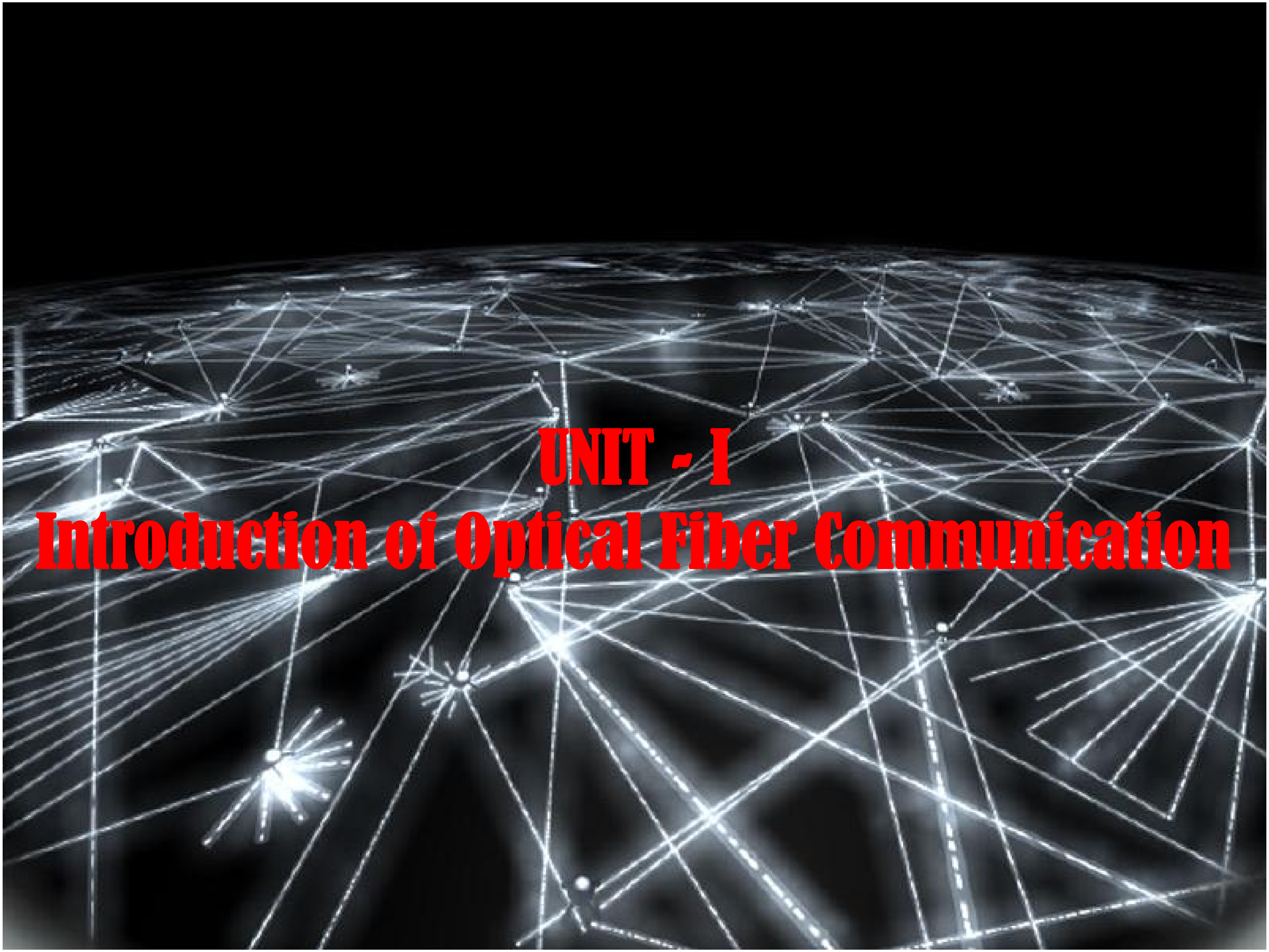


UNIT - I

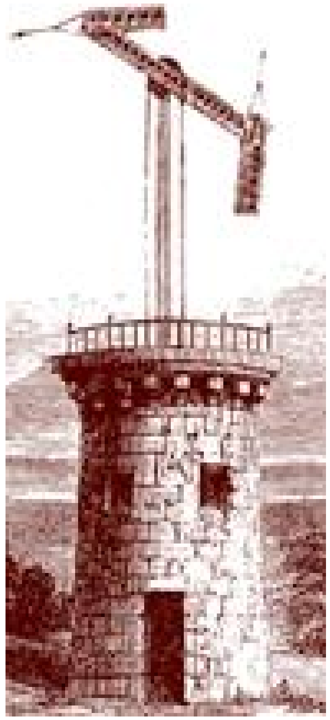
Introduction of Optical Fiber Communication

Optic fiber and light –What a brilliant combination?

- ❖ If we want to transfer the information to a long distance we use modulation or superimposing technique in communication system.
- ❖ Sophisticated techniques have been developed for information transfer using electromagnetic carrier wave operating at radio frequencies as well as millimeter wave.
- ❖ This is also possible with an electromagnetic carrier which is selected from the optical range of frequencies.
- ❖ The visible optical carrier waves or light has been commonly used for communication purpose from many years like reflecting mirrors, signal fires, signaling lamps etc.

Early Optical Communications

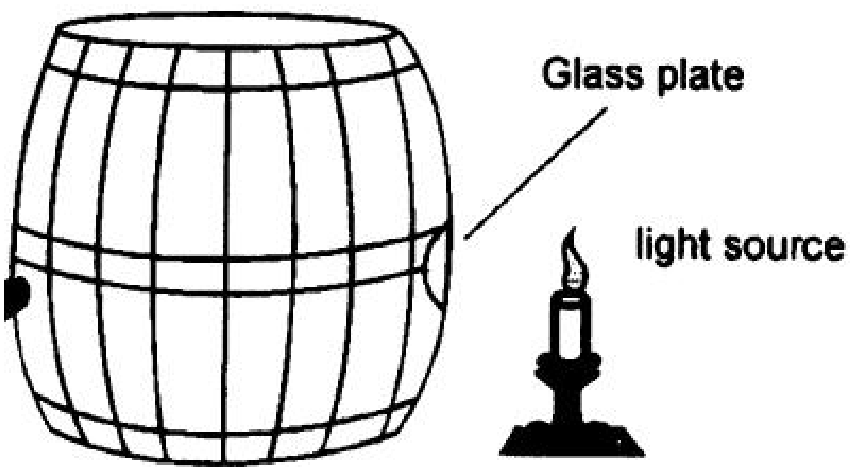
- The French used semaphores to transmit messages in the 1790s.
- Later systems also sent optical signals through the air
  - But clouds, rain, and other atmospheric disturbances can disrupt optical signals sent through the air.
  - Electric signals through wires avoid that problem.



First public demonstration by Irish Physicist John Tyndall

- ❖ It was a well known fact that, light travels in straight line, it is impossible to make it follow a curved path.
- ❖ An Irish Physicist John Tyndall in 1870 first demonstrated how to guide a light.
- ❖ He filled the container having a glass plate at one side and bung on other with a water & placed it in a dark room and shone a light into it.

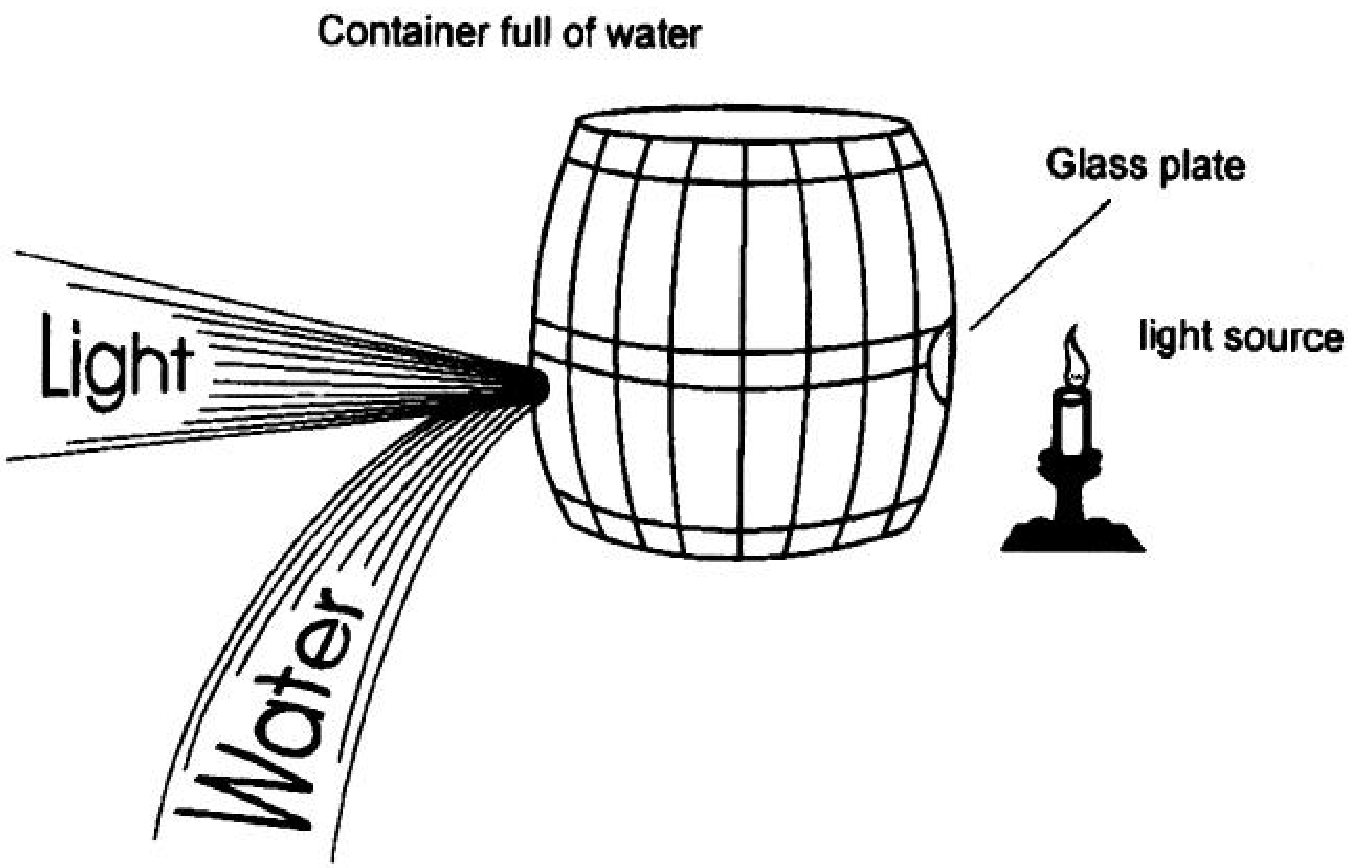
Container full of water



What was expected to happen ?

❖ When he pulled out the bung.

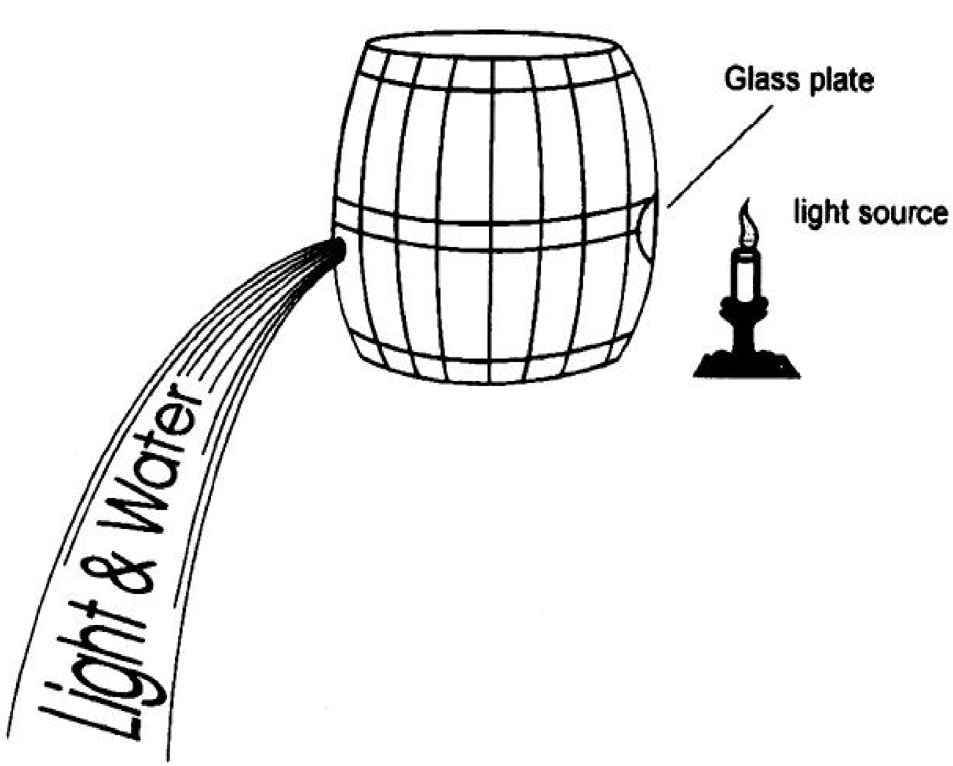
❖ It was expected that the light would shine straight out of the hole and water would curve downward.

