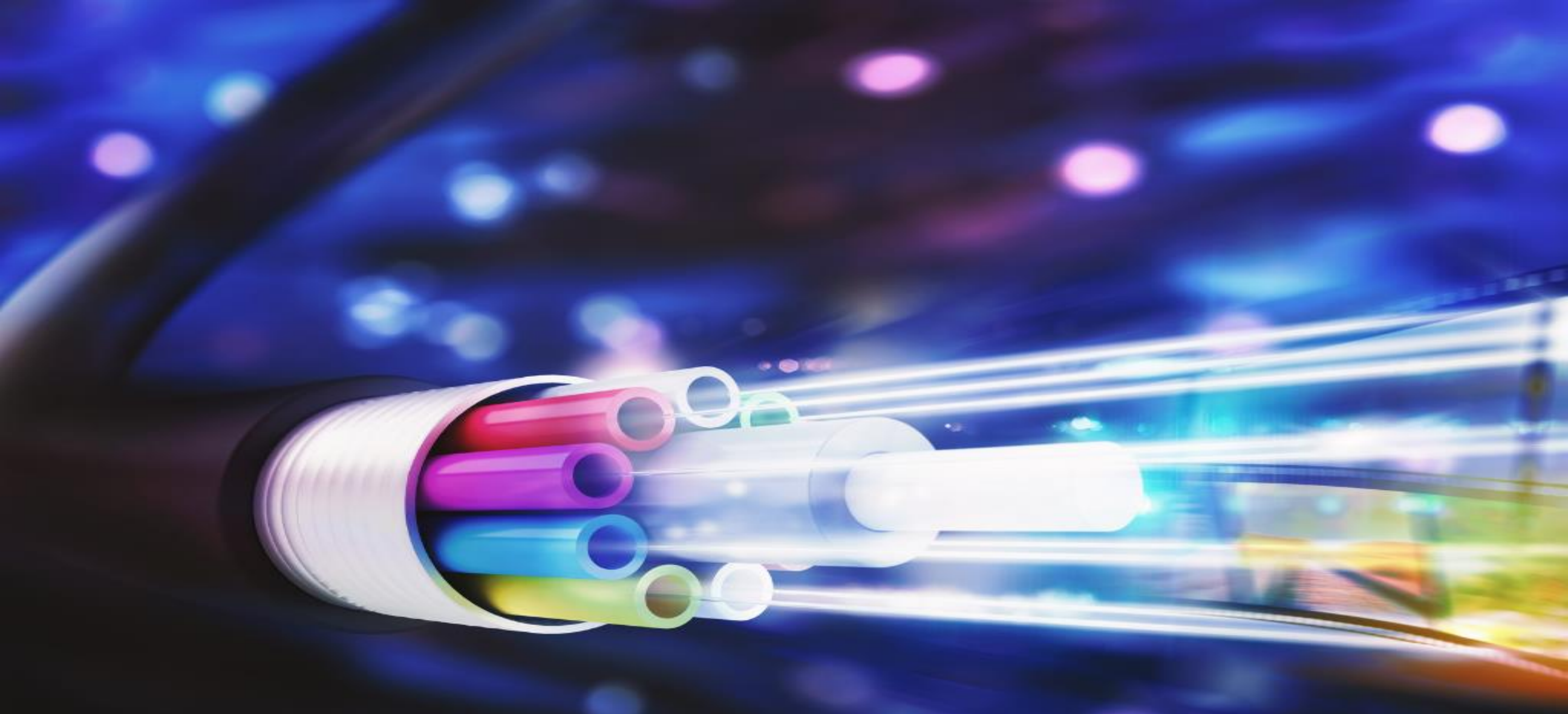
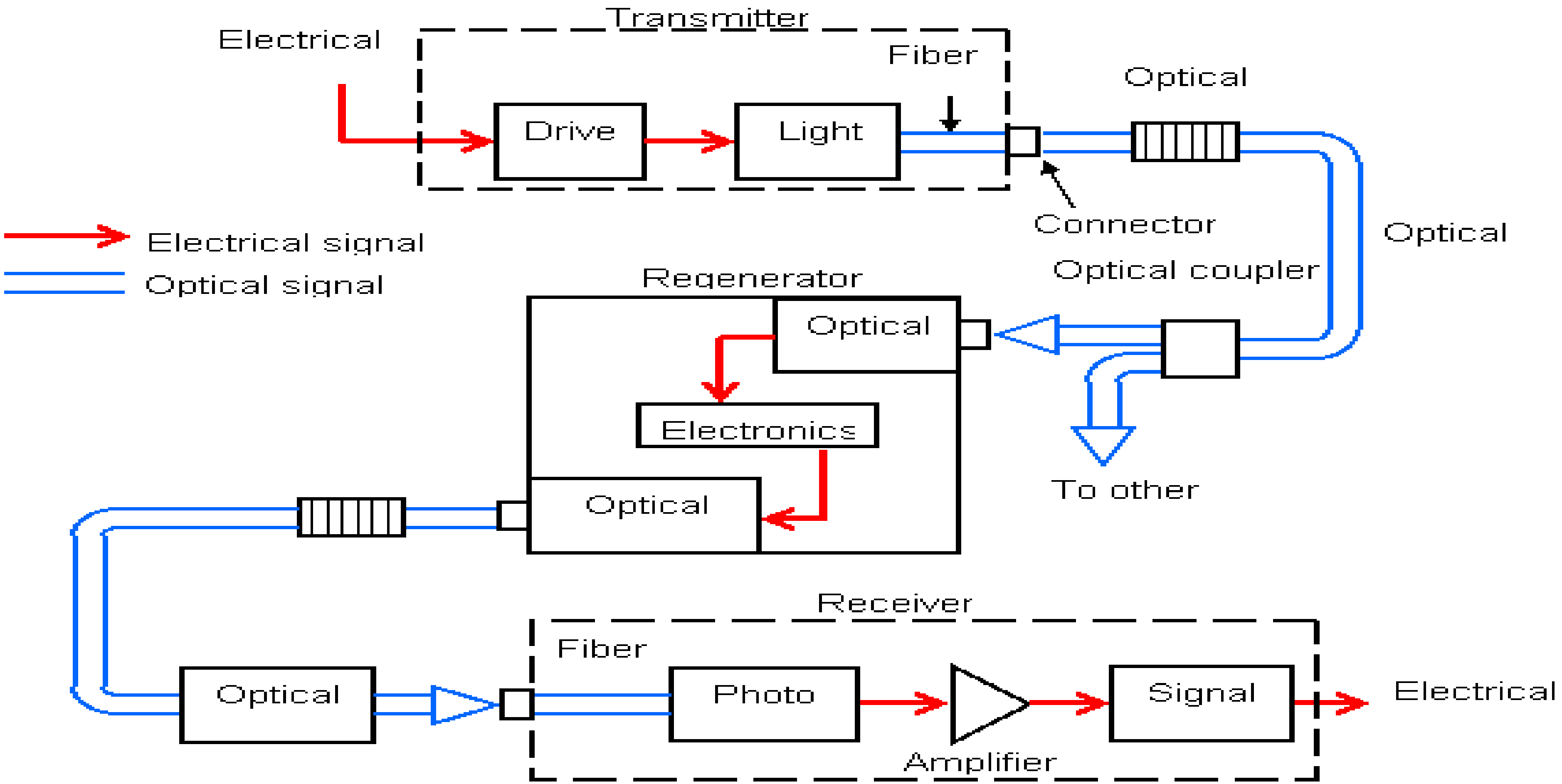
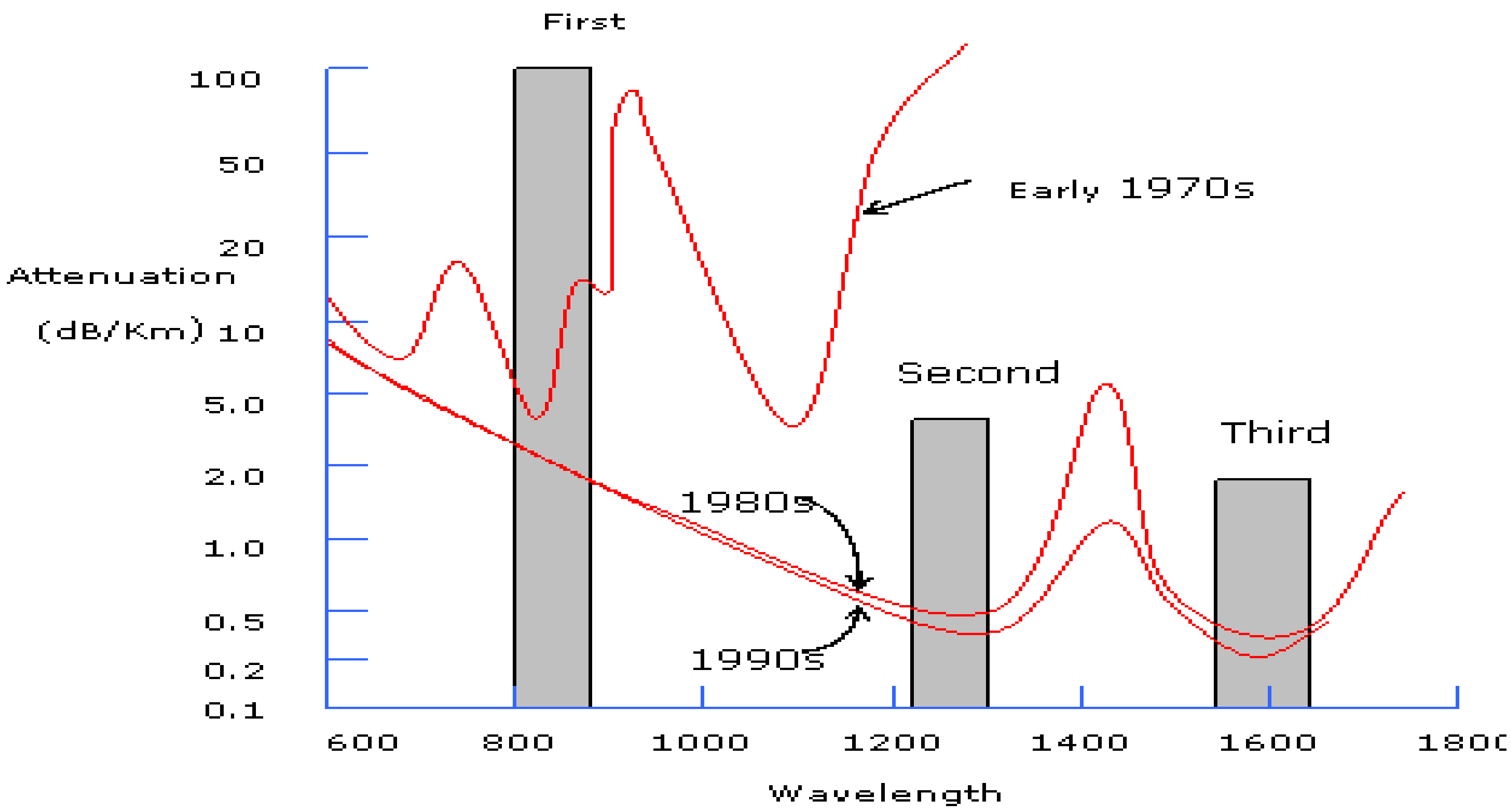


