Jaipur Engineering College and Research Center

- Year & Sem. – B. Tech. I-Year, Semester - I
- Subject – Engineering Physics (1FY2-02)
- Chapter - Optical Fibre
- Department - Applied Science

Vision and Mission

- **Vision:**
- ➢ To become a renowned centre of outcome based learning, and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

- **Mission:**
- ➢ Focus on evaluation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- ➢ Identify, based on informed perception of Indian, regional and global needs, the areas of focus and provide platform to gain knowledge and solutions.
- ➢ Offer opportunities for interaction between academia and industry.
- ➢ Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders may emerge.

Syllabus and Course Outcome of Coherence and Optical Fibre

- **Syllabus:** Spatial and temporal coherence, Coherence length, Coherence time and Q- factor for light, Visibility as a measure of Coherence and spectral purity, Optical fiber as optical wave guide, Numerical aperture; Maximum angle of acceptance and applications of optical fiber.

- **CO3**: Students will be able to learn all basic aspects of coherence, its properties in fibre optics and its applications in various fields.

Lecture Plan of Coherence and Optical Fibre

S. No	Topics	Lectures required	Lect. No.
1	Definition of Coherence, spatial & temporal coherence, Coherence length & Coherent time	1	16
2	Q - factor for light (spectral purity), Visibility as measures of Coherence	1	17
3	Optical fibers as optical wave guide, Types of fibres & working principle.	1	18
4	Numerical aperture of step index fiber, maximum angle of acceptance and it's application.	1	19

Content

Plan of Presentation

- Introduction
- Working Principle
- Structures of Fibre Cable
- Classification

- Numerical Aperture and Maximum angle of acceptance
- Applications
- Suggested reference books & links from NPTEL/IIT/RTU Platforms
- Important Questions.

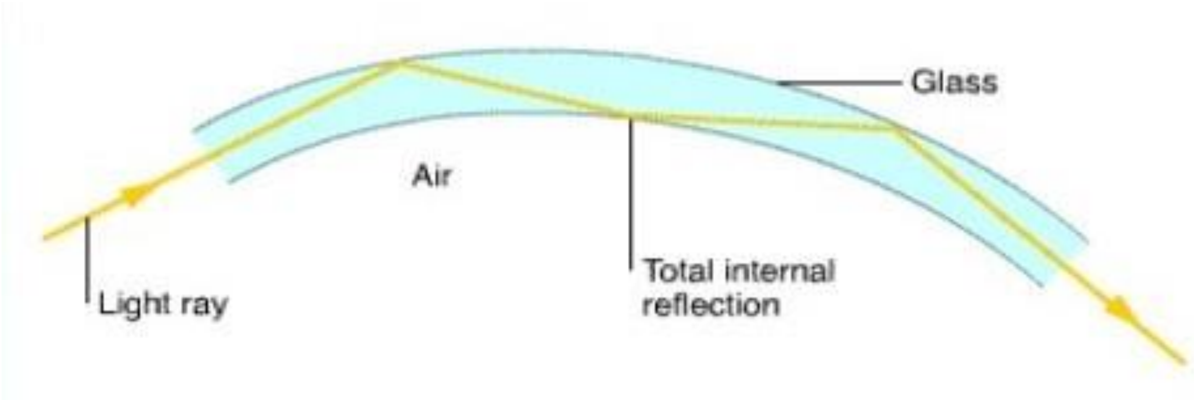
Introduction

- Fibre optics is a technology in which electrical signals are converted into optical signals transmitted through a thin glass fibre and reconverted into electrical signals.
- An optical fiber is a flexible, made by glass (silica) or plastic to a diameter slightly thicker than that of a human hair.
- An optical fibre is a cylindrical wave guide made of transparent dielectric (glass or clear plastic) which guides light waves along its length by total internal reflection (TIR).
- Optical fibers typically include a core surrounded by a transparent cladding material with a lower refractive index. Light is kept in the core by the phenomenon of total internal reflection which causes the fiber to act as a waveguide.
- The first working fiber-optical data transmission system was demonstrated by German physicist Manfred Borner in 1965 and patented in 1966.