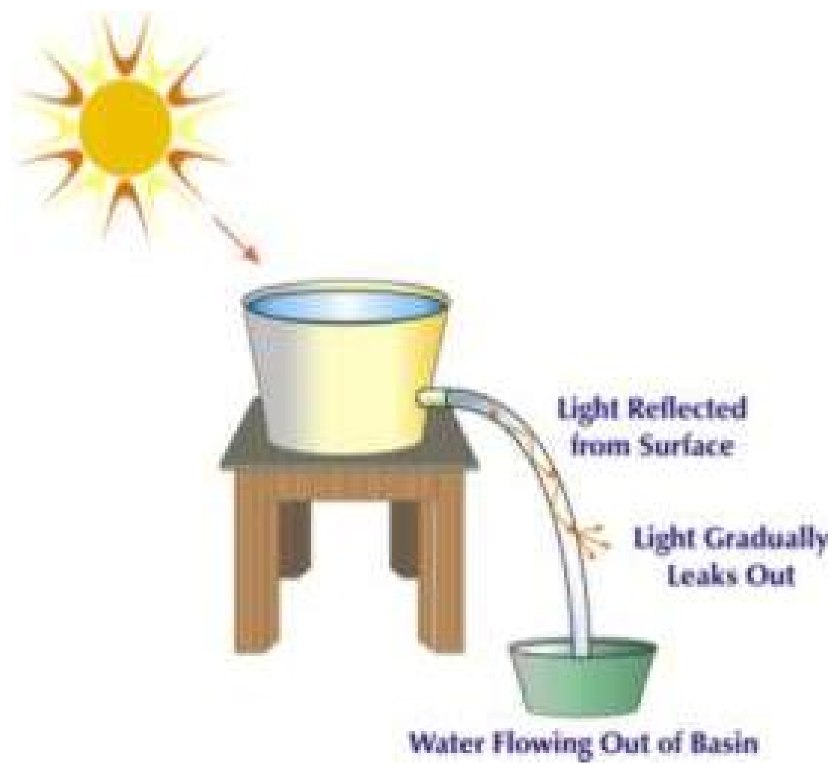


What actually happened?

❖ But actually the light stayed inside the water column and followed the curved path.

❖ In this way he had found a way to guide the light!





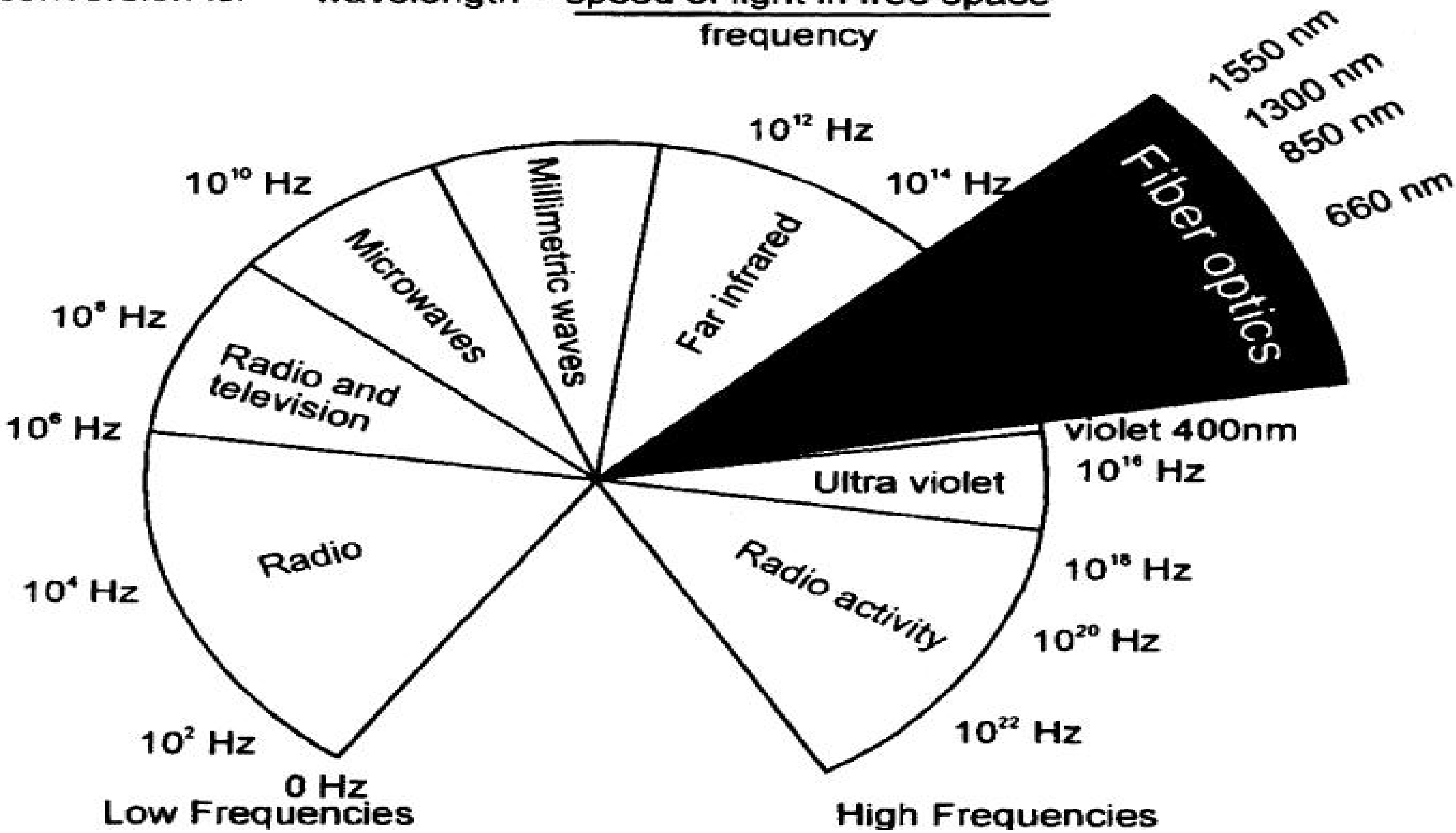
Evolution of Fiber

- 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 – Optical Fiber technology becomes backbone of long distance telephone networks in North America.

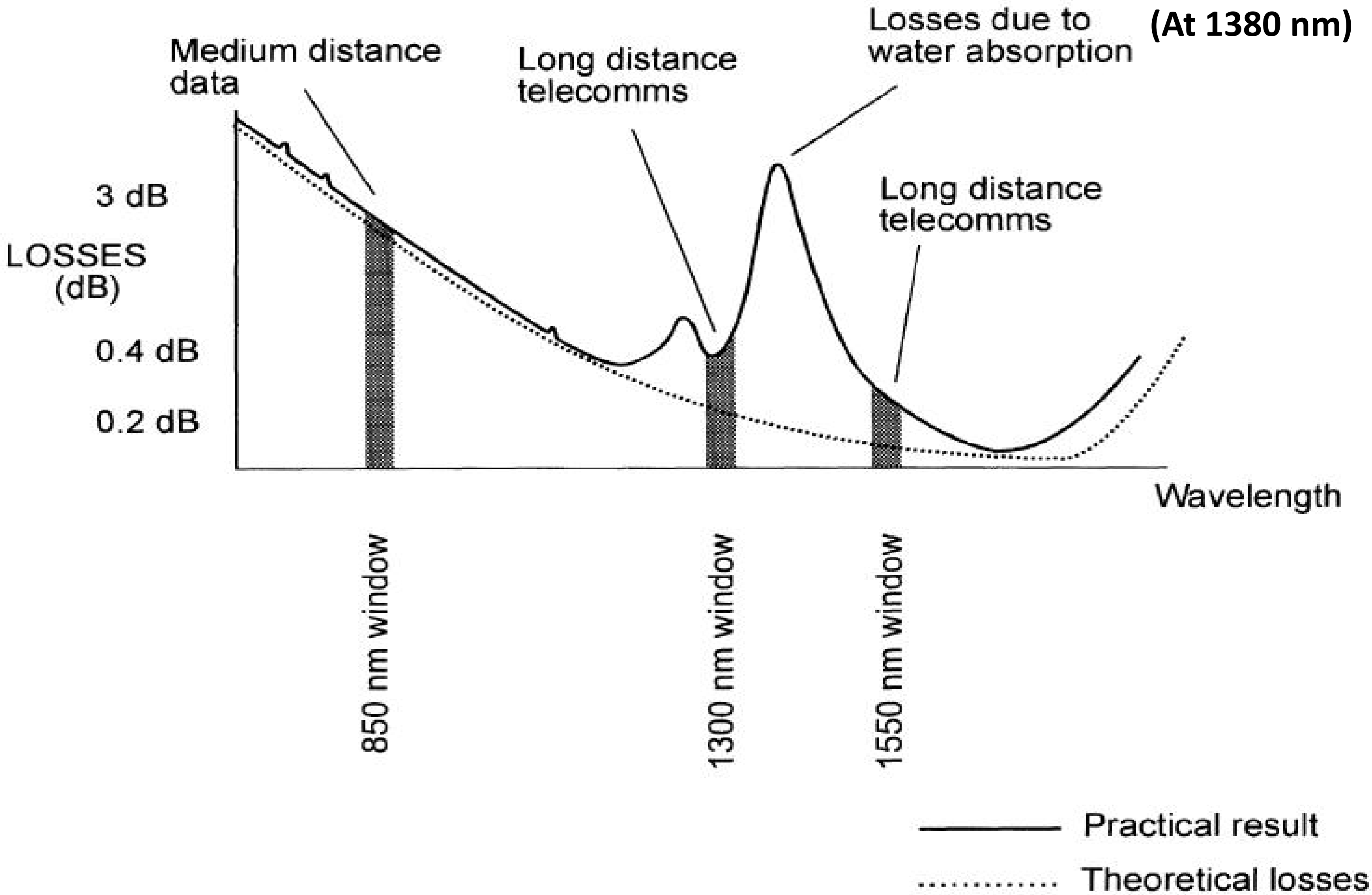
Spectrum used in optical fiber communication

In fiber optics, we find it more convenient to use the wavelength of the light instead of the frequency.

