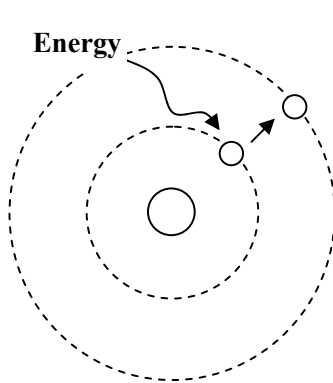
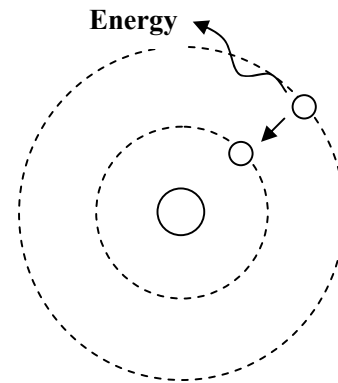


Light

- A form of energy visible to the eye that is radiated by moving charged particles
- Radiated or emitted by electrons circling the nucleus of an atom



Absorption of Light



Emission of Light

Energy Level

- specific amount of energy in each orbital that electrons need to circle the nucleus
- electrons closer to the nucleus have the lowest energy level, so its motion does not radiate energy

→ if a packet of energy excite the electron, it must transfer to a higher energy level

→ if an electron loses energy, it must transfer to a lower energy level

→ the difference between the higher and lower energy levels is equal to the energy released by the electron, which may be in the form of a photon of light

Photons

- a packet of light energy
- $E = hf$

Where:

E	Energy in one quantum in Joules or electron volt
H	Planck's constant ($6.626 \times 10^{-34} \text{ J} \cdot \text{s}$)

Electron Volt: energy gained or lost by one electron moving through a potential difference of one volt ($1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joules}$)

Detection of Light

Photoelectric Effect

- A process in which an atom absorbs a photon that has so much energy that the photon sets one of the atom's electrons free to move to the next orbital

Activation Energy

- A part of the photon's energy that is needed in releasing the electron; while the rest of the energy is transferred to the released electron in the form of motion

- Since the photon energy is proportional to frequency, the released electron (photoelectron) moves faster when it has absorbed a high frequency light
- Metals with low activation energies are used to make photoelectrons

Behavior of Light Categories

I. Propagation of Light

A. Interference

- Occurs when light waves overlap

Constructive Interference: if two waves are in phase, the peaks become additive

Destructive Interference: if two waves are out of phase, the peak and trough will cancel each other

B. Diffraction

- Spreading of light waves as they pass through a small opening or a boundary

II. Interaction of Light with Materials

- In transparent materials, the electrons in the material vibrate when light is present. The oscillation takes away energy from the light wave and then puts it back again, the result is to slow down the light wave without leaving the energy behind
- Denser materials generally slow the light more than less dense materials. Therefore,

$$D \propto \frac{1}{\text{velocity of light}}$$

- Materials that are not completely transparent either absorb light or reflect it. If it is absorbed, the energy lost to the vibrating electrons does not go back to the light thus increasing the motion of the atoms causing the material to heat up. If it is reflected, only the re-radiated light can be absorbed because the re-radiated light cancels out the original wave.

A. Reflection

- Occurs when light hitting the boundary returns into the material

B. Scattering

- Occurs when the atoms of a transparent material are not smoothly distributed over distances greater than the length of the light wave, but are bunched up into lumps of molecules or particles
- Example: The atmosphere scatters violet the most but the human eyes do not see this frequency well. The human eye responds well to blue, which is the next most scattered color. Sunsets took red because the sun is at the horizon and light has to travel through a longer distance of atmosphere to reach the eye

C. Refraction

- Bending of light when it passes from one type of material to another. If a light wave hits the boundary at an angle, this light wave will be forced to either speed up or slow down before light on the other side hits the new material which makes the beam bend at the boundary.

$$n = \frac{c}{v} \frac{\text{speed of light in free space}}{\text{speed of light in the material}}$$

$$n > 1, \text{ always}$$

Recall:

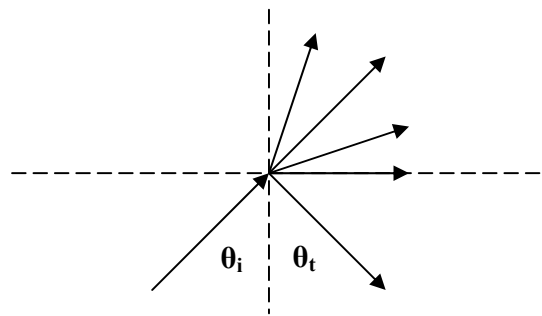
$$\epsilon = \left(\frac{c}{v}\right)^2 \text{ dielectric constant}$$

So:

$$n = \sqrt{\epsilon}$$

Snell's Law

$$n_1 \sin \theta_i = n_2 \sin \theta_t$$



5 Conditions

- A. $\theta_i > \theta_t$; $n_1 < n_2$
- B. $\theta_i = \theta_t$; $n_1 = n_2$
- C. $\theta_i < \theta_t$; $n_1 > n_2$
- D. $\theta_t = 90$; $n_1 > n_2$;

$\theta_i = \theta_c$ (critical angle of incidence: boundary of reflection and refraction)

$$n_1 \sin \theta_c = n_2 \sin 90, \text{ but } \sin 90 = 1$$

$$n_1 \sin \theta_c = n_2; \text{ therefore}$$

$$\theta_c = \sin^{-1} \frac{n_2}{n_1}$$

- E. $\theta_i < \theta_c$: light is reflected back into the medium

Observations:

Since density is inversely proportional to velocity, and index of refraction is also inversely proportional to velocity, we can say that density is directly proportional to index of refraction.

For the first condition, material 1 is less dense than material 2.

For the second condition, material 1 and 2 have similar densities.

For the third condition, material 1 is denser than material 2.

Fresnel Reflections

- occurs when light passes from one index to another, a small portion is always reflected back into the first material

$$\rho = \left(\frac{n_1 - n_0}{n_1 + n_0} \right)^2 \quad dB_{loss} = 10 \log(1 - \rho)$$

where: ρ Fresnel Reflection
 n_1 refractive index of the material
 n_0 refractive index of air (1.0)

OPTICS

The study of the behavior of light in materials and how to use this behavior to control light

The Fiber Optic System

Advantages:

1. light weight and small size
 - made of glass or plastic, lighter than its copper counterparts
 - “50 miles per gallon” (50 miles of fiber cable occupies the volume of a one – gallon container)
2. immunity to EMI and crosstalk
 - crosstalk: noise caused by a signal traveling on an adjacent line
 - fibers are non – conducting, they neither generate nor receive EMI
3. no sparking
 - only light travels in the fiber, no possibility of spark from a broken fiber
4. does not corrode and unaffected by most chemicals
5. cost effective for wideband signals with data rates of over tens of megabits per second (more voice channels / cable)
6. low loss / flat attenuation
 - optical fibers are operated from 100 THz to 400 THz
 - for copper cables, attenuation increases with modulation frequency; the higher the frequency of the information signal, the greater is the loss
 - for optical fiber, attenuation is flat; 20 dB/km as compared to the 30dB/km for copper cables
7. no emission licenses
 - no government licenses are required to implement a link
8. security
 - difficult to tap but easy to monitor and absolutely no electrical radiation from a fiber

Disadvantages

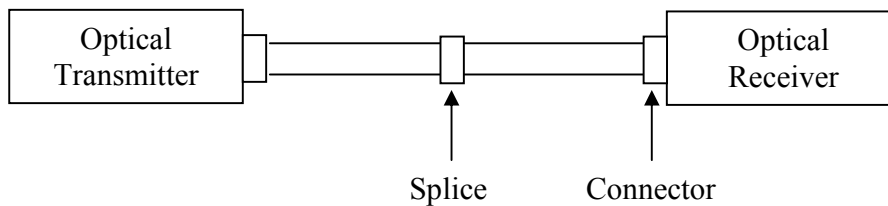
1. Radiation Darkening
 - Susceptible to interruption by nuclear radiation
2. Lack of standards
 - Manufacturers may claim product superiority