Working Principle: TIR

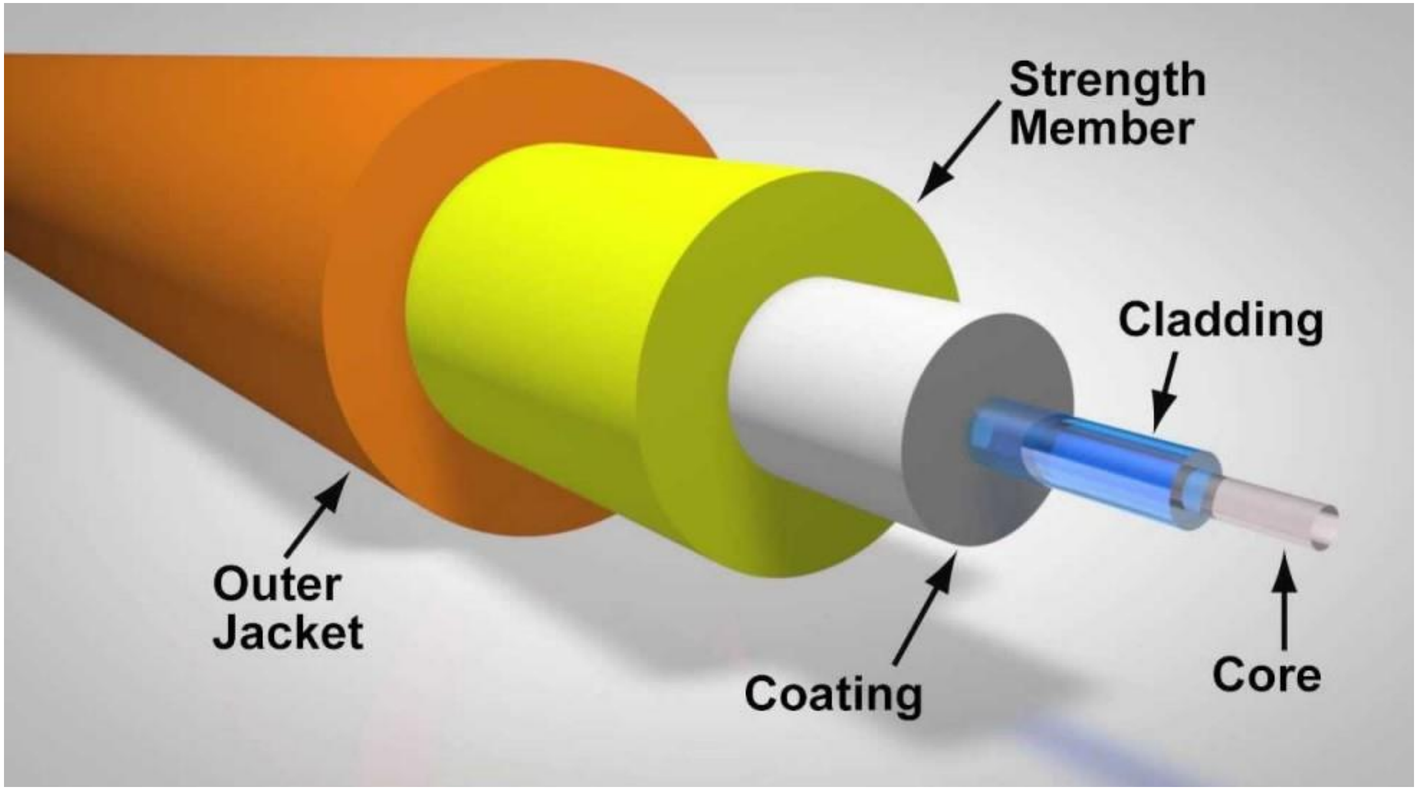
- When an ray of light travels from a denser to a rarer medium such that the angle of incidence is greater than the critical angle, the ray reflects back into the same medium this phenomena is called total internal reflection (TIR).

- When light enters from one end of fibre, it undergoes successive total internal reflection from side walls and travels down the length of the fibre along a zig-zag path.