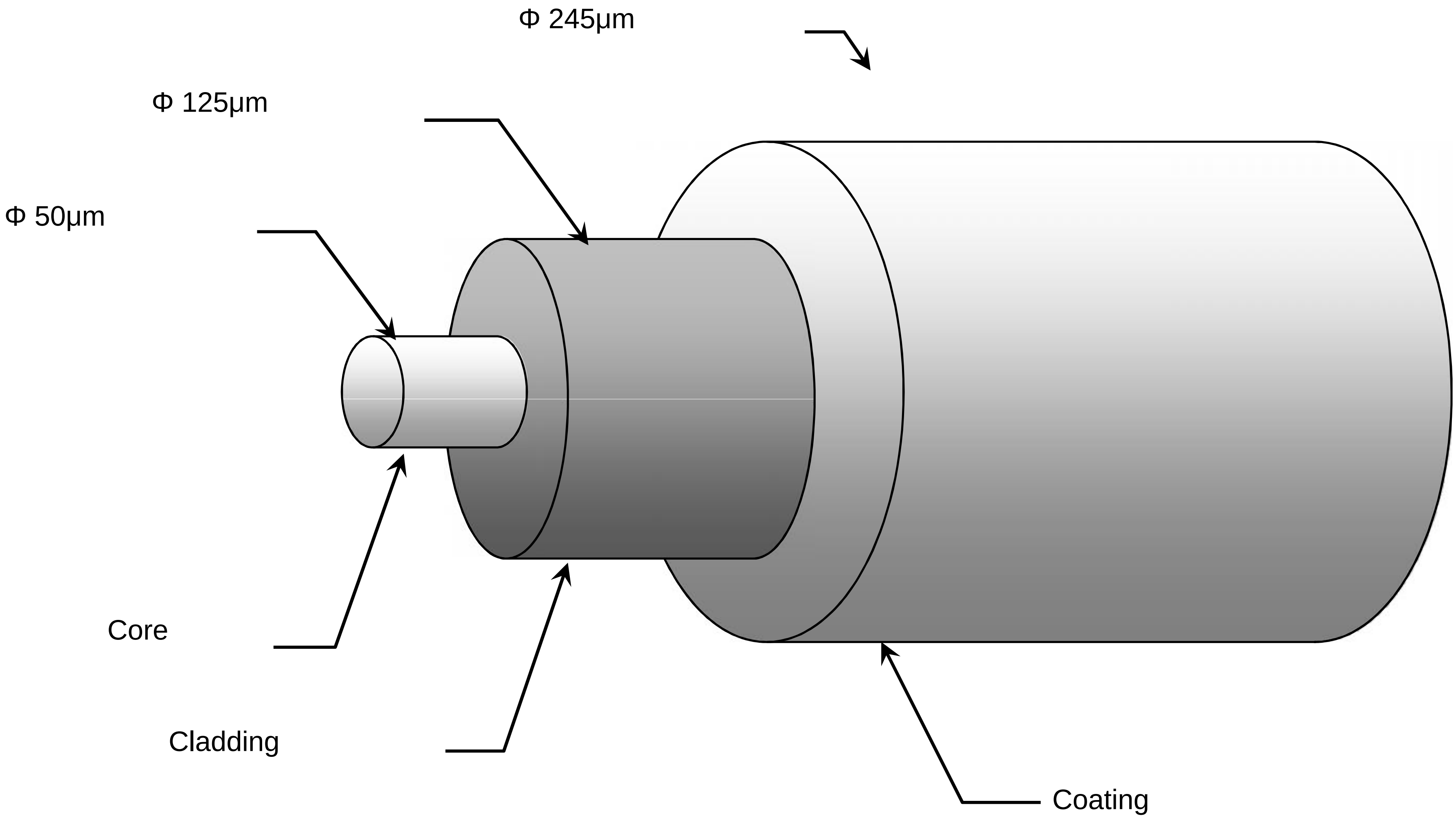
The conversion is: $$\text{wavelength} = \frac{\text{speed of light in free space}}{\text{frequency}}$$



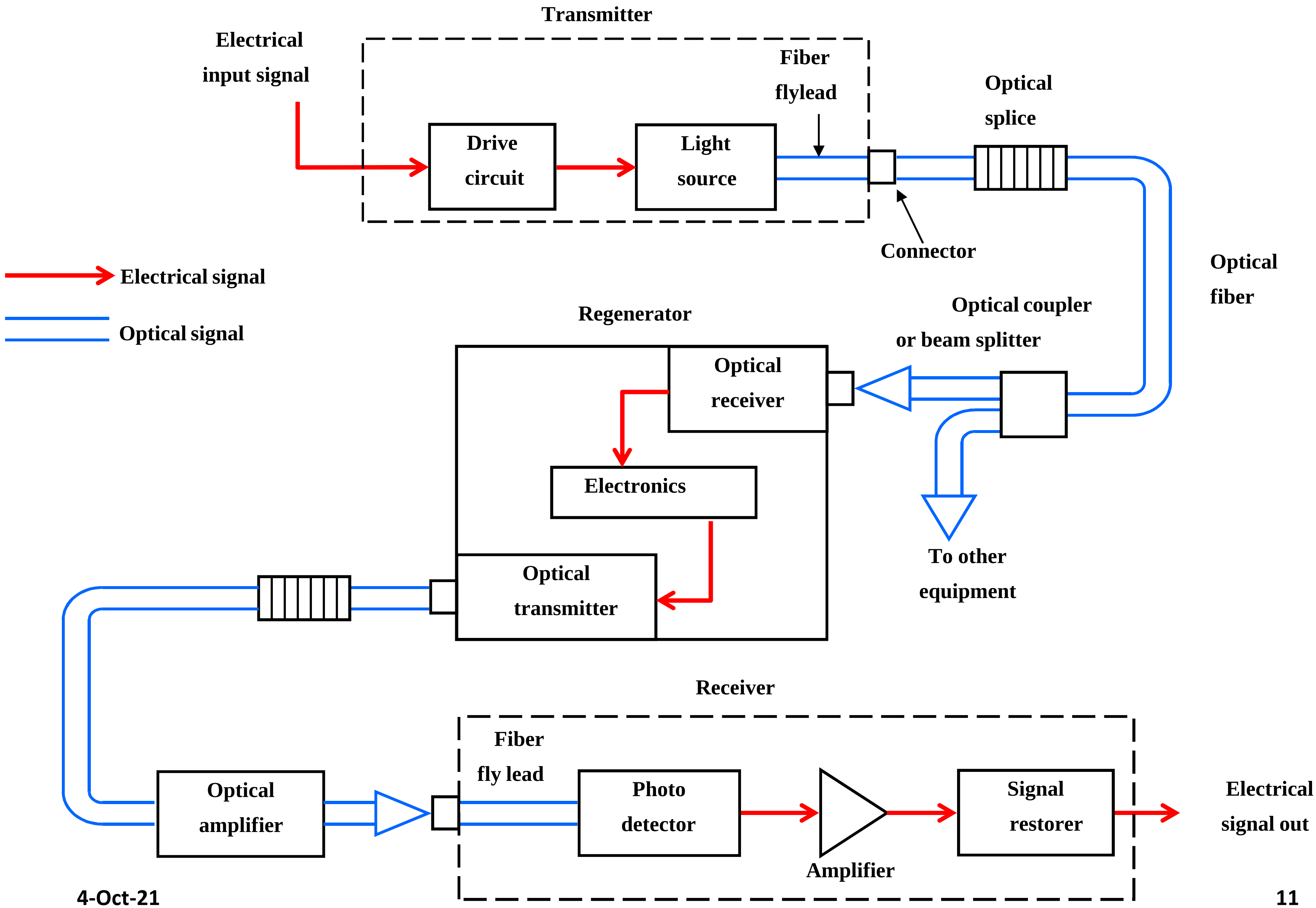
The infrared windows used in fiber optics



Actual optical fiber cable and its dimensions



Basic block diagram of Optical fiber communication system



Advantages of optical fiber cables over copper cable

- ❖ Small size and weight.
- ❖ Ruggedness and flexibility (storage, handling, installation and transportation).
- ❖ Low transmission loss cable (Typically 0.2dB/km).
- ❖ Electrical isolation.
- ❖ Enormous potential band width (at several GHz over about 100 km and over 100s of MHz over about 300 km without repeater is possible).
- ❖ Signal security.
- ❖ Immunity to interference and cross talk.
- ❖ System reliability and ease of maintenance.
- ❖ Potential low cost.

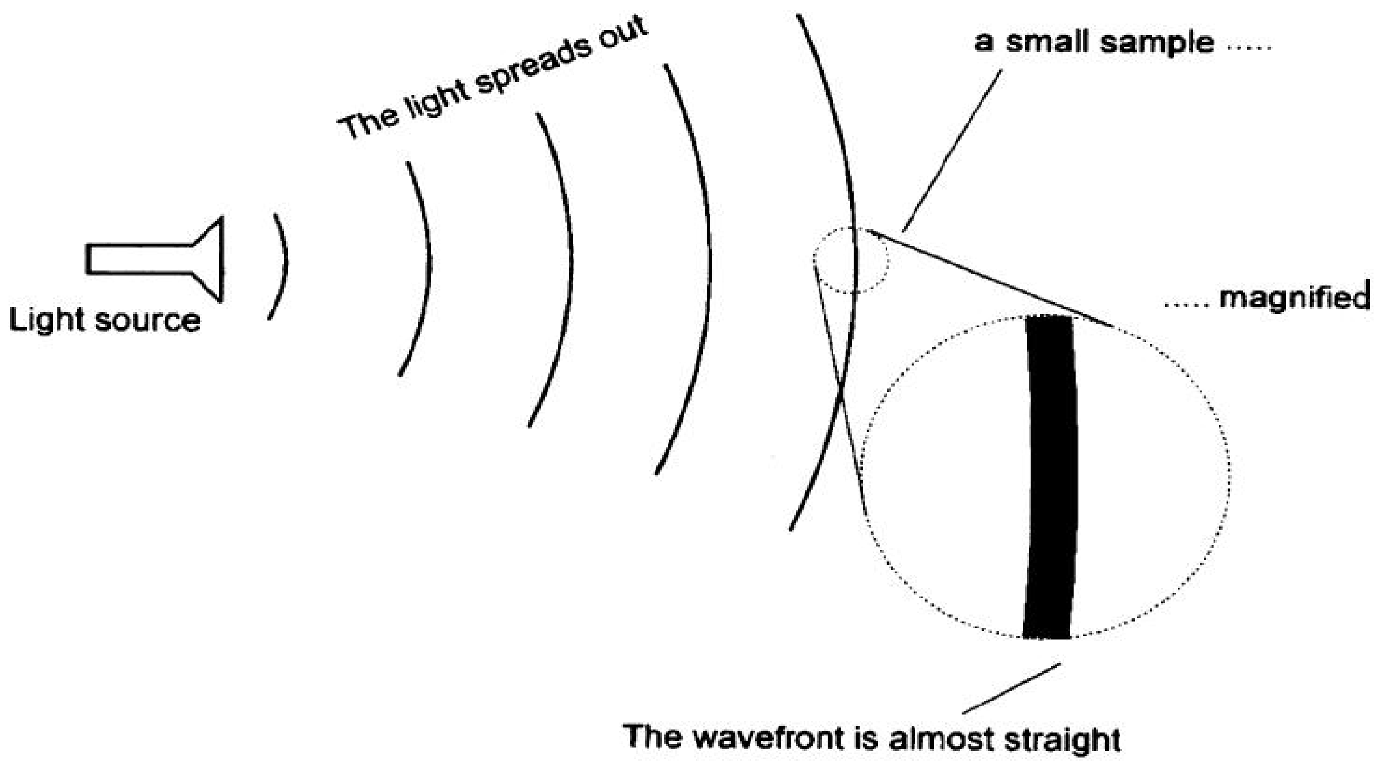
Disadvantages of optical fiber cables

- ❖ Terminating equipment is still costly as compared to cu equipment.
- ❖ Optical fiber is delicate so has to be handled carefully.
- ❖ Communication is not totally in optical domain, so repeated electric – optical – electrical conversion is needed.
- ❖ Optical amplifiers, splitters, MUX-DEMUX are still in development stages.
- ❖ Tapping is not possible. Specialized equipment is needed to tap a fiber.
- ❖ Optical fiber splicing is a sophisticated technique & needs skilled manpower.
- ❖ The splicing and testing equipments are very expensive as compared to copper equipments.

What makes the light stay in the fiber ?

❖ As we move further from the light source, the wave front gets straighter and straighter.

❖ At a long distance from the light source, the wave front would be virtually straight.



Continued……

- There is a widely held view that the light always travels at the same speed.
- This fact is simply not true.
- The speed of light depends upon the material through which it is moving.
- When it passes through a clear material, it slows down by an amount depending upon a property of the material called as its refractive index.

