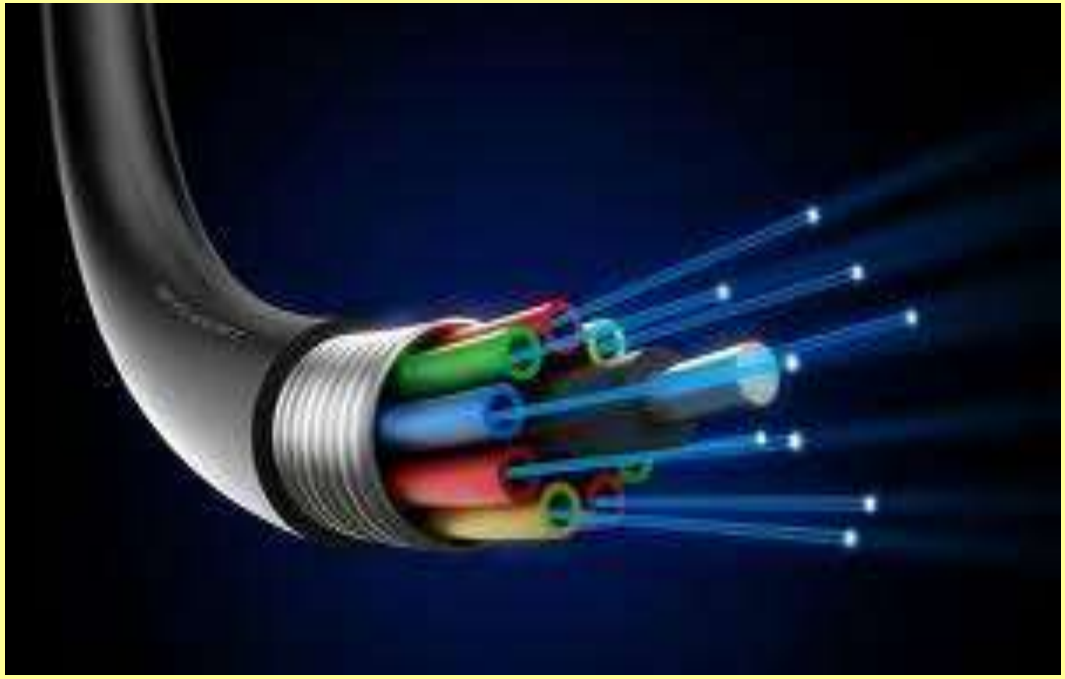
# OPTICAL FIBER COMMUNICATION



# UNIT – I

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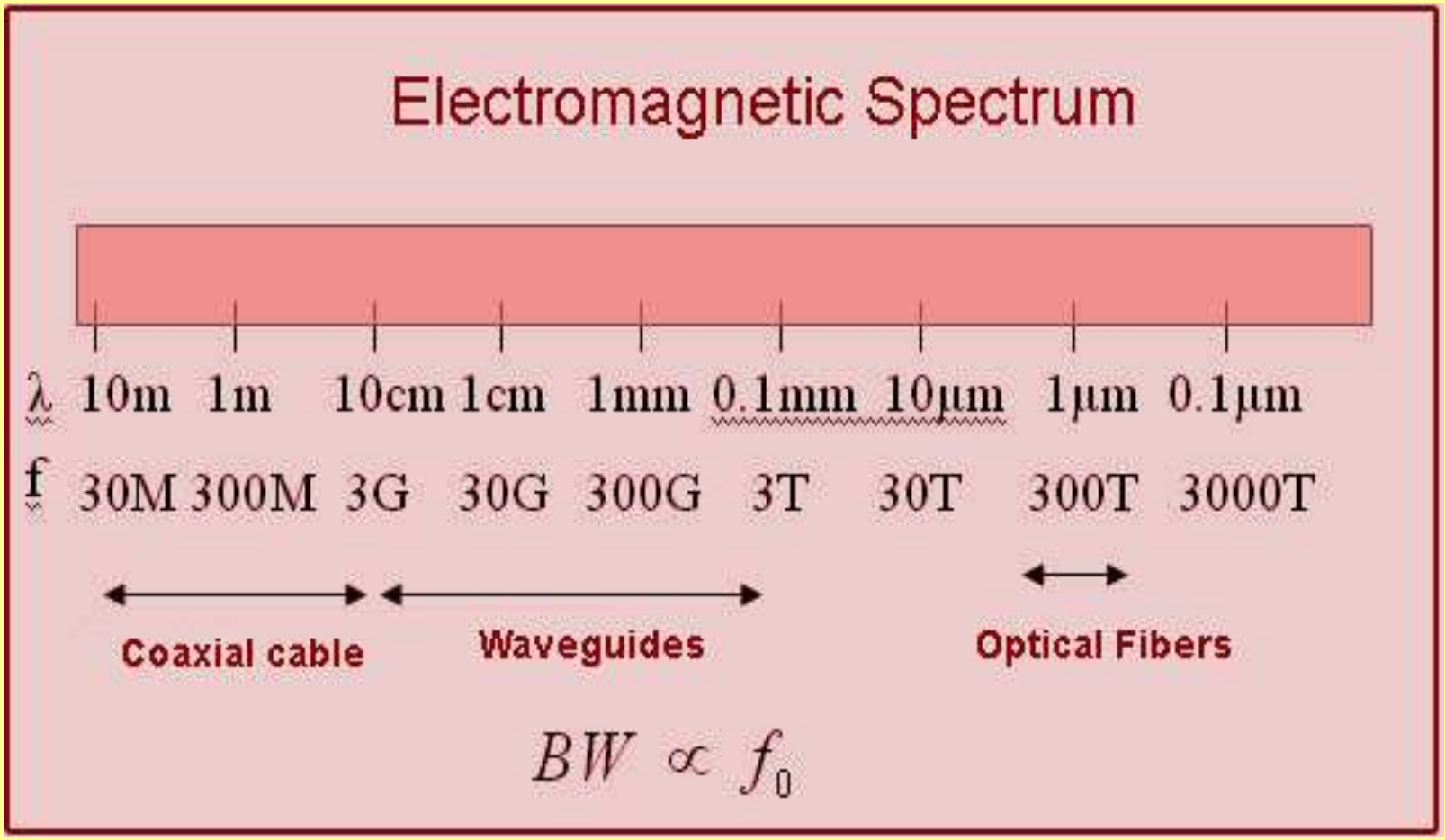
- Introduction to Optical Fiber
- Evaluation of  Optical Fiber
- Elements of an optical fiber transmission link
- Ray optics
- Optical fiber modes and configurations
- Mode theory of Circular Wave guides
- Overview of Modes- Linearly Polarized Modes
- Single mode fibers and Graded Index fiber structure