Module – 1
Optical Fiber: Structures, Waveguides

Basic block diagram of OCS



Attenuation as a function of wavelength



Electromagnetic Waves

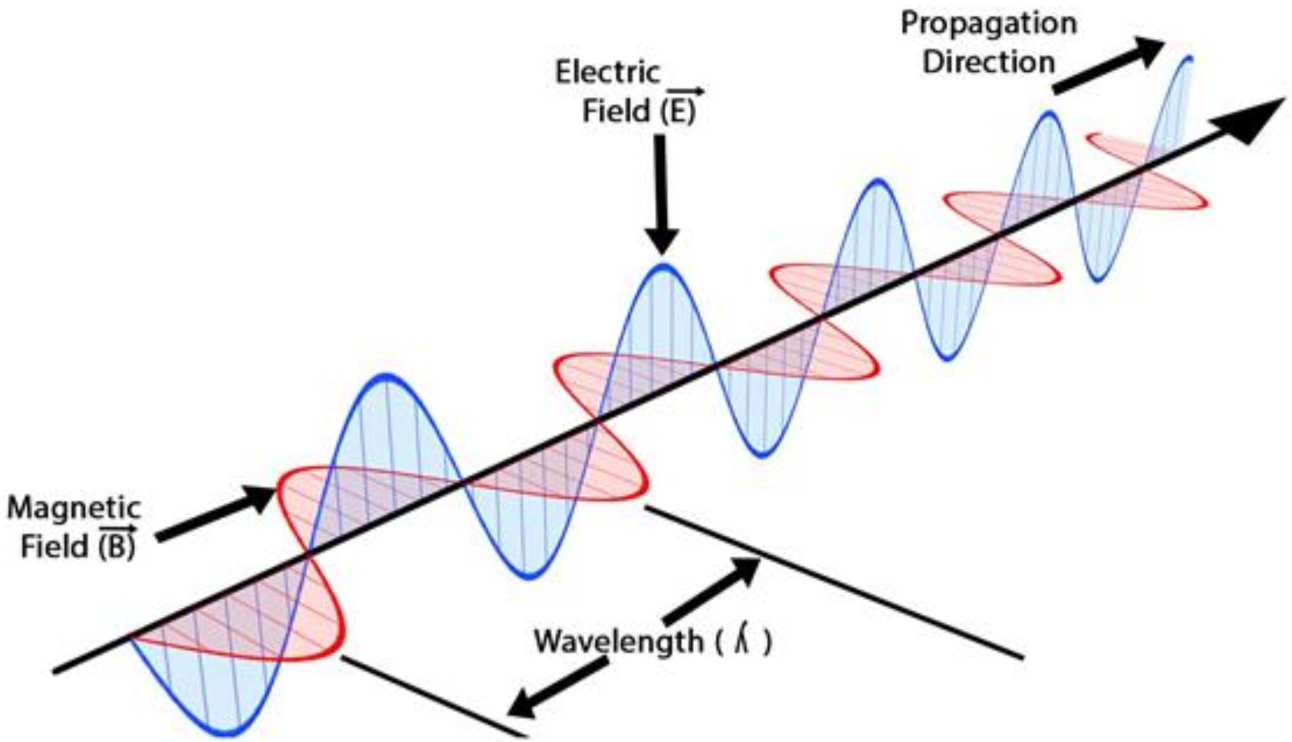
- According to Maxwell, in an electromagnetic wave, there is a magnetic field component and an electric field component that are perpendicular to each other and the direction of propagation of the wave is perpendicular to both the component vectors

