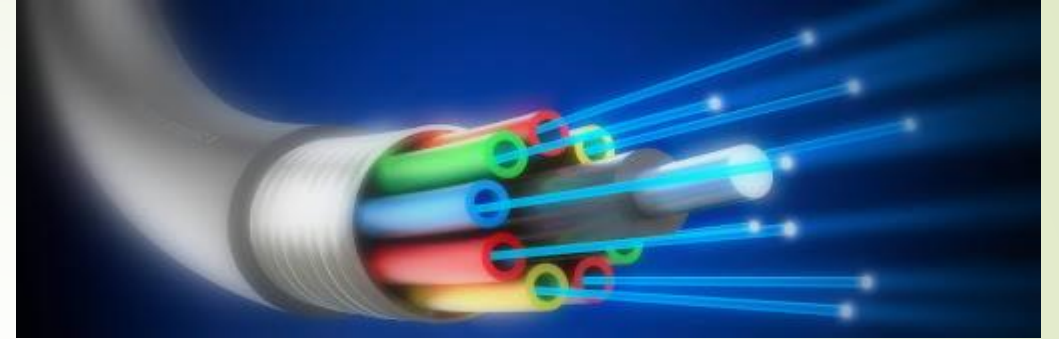


The Higher Institute of
Telecommunications &
Navigation

Transmission Department



Introduction to Fiber Optics TR-165 مقدمة في الألياف الضوئية

► Eng. Saleh Al-sarraf

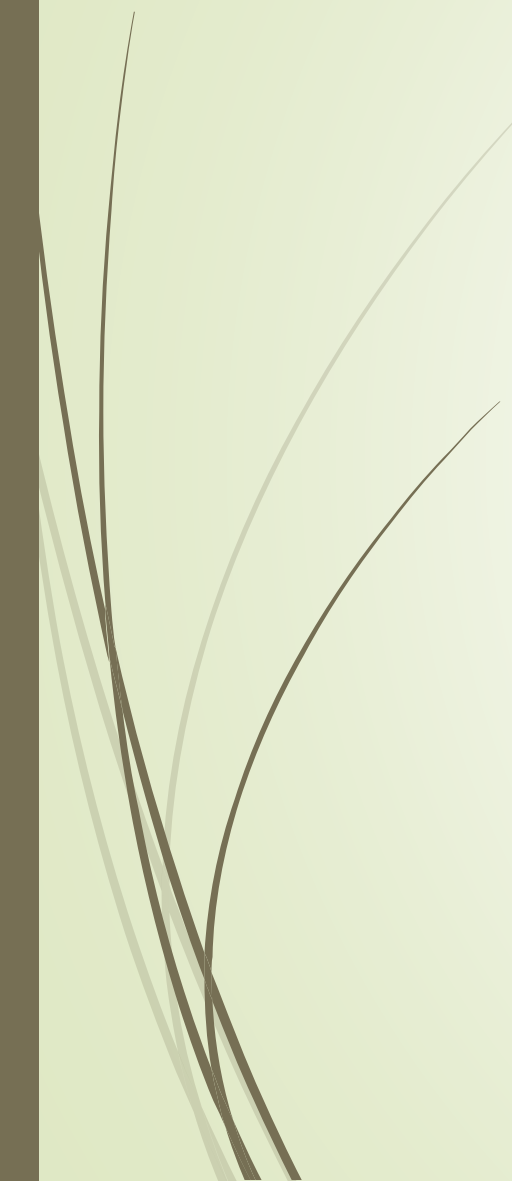


Basic of communications

- Communication means “the exchange of information from one location to another location.
- The main components of any communication system are:
Sender, Receiver, and a message over a channel.
- Data could be transfer of digital or analog.
- All types of data is transmitted over a transmission medium, such as cables, wires, parallel lines, coaxial cable, and fiber optics.
- Also, via Air (free-space) in case of wireless transmission.



