University of Mosul

College of Science

Department of Physics

Third Stage

Lecture 11

Geometric Optics

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Lecture 11: Fiber Optics

Preparation

M. Rana Waleed Najim

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Fibre Optics:

Optical frequencies are very large ($\sim 10^{15}$ Hz) as compared to the conventional radio waves ($\sim 10^{6}$ Hz) and microwaves ($\sim 10^{10}$ Hz). So alight beam acting as a carrier wave is capable of carrying far more information than radio waves and microwaves. Thus optical communication is a superior to radio and microwave communication.

Optical fiber is a hair structure made up of transparent material which can guide the. light beam from one place to another by total internal reflection.

The combination of low loss (~ 0.2 dB/km) and wide band width available at optical frequencies make these fibres extremely attractive for the transmission medium in communication systems.

Optical fibres are replacing the Copper cables previously used in tele communications. Fibre optics is being used to transmit voice, television and digital data signals by light waves.

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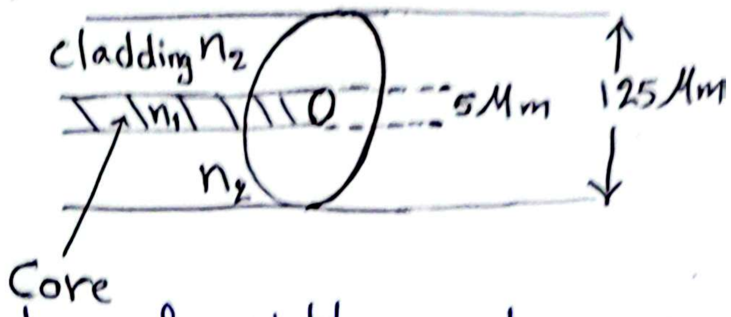
Fibre Construction:

An optical fibre consist of a central cylindrical Core with refractive index n_1 Surrounded by a layer of material, called cladding, with a lower refractive index n_2. The core transmits the light waves within the core and strengthens the fibre.



and the cladding are made of either glass or plastic. Core diameters range from (5 to 600 μm). and cladding diameters vary from (125 to 750 μm). To keep the light in the core, the thickness of the cladding must be one or two wavelengths of the light transmitted.

Light propagation in Fibres:

let a = Core radius and b = cladding radius. The refractive index distribution (in the transverse direction) is given by

$n(r) = n_1 \qquad 0 < r < a \qquad$ core

$n(r) = n_2 \qquad r > a \qquad$ cladding

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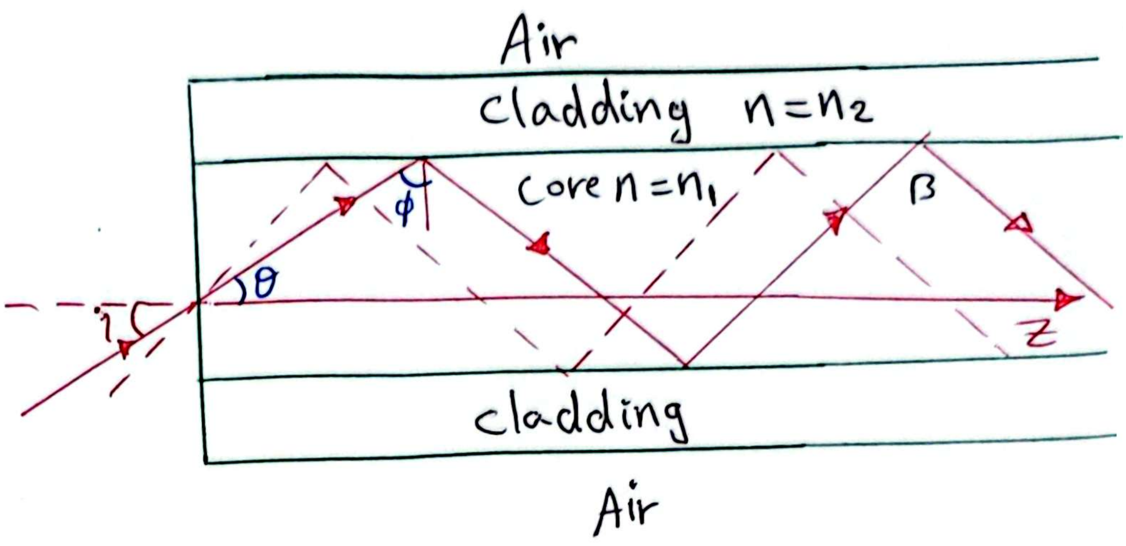
$n_{core} > n_{cladding} > n_{air}$

$n_1 > n_2 > n_0$

Consider aray which is incident on the entrance aperture of the fibre making an angle (i) with the axis as in Fig below.



