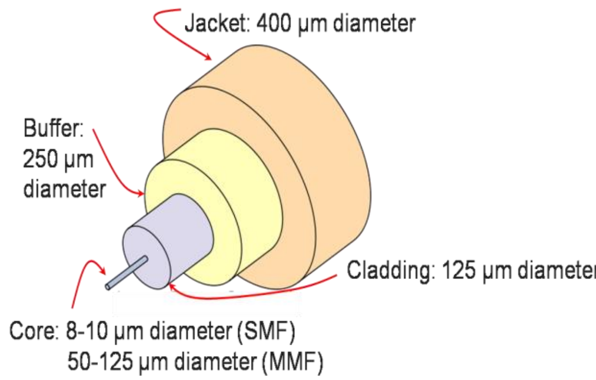
Q. 1 what is an Optical fibre cable?

An **optical fiber** or **optical fibre** is a flexible, transparent fiber made by drawing **glass (silica)** or **transparent plastic** to a diameter slightly thicker than that of a human hair.

In other words, it is a **conduit** or **a wave guide** for transmission of an optical data (transmit light) between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than wire cables.

Principle of transmission of Laser (optical data) is **Total Internal Reflection (TIR).**



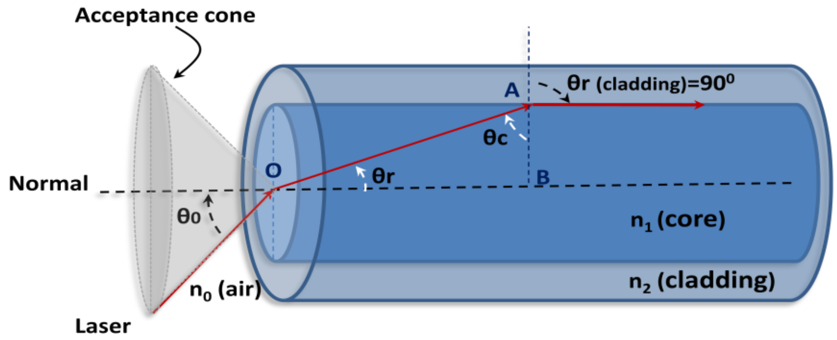
Structure of a Typical Single-Mode-Fibre (SMF)

Advantages of a Fibre Cable over a conductor wire (cable).

- They consist of electrically insulating material, which makes possible their ***use in high voltage environments.***
- Since there is ***no risk of electrical sparks***, even in the case of defects, these can be safely used in explosive environments.
- They are ***immune to electromagnetic interference (EMI)***.
- Their materials can be ***chemically inactive***.
- They can ***operate over a broad range of temperature***.
- They have ***multiplexing capabilities***, *i.e.,* multiple sensors in a single fibre can be interrogated with a single optical source.

The ***advancement in fibre optics*** is a **Photonic-crystal fiber** which is made with a regular pattern of index variation (often in the form of cylindrical holes that run along the length of the fiber). ***Such fiber uses diffraction effects*** instead of or ***in addition to total internal reflection***, to confine light to the fiber's core. The properties of the fiber can be tailored to a wide variety of applications.

Q.2 Define the **Numerical Aperture (NA), acceptance angle and acceptance cone** in fibre optics.



θ_0 *(Acceptance angle)* is the maximum angle for the incident light ray at which *total internal reflection(TIR)* takes place in core medium

As shown above in fig., the condition for $\boldsymbol{\theta_0}$ is the **condition of maximum angle** for the incident light ray at which the **total internal reflection** takes place in **core medium**

Therefore, applying Snell's law at interface of air medium and core medium **(i.e., at Point O)**

$$\frac{\sin\theta_0}{\sin\theta_r} = \frac{n_1}{n_0} \dots\dots\dots\dots\dots\dots\dots\dots (1)$$

From fig., in ΔABO

$$\sin\theta_r = \sin(90^0 - \theta_c) = \cos\theta_c$$

Therefore eq. (1) becomes

$$\sin\theta_0 = \frac{n_1}{n_0}\cos\theta_c \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Applying the Snell's law at core medium and cladding medium **(i.e., at Point A)**

$$\frac{\sin\theta_c}{\sin r_{cladding}} = \frac{n_2}{n_1} \qquad [\,r_{cladding} = 90^0]$$

$$\therefore \cos\theta_c = \sqrt{1 - \left(\frac{{n_2}^2}{{n_1}^2}\right)}$$

$$\text{or } \cos\theta_c = \sqrt{\frac{{n_1}^2 - {n_2}^2}{{n_1}^2}}$$

$$\text{or } \cos\theta_c = \frac{\sqrt{({n_1}^2 - {n_2}^2)}}{n_1} \dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Eq. (3) into (2)