Fiber Optics Introduction

- Fiber optics is a transmission line that carry/transfer light signal and connected between the sender and the receiver.
 - Fiber optics cable are similar a pipe that carry light from point to another point.
 - Fiber is most like the diameter of human hair, some are thinner.
 - Fiber optics are made of glass or plastic.
 - Fiber is the greatest developed communication technology.
- 



Fiber Optics Communication System

➤ The components of the communication system:

1- Transmitter:

Produce and encode the light signals.

2- Optical Fiber:

Conduct & carry the light signals over distance

3- Optical regenerator:

Boost the light signal in case of long-distance transmission

4- Optical Receiver:

Receive and decode the light signals



Advantages of Fiber & Applications

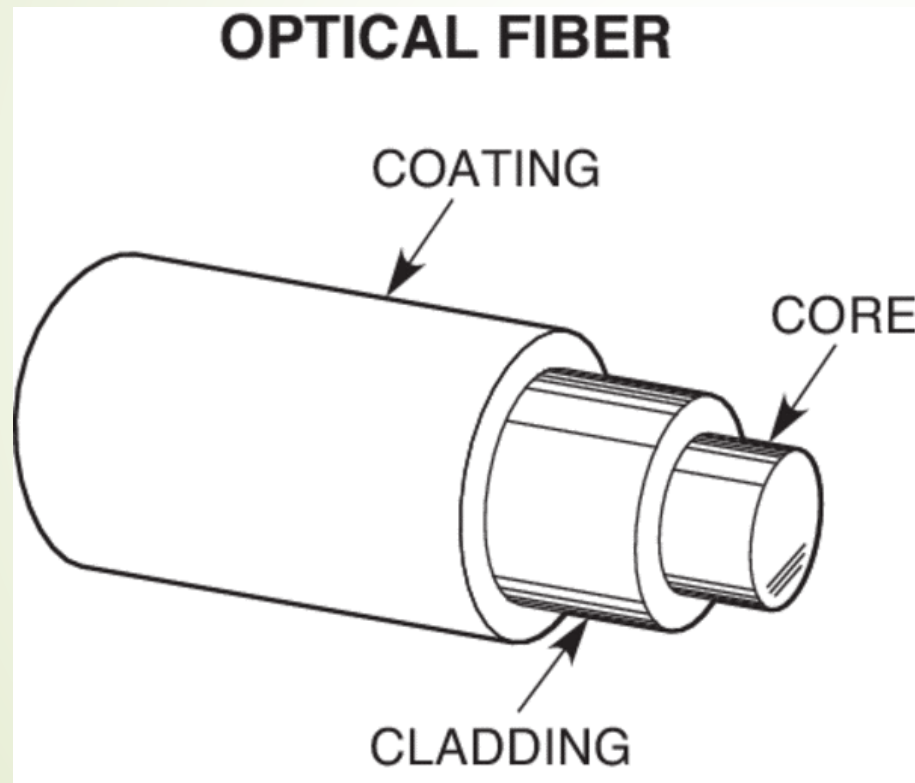
► **Advantages:**

- ❑ Electrical isolation
- ❑ Low power loss
- ❑ Small size & weight
- ❑ Less expensive
- ❑ No electromagnetic interference
- ❑ High security
- ❑ Difficult to be tapped
- ❑ No interference

► **Applications:**

- ❑ Communications
- ❑ Sensing
- ❑ Power delivery
- ❑ Illumination
- ❑ Computers, vehicles, airplanes and spacecrafts

Fiber Optics Cable Structure



► **Core:**

Is the light carrying element at the center of fiber cable

► **Cladding:**

Surrounding the core, has lower refractive index than the core

► **Coating:**

A plastic coat or jacket to protect the cable from moisture and other damages. Also called "Buffer"

Light Propagation

- ▶ Light propagates in free-space with velocity of 3×10^8 m/sec
- ▶ The speed of light depends on the medium it passes through.
- ▶ Each medium has Refractive Index (n)
- ▶ The speed of light is affected by (n) factor or value.
- ▶ The speed of light (velocity) is calculated by:

$$v = \frac{\text{speed of light at free space}}{\text{refractive index}} = \frac{c}{n}$$

- ▶ The lower refractive index (n), the higher speed of light (v).

