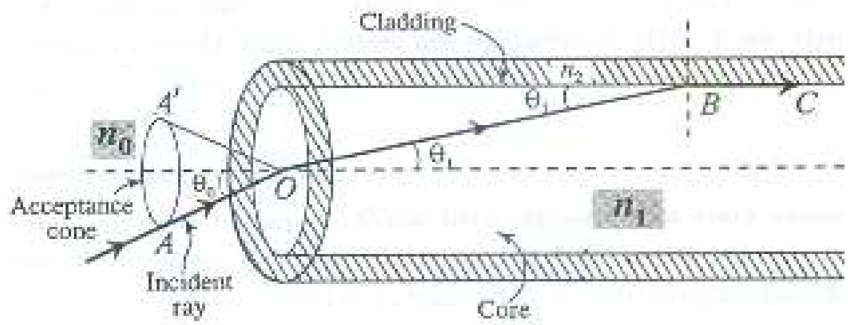
Module-III

<u>Optical Fibers</u>

Important Questions & Answers

1. What is numerical aperture? Derive an expression for the same. **(VTU-DEC-18/Jan-19)**

Sine of the acceptance angle θ_0 , $\sin\theta_0$ is called the **numerical aperture (NA)** of the fiber. It represents the light gathering capacity of the optical fiber.



Consider an optical fiber into which light is launched at one end from a medium of RI $\mathbf{n_0}$. Let $\mathbf{n_1}$ be the RI of core and $\mathbf{n_2}$ be that of the cladding. Assume that a ray of light enters the fiber at an angle θ_0 known as acceptance angle with respect to the axis of the fiber. The light ray refracts at an angle θ_1 and strikes the core – cladding interface at an angle of $(90-\theta_1)$ which is equal to the critical angle for the core – cladding interface.

Applying Snell's law at 'O'

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

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

$$sin\theta_0 = \frac{n_1}{n_0}\left(\sqrt{1-cos^2\theta_1}\right) ------(1)$$

Applying Snell's law at 'B'

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

$$cos\theta_1 = \frac{n_2}{n_1} ------(2)$$

Substituting (2) in (1)we get,

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

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

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

By definition, sine of the angle of acceptance is known as numerical aperture (N.A)

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

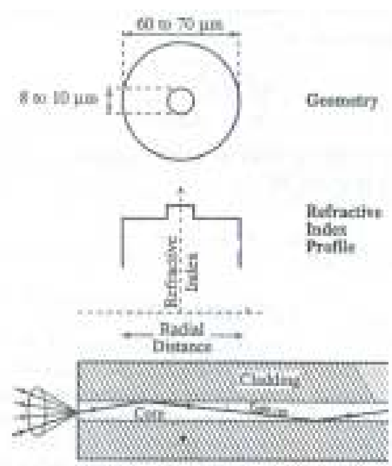
If the medium surrounding the fiber is air, then $n_0 = 1$

$$\mathrm{N.A.} = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

2. Explain the types of fiber losses. **(VTU-DEC-18/Jan-19)**

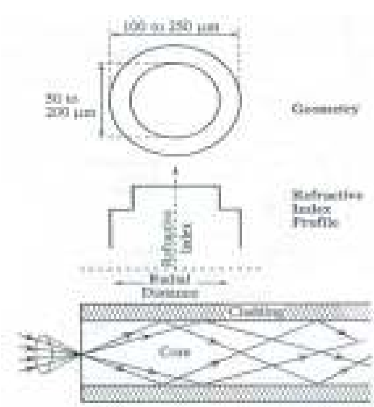
There are three types of optical fibers.

1. Step index single mode fiber:



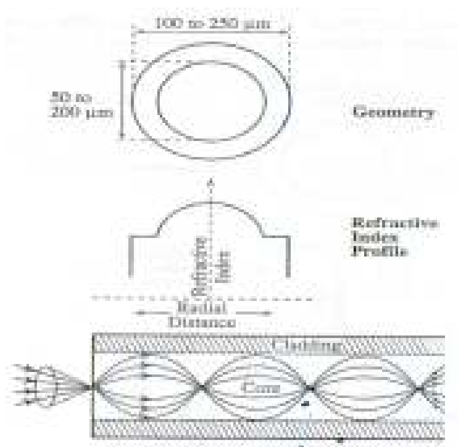
This fiber has a core diameter of about 8 to 10 μm and external diameter of cladding is 60 to 70 μm. The RI of the core and cladding region remains constant. But, there is a sudden/ abrupt decrease in the RI at the core – cladding interface. This fiber can support only one mode of propagation along its axis as shown in the figure above.