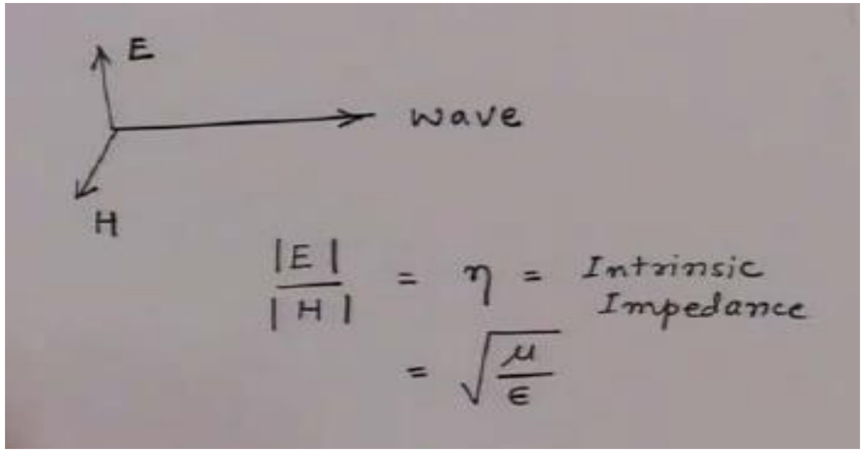
- A changing magnetic field induces an electric field and a changing electric field produces a magnetic field

- The Law of electromagnetism states that "An accelerated charge produces electromagnetic wave"

- Electromagnetic waves do not need a medium to propagate.

Light as an EM wave





Light as an EM wave

- Maxwell predicted that electromagnetic waves move at the speed of light. This led to the theory that light is also an electromagnetic wave.
- Light is also a combination of the oscillating electric and magnetic fields that are perpendicular to each other and wave propagation is perpendicular to both fields.
- Light is produced by acceleration of charged particles (photons), therefore, by law of electromagnetism light is an electromagnetic wave.
- Also like an electromagnetic wave, light also does not need any medium to propagate. It can travel in a vacuum too.
- So by all these properties, light is considered as an electromagnetic wave.

Characteristics of light

- Intensity

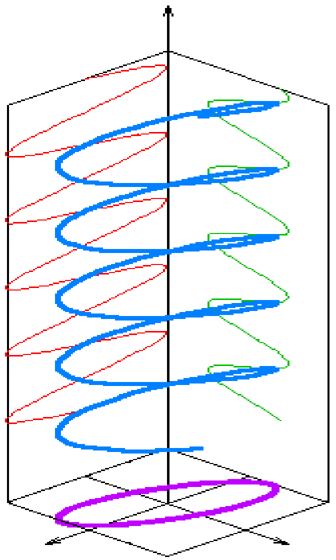
- Wavelength (Colour)

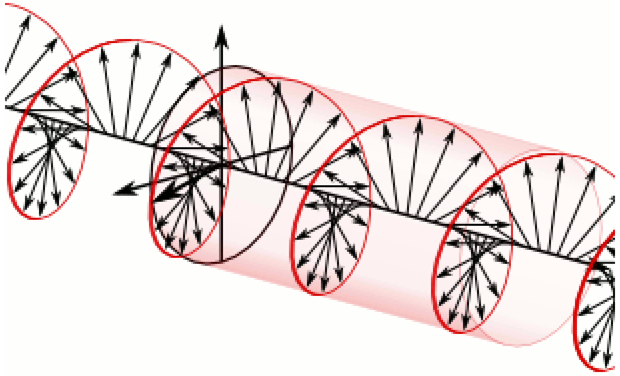
- Spectral width (Purity of colour)

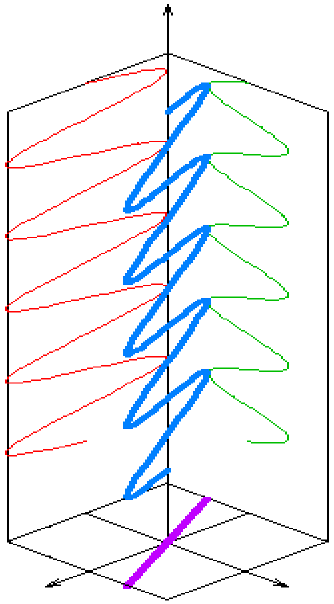
- Polarization
  - Linear
  - Circular
  - Elliptical
  - Random

Polarization of light

- The way E field behaves as a function of time
- Vector nature of light
- Random polarization – Incoherent light







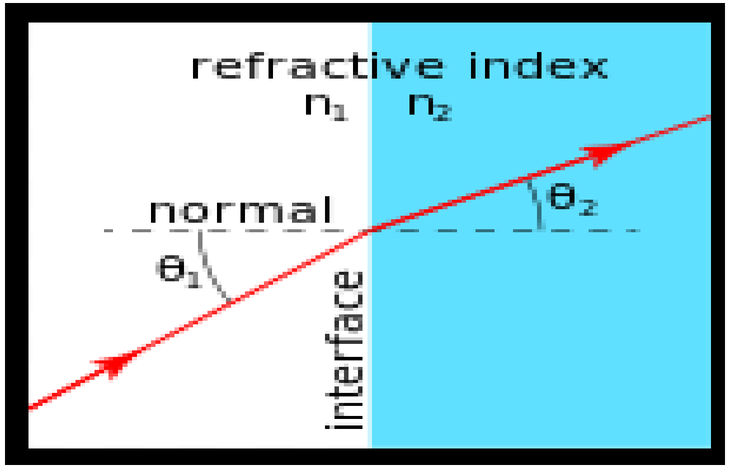
Willebrord Snellius
(13 June 1580 – 30 October 1626)

Refractive index

- In optics the refractive index or index of refraction n of a substance (optical medium) is a dimensionless number that describes how light or any other radiation, propagates through that medium.