# Introduction to Optical Fiber

## What is an Optical Fiber

- Optical fiber is a transparent and flexible transmission medium made with highly purified glass
- It is a waveguide for light
- It carries data over long distance at very high speed
- Immune to electromagnetic noise
- It is light in weight
- Unaffected by atmospheric agents
- Fiber can be bent or twisted
- In fiber no electrical hazards




- Optical fiber has wider bandwidth

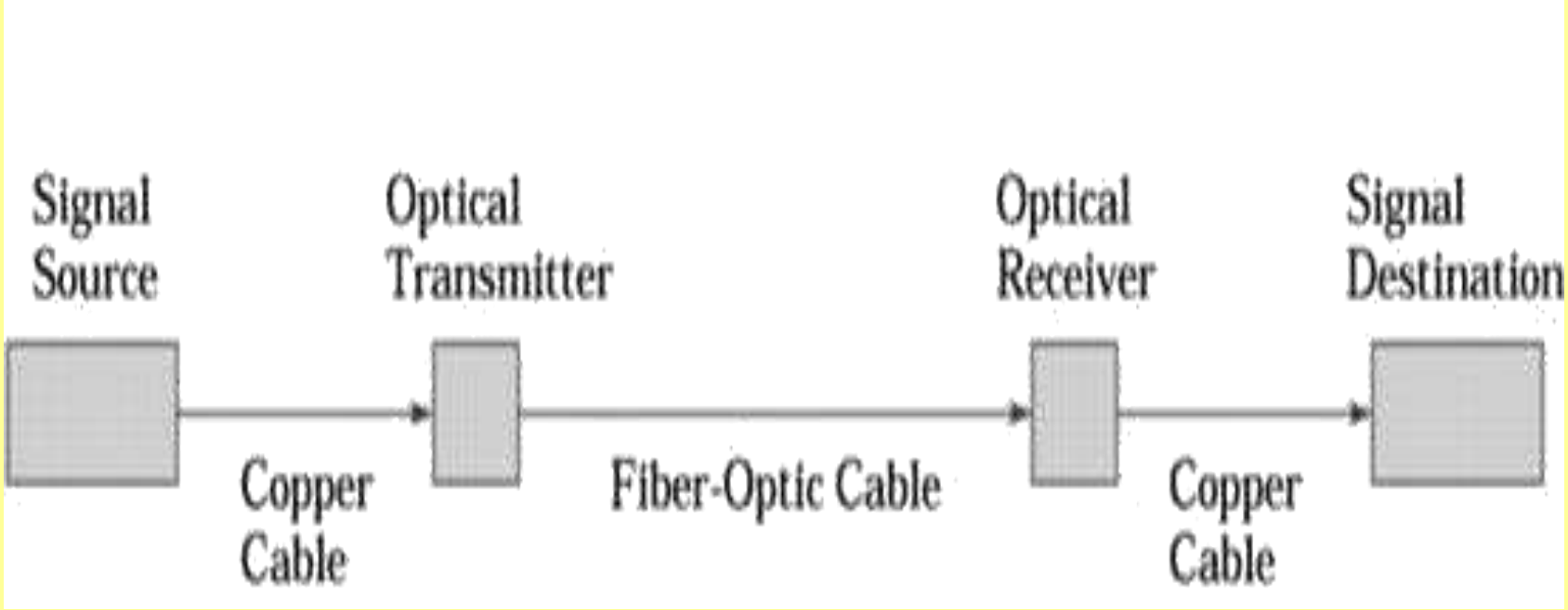
## Evaluation of Optical Fiber

- 1880 – Alexander Graham Bell
- 1930 – Patents on tubing
- 1950 – Patent for two-layer glass wave-guide
- 1960 – Laser first used as light source
- 1965 – High loss of light discovered
- 1970s – Refining of manufacturing process
- 1980s – OF technology becomes backbone of long distance telephone networks

# Elements of an optical fiber transmission link

The optical communication systems mostly have three components:

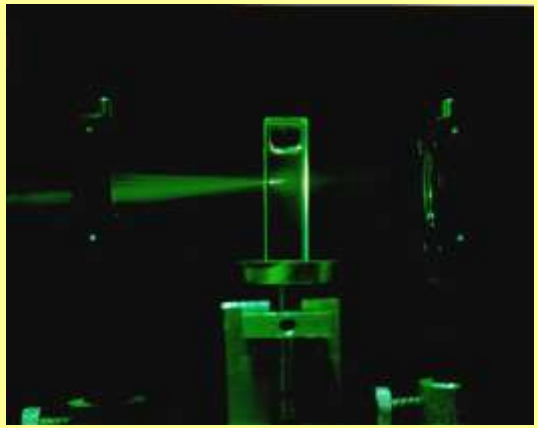
- Source
- Transmission medium
- Detector



# Sources of light

- Light  Emitting Diodes (LEDs)

- Lasers

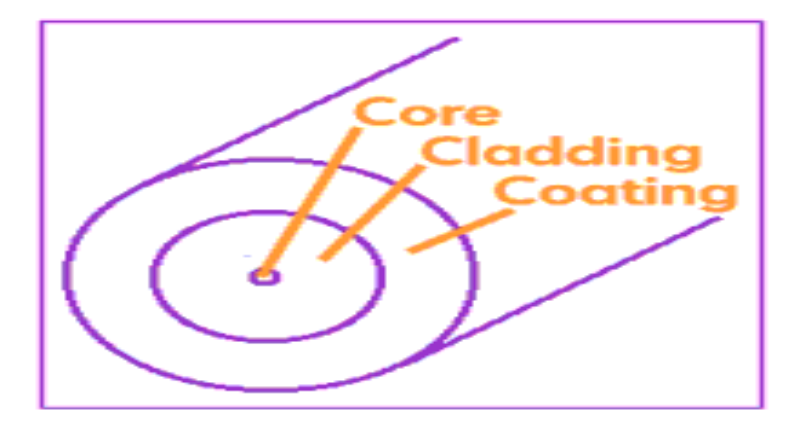


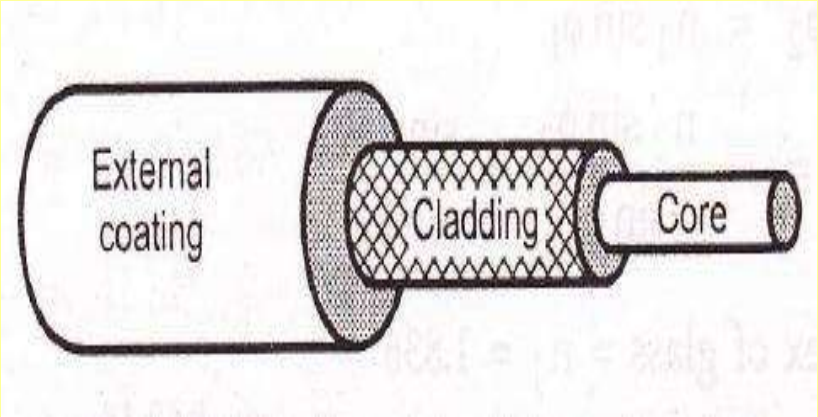
# Sources

- Modulate electrical signals into optical signals
- Mostly modulate at 850nm, 1300nm and 1550 nm
- Laser gives high intensity and high frequency light
- LEDs are economical

# Transmission medium

- Optical fiber is a transmission medium replacing copper wire
- Light is used as the carrier of information




The optical fiber

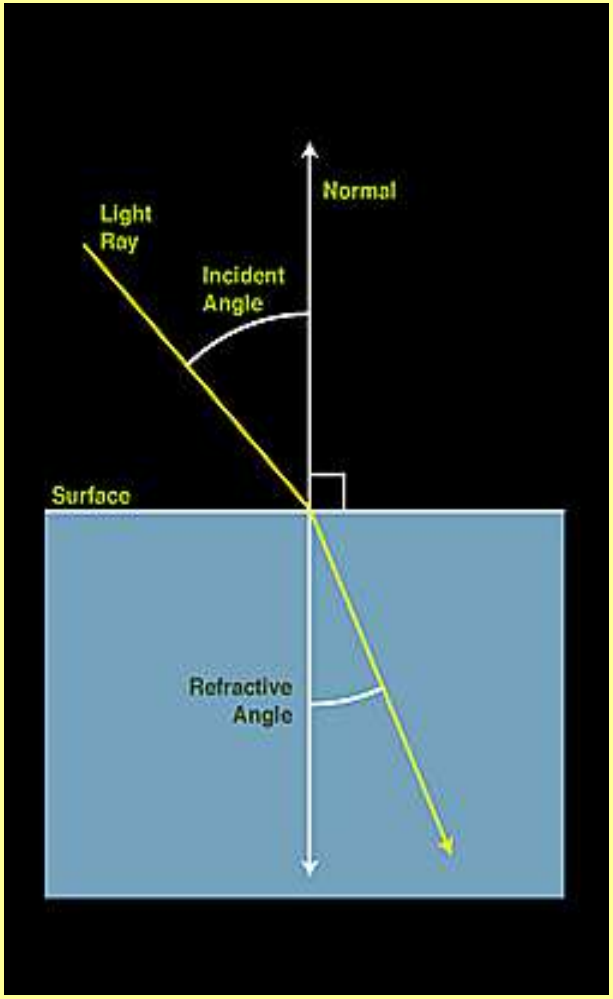
# Ray optics

- Index of refraction of material : Ratio of speed of light in vacuum to speed of light in medium
- Refraction of light : bending of light as it travels from one media to another

$$\text{Refractive index } n = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