Structure of optical fibre

Single Fibre Cable

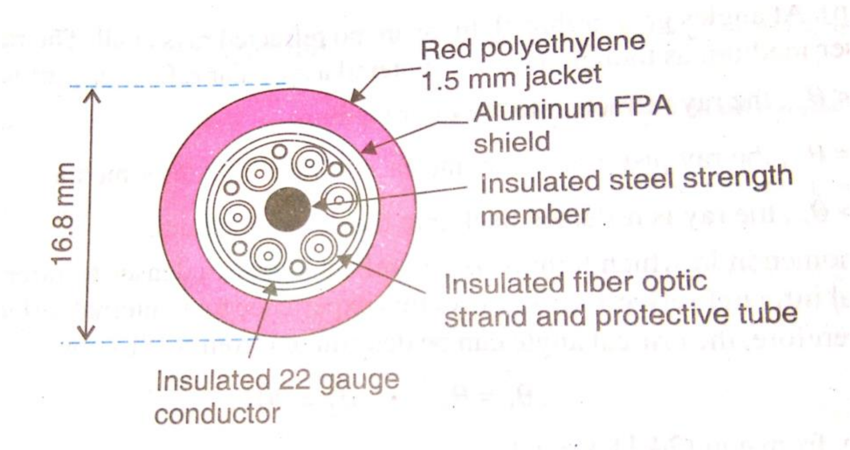


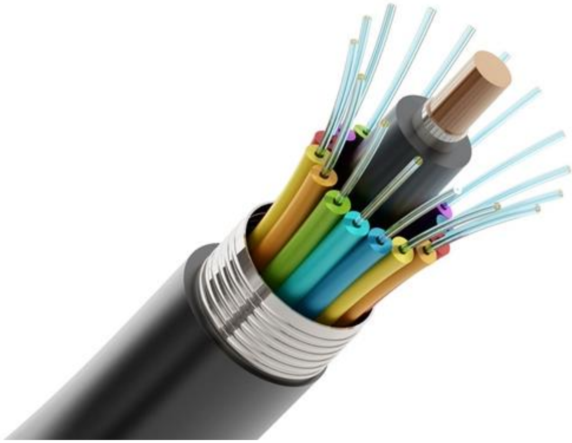
- Core – central tube of very thin size made up of optically transparent dielectric medium and carries the light form transmitter to receiver. The core diameter can vary from about 5 μm to 100 μm.

- Cladding – outer optical material surrounding the core having reflective index lower than core. It helps to keep the light within the core throughout the phenomena of total internal reflection.

- Plastic Covering– plastic coating that protects the fibre made of silicon rubber. The typical diameter of fibre after coating is 250-300 μm.

Multi Fibre Cable





Multi Fibre Cable

- Multi fibre cable consists of a number of fibres in a single jacket. Each fibre carries light independently.
- The cross sectional view of a typical telecommunication cable is shown in figure.
- It contains six insulated optical fibre stand consists of a core surrounded by a cladding which is coated with insulated jacket.
- The fibres are individually buffered and strengthened.
- Six insulated copper wires are distributed in the space between the fibres.
- They are used for electrical transmission.
- The assembly is then fitted with in a corrugated aluminium sheath.
- A polythene jacket is applied over the top for protection.

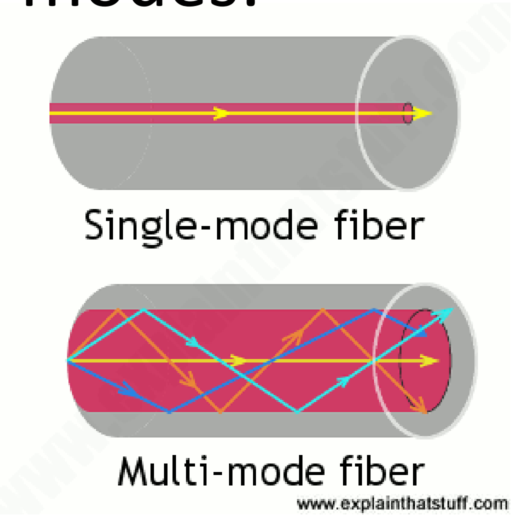
Classification of Optical Fiber

- Optical fiber is classified into two categories :

1) On the basis of the number of modes:

   a) Single mode fiber (SMF)

   b) Multi-mode fiber (MMF)