$$n=c/v$$

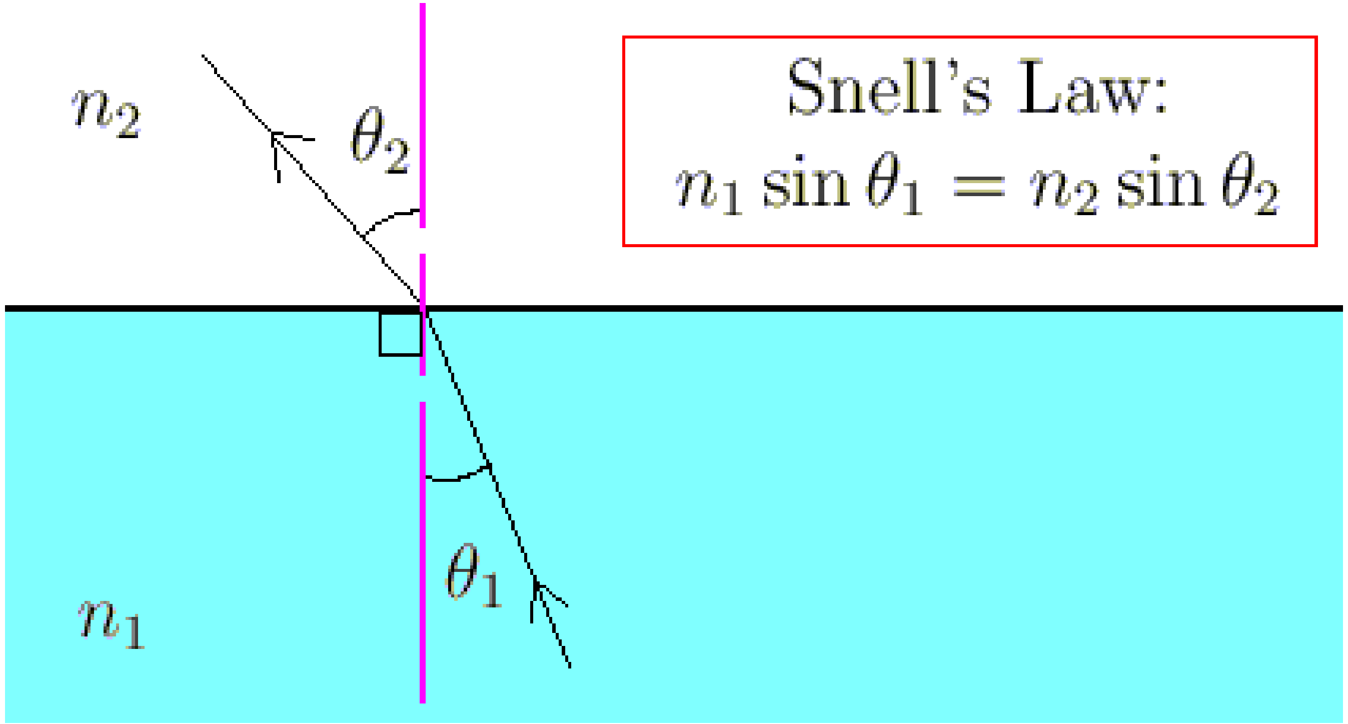
- where 'c' is the speed of light in vacuum and 'v' is the speed of light in the substance



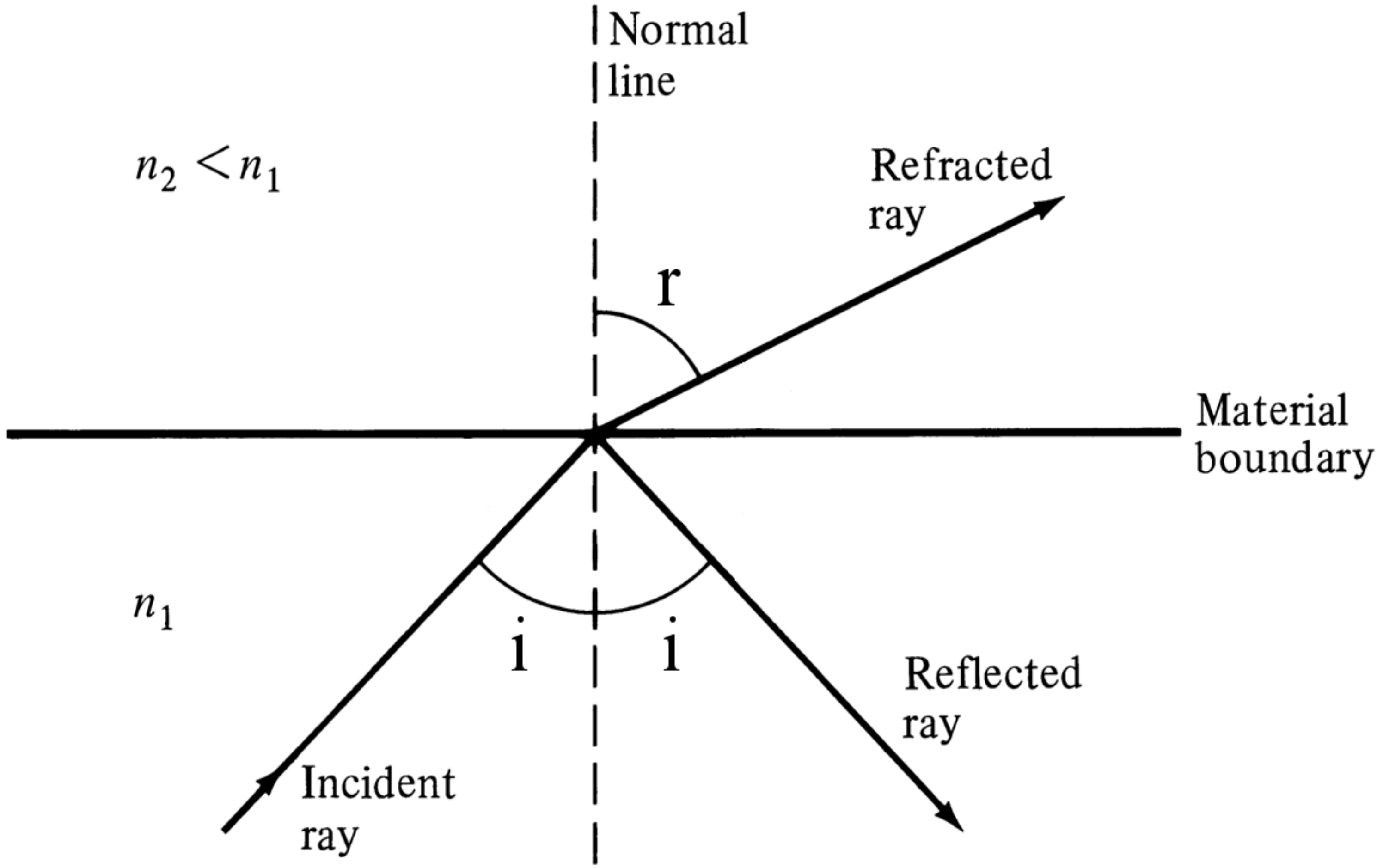
Material	Absolute Refractive Index
Air	1.0008
Water	1.330
Glass, soda-lime	1.510
Diamond	2.417
Ruby	1.760

Snell's Law

- When the ray travels from a denser medium to the rarer medium, it bends away from the normal. This phenomenon is called refraction.
- Snell's law gives a relationship between the angles of incidence and refraction.