# Refraction of light

- Speed of light changes as it across the boundary of two media
- Angles w.r.t normal



# Refraction Indices

- Vacuum…….1.00000 (exactly)
- Air ……1.00029
- Alcohol ……1.329
- Diamond …… 2.417
- Glass …….. 1.5
- Ice ……. 1.309
- Sodium Chloride (Salt) …. 1.544
- Sugar Solution (80%) …….. 1.49
- Water (20 C) …… 1.333

# Snell's Law

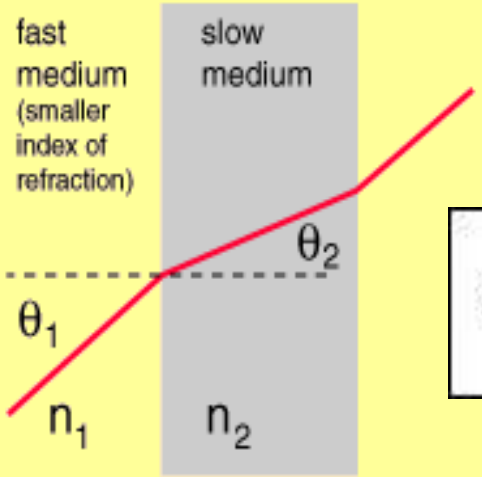
- Snell's law states that how the light ray reacts when it meets the interface of two media having different indexes of refraction.

- Let the two medias have refractive indexes n1 and $n_2$ where $n_1 > n_2$.

$$n1 \sin\theta 1 = n2 \sin\theta 2$$

Snell's Law

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$




$$\text{Critical angle } \phi_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

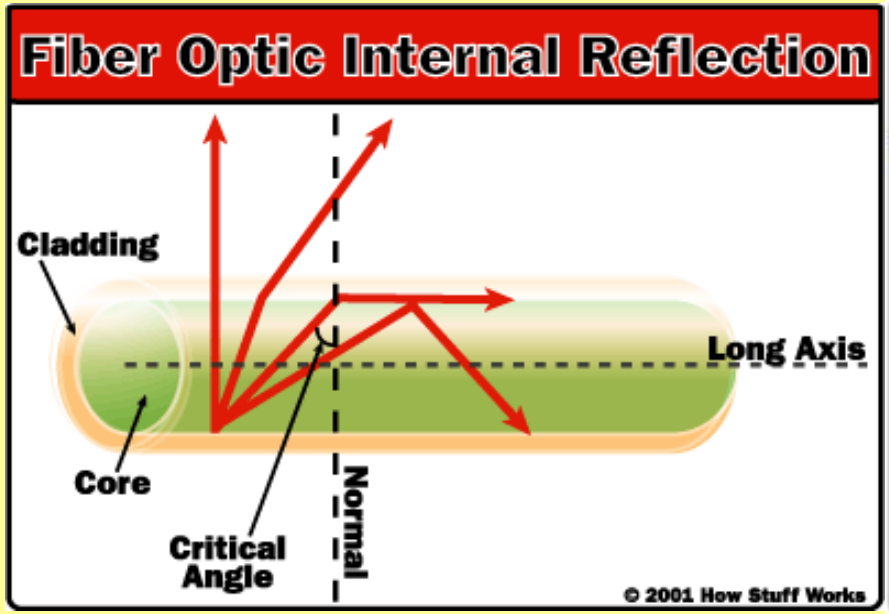
- Critical angle: Angle of incidence at which angle of refraction = $90^0$

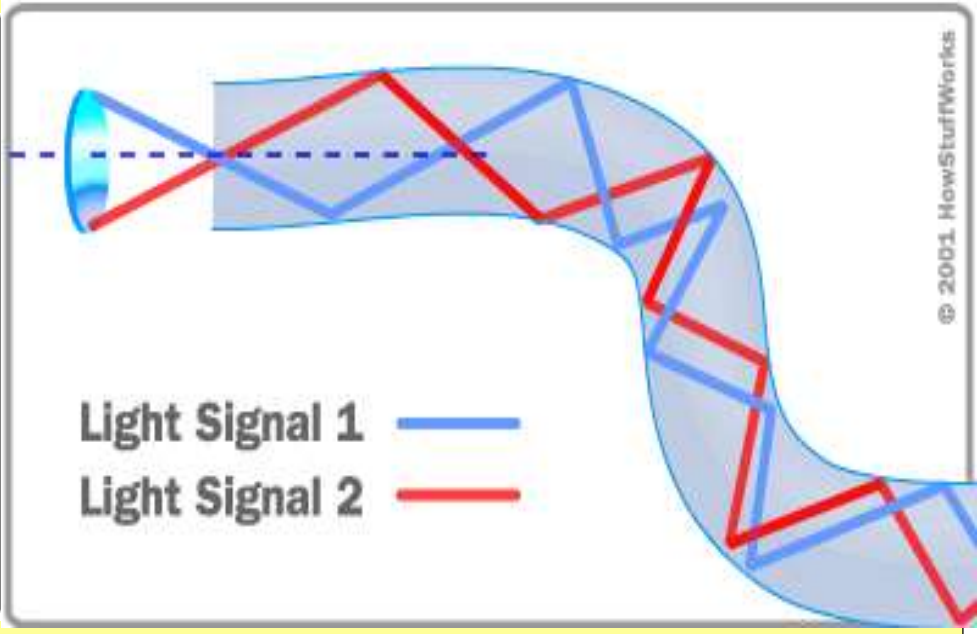
# Total Internal Reflection (TIR)

- The refractive index of first medium must be greater than the refractive index of second one. $n_1 > n_2$.