2) On the basis of the reflective index:

   a) Step index optical fiber

   b) Graded- index optical fiber

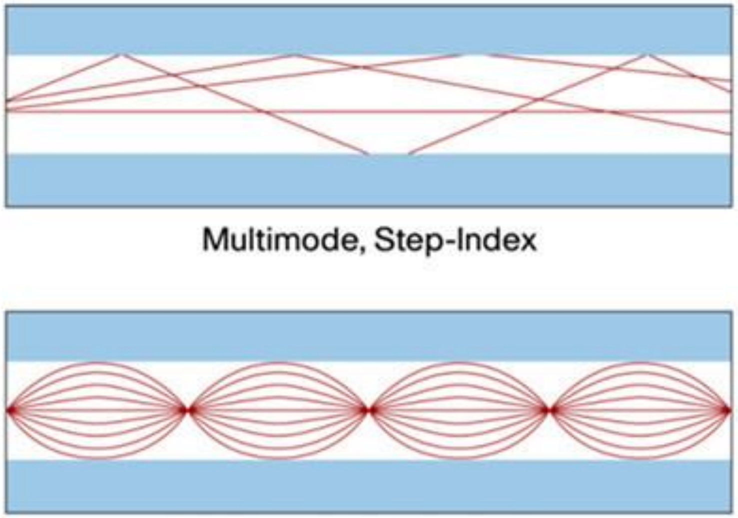
Single Mode Fibre(SMF)

- In single mode fibre only one mode can propagate through the fibre.
- It has small core diameter (5um) and high cladding diameter (70um).
- Difference between the refractive index of core and cladding is very small.
- There is neither dispersion nor degradation therefore it is suitable for long distance communication.
- The light is passed through the single mode fibre through laser diode.

Multi- Mode Fibre (MMF)

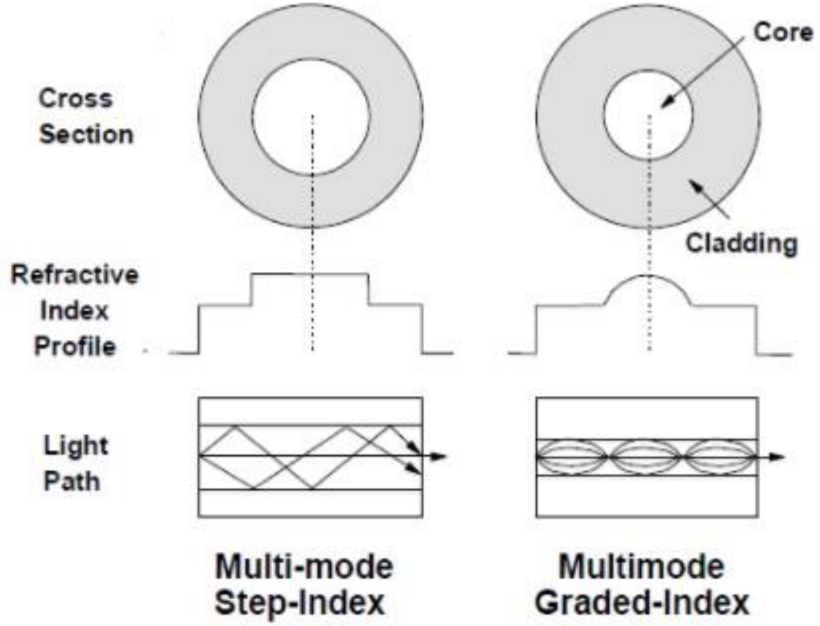
- It allows a large number of modes for light ray travelling through it.
- The diameter of core is 40 μm and of cladding is 70 μm.
- The relative refractive index difference is also large than single mode fiber.
- There is signal degradation due to multimode dispersion.
- It is not suitable for long distance communication due to large dispersion and attenuation of signal.

Step Index and Graded Index Fibre



Multimode, Step-Index

Multimode, Graded Index



Step Index fiber

- Step index fiber is a fiber characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface so that the cladding is of a lower refractive index.

- In a step index fiber, the light rays propagate in zig-zag manner inside the core. The rays travel in the fiber as meridional rays and they cross the fiber axis for every reflection.