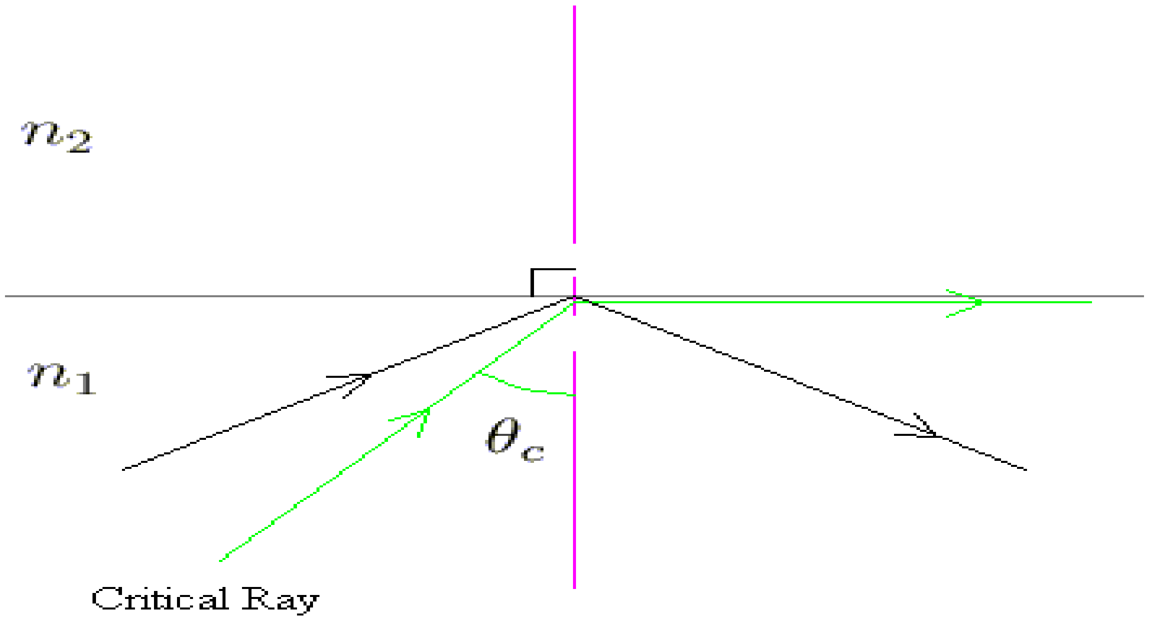


Refraction and reflection of a light ray at the material boundary



Critical angle

- Angle of incidence (inside the higher-index material) for which Snell's Law predicts a 90-degree angle of refraction -- light follows the surface rather than entering the low-index material.

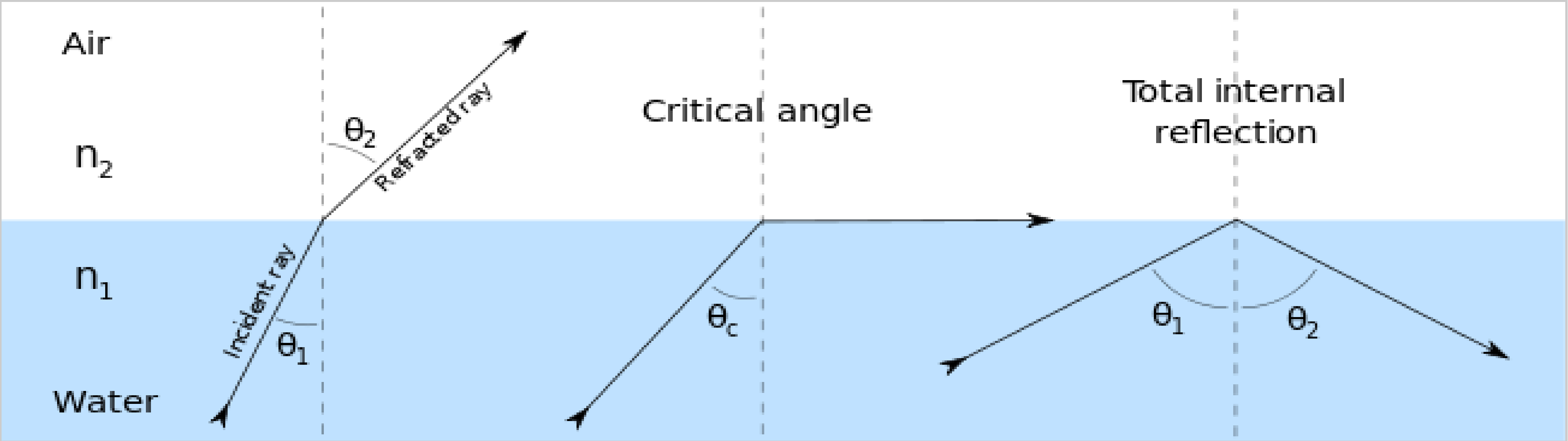


$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
$$n_1 \sin\theta_c = n_2 \sin 90^\circ = n_2$$
$$\sin\theta_c = \frac{n_2}{n_1}$$
$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

Total Internal Reflection

- Propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface.

$$\theta_i > \theta_c$$



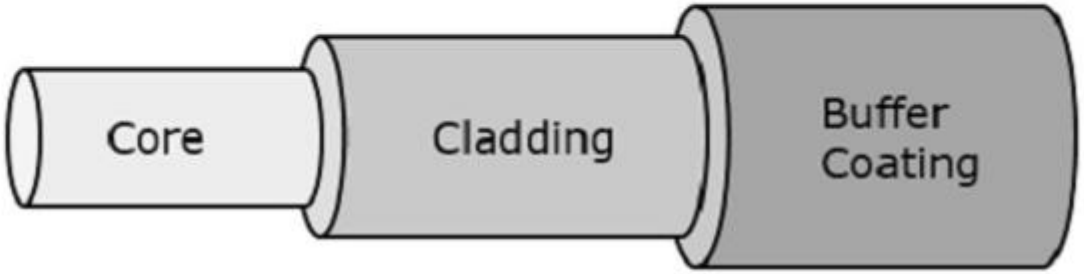
Refraction, critical angle and total internal reflection of light at the interface between two media.