- The angle of incidence must be greater than the critical angle. $\theta i > \theta c$

- Trapping light in the fiber



# Acceptance Angle$\phi_0$ (max)

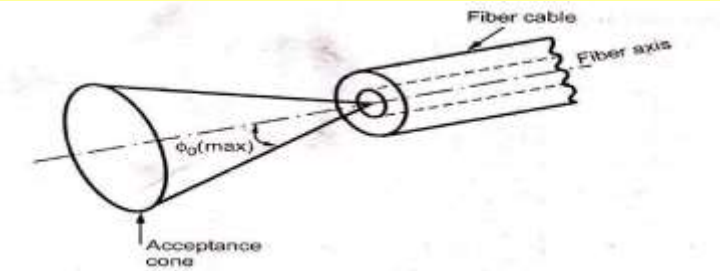
- The angle $\phi_0$ is called as **acceptance angle** and defines the maximum angle in which the light ray may incident on fiber to propagate down the fiber.

$$\phi_{0(max)} = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)$$

## Acceptance Cone

Rotating the acceptance angle around the fiber axis, a cone shaped pattern is obtained, it is called as **acceptance cone** of the fiber input.

Fig.shows formation of acceptance cone of a fiber cable



# Numerical Aperture (NA)

- The **numerical aperture** (NA) of a fiber is a figure of merit which represents its light gathering capability.
- Larger the numerical aperture, the greater the amount of light accepted by fiber.
- The acceptance angle also determines how much light is able to be enter the fiber and hence there is relation between the numerical aperture and the cone of acceptance.
- acceptance angle = $\sin^{-1}$ NA

$$NA = \sqrt{n_{core}^2 - n_{cladding}^2}$$

$$NA = \sqrt{n_1^2 - n_2^2}$$

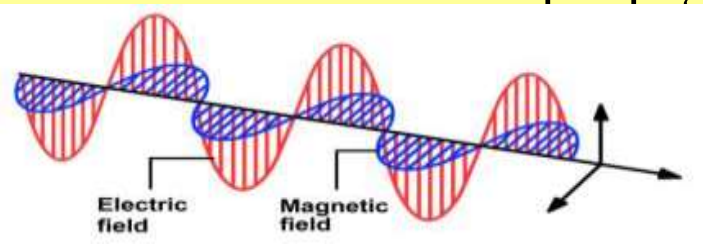
$$NA = n_1 (2\Delta)^{1/2}$$

# Optical Fiber Modes and Configurations

- Mode theory considers light to be electromagnetic waves.
- Describes light propagation in the optical fiber as a propagation of electromagnetic waves.
- A set of electromagnetic field patterns , forms a **mode**

**Light inside the fiber optics:**

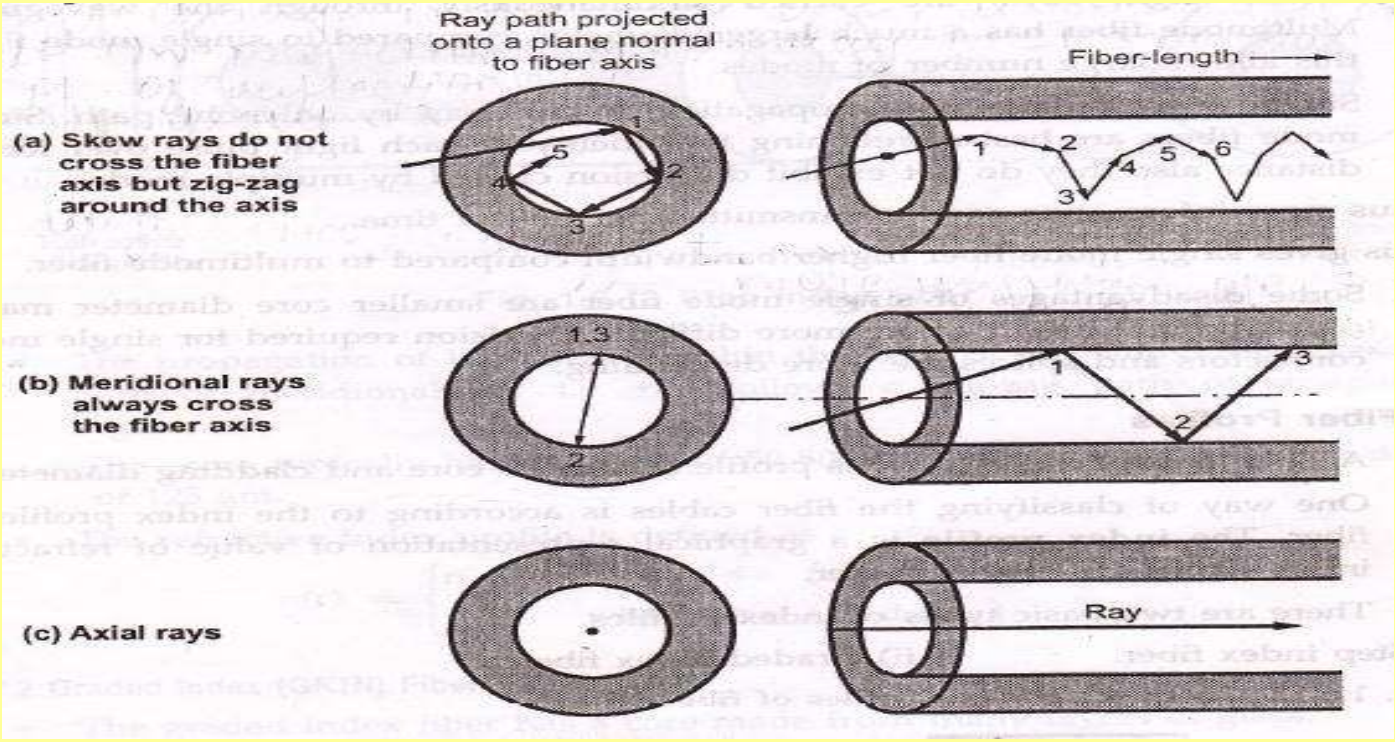
- The electromagnetic wave is composed by an electric field and a magnetic field.
- If the magnetic field is in the direction of the propagation, the mode is called **TM**.
- If the electric field is the direction of the propagation, it is called **TE**