Refractive index of material = (Speed of light in free space / Speed of light in the material)

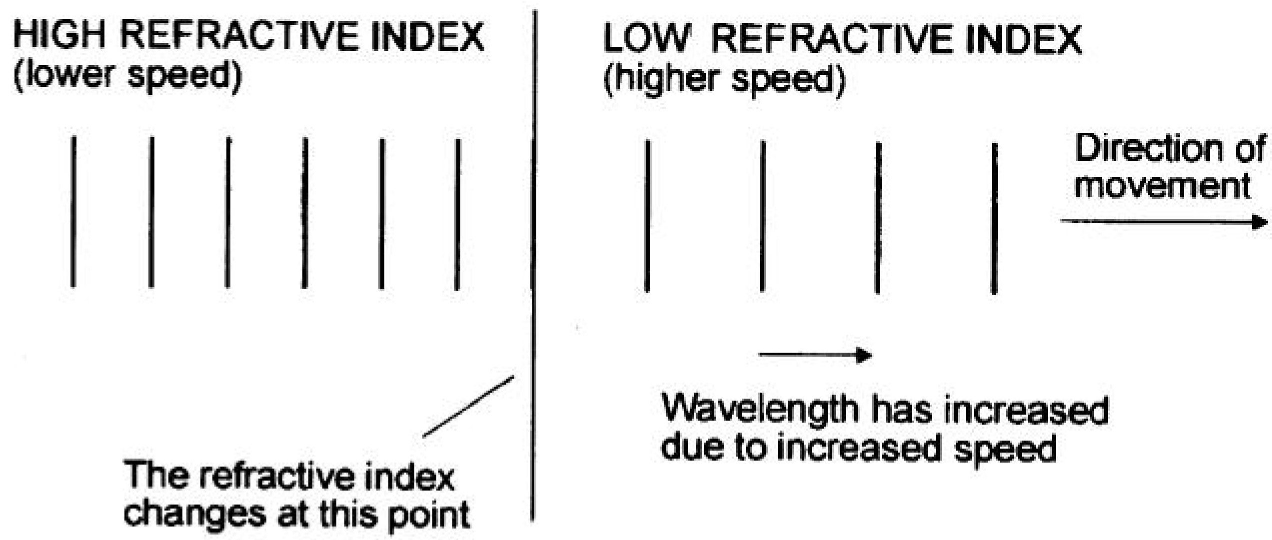
Refractive index of different materials

Material	n	Material	n
Vacuum	1.0000	Crown Glass	1.52
Air	1.0003	Salt	1.54
Water	1.33	Asphalt	1.635
Ethyl Alcohol	1.36	Heavy Flint Glass	1.65
Fused Quartz	1.4585	Diamond	2.42
Whale Oil	1.460	Lead	2.6

Why light changes its speed?

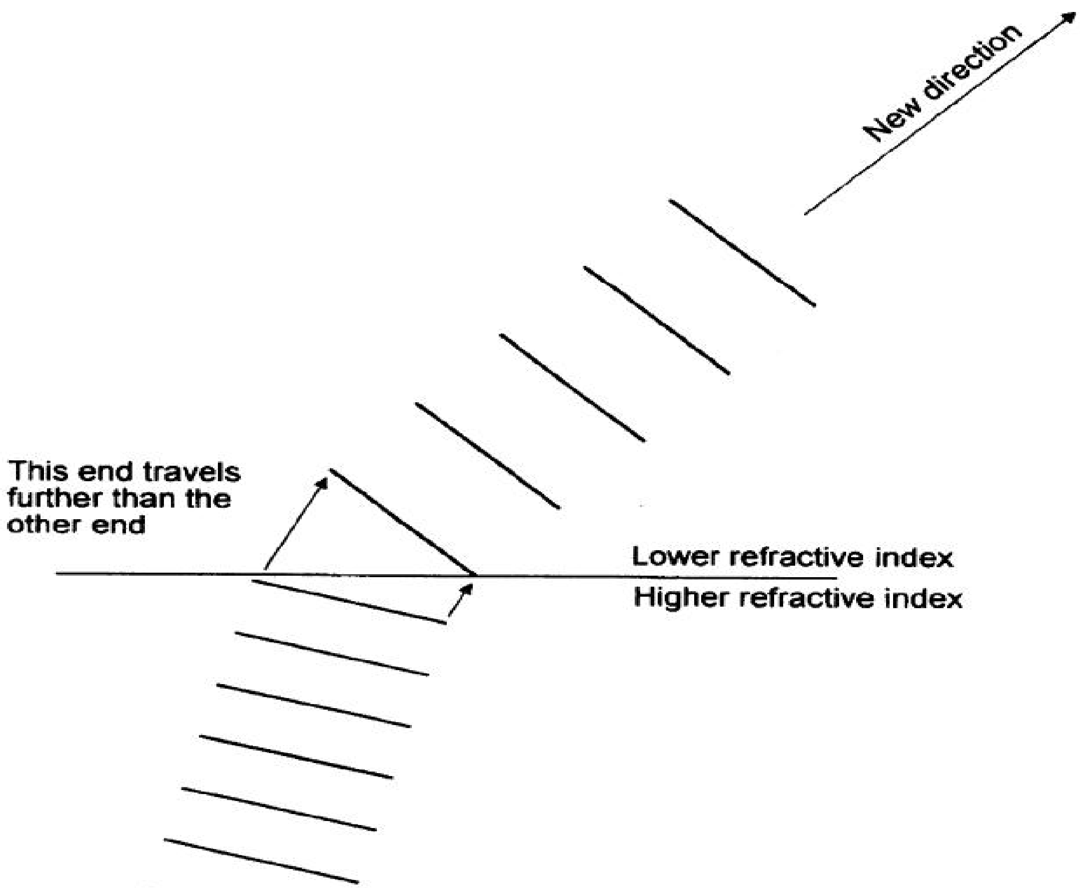
❖ The wavelength of light λ_n in a given medium having index of refraction (n) is found by $\boldsymbol{\lambda_n = \lambda_0/n}$.

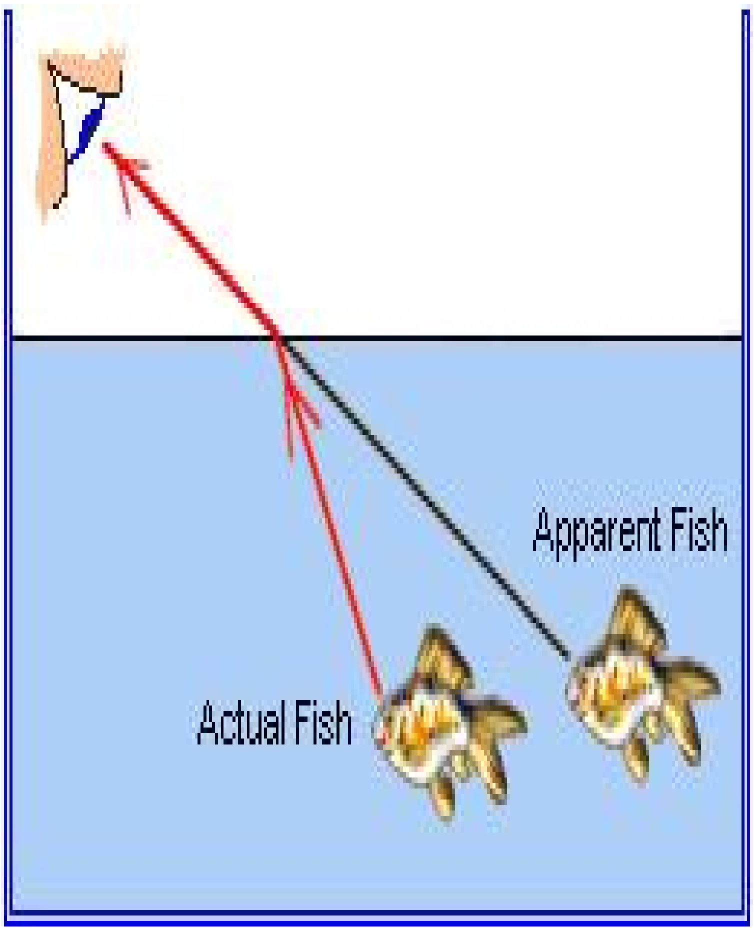
❖ Where λ_0 is the wavelength of light in vacuum. The frequency of light is unchanged as the light moves from one medium to the other.



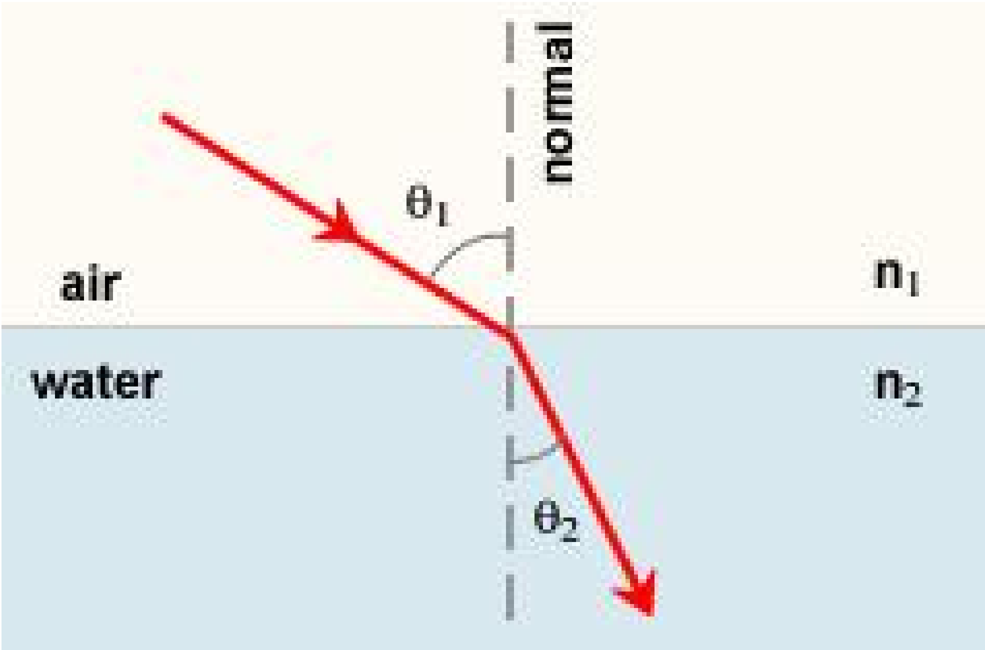
Concept of Refraction

❖ Refraction occurs because a wave front moving from air to water at an angle to the water's surface does not reach the water all at once.





Snell's Law



$$n_1\sin(\theta_1) = n_2\sin(\theta_2)$$

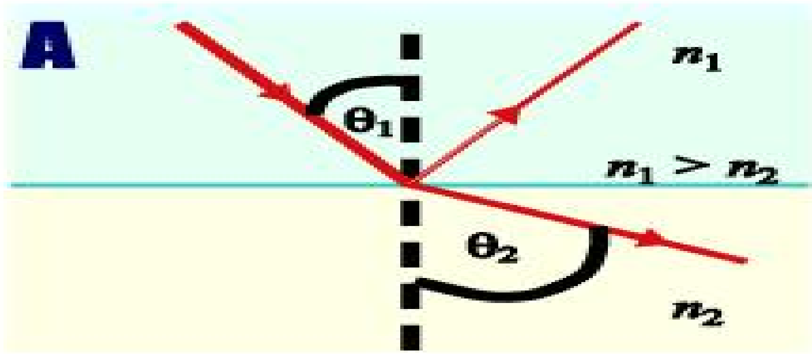
n_1 : The refractive index of the medium the light is leaving.

θ_1 : The incident angle between the light beam and the normal (normal is 90° to the interface between two materials).

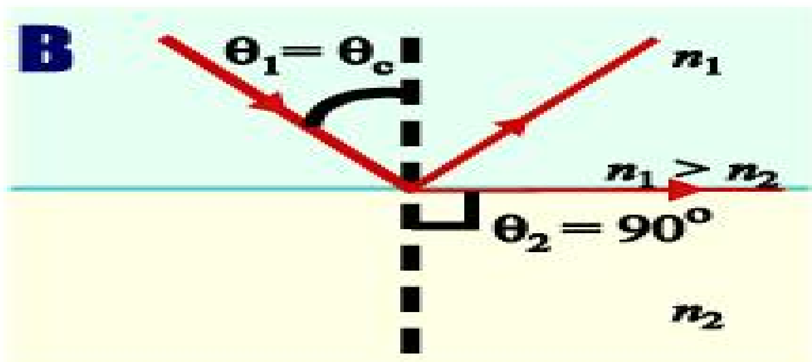
n_2 : The refractive index of the material the light is entering.

θ_2 : The refractive angle between the light ray and the normal.