- Step index fiber is found in two types, that is mono mode fiber and multi mode fiber.

- Signal distortion is more in case of high-angle rays in multimode step index fiber.

- In single mode step index fiber, there is no distortion. The Step index fiber has a lower bandwidth.

Graded Index Fibre

- Graded index fiber is a type of optical fiber where the refractive index of the core is uniform at the center core and then it decreases towards core-cladding interface.

- The uniformity is present because the refractive index is higher at the axis of the core and continuously reduces with the radial movement away from the axis.

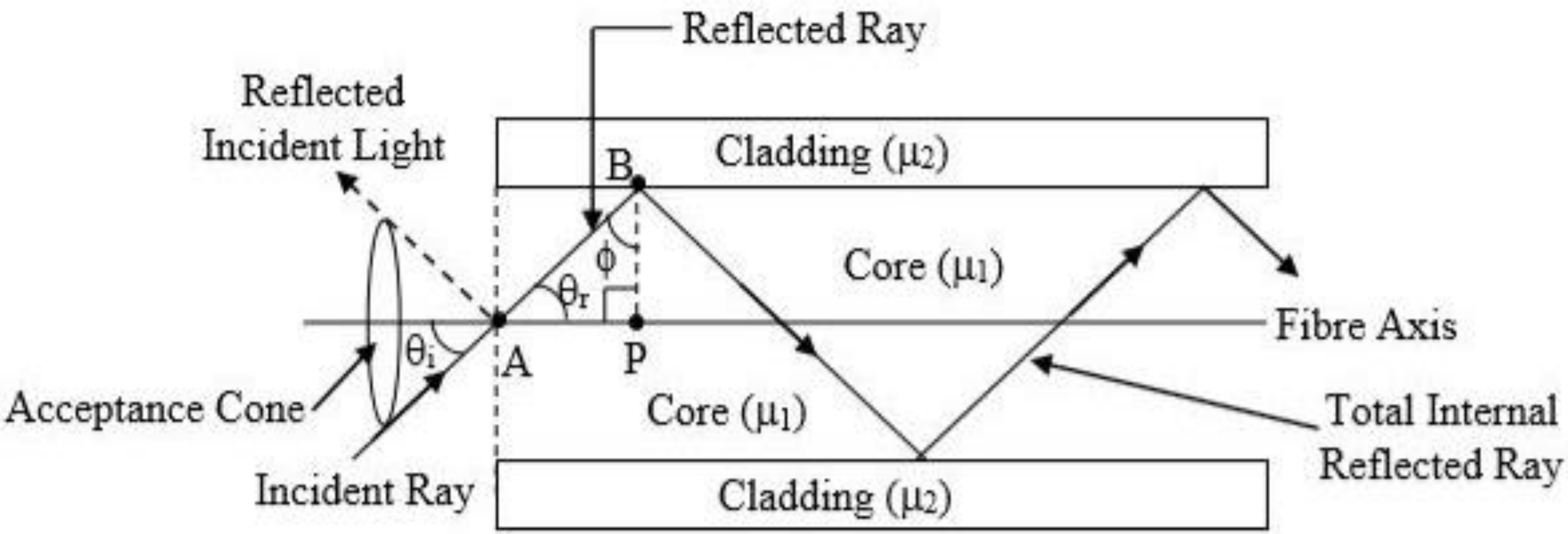
- However, the refractive index of the cladding is constant in the case of graded index fiber, hence the nature of the refractive index is somehow parabolic.

- The light rays in graded index fiber, propagate in the form of skew rays or helical rays. They will not cross the fiber axis. Also, it is important to note that inside the fiber, signal distortion is very low even though the rays travel with different speeds. The graded index fiber has a higher bandwidth.

Numerical Aperture and Angle of Acceptance of an Optical Fibre

The numerical aperture accounts for the light gathering ability of the fibre and it measures the amount of light accepted by the fibre.

When a light ray incident at one end of the fibre, the light ray going in to the fibre makes an angle greater than the critical angle i.e. $\phi > \theta_c$ at core cladding interface and light ray undergoes successive total internal reflection because the refractive index of core is greater than the refractive index of cladding i.e. $\mu_{core} > \mu_{cladding}$ and the light will remain within the fibre.



