Introduction

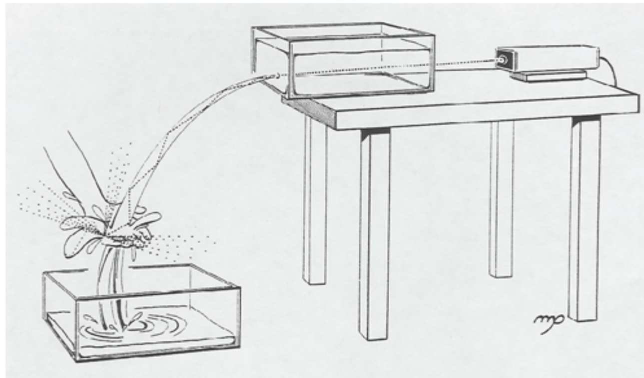


Figure-1

Figure-2

Chelonia mydas

What phenomenon in Physics is associated with the above pictures?

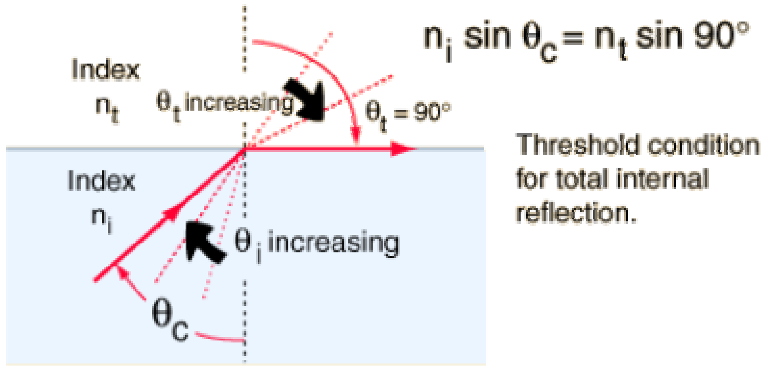
Learning Objectives

On completion of this topic you will be able to:

1. What is the basic principle of fiber optic communication? Explain it.
2. Explain the structure of fiber optic cable?
3. Definition for Numerical aperture and Acceptance angle.
4. Derivation of expression for Numerical aperture and Acceptance angle.

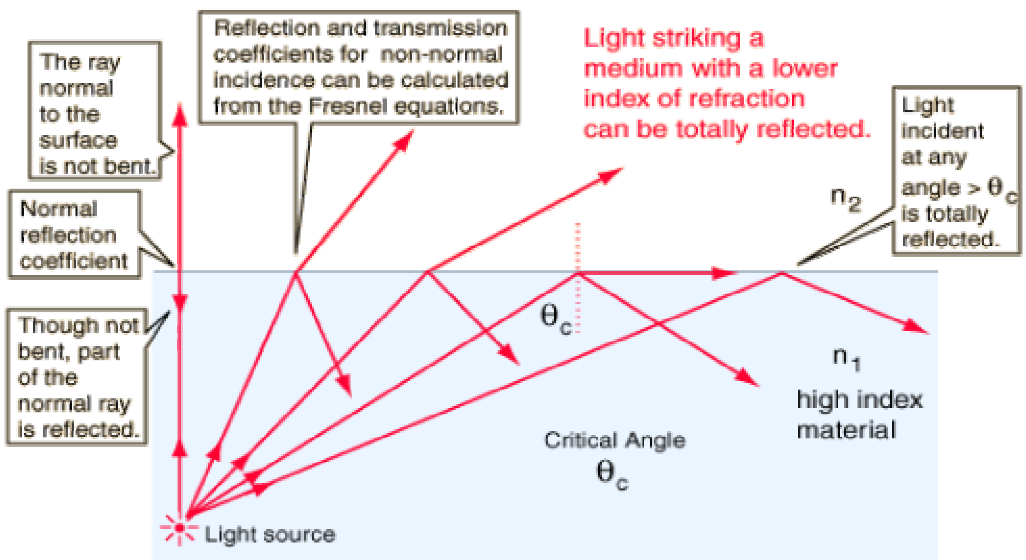
Total internal reflection.