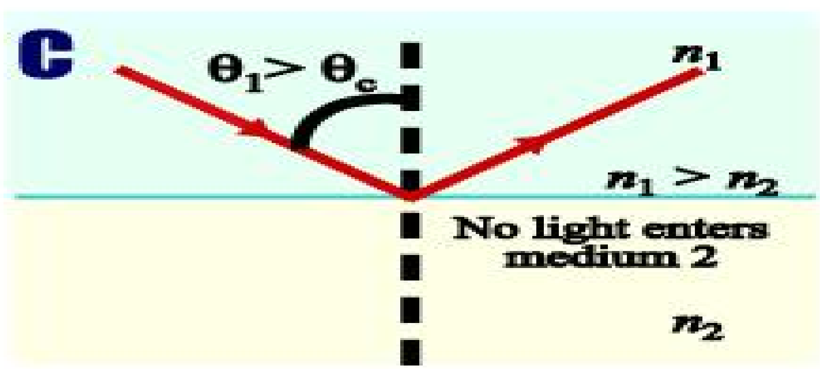
Concept of total internal reflection



A. When light travels from a denser medium to a rarer medium, it bends away from the normal.

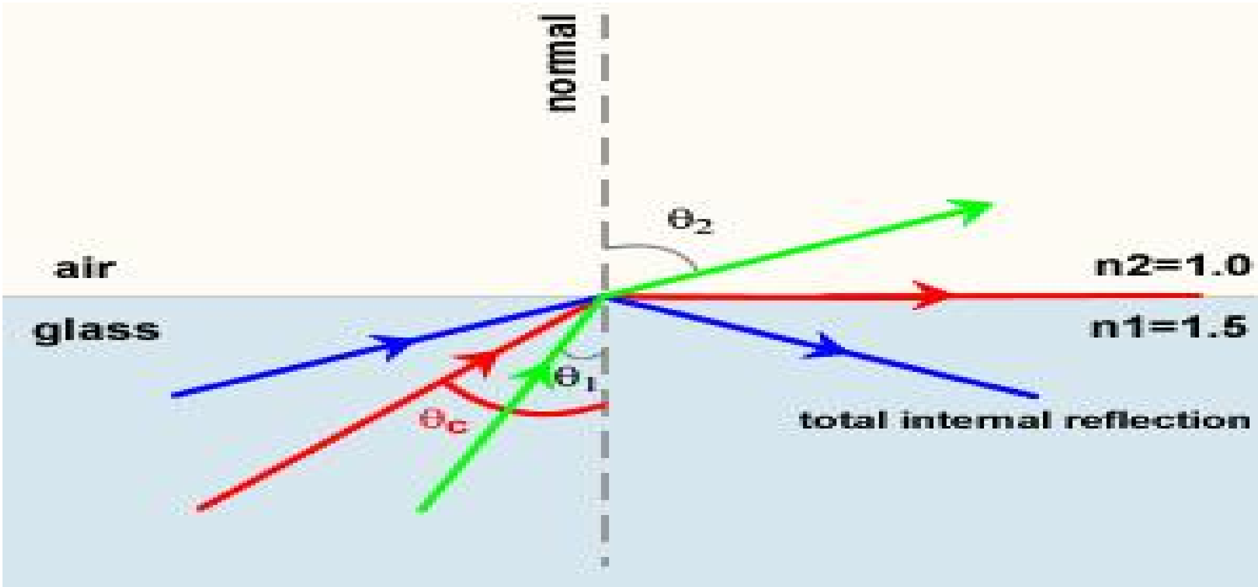


B. Since the angle in the second medium is greater than the angle in the first medium, it can become as large as 90 degrees. When this occurs, the first angle is called the **critical angle** and is represented as $\boldsymbol{\theta_c}$.



C. If the angle θ_1 in the first medium is larger than the critical angle, no light makes it into the second medium. This condition is called **total internal reflection (TIR)**.

Critical angle



$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\sin\theta_1 = \boldsymbol{(n_2/n_1)} \sin\theta_2$$

$$\theta_1 = \sin^{-1}[(n_2/n_1) * \sin\theta_2]$$

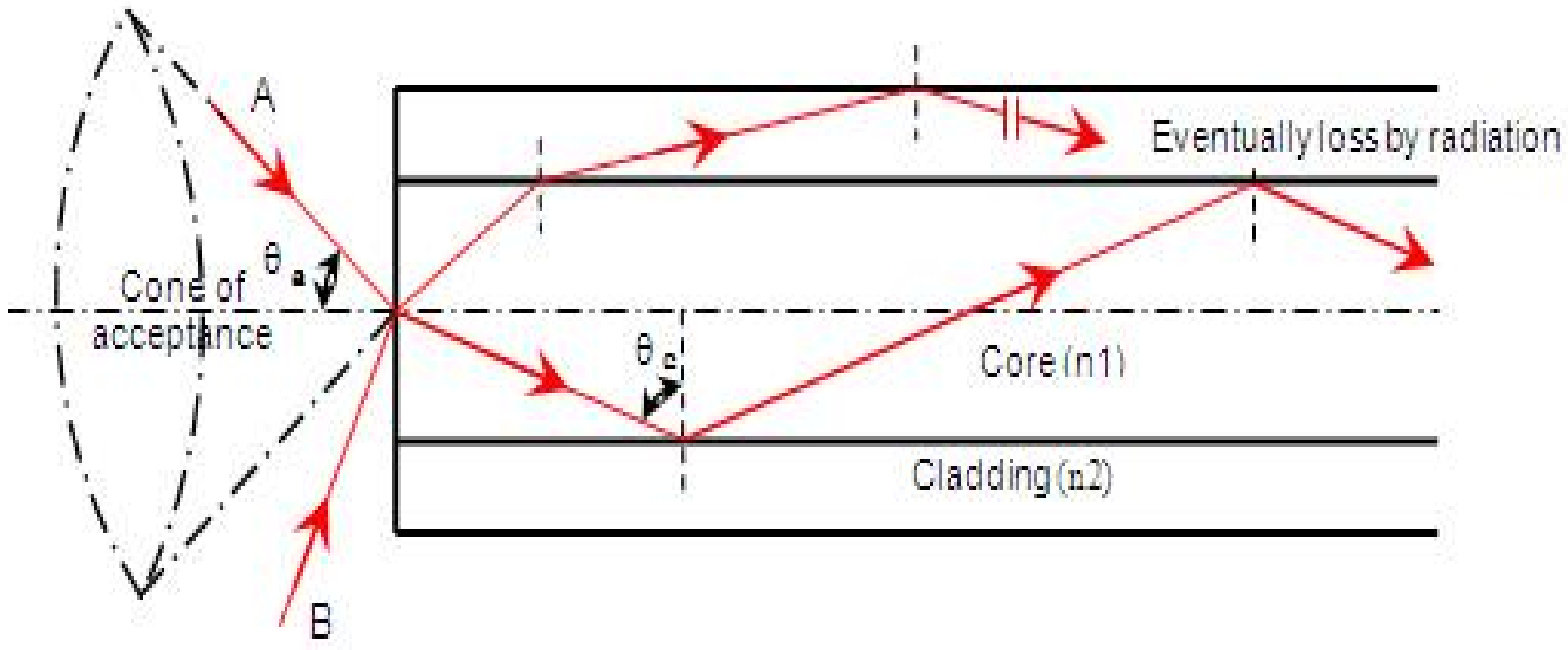
Since $\theta_2 = 90°$

$$\boxed{\boldsymbol{\theta_c = \theta_1 = \sin^{-1}(n_2/n_1)}}$$

Sample Problem

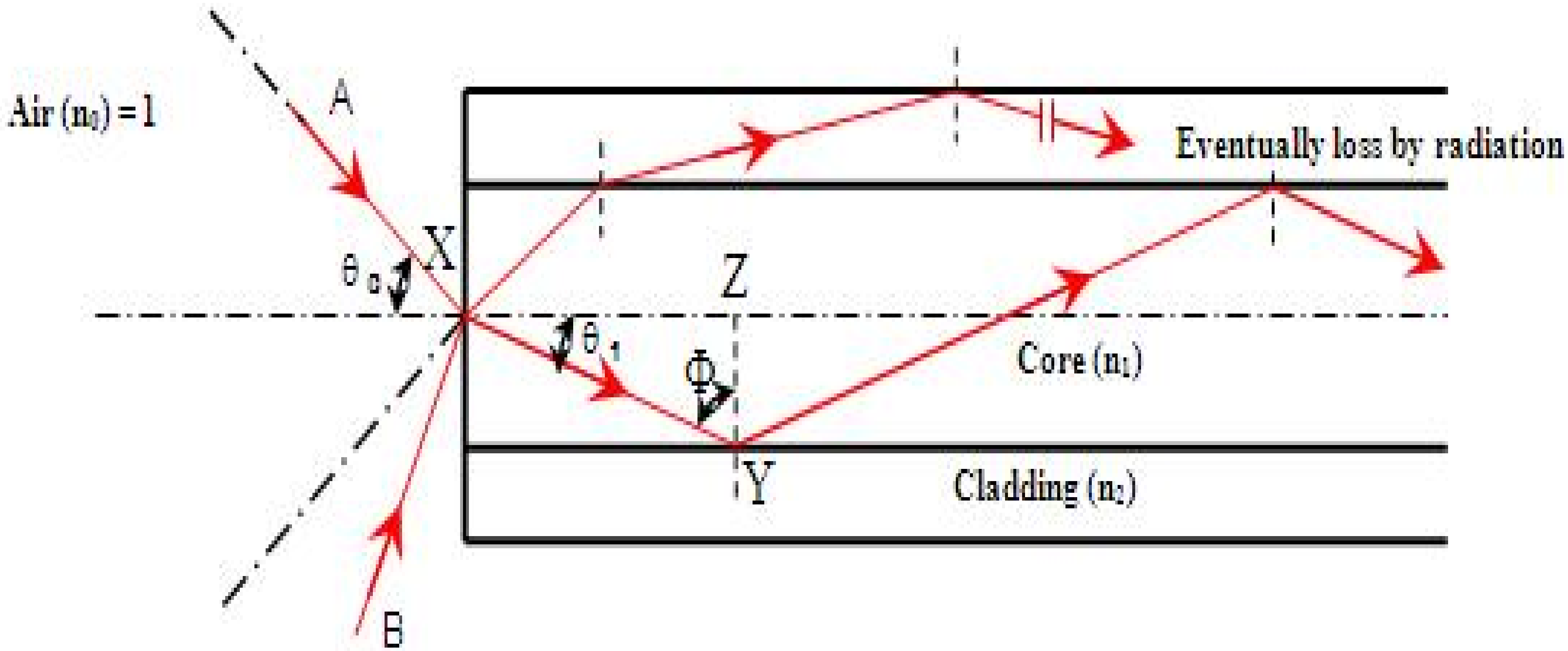
You are approached by a man on the street who offers to sell you a rather impressive “genuine diamond.” He produces a certificate of authenticity while telling you of the hardships forcing him to part with his wife’s engagement stone (a family heirloom). Being skeptical, you decide to verify the composition of the stone with the laser pointer attached to your key ring. (a) What is the critical angle for a diamond/air interface? For a glass/air interface? (b) How could you use this information to determine the composition of the stone?

Acceptance angle and the Cone of Acceptance



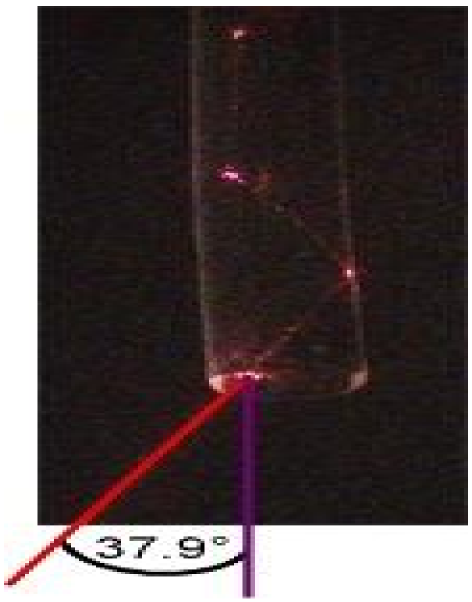
θ_a is a maximum angle w.r.t the axis of optical fiber at which the light may enter into the fiber in order to propagate it by total internal reflection. This angle is called **acceptance angle**.