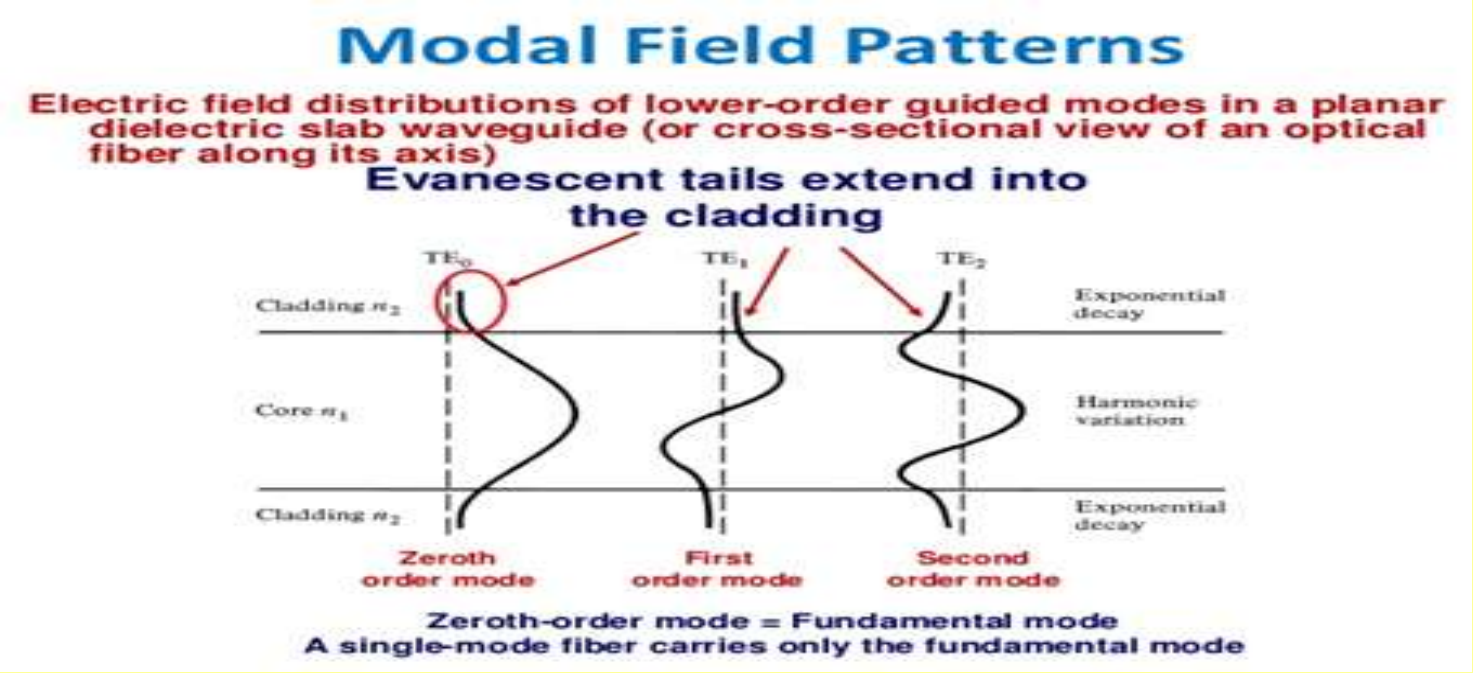
# Types of Rays

- If the rays are launched within the core of acceptance can be successfully propagated along the fiber. But the exact path of the ray is determined by the position and angle of ray at which it strikes the core.
- There exists three different types of rays.
- i) Skew rays ii) Meridional rays iii) Axial rays.
- **The skew rays** does not pass through the center, as show in Fig. 1.6.11 (a). The skew rays reflects off from the core cladding boundaries and again bounces around the outside of the core. It takes somewhat similar shape of spiral of helical path.