When light is incident upon a medium of lesser index of refraction, the ray is bent away from the normal, so the exit angle is greater than the incident angle. Such reflection is commonly called "internal reflection". The exit angle will then approach 90° for some critical incident angle θ_c, and for incident angles greater than the critical angle there will be total internal reflection.



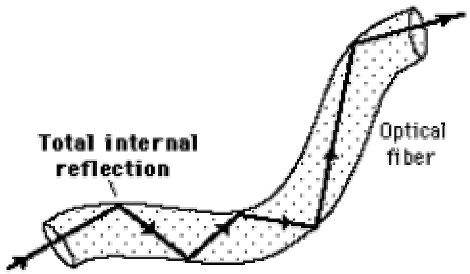
The critical angle can be calculated from Snell's law by setting the refraction angle equal to 90°. Total internal reflection is important in fiber optics and is employed in polarizing prisms.

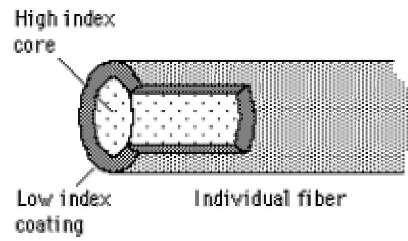
For any angle of incidence less than the critical angle, part of the incident light will be transmitted and part will be reflected.



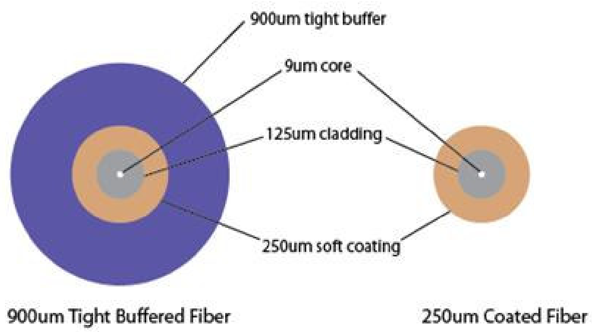
Total internal reflection in fiber optics

The field of fiber optics depends upon the total internal reflection of light rays traveling through tiny optical fibers. The fibers are so small that once the light is introduced into the fiber with an angle within the boundaries of the numerical aperture of the fiber, it will continue to reflect almost lossless off the walls of the fiber and thus can travel long distances in the fiber. Bundles of such fibers can accomplish imaging of otherwise inaccessible areas.