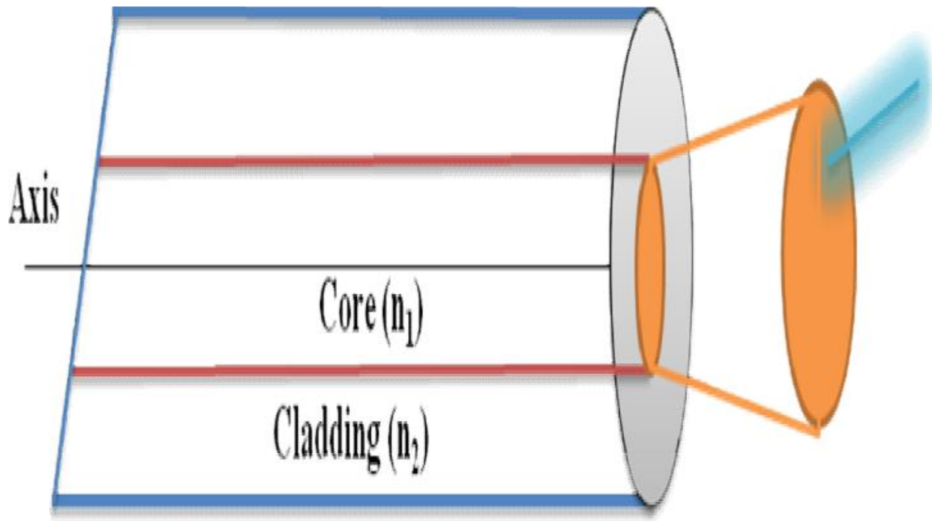
Numerical aperture calculation

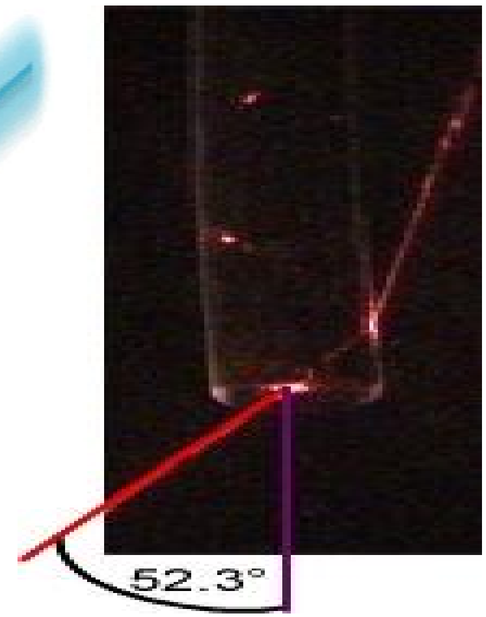


$$\boxed{n_0 \sin \theta_a = (n_1^2 - n_2^2)^{1/2} = NA}$$

What happens when light incident on fiber with acceptance angle is 40 ° ?







(a) an entrance angle of 37.9° results in the light being trapped within the water- clad fiber.

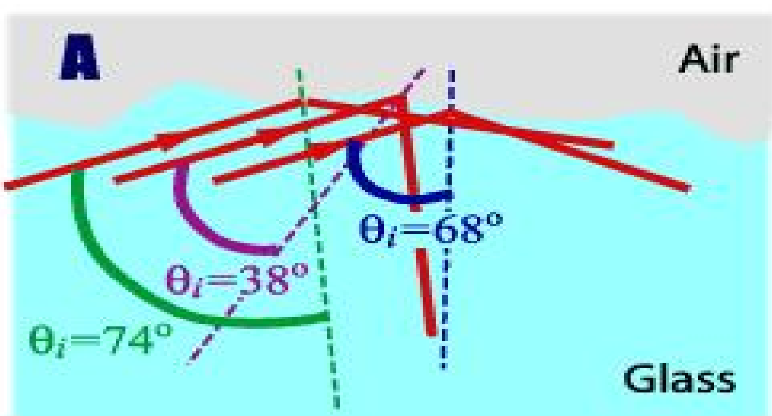
(b) This entry angle of 52.3 ° is outside the cone of acceptance, so light escapes the water-clad fiber.

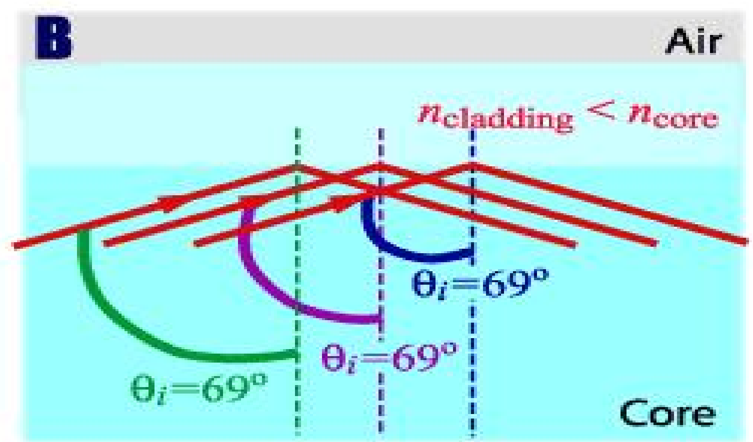
Adding a Cladding

The optical fibers use at least two layers of different transparent media. This is done for two primary reasons:

A. To protect the reflecting edge of the inner layer from chipping.

B. To reduce the size of the cone of light that will be trapped in the fiber.

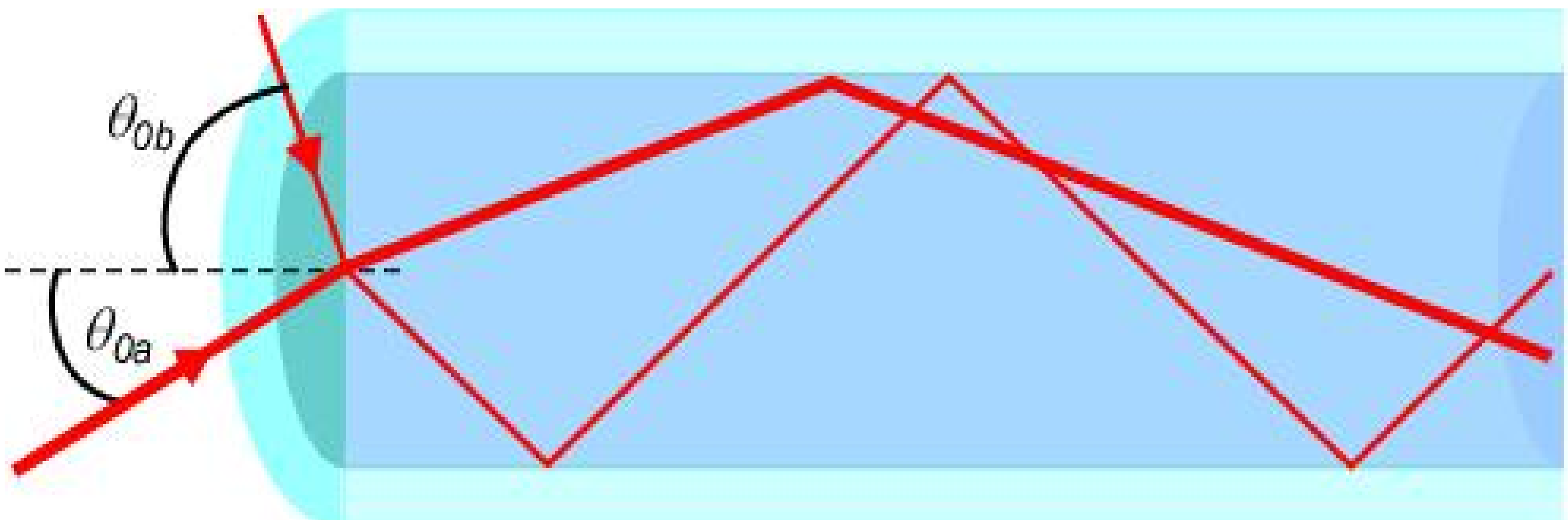




Continued…….

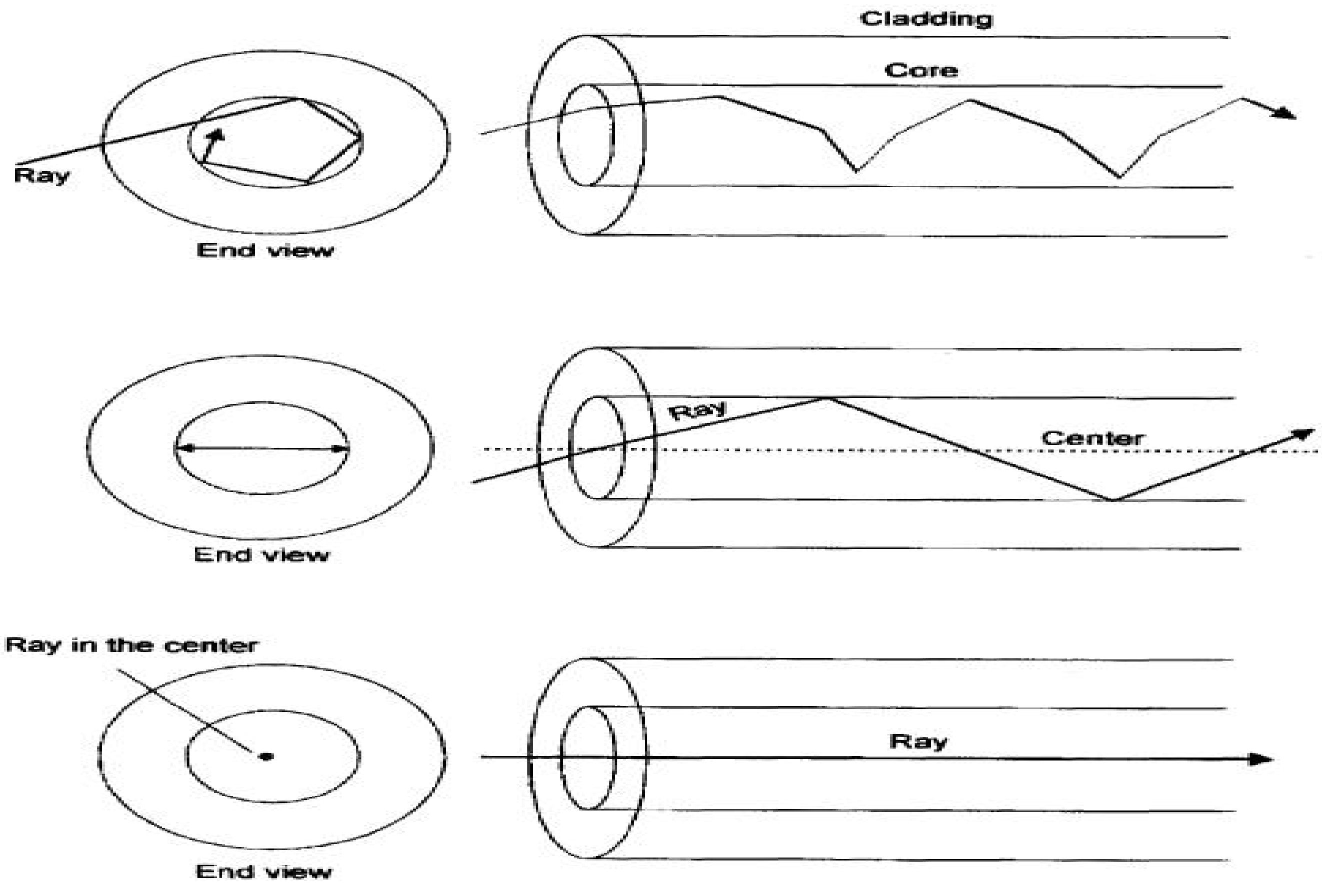
➢ Fibers with a cladding are able to carry information at a much higher bit rate than those without a cladding.

➢ A pulse sent using a large cone of acceptance will thus spread out more than a pulse sent using a narrow cone of acceptance, limiting how quickly the next pulse can be sent.



Names given to different rays

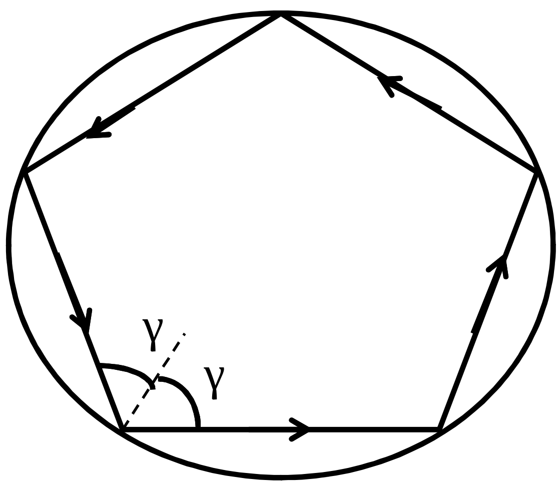
- The skew ray does not pass through the center (top).
- The meridional ray passes through the center (middle).
- The axial ray stays in the center all the time (bottom).