Optical Fiber

- Optical fiber is made from thin strands of either glass or plastic
- It has little mechanical strength, so it must be enclosed in a protective jacket
- Often, two or more fibers are enclosed in the same cable for increased bandwidth and redundancy in case one of the fibers breaks
- It is also easier to build a full-duplex system using two fibers, one for transmission in each direction

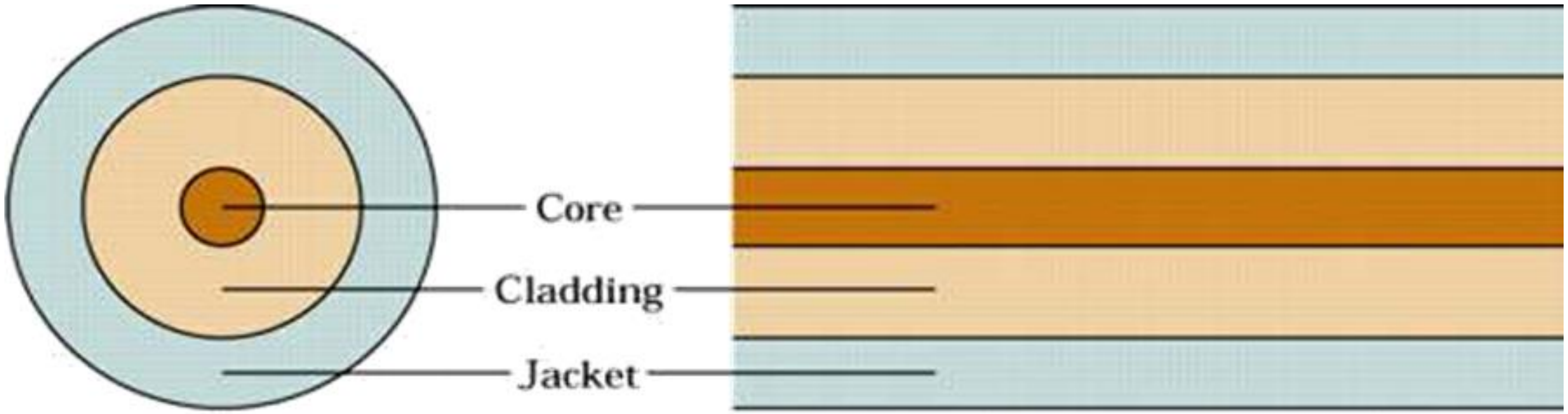
Parts of a Fiber

- The most commonly used optical fiber is single solid di-electric cylinder of radius a and index of refraction n_1

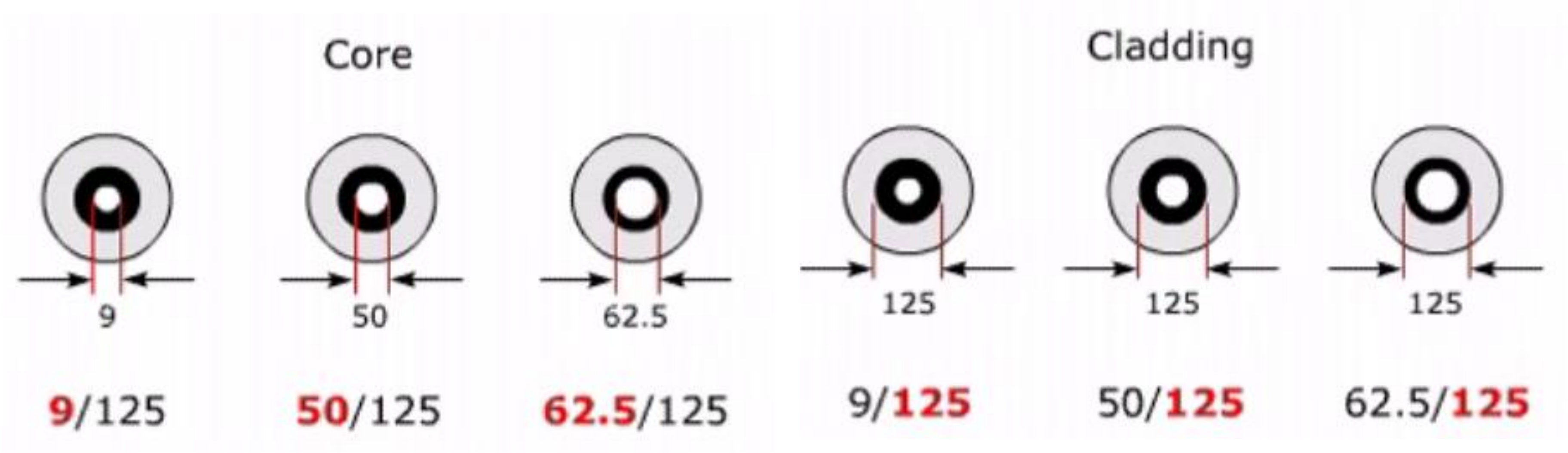


- A thin glass center of the fiber where light travels is called the Core of the fiber
- A solid di-electric material surrounds the core, which is called as Cladding
- Cladding has a refractive index n_2 which is less than n_1
- Buffer Coating is the plastic coating that protects the fiber

Parts of a Fiber – Cross sectional view



What do the fiber terms 9/125, 50/125 and 62.5/125 (micron)?



Remember: A micron (short for micrometer) is one-millionth of a meter

Typically n(cladding) < n(core)

Types of Optical Fibers

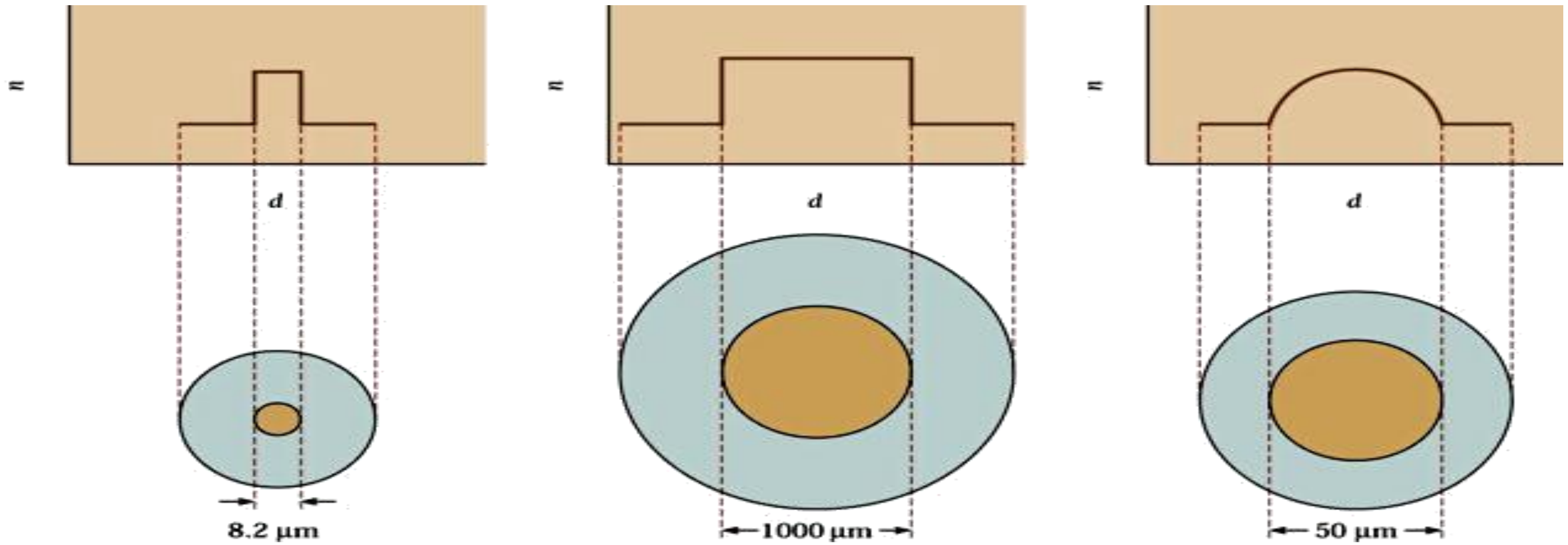
- Modes of operation (the path which the light is traveling on)
  - Single mode
  - Multimode