In above diagram:

θ_r	=	$90 - \phi$	θ	=	Acceptance angle
μ_2	=	Refractive index of cladding	μ_1	=	Refractive index of core

μ_0 = Refractive index of outside medium from which light is entered into the fibre

Let μ_0 be the refractive index of medium, through which light entered the fibre. Let light enters the fibre at an angle θ_i with the fibre axis and refracts at an angle θ_r and strike core cladding interface at an angle ϕ.

Now from snell's law at point A, we have

$$\frac{\sin \theta_i}{\sin \theta_r} = \frac{\mu_1}{\mu_0} \qquad \text{.......... (1)}$$

From Δ ABP, we have

$$\sin \theta_r = \sin (90 - \phi) = \cos \phi \qquad \text{.......... (2)}$$

Now from equation (1), we have

$$\frac{\sin \theta_i}{\cos \phi} = \frac{\mu_1}{\mu_0} \quad \Rightarrow \quad \sin \theta_i = \frac{\mu_1}{\mu_0} \cos \phi \qquad \text{.......... (3)}$$

when $\phi = \phi_c$ $\Rightarrow$ $\theta_i = \theta_{max.}$ (Maximum Acceptance angle)

So, from equation (3), we have

$$\sin \theta_{max.} = \frac{\mu_1}{\mu_0} \cos \phi_c \qquad \text{.......... (4)}$$

Now by snell's law at point B $\sin\phi_c = \dfrac{\mu_2}{\mu_1}$ .... (5)

$$\Rightarrow \quad \cos\phi_c = \sqrt{1-\sin^2\phi_c}$$

$$\Rightarrow \quad \cos\phi_c = \sqrt{1-\left(\frac{\mu_2}{\mu_1}\right)^2} \qquad \text{.......... (6)}$$

Now from equation (6) and (4), we have

$$\sin\theta_{max.} = \frac{\mu_1}{\mu_0}\sqrt{1-\left(\frac{\mu_2}{\mu_1}\right)^2} \quad \Rightarrow \quad \sin\theta_{max.} = \frac{\sqrt{\mu_1^2-\mu_2^2}}{\mu_0}$$

$$\Rightarrow \quad \mu_0 \sin\theta_{max.} = \sqrt{\mu_1^2-\mu_2^2}$$

Now the Numerical Aperture of optical fibre

$$\mathbf{N.\ A.} = \mu_0 \sin\theta_{max.} = \sqrt{\mu_1^2-\mu_2^2} \qquad \text{.......... (7)}$$

$$\Rightarrow \quad \mathbf{N.\ A.} = \sin\theta_{max.} = \sqrt{\mu_1^2-\mu_2^2} \qquad (\mu_0 = 1, \text{ for air}) \qquad \text{.......... (8)}$$

And Maximum Acceptance Angle

$$\theta_{max.} = \sin^{-1}\sqrt{\mu_1^2 - \mu_2^2} \qquad \text{.......... (9)}$$

where, μ_1 refractive index of core and μ_2 refractive index of cladding

From equation (8), we have

$$\text{N. A.} = \sqrt{(\mu_1 + \mu_2)(\mu_1 - \mu_2)}$$

$$\Rightarrow \text{N. A.} = \sqrt{2\mu_1(\mu_1 - \mu_2)} \qquad \because \quad \mu_1 \text{ is nearly equal to } \mu_2$$