Laws of Reflection and Refraction

- When light **Reflection** happen to a light ray when it strikes a reflective surface, like mirror.
- Law of reflection is that the angle of incidence (θ_1) is equal to angle of reflection (θ_2) .
- Inside the fiber optics cable, a series of total reflections happens.
- **Refraction** of light happen when light ray pass through two different mediums.
- Meaning (n) of medium 1 is different than (n) of medium 2
- Snell's law: $n_1 \sin \theta_1 = n_2 \sin \theta_2$
- When light pass-through different medium to changes must change direction of light (θ), and the velocity of light (v)

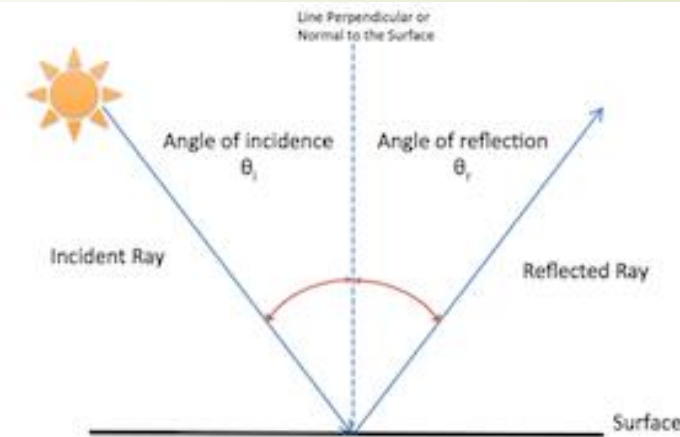
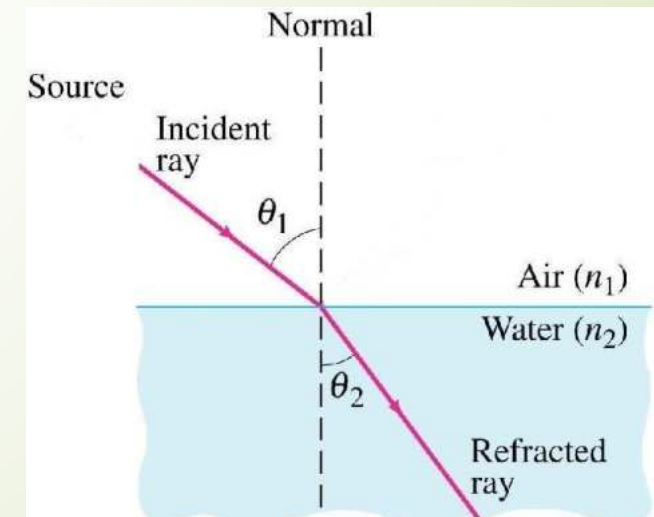


Figure 1: Law of reflection - the angle of incidence, θ_1 is equal to the angle of reflection, θ_r .



Light inside the Fiber cable

- In fiber construction, core and cladding have made with different refractive index (n)
- Relationship: $n_{core} > n_{cladding}$
- Every fiber optics cable has a specific Critical Angle θ_c and Acceptance Angle θ_a , calculated from refractive indexes of core and cladding.
- The value of Critical Angle and Acceptance Angle are dependable on core & cladding refractive indexes values that given.
- Acceptance angle & Critical Angel are important to determine how light enter the fiber optics cable.



Critical Angle (θ_c)

- Critical Angle is defined as the angle of incidence that provides an angle of refraction of 90°
- If the angle of incidence (θ_1) is greater than the critical angle (θ_c), the light ray will totally reflect and do not enter the fiber.
- The critical angle can be calculated by the following formula:

$$\theta_c = \sin^{-1} \frac{n_{cladding}}{n_{core}}$$

If the light ray has incidence angle (θ_1) larger than the critical angle (θ_c) of the fiber cable, that light will reflect out the fiber causing total loss.