2. Step index multi mode fiber:



This fiber has a core diameter of about 100 μm. The RI remains uniform in the core and cladding region. But the RI changes abruptly at the core – cladding interface. Because of larger diameter, this fiber allows many modes to propagate through it as shown in the figure.

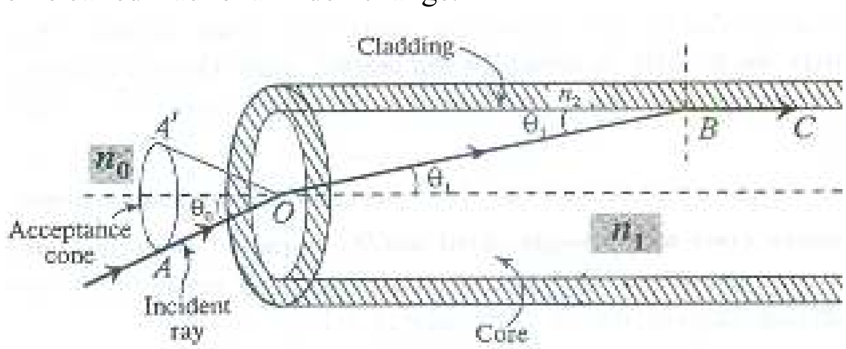
3. Graded Index multimode fiber:



It is a multimode fiber with a core consisting of concentric layers of different refractive indices. Therefore RI of the core decreases with distance from the fiber axis. The RI of the cladding remains uniform. The RI profile and the modes of propagation are shown in fig. such a RI profile causes a periodic focusing of light propagating through the fiber.

3. Define fractional index change. Derive an expression for the numerical aperture and angle of acceptance of an optical fiber. **(VTU-Jun/July-19).**

The ratio of the RI difference between the core and cladding to the RI of core of an optical fiber is called fractional index change.



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Angle of acceptance of the fiber, $\theta_0 = sin^{-1}\left(\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right)$

By definition, sine of the angle of acceptance is known as numerical aperture (N.A)

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

4. Describe different types of optical fibers with neat diagrams. Mention any two mechanisms involved in fiber loss. **(VTU-Jun/July-19).**

For the types of optical fibers refer the answer to Q. N. 02.

Two attenuation mechanisms involved in fiber loss are

1. **Absorption Losses**
2. **Scattering Losses**

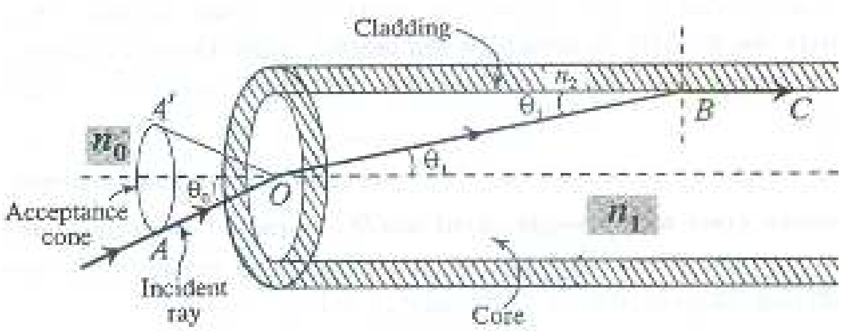
5. Define V-number and fractional index change. With neat diagrams, explain different types of optical fibers. **(VTU-DEC-19/Jan-20), (VTU Model QP)**

V-number or normalized frequency is a parameter that relates the fiber diameter, refractive indices of core and cladding and the wavelength of the light.