Numerical: 1. An optical fiber has N.A. of 0.4 determine acceptance angle for meridional and skew ray. The skew ray changes the direction by 100^0 with each reflection.

2. Optical fiber has refractive index of core as 1.55 and that of cladding is 1.52. The skew ray change its direction by 150^0 with each reflection calculate N.A. of optical fiber required for skew and meridional ray

Hints for the numerical

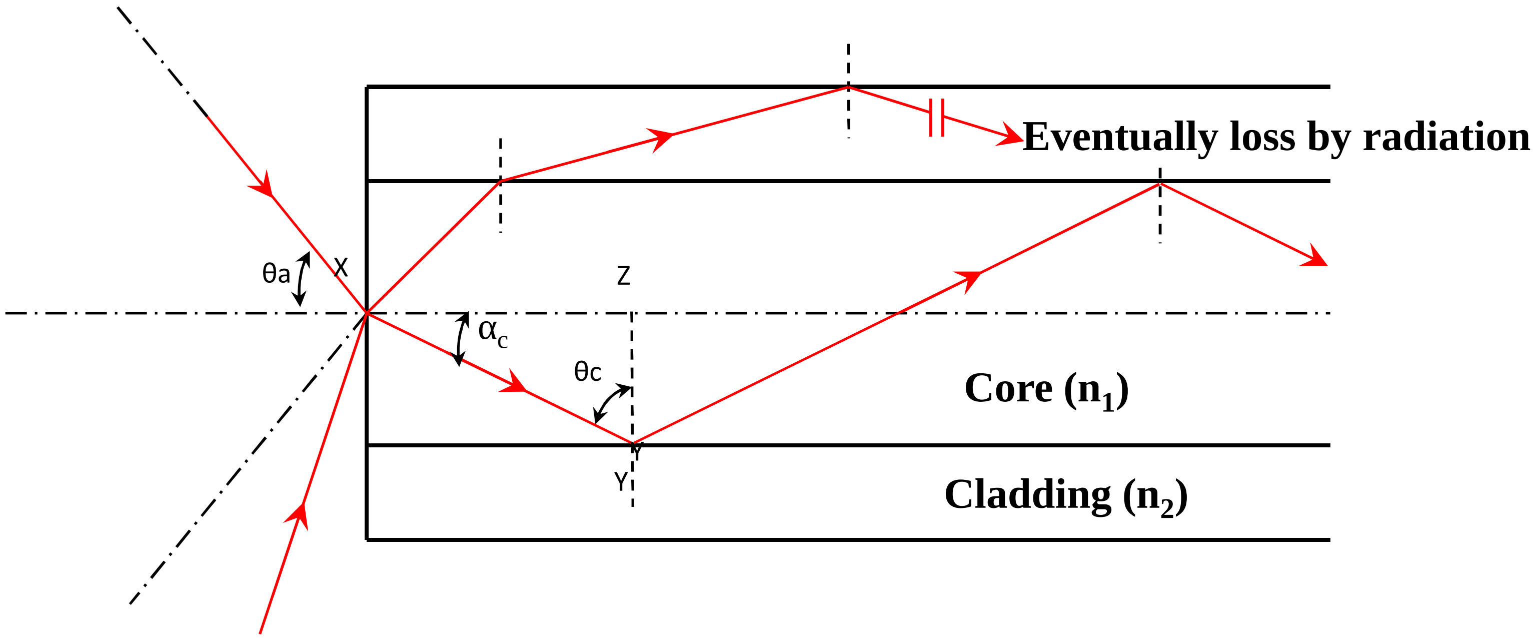


For skew ray's

$$\mathbf{NA = n_0 \sin \theta_a \; \cos \gamma \quad and}$$

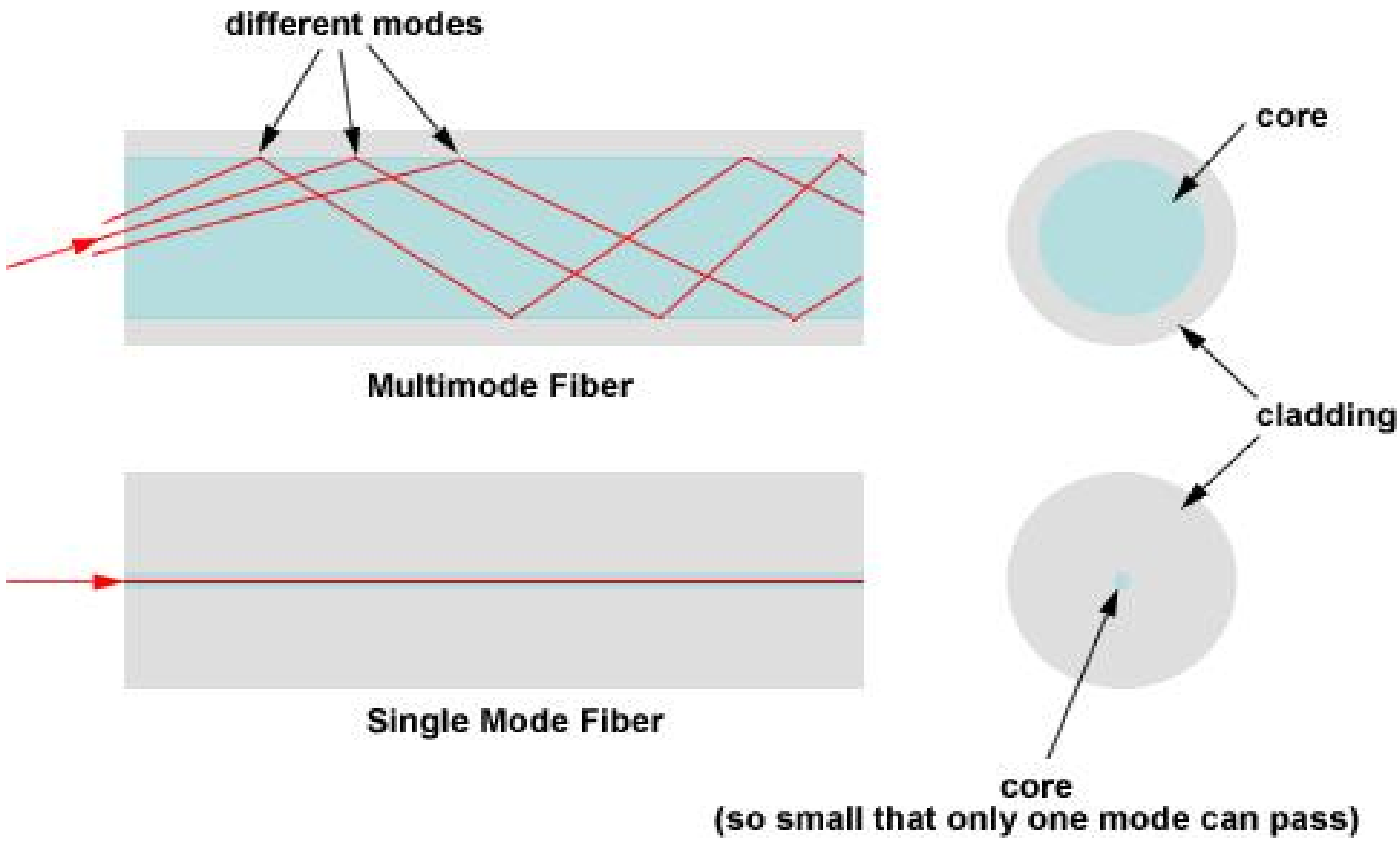
$$\mathbf{\gamma = ((change\ in\ direction\ with\ each\ reflection)\ /2\ )}$$