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

$$\therefore \sin\theta_0 = \frac{\sqrt{(n_1{}^2 - n_2{}^2)}}{n_{0\,(air)}}$$

Here the Numerical-aperture (NA) is defined as $\mathbf{NA} = \boldsymbol{n_0 \sin\theta_0} = \sqrt{(\boldsymbol{n_1}^2 - \boldsymbol{n_2}^2)}$**.**

Acceptance Angle:

Since $\mathbf{NA} = \boldsymbol{n_0 \sin\theta_0} = \sqrt{(\boldsymbol{n_1}^2 - \boldsymbol{n_2}^2)} = \sqrt{(\boldsymbol{n_{core}}^2 - \boldsymbol{n_{cladding}}^2)}$**.**

Here θ_0 is known as acceptance angle. If the light ray is incident at an angle less than θ_0 then the phenomena of total internal reflection take place otherwise at an angle greater than θ_0 the phenomena of total internal reflection does not take place.

$$\boldsymbol{\theta_0 = sin^{-1}\sqrt{(n_1{}^2 - n_2{}^2)}}.$$

Acceptance Cone:

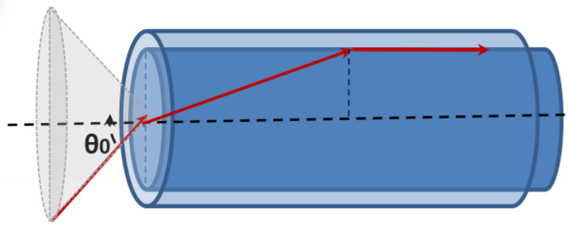
As shown above in figure above, the cone whose angle is $2\theta_0$is known as acceptance cone. **The light entered within this cone exhibit the phenomena of total internal reflection in core medium.**

Numerical problems:

i. In numerical aperture (NA) of an optical fibre is 0.5 and the core refractive index 1.54. Find the refractive index of the cladding.
ii. A light ray is travelling in a transparent material of refractive index 1.51 and approaches a second material of refractive index 1.46. Calculate the critical angle.

[Hint: Applying the Snell's law at core medium and cladding medium (i.e. at Point A) $\frac{\sin\theta_c}{\sin r_{cladding}} = \frac{n_2}{n_1}$ $[\,r_{cladding} = 90^0]$ $or\ \sin\theta_c = \frac{n_2}{n_1}\ or$
$\theta_c = sin^{-1}\frac{n_2}{n_1} = sin^{-1}\frac{1.46}{1.51}$]

Terms used in Fibre Optics



Acceptance Angle:

θ0 is the maximum angle for the incident light ray at which **total internal reflection(TIR)** takes place in core medium. Here **θ0 *is called the acceptance angle***.

Acceptance Cone:

As shown in fig., only if the ***light is incident within the cone,*** the TIR takes place. This cone is called ***acceptance cone.*** The ***angle of cone*** is **2θ0.**

Numerical Aperture (NA):

Since from Theory of Fibre optics -

$\sin\theta_0 = \sqrt{(\mu_1^2 - \mu_2^2)}$

Here **NA = $\mu_0 \sin\theta_0$** **Here μ_0=1 for air**

The maximum value of NA is 1(unity) for $\theta_0 = 90^0$. Fibre optics of wide variety of NA running from 0.2 up to 1 and including 1.0 may be commercially be obtained.

Q. What is dispersion in a fibre?

Dispersion ***(****chromatic dispersion (also called group velocity dispersion), which occurs because the index of the glass varies slightly depending on the wavelength of the light,* ***)* limits the bandwidth** of the fiber because the spreading optical pulse limits the rate that pulses can follow one another on the fiber and still be distinguishable at the receiver.

Q. What is Attenuation in a fibre?

Attenuation in fiber optics, also known as transmission loss, is the reduction in intensity of the light beam (or signal) as it travels through the transmission medium. Attenuation coefficients in fiber optics usually use units of dB/km through the medium due to the high quality of transparency of modern optical transmission media. Attenuation is caused by **physical stresses to the fiber**, **microscopic fluctuations in density**, and **imperfect splicing techniques**.

Attenuation is an important factor limiting the transmission of a digital signal across large distances.

Corning's SMF-28 fiber, a standard single-mode fiber for telecommunications wavelengths, has a loss of 0.17 **dB/km** at 1550 nm.

For example, an 8 km length of SMF-28 transmits 75% of light at 1,550 nm. It has been noted that if ocean water was as clear as fiber, one could see all the way to the bottom even of the Marianas Trench in the Pacific Ocean, a depth of 36,000 feet.