Let the refracted ray makean angle θ with the axis let ϕ be the angle incidence of the ray Core-cladding inter face.

if ϕ_c is the critical angle of the core-cladding interface.

$$\sin\phi_c = \frac{n_2}{n_1}$$

If ϕ is greater than the critical angle ϕ_c $\phi_c = \left(\sin^{-1}\frac{n_2}{n_1}\right)$, Then the ray undergo total internal reflection at that interface, Further, because of the cylindrical semmetry in the fibre structure, this ray will suffer total internal

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reflection at the lower interface also and therefore get guided through the Core by repeated total internal reflection.

In this way, by total internal reflection, a ray emerging on end of a fibre can travel along the fibre by multiple reflections with a fairly high intensity.

Numerical Aperture:

let n_o be the refractive index of the outside medium.

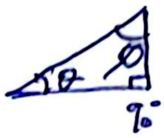
Then, using snell's law

$$\frac{\sin i}{\sin \theta} = \frac{n_1}{n_o}$$

If this ray has to suffer total internal reflection at the core- cladd interface

$$\sin \phi = \cos\theta > \frac{n_2}{n_1} \Rightarrow \sin\phi = \sin(90-\theta) = \cos\theta$$

$$\sin \phi_c = \frac{n_2}{n_1}$$



$$\cos\theta = \frac{n_2}{n_1} \Rightarrow \cos^2\theta = \left(\frac{n_2}{n_1}\right)^2$$

$$\sin^2\theta + \cos^2\theta = 1$$

$$\sin^2\theta = 1 - \cos^2\theta$$

$$=$$

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

$$\sin\theta = \left[1-\left(\frac{n_2}{n_1}\right)^2\right]^{1/2}$$

But $\sin i = \frac{n_1}{n_0} \sin\theta$

total internal reflection will occure assuming $n_0 = 1$

$$\boxed{\sin i = n_1\left[1-\left(\frac{n_2}{n_1}\right)^2\right]^{1/2}}$$

$$= \left[n_1^2 - n_2^2\right]^{1/2}$$

The maximum value of $\sin i$ for a ray to be guided is given by:

$\sin i$ is less than i_m.

$$\boxed{\sin i_m = \left[n_1^2 - n_2^2\right]^{1/2}}$$

Angle of acceptance is the maximum angle i_m

we define the numerical aperture (NA) of the fibre by the following equation:

$$\boxed{NA = (n_1^2 - n_2^2)^{1/2}}$$

($\sin i_m$) This angle is a measure of the light gathering power of the fibre.

Numerical aperture of the optical fibre is measure of the amount of light rays that can be accepted by the fibre.

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Numerical aperture is the sine of angle of acceptance.

$$\boxed{NA = \sin i_m}$$

H.w.
Example: The core and the cladding of a silica optical fibre have refractive indices of $n_1 = 1.5$ and $n_2 = 1.4$. respectively.

ⓐ Calculate the critical angle of reflection for the core-cladding boundary.

ⓑ Calculate the acceptance angle of the fibre.

Sol.

ⓐ $\sin \phi_c = \frac{n_2}{n_1}$

$$\phi_c = \sin^{-1}\left(\frac{1.4}{1.5}\right) = 68.96^\circ$$

ⓑ $\sin i_m = (n_1^2 - n_2^2)^{1/2}$

$$i_m = \sin^{-1}[(n_1^2 - n_2^2)^{1/2}]$$

$$i_m = \sin^{-1}[(1.5)^2 - (1.4)^2] = 32.58^\circ$$

Example:- calculate the numerical aperture and hence the acceptance angle for an optical fiber given that $n_1 = 1.45$, $n_2 = 1.40$

Sol. $NA = (n_1^2 - n_2^2)^{1/2} = [(1.45)^2 - (1.40)^2]^{1/2} = 0.37$

Acceptance angle i_m is given by

$$i_m = \sin^{-1}(n_1^2 - n_2^2)^{1/2} = \sin^{-1} 0.3775 = 22.18^\circ$$

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