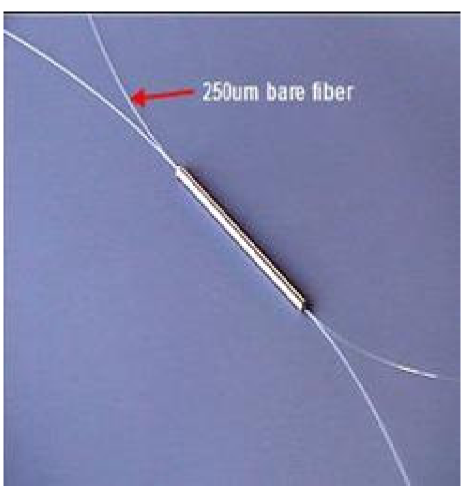


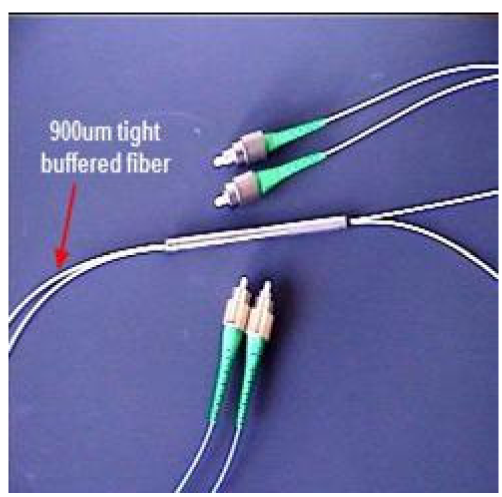
Basic structure of a fiber optic cable

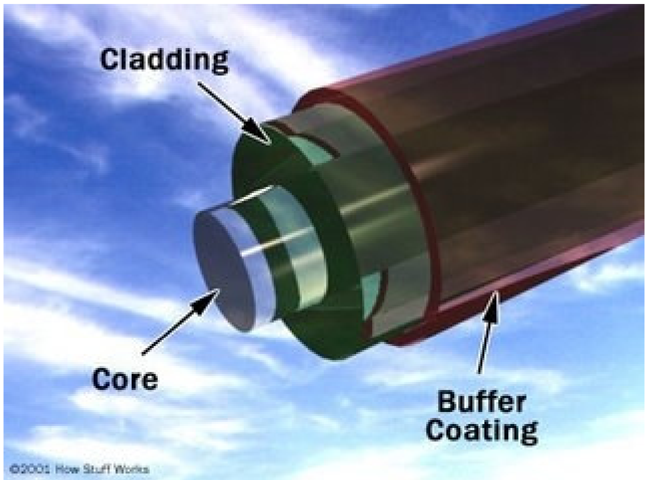


Note: Coated fiber is also called "bare fiber"

The Difference Between Tight Buffered Fiber and Coated Fiber

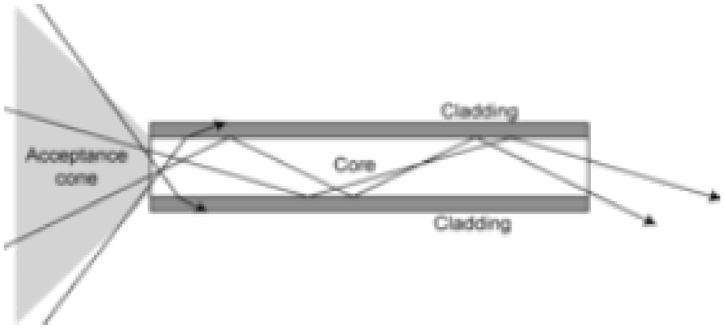






A practical optical fiber has in general three coaxial regions. The innermost region is the light guiding region called the core. It is surrounded by a coaxial middle region called the cladding. The outermost coaxial region is called the sheath. The refractive index of cladding is always lower than that of core. The purpose of the cladding is to make the light to be confined to the core. Light launched into the core and striking the core to cladding interface at greater than critical angle will be reflected back into the core. Since the angles of incidence and reflection are equal, the light will continue to rebound and propagate through the fiber. The sheath protects the cladding and the core from abrasions, contaminations and the harmful influence of moisture. In addition, it increases the mechanical strength of the fiber.

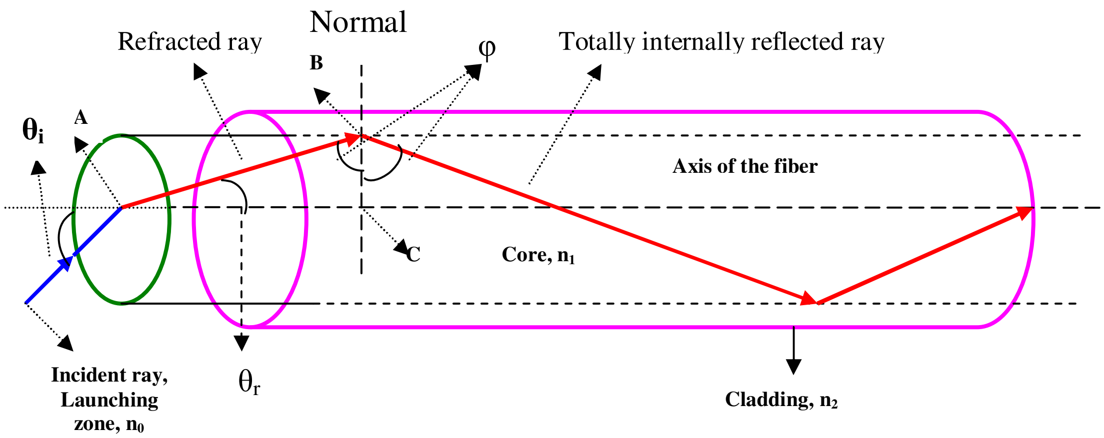
Propagation of light through a cladded fiber:



Refractive index of the light ray launching medium = n_0 ; Refractive index of the core material = n_1 ; Refractive index of the cladding material = n_2

Angle of incidence = θ_i ; Angle of refraction = θ_r

The refracted ray strikes the core-cladding interface at an angle 'φ' greater than critical angle of incidence 'φ_c' and therefore the ray undergoes total internal reflection at the interface, since 'n_1'> 'n_2'. As long as the angle 'φ' greater than critical angle of incidence 'φ_c', the light ray will stay within the core of the fiber.