The ratio of the RI difference between the core and cladding to the RI of core of an optical fiber is called **fractional index change.**

For the types of optical fibers refer the answer to Q. N. 02

6. Derive an expression for the numerical aperture of an optical fiber and state the condition for propagation. (**VTU-DEC-19/Jan-20)**



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If the medium surrounding the fiber is air, then $n_0 = 1$

$$\mathrm{N.A.} = \sin\theta_0 = \sqrt{\mathrm{n}_1^2 - \mathrm{n}_2^2}$$

The condition for propagation of light in a fiber is the sine of the angle of incidence must be less than the numerical aperture of the fiber. i.e.

$$\sin\theta_i < N.A.$$

7. Name the three types of attenuation in optical fiber. Obtain the expression for attenuation coefficient. **(VTU Model QP)**

The different types of attenuation in optical fibers are,

1. Absorption losses
2. Scattering losses
3. Radiation or bending losses

When light travels in a material medium there will always be a loss in its intensity with distance travelled. This loss takes place according to **Lambert's law.**

According to **Lambert's law**, "the rate of decrease of intensity of light with distance travelled in a homogeneous medium is proportional to the initial intensity". If 'P' is the initial intensity and 'L' is the distance propagated in the medium, then

$$-\frac{dP}{dL} \; \alpha \; P$$ (Negative sign indicates that it is decrease in intensity)

Or $$-\frac{dP}{dL} = \alpha P$$ ----- (1) where α is a constant called the attenuation coefficient, or simply attenuation.

From (1), $$\frac{dP}{P} = -\alpha dL$$

Integrating both sides, $$\int \frac{dP}{P} = -\alpha \int dL$$ ----- (2)

Considering a fiber of length 'L' and taking P_{in} as the initial intensity of light launched into the fiber and P_{out} as the intensity of light received at the other end of the fiber, equation (2) can be written as

$$\int_{P_{in}}^{P_{out}} \frac{dP}{P} = -\alpha \int_0^L dL$$

$$\left[\log P\right]_{P_{in}}^{P_{out}} = -\alpha \left[L\right]_0^L$$

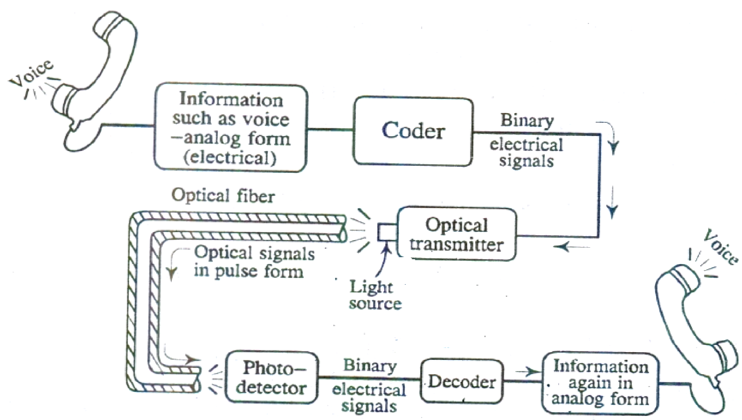
$$\log\left[\frac{P_{out}}{P_{in}}\right] = -\alpha L$$

Or, $$\alpha = -\frac{1}{L}\log\left[\frac{P_{out}}{P_{in}}\right] \text{---------} (3)$$

In terms of decibel/kilometers or dB/km we have

$$\alpha = -\frac{10}{L}\log\left[\frac{P_{out}}{P_{in}}\right] \text{dB/km}$$

8. With the help of Block diagram, explain point to point communication using optical fiber. Mention the merits and de merits of optical fiber communications. **(VTU Model QP)**



In a point - point communication system, we have analog information such as voice of a telephone user. The voice gives rise to electrical signals in analog form coming out of the transmitter section of the telephone. With the help of a coder, the analog signal is converted into binary data. The binary data in the form of a stream of electrical pulses are converted into pulses of optical power by an optical source such as a laser diode or LED. This unit is called optical transmitter, from which the optical power is launched into the fiber.

During the propagation of the signal, attenuation or losses occurs. In order to prevent the complete loss of signal a repeater is used. A repeater consists of a receiver, an amplifier and a transmitter. The receiver converts the optical signal into corresponding electrical signal and then it is amplified. These electrical signals are again converted into optical signals and fed into the optical fiber.

At the receiving end the optical signal from the fiber is fed into a photo detector. Hence signal is converted to pulses of electric current. This is then fed to a decoder which converts the binary data into an analog signal, which is then converted in to the required form using a transducer.