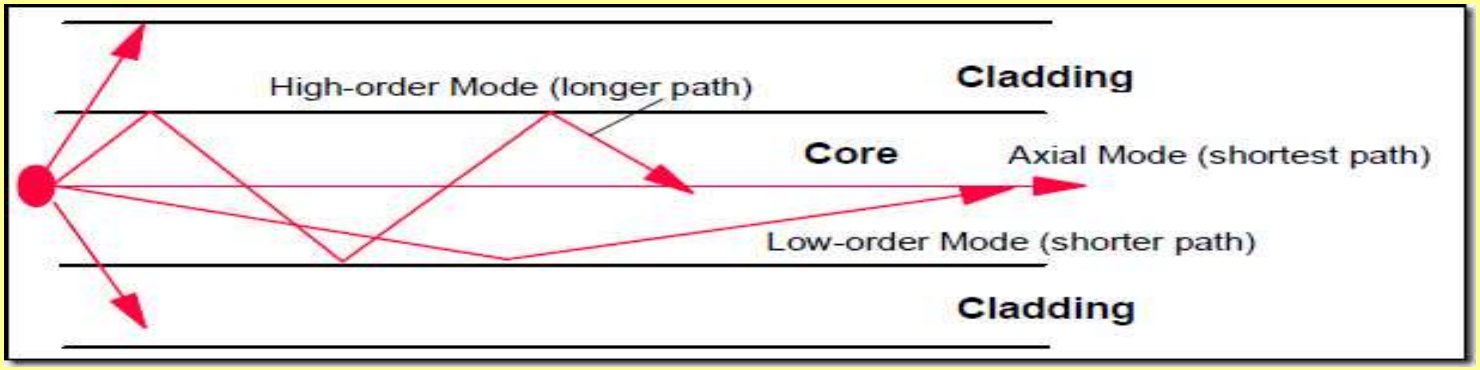
- The **meridional** ray enters the core and passes through its axis. When the core surface is parallel, it will always be reflected to pass through the enter. The meridional ray is shown in fig. 1.6.11 (b).
- The **axial ray** travels along the axis of the fiber and stays at the axis all the time. It is shown in fig. 1.6.11 (c).



# Mode theory of Circular Wave guides




Order of a mode equal to the number of field zeros across the guide




Low order modes have high incident angle, while high order modes have low incident angle

# Normalized frequency variable, V is defined as

$$V = \frac{2\pi a(n_1^2 - n_2^2)^{1/2}}{\lambda}$$

$$V = \frac{2\pi a}{\lambda} NA$$

where,

a = Core radius

λ = Free space wavelength

The total number of modes in a multimode fiber is given by

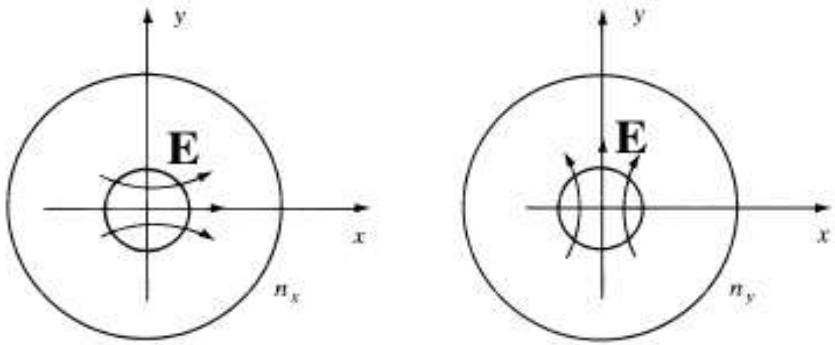
$$M = \frac{1}{2}\left[\frac{2\pi a}{\lambda} NA\right]^2 = \frac{[V]^2}{2}$$

$$M = \frac{1}{2}\left[\frac{\pi d}{\lambda}.NA\right]^2$$

# Linearly Polarized Modes

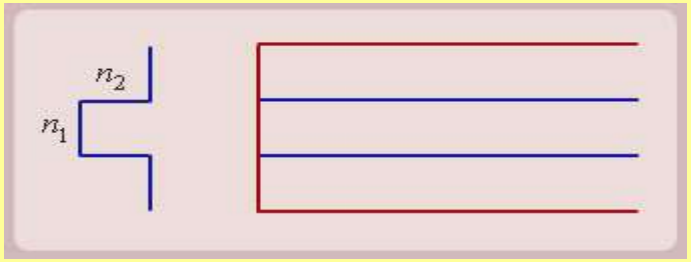
**Remarks on single-mode fibers:**

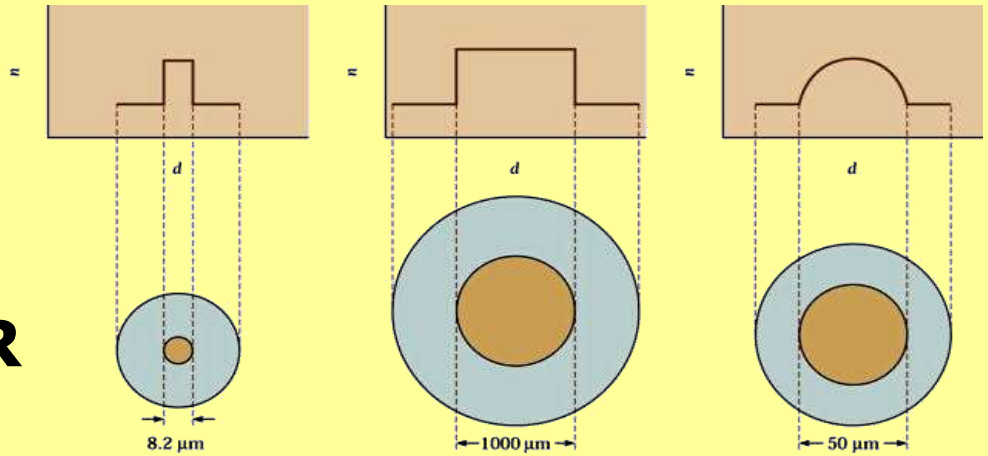
- no cutoff for the fundamental mode
- there are in fact *two modes with orthogonal polarization*



