases gradually from the centre towards the core-cladding interface

Ⓑ increases gradually from the centre towards the core-cladding interface

Ⓒ none **Ans.** Ⓐ

10. The maximum angle of incidence at the entrance aperture of the fibre for which the light ray is totally reflected at the core-cladding interface is called—

Ⓐ critical angle Ⓑ acceptance angle Ⓒ none **Ans.** Ⓑ

11. An optical fibre of refractive indices n_1 and n_2 for core and cladding respectively is placed in air medium. The acceptance angle is defined as—

Ⓐ $\sqrt{n_1^2 - n_2^2}$ Ⓑ $\sin^{-1}\sqrt{n_1^2 - n_2^2}$ Ⓒ $\sin^{-1}\sqrt{n_2^2 - n_1^2}$ **Ans.** Ⓑ

12. An optical fibre of refractive indices n_1 and n_2 for core and cladding respectively is placed in air medium. The numerical aperture is defined as—

Ⓐ $\sin^{-1}\sqrt{n_1^2 - n_2^2}$ Ⓑ $\sqrt{n_1^2 - n_2^2}$ Ⓒ $\sqrt{n_2^2 - n_1^2}$ **Ans.** Ⓑ

13. Which of the following statements is correct ?

Ⓐ Optical fibres can bend light using the principle of Poiseluille's law

Ⓑ Optical fibres cannot bend the light

Ⓒ Optical fibres bend the light beam using the principle of total internal reflection **Ans.** Ⓒ

14. In an optical fibre the intensity of light —

Ⓐ attenuates linearly with the length of the fibre

Ⓑ attenuates exponentially with the length of the fibre

Ⓒ attenuates logarithmically with the length of the fibre **Ans.** Ⓑ

[W.B.U.T. 2007]

15. The unit of measurement of attenuation in fibre optics is —

Ⓐ dB Ⓑ $dB \cdot km^{-1}$ Ⓒ km **Ans.** Ⓑ

16. For an optical fibre, if n_0, n_1 and n_2 are refractive indices of air, core and cladding region respectively, then

Ⓐ $n_0 > n_2 > n_1$ Ⓑ $n_1 > n_2 > n_0$ Ⓒ $n_2 > n_1 > n_0$ **Ans.** Ⓑ

[W.B.U.T. 2009]

Short Answer Type Questions

1. [a] What do you mean by optical fibre ? [See Article 8.2]

   [b] Discuss the construction of optical fibre. [See Article 8.2.1]

2. [a] What are the advantages of an optical fibre ? **[W.B.U.T. '09]** [See Article 8.3]

   [b] State the working principle of an optical fibre ? [See Article 8.4]

3. Define graded-index optical fibre and step-index optical fibre with necessary diagram. [See Article 8.5]

4. What do you mean by numerical aperture of an optical fibre? Find out an expression of NA for a step-index optical fibre. [See Article 8.6]

5. [a] Define acceptance angle.

   [b] Calculate the numerical aperture of a fibre with refractive indices of the core and cladding 1.54 and 1.50 respectively. **[W.B.U.T. 2005]**

   [**Hint:** Numerical aperture $\sin\theta_A = \sqrt{n_1^2 - n_2^2}$

   $= \sqrt{(1.54)^2 - (1.50)^2} = 0.3487$]

Long Answer Type Questions

1. [a] What is optical fibre ? [See Article 8.2]

   [b] Give the construction of optical fibre. [See Article 8.2.1]

   [c] Discuss the working principle of optical fibre. [See Article 8.4]

2. [a] What are the advantages of optical fibre over wire or cable ?

   [See Article 8.3]

[b] What do you mean by graded-index optical fibre and step-index optic fibre? [See Article 8.

[c] Define numerical aperture of a fibre and find out expression for the same in step-index optical fibre. [See Article 8.6] [B.U. (H) 2000,'0

[d] Give three uses of optical fibre. [See Article 8.

3. [a] What is an optical fibre? [See Article 8.2] [W.B.U.T. B.OPT '04]

[b] Discuss briefly the basic structure and the principle of optical fibres.

[See Article 8.2.1 and then Article 8.4] [W.B.U.T. B.OPT '04]

[c] What do you mean by acceptance angle and numerical aperture of a fibre?

[See Article 8.6] [W.B.U.T. B.OPT '04]

Numerical Problems

1. Find the numerical aperture and the critical angle of a fibre with refractive index of core and cladding are 1.6025 and 1.59 respectively.

[Ans : $NA = 0.20$, $\theta_c = \sin^{-1}0.9921$]

[**Hint :** critical angle $\theta_c = \sin^{-1}\dfrac{n_2}{n_1} = \sin^{-1}\dfrac{1.59}{1.6025} = (\sin^{-1}0.9921)$]

2. In an optical fibre, the refractive index of a cladding is 1.45 and its numerical aperture is 0.18. Find the acceptance angle for the fibre in water. Given refractive index of water is 1.33. [Ans : $\sin^{-1}\sqrt{0.1344}$]

[**Hint :** (i) $n_1 = \sqrt{(NA)^2 + n_2^2} = 1.461$

(ii) In water $NA = \dfrac{\sqrt{n_1^2 - n_2^2}}{n_{\text{water}}}$

(iii) $\theta_A = \sin^{-1}(NA)$]

3. Find the numerical aperture and angle of acceptance of a given optical fibre if the refractive indices of the core and cladding are 1.562 and 1.497 respectively. [W.B.U.T. B.OPT '04, 09]

[**Hint :** $NA(=\sin\theta_A) = \sqrt{(1.562)^2 - (1.497)^2} = 0.446$ or $\theta_A = 26.5°$]

4. The refractive indices of the core and cladding of an optical fibre are 1.523 and 1.472 respectively. Find numerical aperture and the angle of acceptance of the optical fibre. [W.B.U.T. '06]

Chapter-9

Holography

9.1. Introduction

Holography is a method for recording and reproducing a three dimensional image of object without the use of lens but using the coherence properties of laser beams. It depends on the principle of interference of an object wave with a reference wave of highly coherent in nature. *In holography,*[1] *both the phase and intensity (amplitude) of light waves are recorded on the film and when the photograph is viewed, it shows a three dimensional image of the object. Such a photograph is called a Hologram.*

9.1.1. Difference between Ordinary Photography and Holography

① In ordinary photography, the image of a three dimensional object is recorded on a two dimensional photographic plate by using lenses. It is a two dimensional record of light intensity from the different parts of the three dimensional object without considering the phase of the light wave. Due to this reason, the three dimensional character of the object is lost. But in holography, we record both the intensity and phase of the light waves on the film.

② In ordinary photography plate, the superposition of number of images in a single plate can not be possible. While in holography, one can record many independent pictures.

9.2. Basic Principle of Holography

It can be explained using the idea of a zone plate.[2] The point object A is embedded in a beam of coherent laser light. The diffracted light, called the object beam from the object A superposes on the coherent incident light (called the reference beam) on a photographic film PQ [Fig. 1]. On the film, the interference of these two sets of waves (coherent waves) produces a pattern of light and dark ring. **This film having a dark and opaque region is called a hologram.**

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[1] The word '**hologram**' is derived from Greek word '**holos**' meaning '**the whole**' *i.e.* the whole of information.

[2] **Zone plate** : This is a special diffracting obstacle designed to block off the light from alternate half period zones.