- Index profile
  - Step
  - Graded

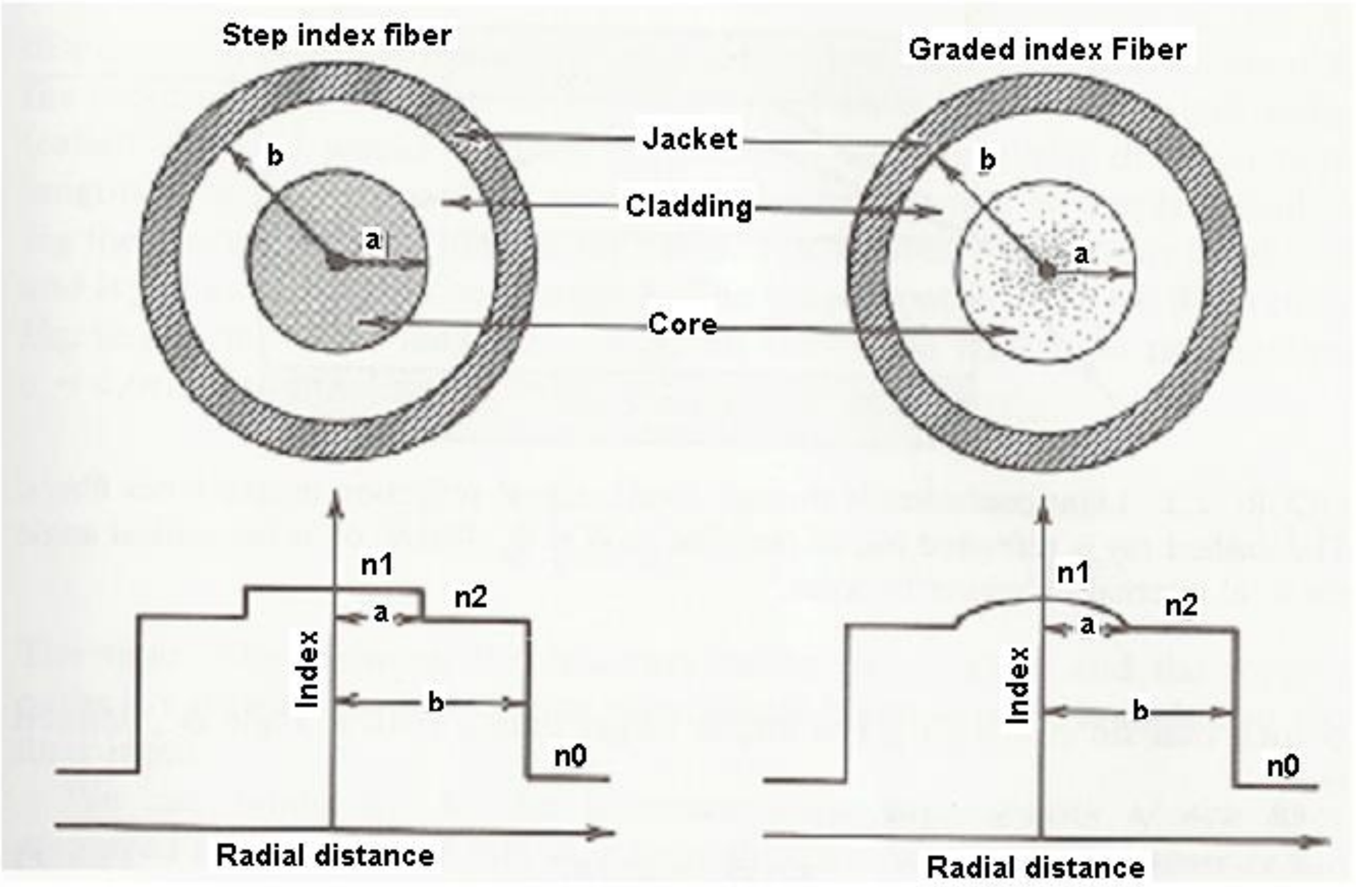
- Major Performance Concerns for Fibers
  - Wavelength range
  - Maximum Propagation Distance
  - Maximum bit rate
  - Crosstalk

Index profiles

- Step-index :Index of refraction changes radically between the core and the cladding
- Graded-index: Index of refraction gradually decreases away from the center of the core
- Graded-index fiber has less dispersion than a multimode step-index fiber