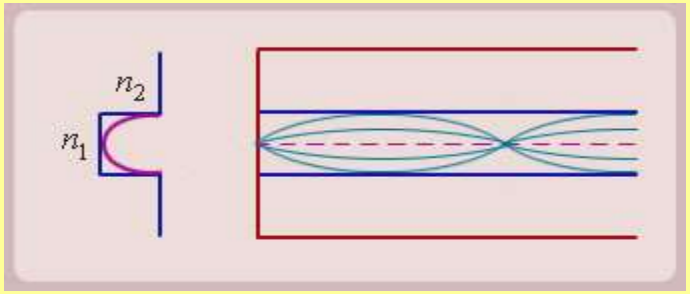

Horizontal mode  Vertical mode

# STEP INDEX FIBER




# GRADED INDEX FIBER




Single mode

only one signal can be transmitted

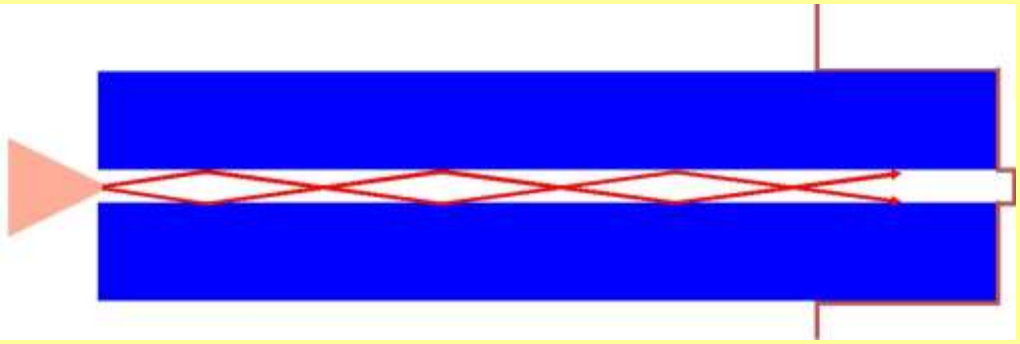
use of single frequency

Multi mode

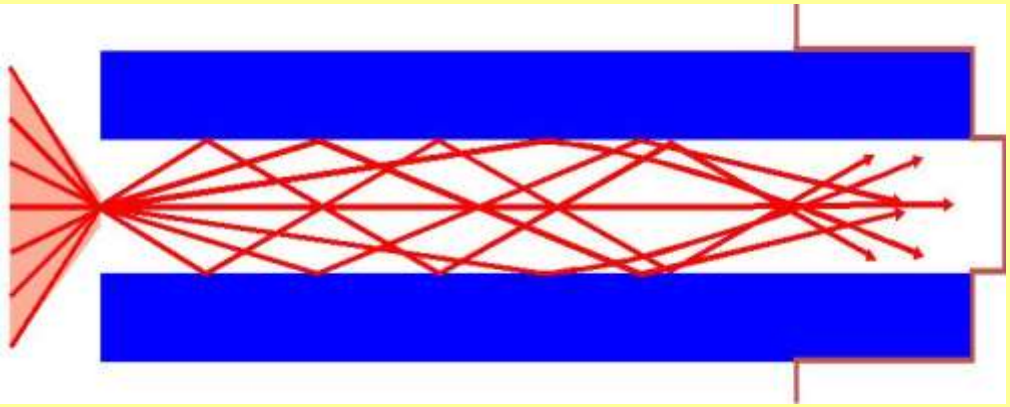
Several signals can be transmitted

Several frequencies used to modulate the signal

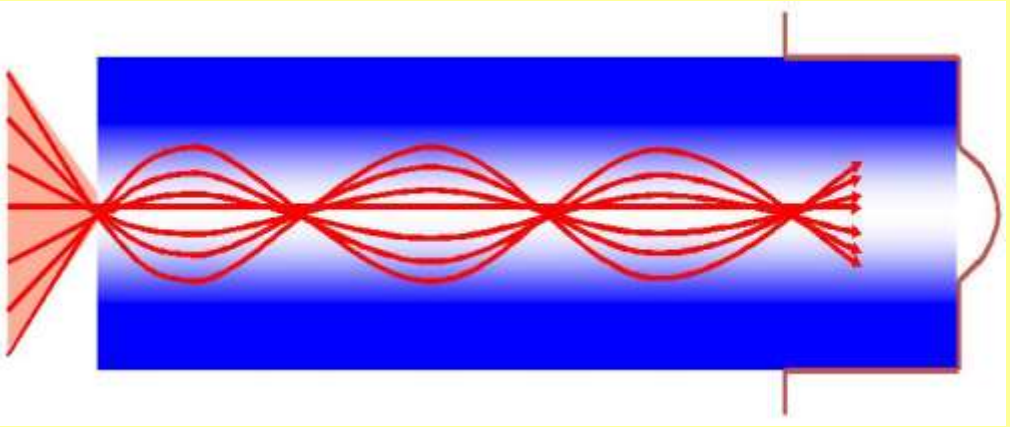
- **SM-SI**
- Single-Mode
- Step Index



- **MM-SI**
- Multi-Mode
- Step Index



- **MM-GI**
- Multi-Mode
- Graded Index




Thank you ...