Q. Discuss the allowed modes in a fibre.

There are 2 commercially used modes: Single-mode fiber and Multi-mode fiber.

The **Single-mode fiber (SMF)** has a smaller core (**8-10 µm** in diameter) which means only a single mode can pass-thru at a time. A single mode passing through implies less loss and hence, longer distances & more bandwidth.

The **Multi-mode fiber (MMF)** allows multiple modes to pass through due to its **larger core (50-125 µm** in diameter**)**. The multiple modes passing **cause** pretty **large losses during transmission** and thus, can only be used over shorter distances and lower bandwidths.

However, single mode transmission is costly business due to smaller core diameter and costlier Lasers associated with it. So multi-mode still has something going for it when it comes to rack-rack, within-the-room aka LAN connections.

Allowed Modes in a Fibre:

Not only the ***acceptance cone (i.e., NA) but*** diameter ***of core (d) and wavelength (λ)*** also has ***significance*** in deciding the direction of a ray or modes which are allowed to propagate successfully through the fibre (only those waves will sustain which satisfy a condition of resonance).

The ***maximum no. of modes that*** propagates successfully in the fibre are given by a $\mathbf{M_m}$ as

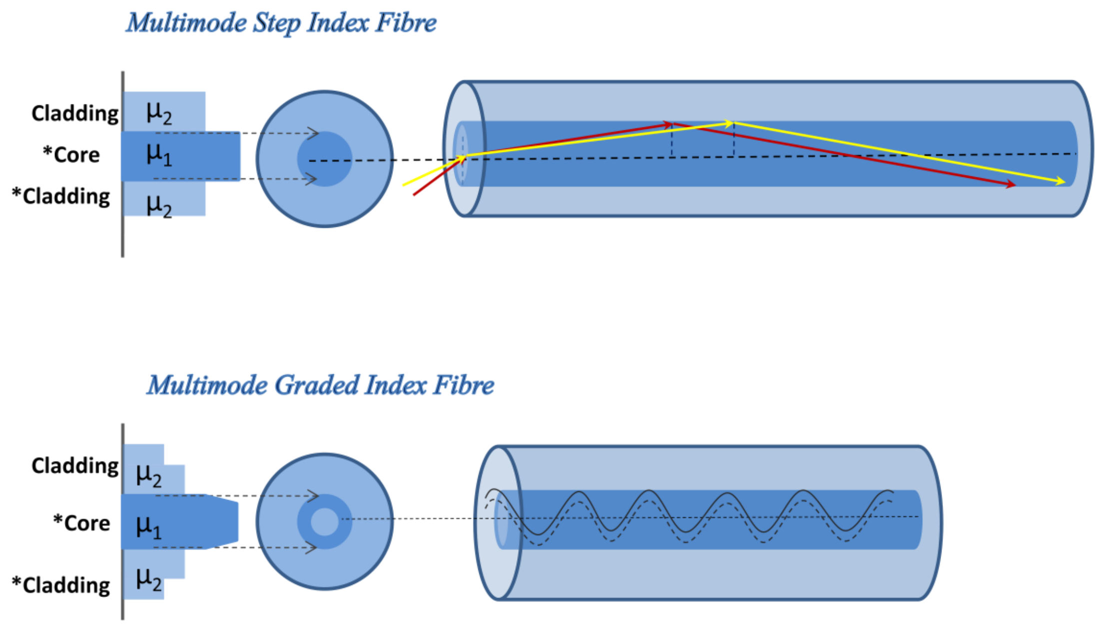
$M_m = (½)(\pi.d.NA/\lambda)^2$

If **d/λ** is **small** such that ***Mm is less than 2***, the fibre will allow only one mode. So, this type of ***fibre is called single mode fibre*** otherwise called ***multimode fibre.***

Types of Fibre Optics (*on manufacturing bases*):

Optical fibers are categorized based on their ***transmission properties*** and ***structure*** as

1. ***Single mode fibre-*** Only One wave can propagate in the fibre**.**
2. ***Multimode fibre –***
    - ✓ ***Multimode Step Index Fibre***
    - ✓ ***Multimode Graded Index Fibre***



*Here the height or shape of rectangular box corresponds the value refractive index of core and cladding

Q. Discuss the fibre-based devices.

Fibre Optics Based Devices ⇨

- ✓ *Sensors*
- ✓ *Connectors and*
- ✓ *Couplers*

Sensors

These are used to sensing temperature, pressure , mechanical strain, acceleration or concentrations of chemical species.