Acceptance angle (θ_c)

- Acceptance Angle is defined as the greatest possible angle at which light can be launched into the core.
- The Acceptance angle can be calculated by the following formula:
- $\theta_a = \sin^{-1} (NA)$
- Numerical Aperture (NA) is the light gathering ability of an optical fiber.
- NA can be calculated by knowing both refractive indexes of core and cladding by the following formula:

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

- by knowing both the critical angle and the acceptance angle for the fiber optics cable, we can figure out how the light will propagate along the fiber cable.

Light Propagation Conditions

- 1- If the light angle (θ_1) is bigger than the critical angle (θ_c), the light will be totally reflected out the fiber and it will be **total loss**.
- 2- If the light angle (θ_1) is smaller than the critical angle (θ_c), then the light will enter / propagate into the fiber.
- 3- Depending on the fiber acceptance angle (θ_a), it will determine the light propagation through the fiber as follows:
 - If the light angle (θ_1) is bigger than the acceptance angle (θ_a) of the fiber cable, then part of the light will propagate through the cladding, which results of **partial loss** into the cladding.
 - If the light angle (θ_1) is smaller than the acceptance angle (θ_a), then the light will propagate through the core with **no loss**.

Example

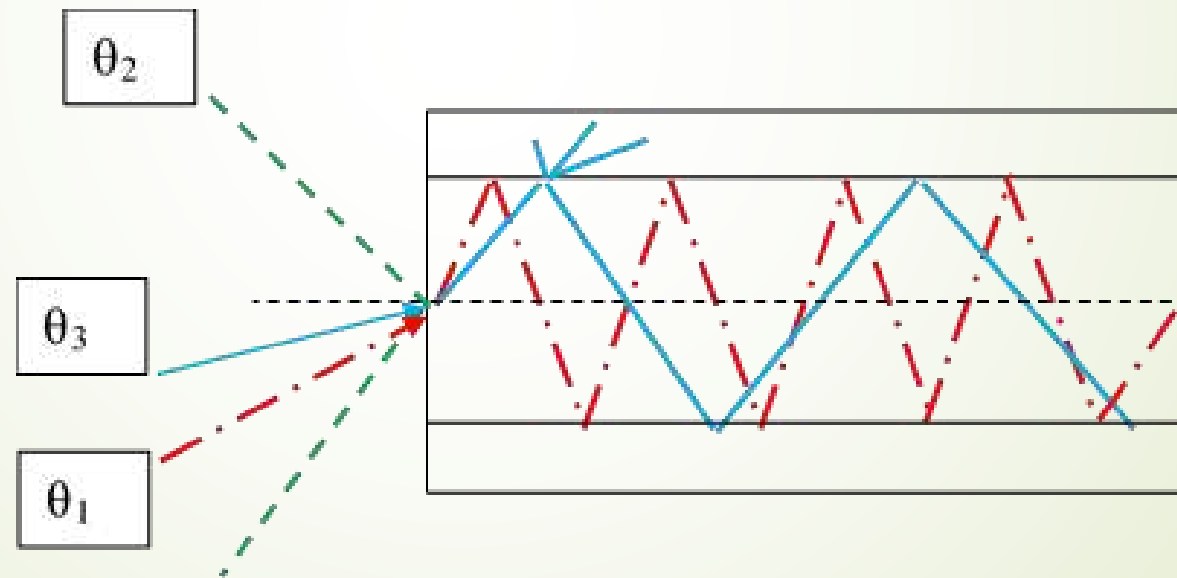
► Fiber critical angle (θ_c) = 45, fiber acceptance angle (θ_a) = 28

And showing three cases of light angle as follows:

1- $\theta_1 = 12$

2- $\theta_2 = 50$

3- $\theta_3 = 25$



Example

- ▶ A fiber optics cable has core refractive index of 1.5 and cladding refractive index of 1.47. Find (a) the Critical angle (θ_c), (b) the Numerical aperture (NA), and (c) the Acceptance angle (θ_a)?