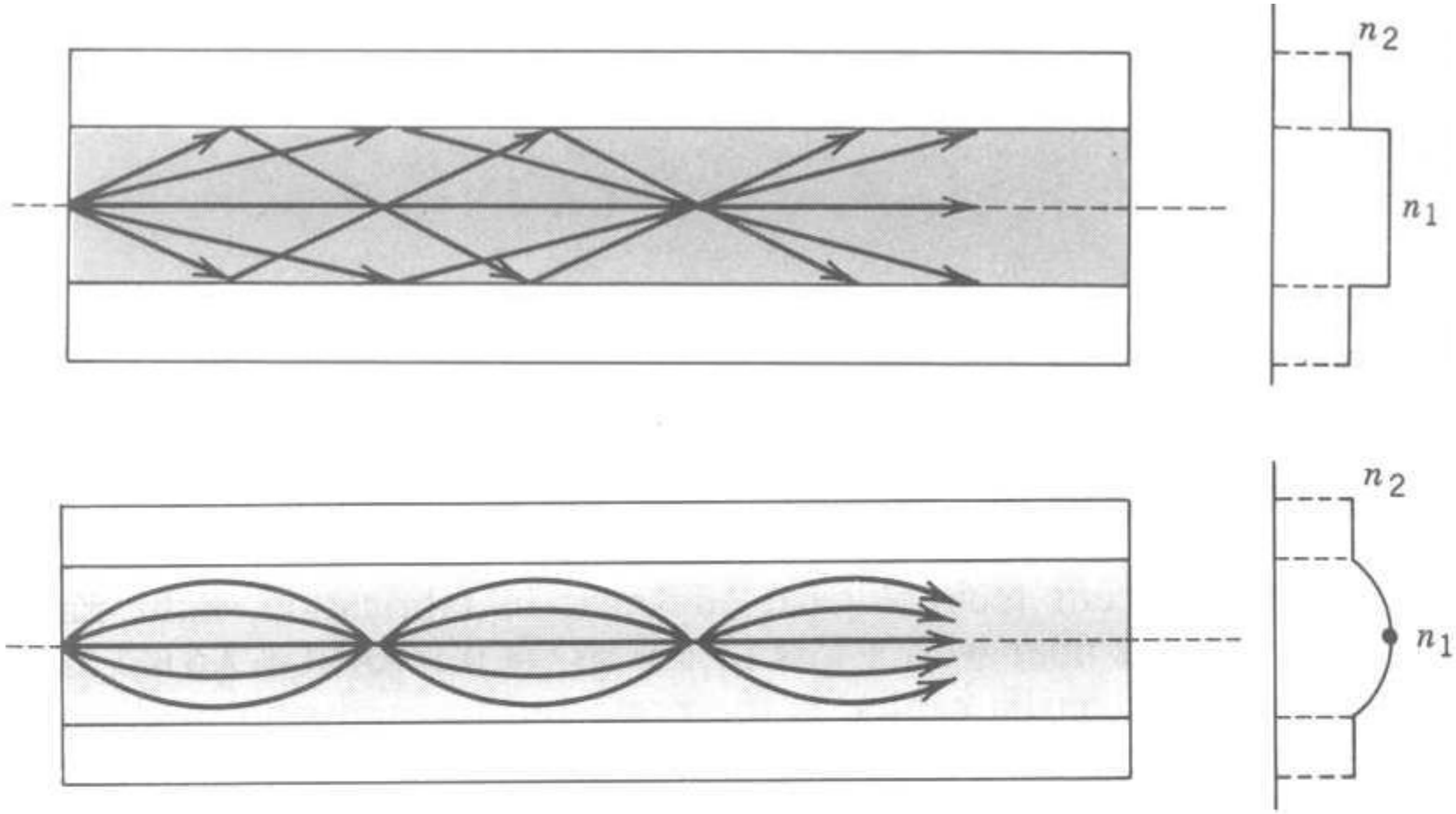


Refractive index profiles

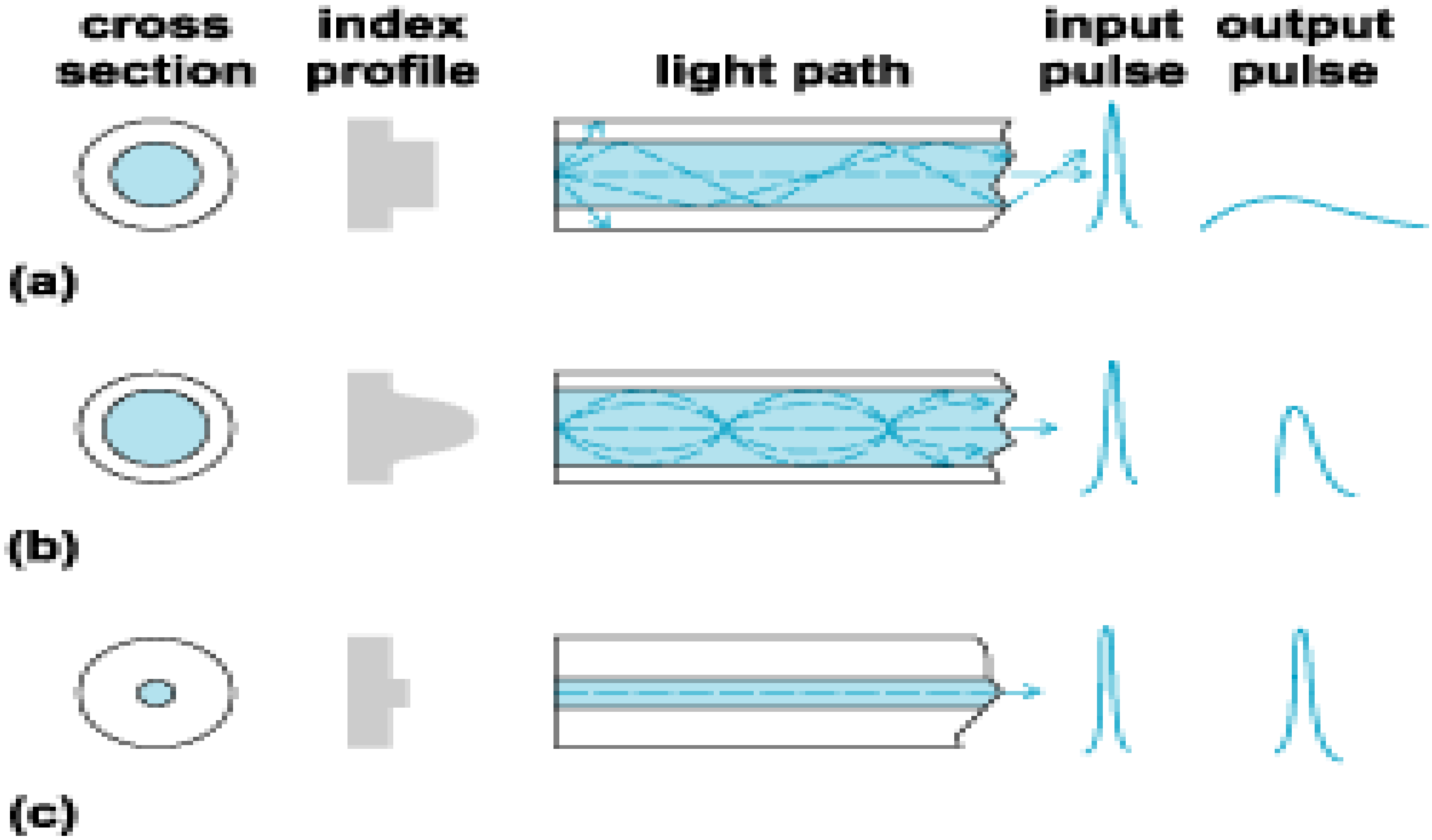


The cross section and the refractive-index profile for step-indexand graded -index fibers.

Propagation in step index and graded index fibers



Intermodal dispersion



Single-mode step-index Fiber

- It will propagate typically 1310 or 1550nm
- Fairly narrow diameter
- Higher transmission rate (up to 50 times more distance than multimode)
- Cost more than multimode

Single-mode step-index Fiber

Advantages:

- Minimum dispersion: all rays take same path, same time to travel down the cable. A pulse can be reproduced at the receiver very accurately.
- Less attenuation, can run over longer distance without repeaters.
- Larger bandwidth and higher information rate

Disadvantages:

- Numerical aperture is smaller than that of multimode fiber, makes it more difficult to couple to light sources
- Highly directive light source (laser) is required
- Interfacing modules are more expensive

Multi-Mode Step-index Fiber

- Made of glass fibers
- Diameter in the 50 to 100 micron range
- Multiple paths of light can cause signal distortion at the receiving end, result in unclear or incomplete data transmission
- Inexpensive
- Easy to couple light into Fiber
- Lower TX rate
- Multimode propagation will cause dispersion, which results in the spreading of pulses and limits the usable bandwidth

- **Multimode graded-index Fiber is intermediate between the other two types of Fibers**