Applying Snell's law at the point 'A',

$$\frac{\sin\theta_i}{\sin\theta_r} = \frac{n_1}{n_0}$$

If θ_i is increased beyond a limit, 'φ' will drop below the critical value 'φ_c' and the ray escapes from the side walls of the fiber. The largest value of 'θ_i' occurs when $\varphi=\varphi_c$. From the right angle triangle ABC, sin θ_r = sin (90 - φ) = cos φ

$$\sin\theta_i = \frac{n_1}{n_0}\cos\varphi$$

When $\varphi=\varphi_c$,

$$\sin[\theta_i(max)] = \frac{n_1}{n_0}\cos\varphi_c$$

Applying Snell's law at the point 'B',

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

$$\cos\varphi_c = \frac{\sqrt{n_1^2-n_2^2}}{n_1}$$

$$\sin[\theta_i(max)] = \frac{\sqrt{n_1^2-n_2^2}}{n_0}$$

Let θ_i (max) $=\theta_0$. The angle θ_0 is called 'Acceptance angle'.

Acceptance angle

$$\theta_0 = \sin^{-1}\left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right]$$

Acceptance angle is defined as the maximum angle that a light ray can have relative to the axis of the fiber and propagate down the fiber.

The light rays contained within the cone having a full angle $2\theta_0$ are accepted and transmitted along the fiber. Therefore the cone is called 'Acceptance cone'.

Numerical Aperture

The numerical aperture is defined as the sine of the acceptance angle. Thus,

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

Numerical aperture is a measure of the amount of light that can be accepted by a fiber.

If the light ray launching zone is air medium, $n_0=1$

$$NumericalAperture(NA) = \sin\theta_0 = \sqrt{n_1^2 - n_2^2}$$

Then, the numerical aperture depends only on the refractive index of the core and the cladding. Its value ranges from 0.13 to 0.50. A large numerical aperture implies that a fiber will accept large amount of light from the source.

Check your understanding

1. What is law of reflection?
2. What is refraction?
3. Explain Snell's law.

Check the correct answers on pages 8 and 9.

Summary

On completion of this chapter you have learned that:

1. Total internal reflection is the basic principle of fiber optic communication.

2. A practical optical fiber has in general three coaxial regions. The innermost region is the light guiding region called the core. It is surrounded by a coaxial middle region called the cladding. The outermost coaxial region is called the sheath. The refractive index of cladding is always lower than that of core. The purpose of the cladding is to make the light to be confined to the core.

3. Acceptance angle

$$\theta_0 = \sin^{-1}\left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0}\right]$$

Acceptance angle is defined as the maximum angle that a light ray can have relative to the axis of the fiber and propagate down the fiber.