Critical angle of propagation

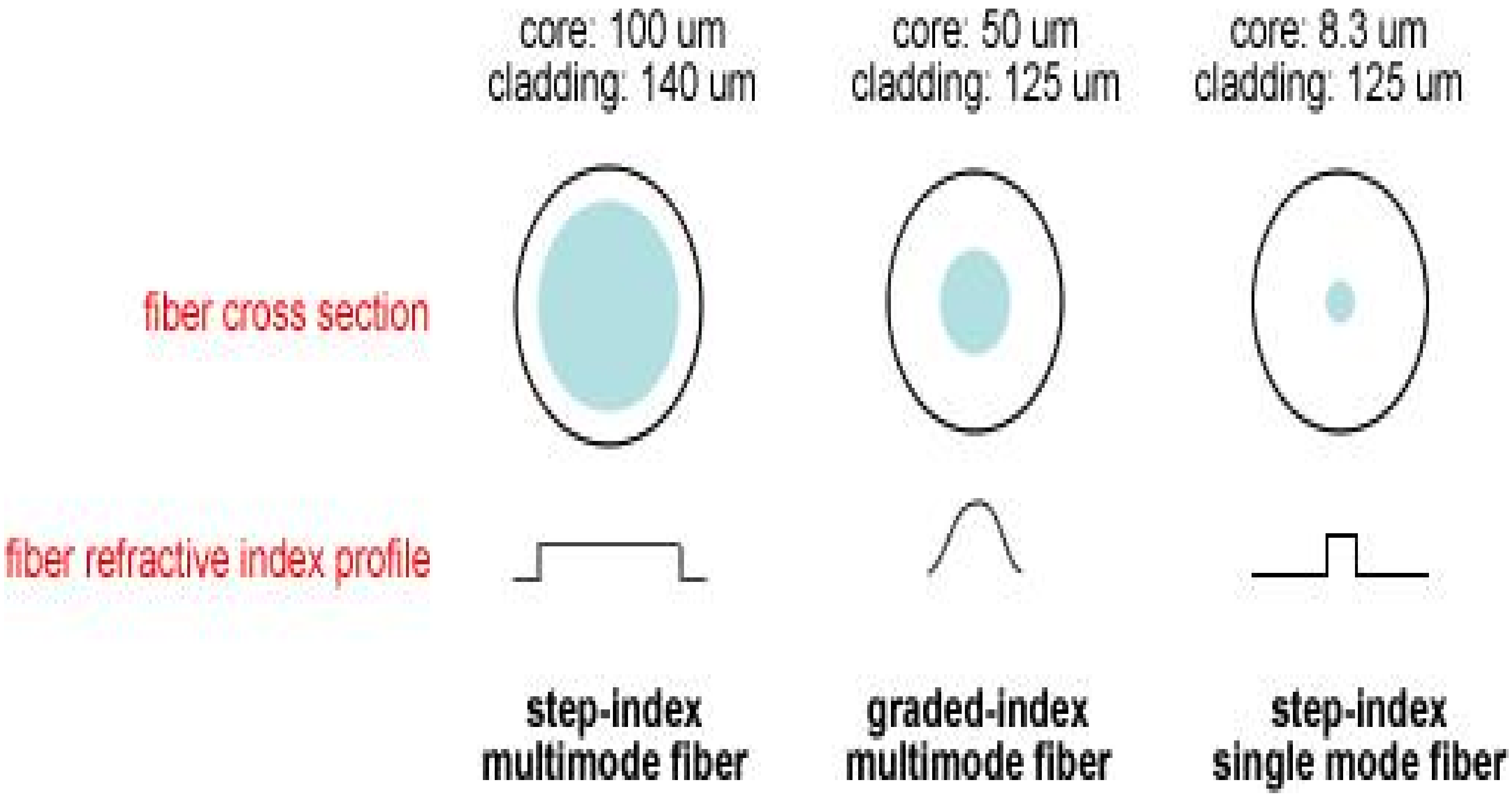


$$\alpha_c = \sin^{-1}\left(\sqrt{1-\left(\frac{n_2}{n_1}\right)^2}\right)$$

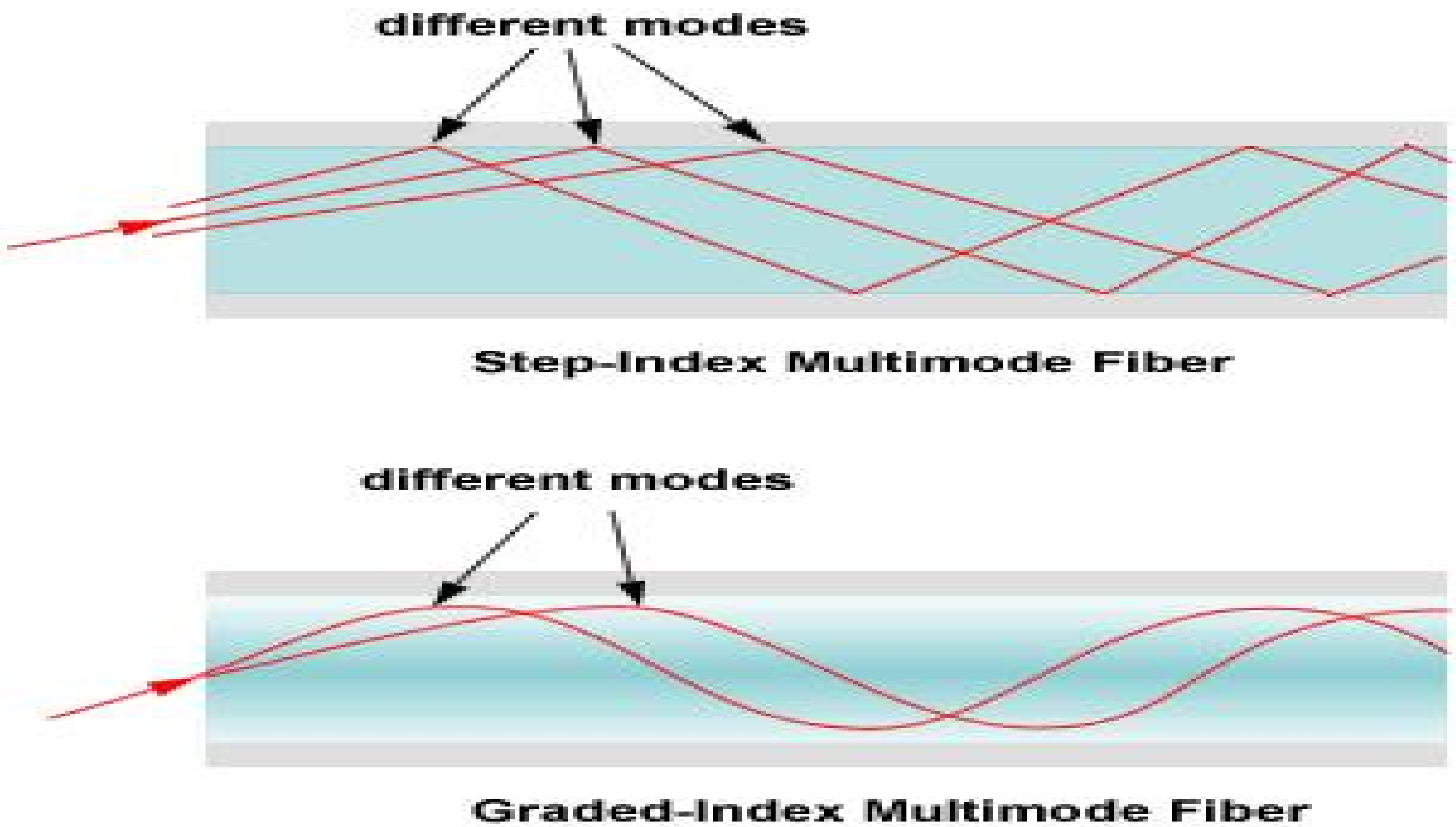
Multimode and single mode fiber



Different optical fiber index profiles



Light transmission in a step-index multimode fiber and a graded-index multimode fiber



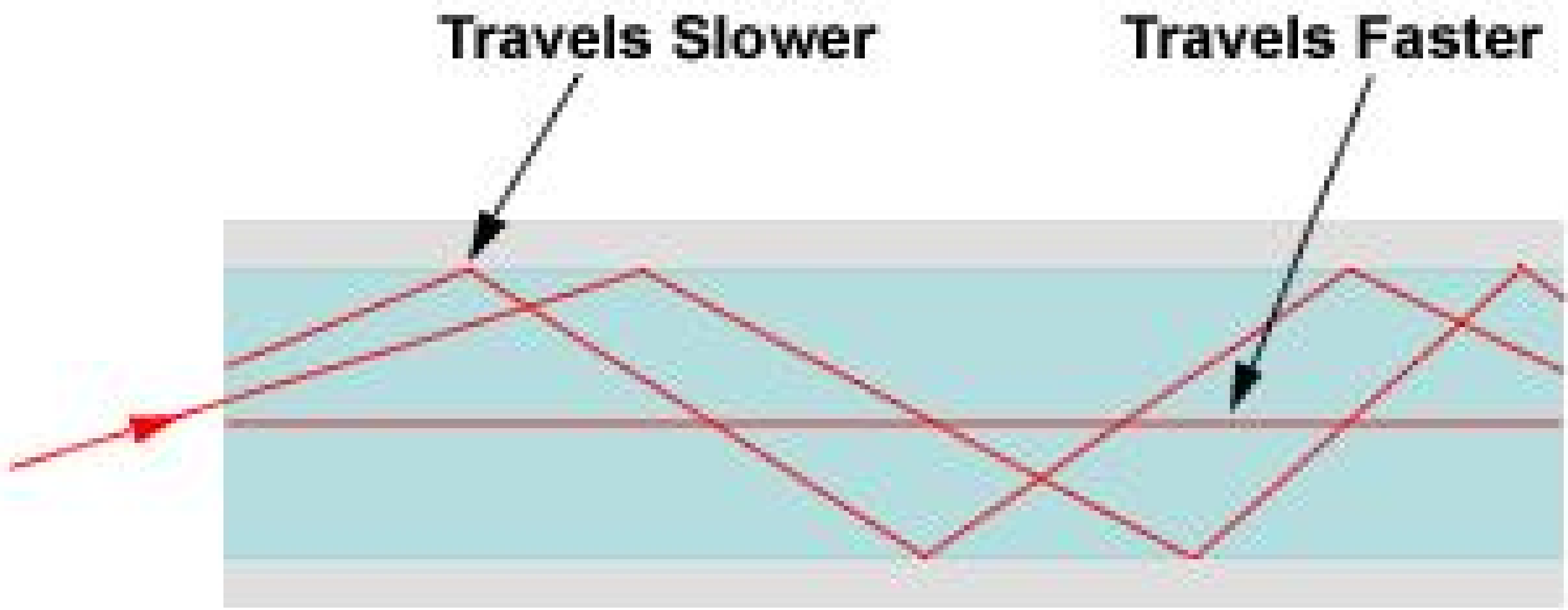
Modal-Dispersion and Limit on Step-Index Multimode Fibers Bandwidth

- Rays that enter with a shallower angle travel by a more direct path, and arrive sooner than those enter at steeper angles (which reflect many more times off the core/cladding boundaries as they travel the length of the fiber).
- The arrival of different modes of the light at different times is called **Modal Dispersion**.
- Modal Dispersion is also called modal distortion, multimode dispersion, intermodal distortion, intermodal dispersion, and intermodal delay distortion.

Continued…….

- Digital communications use light pulse to transmit signal down the length of the fiber.
- Modal dispersion causes pulses to spread out as they travel along the fiber, the more modes the fiber transmits, the more pulses spread out.
- This significantly limits the bandwidth of step-index multimode fibers. Typical step-index multimode fiber with a 50 µm core would be limited to approximately 20 MHz for a 1 Km length, in other words, a bandwidth of 20 MHz·km.

Step index multimode fiber



Step-Index Multimode Fiber

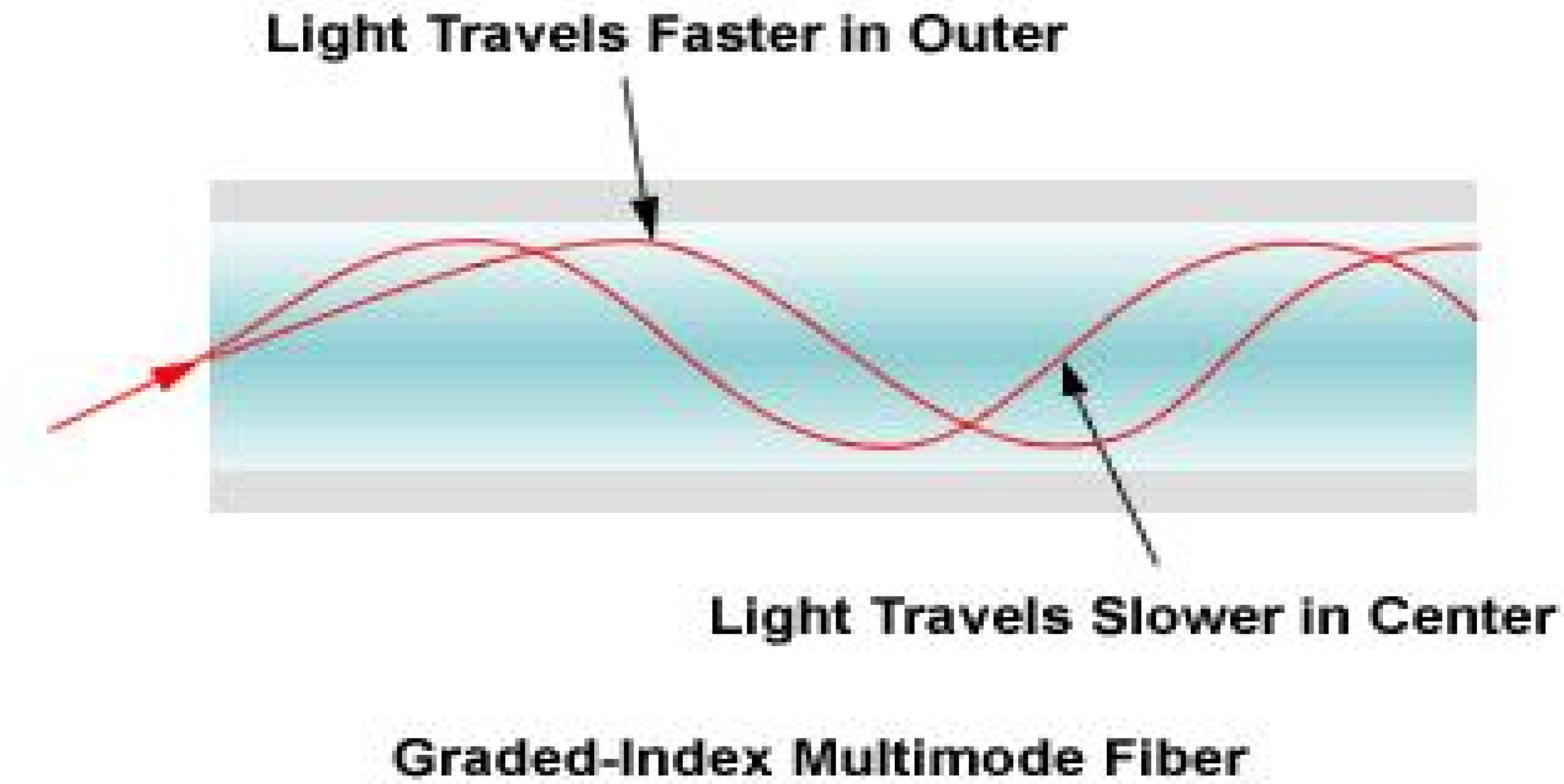
Graded-Index Multimode Fibers Solves the Problem of Modal Dispersion

- Graded-index fiber's R.I. decreases gradually away from its center, finally dropping to the same value as the cladding at the edge of the core.
- However their speeds differ because the speed of guided light changes with fiber core's refractive index.
- Different light modes in a graded-index multimode fiber still follow different lengths along the fiber, as in step-index multimode fiber.
- This equalizing of transit times of different modes greatly reduces modal dispersion.

Continued…….

- The bandwidth of a typical shelf graded-index multimode fiber with a 50 μm core may approach 1 GHz·km or more. Multimode graded-index fibers having bandwidths approaching 3 GHz·km have been produced.
- But please note that modal dispersion may be considerably reduced, but never completely eliminated.

Graded index multimode fiber



Advantages of Single Mode Fiber

- ❖ Single mode fiber does not have modal dispersion, modal noise, and other effects that come with multimode transmission.
- ❖ Single mode fiber can carry signals at much higher speeds than multimode fibers.
- ❖ They are standard choice for high data rates or long distance span (longer than a couple of kilometers) telecommunications which use laser diode based fiber optic transmission equipment.

Disadvantages of Single Mode Fiber

- ❖ Since single mode fiber's core is so much smaller than a multimode fiber's core, coupling light into single mode fiber requires much tighter tolerances than coupling light into the larger cores of multimode fiber.
- ❖ Single mode fiber components and equipment are also more expensive than their multimode counterparts, so multimode fibers are widely used in systems where connections must be made inexpensively and transmission distances and speeds are modest.


Thank You