A. $\theta_c = \sin^{-1} \frac{n_{cladding}}{n_{core}}$

$$= \sin^{-1} \frac{1.47}{1.5}$$

$$= \sin^{-1}(0.513)$$

$$\theta_c = 78.52^\circ$$

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

$$= \sqrt{(1.5)^2 - (1.47)^2}$$

$$= 0.298$$

C. $\theta_a = \sin^{-1} (NA)$

$$= \sin^{-1} (0.298)$$

$$\theta_a = 17.36^\circ$$

Classification of Fiber Optics

➤ Fiber optics cable can be classified in different ways, according to the following:

1) Material:

- Glass (both core & cladding made of glass)
- Plastic (both core & cladding made of plastic)
- Plastic-clad silica (core is made of glass & cladding is made of plastic)

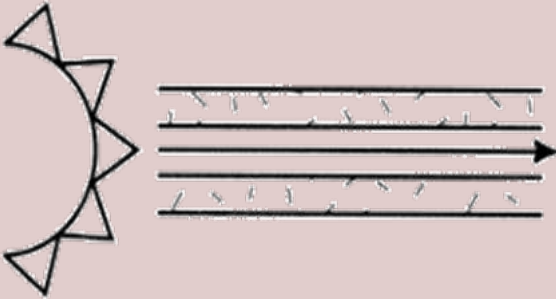
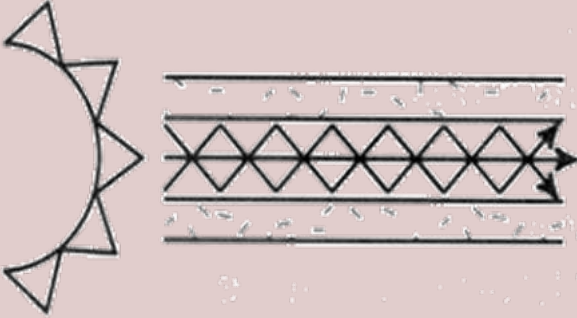
2) Size or Mode:

- Single-mode (core diameter 8-10 μm)
- Multimode (core sizes 50 μm , 62.5 μm , 100 μm)

3) Refractive index:

- Single-mode Step Index
- Single-mode Graded Index
- Multimode Graded Index

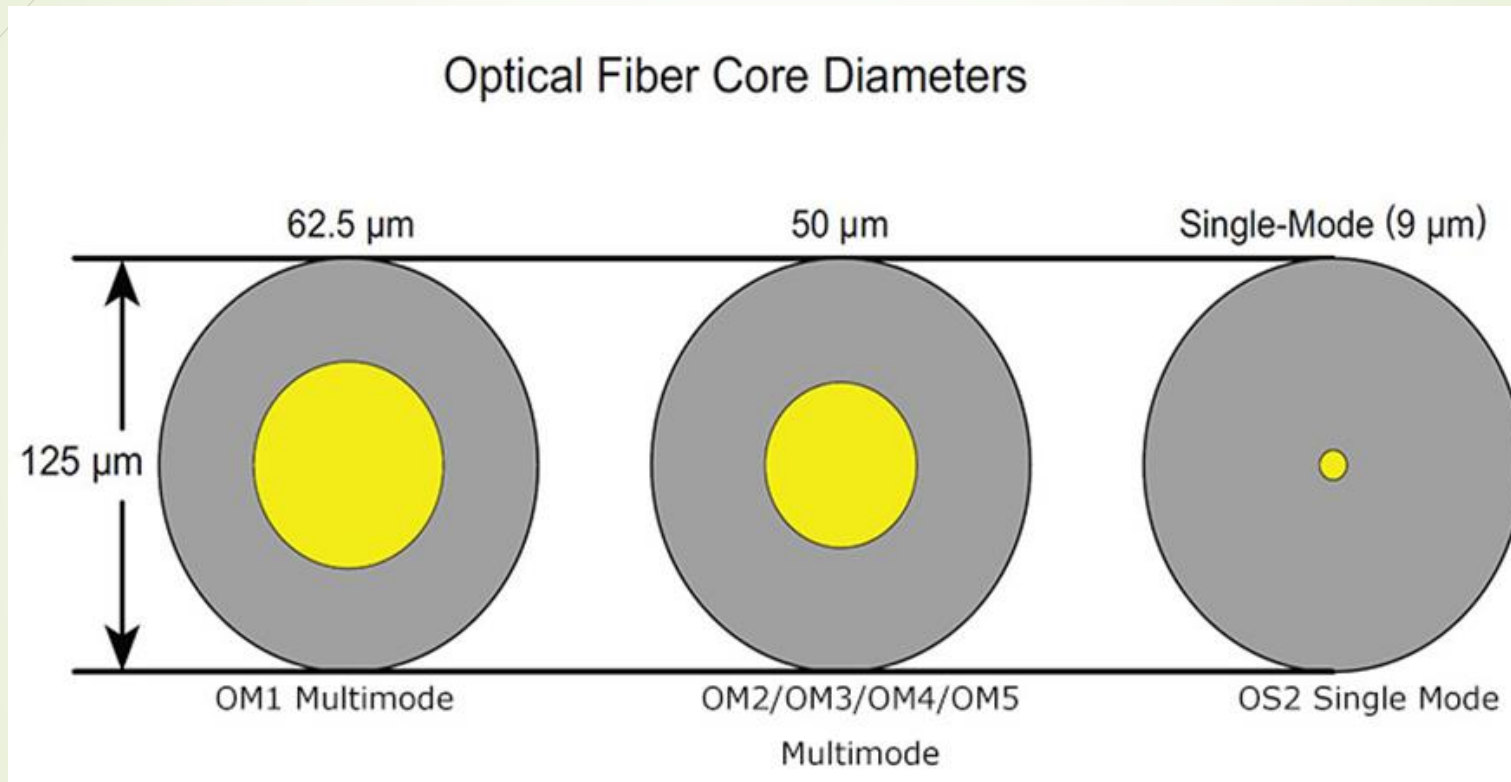
Single mode Vs. Multimode fiber

Single mode fiber	Multimode fiber
<p data-bbox="479 664 1070 785">"Single mode fiber" single path through the fiber</p>  <p>The diagram shows a cross-section of a single mode fiber on the left, represented by a semi-circle with a serrated edge. Three parallel horizontal lines with arrows pointing to the right represent a single path of light through the fiber.</p>	<p data-bbox="1447 664 2051 785">"Multimode fiber" multiple paths through the fiber</p>  <p>The diagram shows a cross-section of a multimode fiber on the left, represented by a semi-circle with a serrated edge. Multiple horizontal lines with arrows pointing to the right represent multiple paths of light through the fiber. A zigzag line is drawn across the center of these paths, indicating light reflecting off the fiber walls.</p>