- Standards exist only for fiber dimension, some measurement techniques and communications networks resulting in incompatibility of connectors

Standards:

FDDI (ANSI X2T9.5): specifies standards for a dual – ring topology using optical fiber cables

SONET (ANSI T1.105) and SDH (European Standard): contains recommendations for the standardization of fiber optic transmission systems (synchronous network)



Transmitter

- Contains the light source; converts an electrical analog or digital signal into a corresponding optical signal
- Sources include LEDs or ILD; popular wavelength of operation for optical sources are 850, 1310 and 1550 nm

Receiver

- Converts the optical signals back into a replica of the original electrical signal
- Detectors include PIN or APD

Fiber Optic Cable

- Acts as a waveguide for the optical signal

Construction

1. Fiber core
 - 8 to 100 micrometer in diameter
2. Fiber Cladding
 - Typical 125 micrometer in diameter
3. Jacket / Coating
 - Layers of polymer
 - No optical properties that may affect the propagation of light within the fiber
 - “shock absorber”

$n_{\text{core}} > n_{\text{cladding}}$ by 1%

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2} \approx \frac{n_1 - n_2}{n_1}$$

Classification of Optical Fibers

- I. According to Material of Construction
 1. Plastic Clad Plastic (PCP)
 - Low cost and easy to use
 - Not for high bandwidth and low loss systems
 2. Plastic Clad Silica (PCS)
 - Respectable performance
 3. Silica Clad Silica (SCS)
 - Best performance but most expensive
- II. According to Index Profile
Index Profile: the graphical representation of the relationship between the core and cladding refractive indices
 1. Step Index Fiber
 - The core refractive index is uniform and a sharp step in the refractive index at the core – cladding interface (200 micrometer diameter cladding, typical)
 2. Graded Index Fiber
 - The core refractive index is non – uniform such that the highest index is at the center and gradually decreases until it matches the cladding index
 - Some refer to it as the optical fiber without a cladding (50, 62.6 and 85 micrometer diameter core, typical)
- III. According to Propagation Modes
 1. Single Mode (Monomode)
 - Signal travels only one path along the core
 - 5 to 10 micrometer core diameter (8 or 9 microns typical)
 - 3 km between repeaters
 - yellow jacket
 - used with ILDs
 2. Multimode
 - 50 to 800 micron core diameter
 - 2km between repeaters
 - orange jacket
 - used with LEDs

Number of Modes, N:

- dependent on the normalized frequency (V number)
- For Step Index
$$N = \frac{V^2}{2}$$

V is very much greater than 2.405
- For Graded Index
$$N \approx \frac{V^2}{4}$$

V is very much greater than 2.405

Normalized Frequency, V

$$V = \frac{2\pi a n_1}{\lambda_o} \sqrt{2\Delta} \quad \text{but} \quad \Delta = \frac{n_1^2 - n_2^2}{2 n_1^2}$$

Therefore:

$$V = \frac{2\pi a}{\lambda_o} \sqrt{n_1^2 - n_2^2}$$

where: a radius of the core
 n₁ index of refraction of the core
 n₂ index of refraction of the cladding

Numerical Aperture, NA

- Light gathering ability of a fiber, defining the maximum angle to the fiber axis at which light will be accepted and propagated through the fiber

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

$$NA = \sin \theta_{\max}$$

Cut off Wavelength for Single Mode Operation

- Value of the wavelength that makes the normalized frequency equal to 2.405
- Defines the smallest wavelength at which a fiber can be operated for single mode

$$\lambda_c = \frac{2\pi a n_1}{2.405} \sqrt{2\Delta} = \frac{2\pi a}{2.405} \sqrt{n_1^2 - n_2^2} = \frac{2\pi a NA}{2.405}$$

Maximum Allowable Radius for Single Mode Operation

- From cut off wavelength formula

$$\lambda = \frac{2\pi a NA}{2.405} \quad \rightarrow \quad a = \frac{2.405 \lambda}{2\pi NA}$$

Therefore,

$$r_{\max} = \frac{0.383 \lambda}{NA}$$