$$\Rightarrow \text{N. A.} = \sqrt{2\mu_1^2 \frac{(\mu_1 - \mu_2)}{\mu_1}}$$

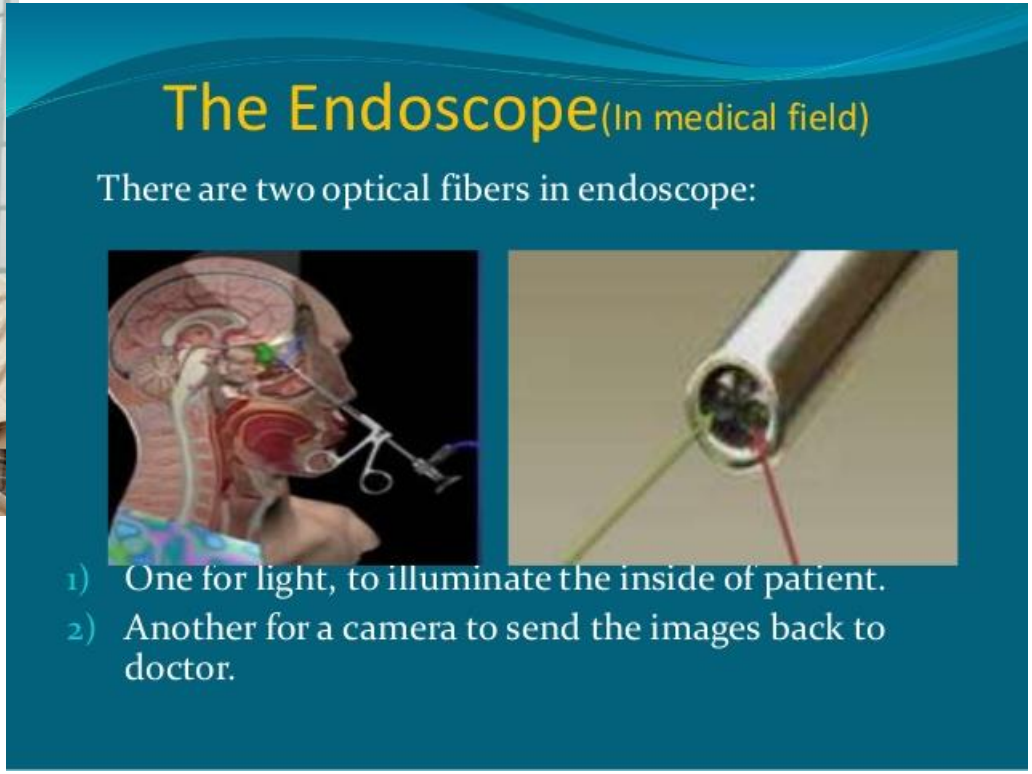
$$\Rightarrow \textbf{N. A.} = \mu_1\sqrt{2\Delta} \qquad \text{.......... (10)}$$

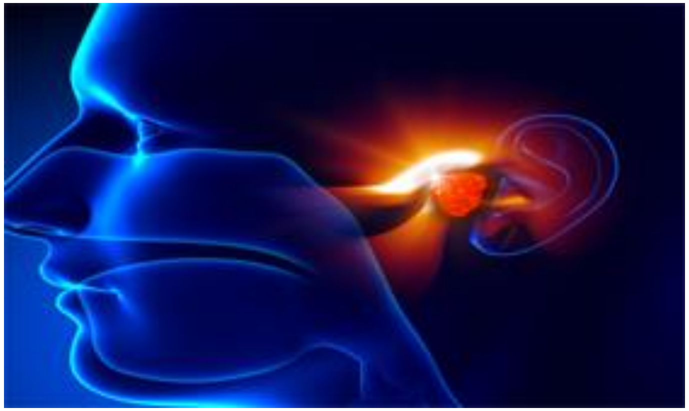
where Δ is a fractional change in refractive index of the core with respect to cladding.

Applications

- Optical fiber have wider range of application in almost all field, some are specified below:
- In military applications e.g. missile guiding, aircraft and tank or ship reduces much weight, maintain true communication silence to enemy.
- In medical field e.g. Endoscopy, cardiology, laser angioplasty, reattach – detached retinas, laser surgeries etc
- In telecommunication field and broadband applications.
- In Civil, Consumer and industrial application.
- In decorations on functions and on festive seasons, etc.