Single mode Vs. Multimode fiber

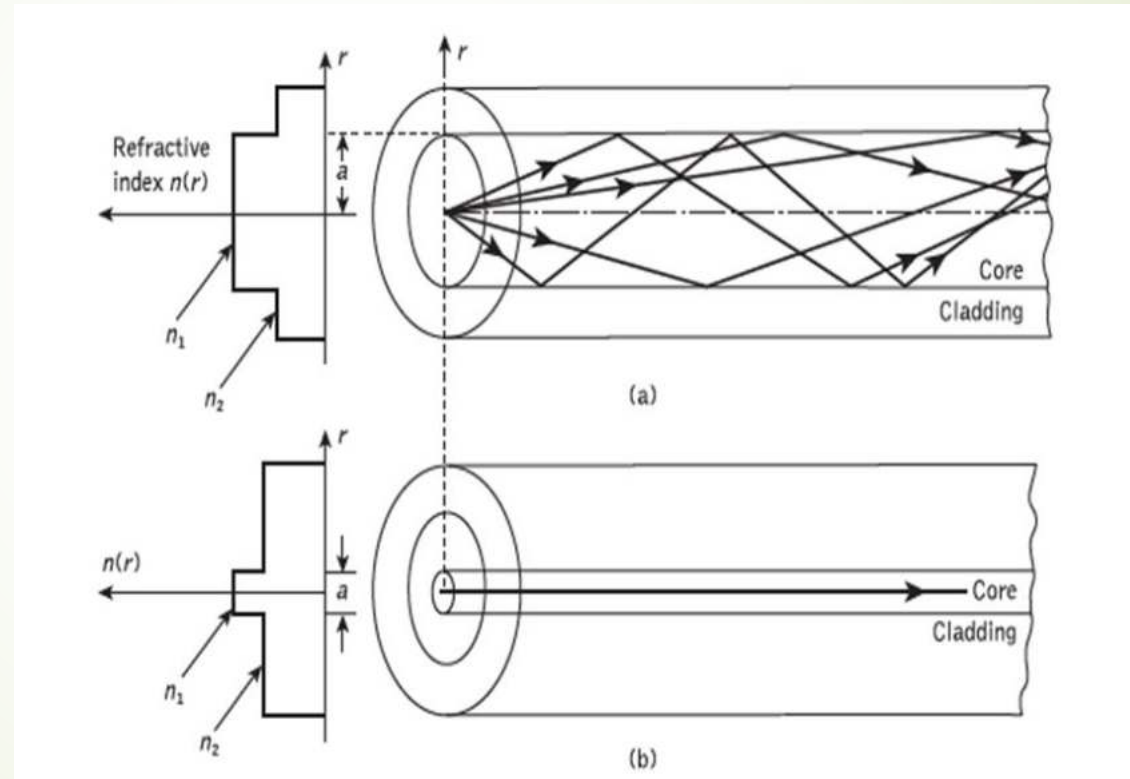
	Single mode fiber	Multimode fiber
Number of modes	1	from 2 to 10,000
Core diameter	8-10 μm	50, 62.5, 100 μm
Cladding diameter	125 μm	125 μm
Light gathering	small	Very high
Bandwidth	Very high	Less than single mode
Transmission Rate	Very high speed (50 times higher than multimode)	High
Wavelength & Light source	Laser of 1310 nm, 1550 nm	LED & laser of 850 nm, 1550 nm

Single mode Vs. Multimode fiber



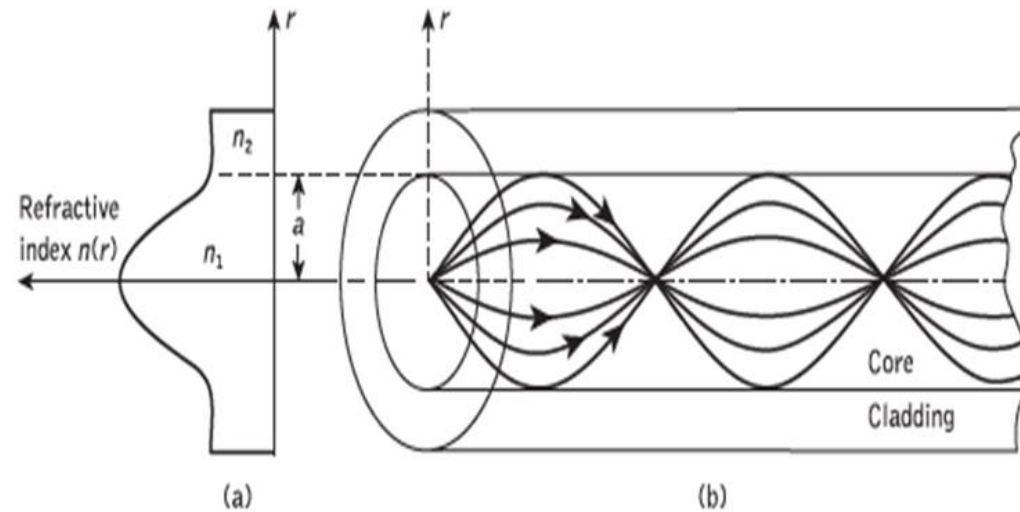
Classification by Refractive Index

1) Step Index



Classification by Refractive Index

2) Graded Index



Classification by Refractive Index (cont.)

- Light passes through different refractive index's (n) values through the core.
- Each area / step, the light makes change in the direction (θ) and the speed (v).