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4 .Numerical Aperture

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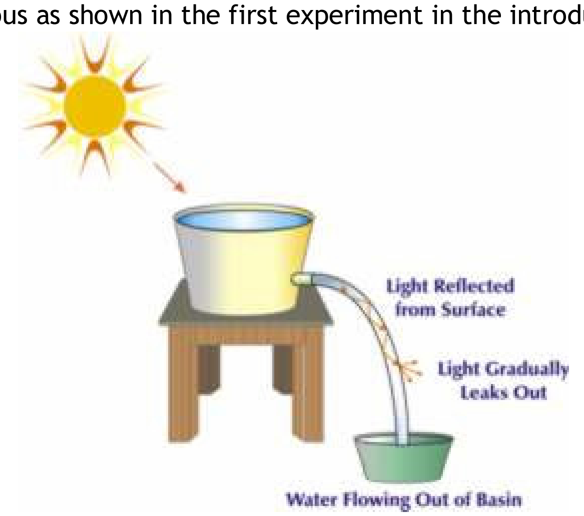
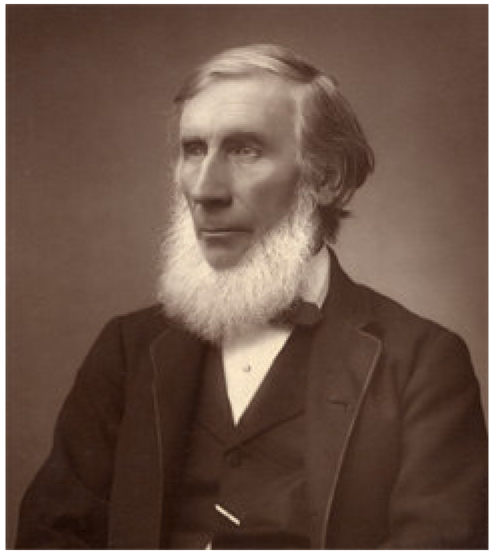
Activity

1. You can see colorful luminous fountains of water in public gardens.
2. We can see how light gets confined to the water stream owing to total internal reflection and the stream appears luminous as shown in the first experiment in the introduction.



3. As a token of gratefulness we can appreciate and salute John Tyndall, a British scientist for having given the wonderful idea of basic principle of optical fiber communication.



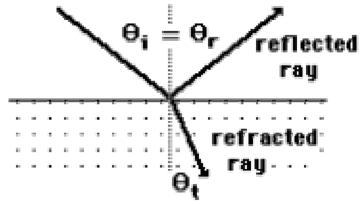
Born	August 2, 1820 Leighlinbridge, County Carlow, Ireland
Died	December 4, 1893 (aged 73) Surrey, England
Nationality	British
Fields	Natural sciences
Institutions	Royal Institution
Known for	Publication and education Tyndall effect

Suggested Reading

1. 'A TEXT BOOK OF ENGINEERING PHYSICS' by M.N Avadhanulu and P.G.Kshirsagar.
2. http://hyperphysics.phy-astr.gsu.edu/hbase/optmod/fibopt.html
3. http://en.wikipedia.org/wiki/Optical_fiber
4.

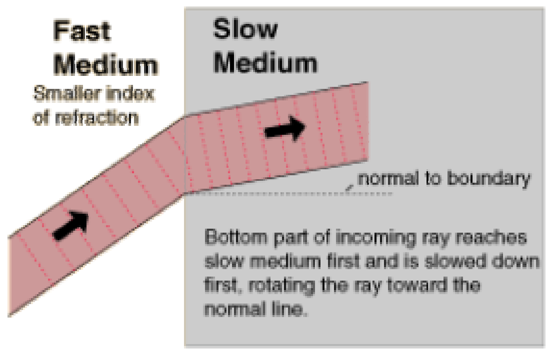
Answers to CYU.

1. The fact that the angle of incidence is equal to the angle of reflection is sometimes called the "law of reflection".



2. Refraction is the bending of a wave when it enters a medium where it's speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media. The amount of bending depends on the indices of refraction of the two media.

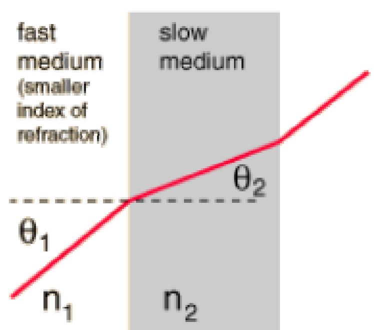
Refraction is responsible for image formation by lenses and the eye.



3. Snell's Law relates the indices of refraction n of the two media to the directions of propagation in terms of the angles to the normal. Snell's law can be derived from Fermat's Principle or from the Fresnel Equations.

Snell's Law

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



Answer to the question in the Introduction

The phenomenon in Physics which is associated with the pictures shown in the introduction (figure-1 and figure-2) is 'total internal reflection'. The water coming out of the vessel in figure-1 and Chelonia mydas and other things present in the vessel shown in figure-2 appear luminous owing to total internal reflection.