Endoscopy & ENT





Suggested reference books & links from NPTEL/IIT/RTU Platforms

Reference Books:

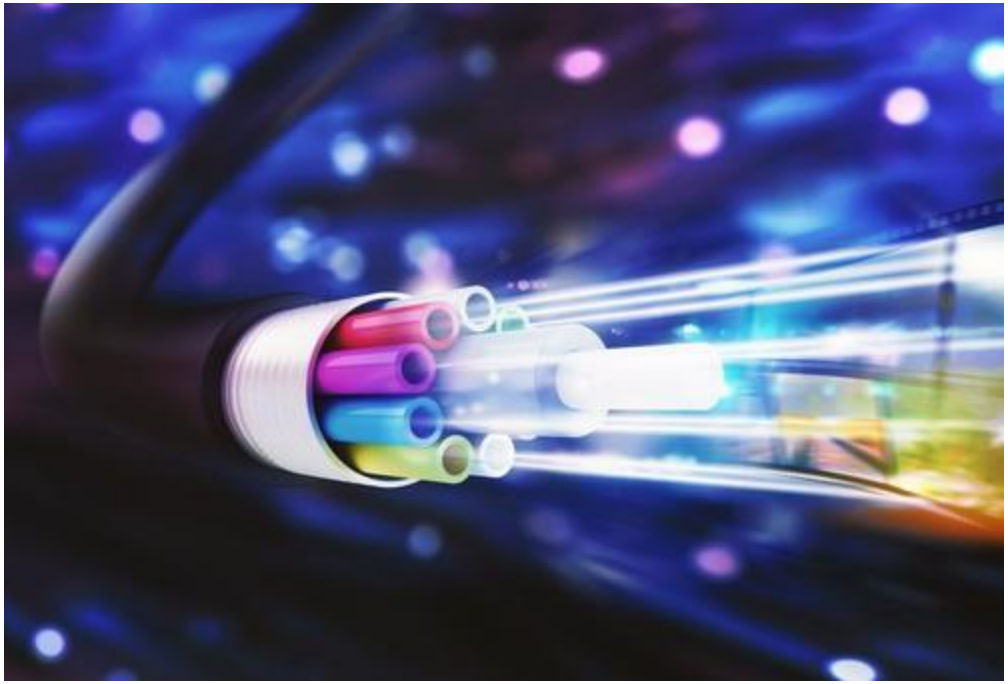
1. Fundamental of Optics: Jetkins and White (Tata McGraw Hill)
2. Engineering Physics: Malik and Singh (Tata McGraw Hill)
3. Engineering Physics: S. Mani Naidu (Pearson Education)
4. Concept of Modern Phyiscs: A. Baiser (Tata McGraw Hill)
5. Engineering Physics : Y. C. Bhatt (Ashirwad Publications)
6. Engineering Physics : S. K. Sharma (Genius Publication)
7. Engineering Physics: D. K. Bhattacharya (Oxford Higher Education)

Suggested Links:

1. http://youtu.be/IoNyH3mm1sQ (a video lecture by Prof. R. K. Mangal, JECRC Jaipur)
2. https://youtu.be/9seDKvbaoHU (a video lecture by Prof. Vipul Rastogi, IIT Roorkee)
3. https://youtu.be/DpSJbtt5V7E (a video lecture by Prof. Pradeep Kumar K, IIT Kanpur)
4. https://youtu.be/oIurmHsRFSc (a video lecture by Prof. R. K. Shevgaonkar, IIT Bombay)

Important Questions

1. Explain classification of optical fibres.
2. Describe the construction and working of an Optical Fiber and Write two applications of an optical fiber.
3. Define acceptance angle and hence derive an expression for the maximum acceptance angle of an optical fiber .
4. Define Numerical aperature and hence derive an expression for the Numerical aperature of an optical fiber.
5. Show that the numerical aperture of step index optical fiber is given by $NA = n_{core} \sqrt{2\Delta}$
6. Compare the maximum angle of acceptance and light gathering capacity (NA) of two fibers characterized by core and cladding indices n_1 and n_2 to be (a) $n_1 = 1.6$, $n_2 = 1.5$, (b) $n_1 = 2.1$, $n_2 = 1.5$ (assume $n_0 = 1$)
7. For a typical step index multimode fiber the core index is n_1=1.45 and the relative refractive index difference of core- cladding (n_1-n_2) is 0.01. Find the numerical aperture and the maximum acceptance angle?
8. Calculate the refractive indices of core and cladding materials of an optical fiber having NA = 0.22 and relative refractive index change is 0.012. Also find the critical angle and maximum acceptance angle.



THANK YOU