TE 357: Optical Communications

Lecture 2: Physics of Light

''whether you can observe a thing or not depends on the theory which you use. It is the theory which decides what can be observed'

By Albert Einstein

Physics of Light

- Fiber-optic communications technology
  - Uses light as a signal carrier
- To understand the basics of the technology
  - we need to examine the various aspects of light
- We will consider light from three vantage points
  1. As a ray, or beam: the geometric optics view
  2. As a stream of photons: the quantum view
  3. As electromagnetic (EM) waves: the wave view

- In solving engineering problems
  i. we need to choose the appropriate and easiest physical theory that can handle the problem
  ii. Artificial Intelligence (AI)

Geometric View (ray theory)

- Light
  - can be treated as a beam (ray)
    - Ray theory
      - That light travels in a straight line obeying the laws of geometric optics
  - rays propagate within different media at different velocities
    - Thus, different media resists light propagation with different strengths
- The characteristic that
  - describes how a medium resists light propagation is the
    - refractive index or index of refraction

Geometric View

- If
  - *v* is the light velocity within a medium
  - c the speed in free space
- Then
  - The refractive index, n is given by

$$n = \frac{c}{\upsilon}$$

  - Thus

$$\upsilon = \frac{c}{n}$$

- All the
  - Characteristics of light in free space are changed inside a material with the refractive index *n*

Geometric View

Index of Refraction –

n = Speed of light in a vacuum / Speed of light in a medium

- Velocity becomes: c/n
- Wavelength becomes: λ/n

Geometric View -Questions

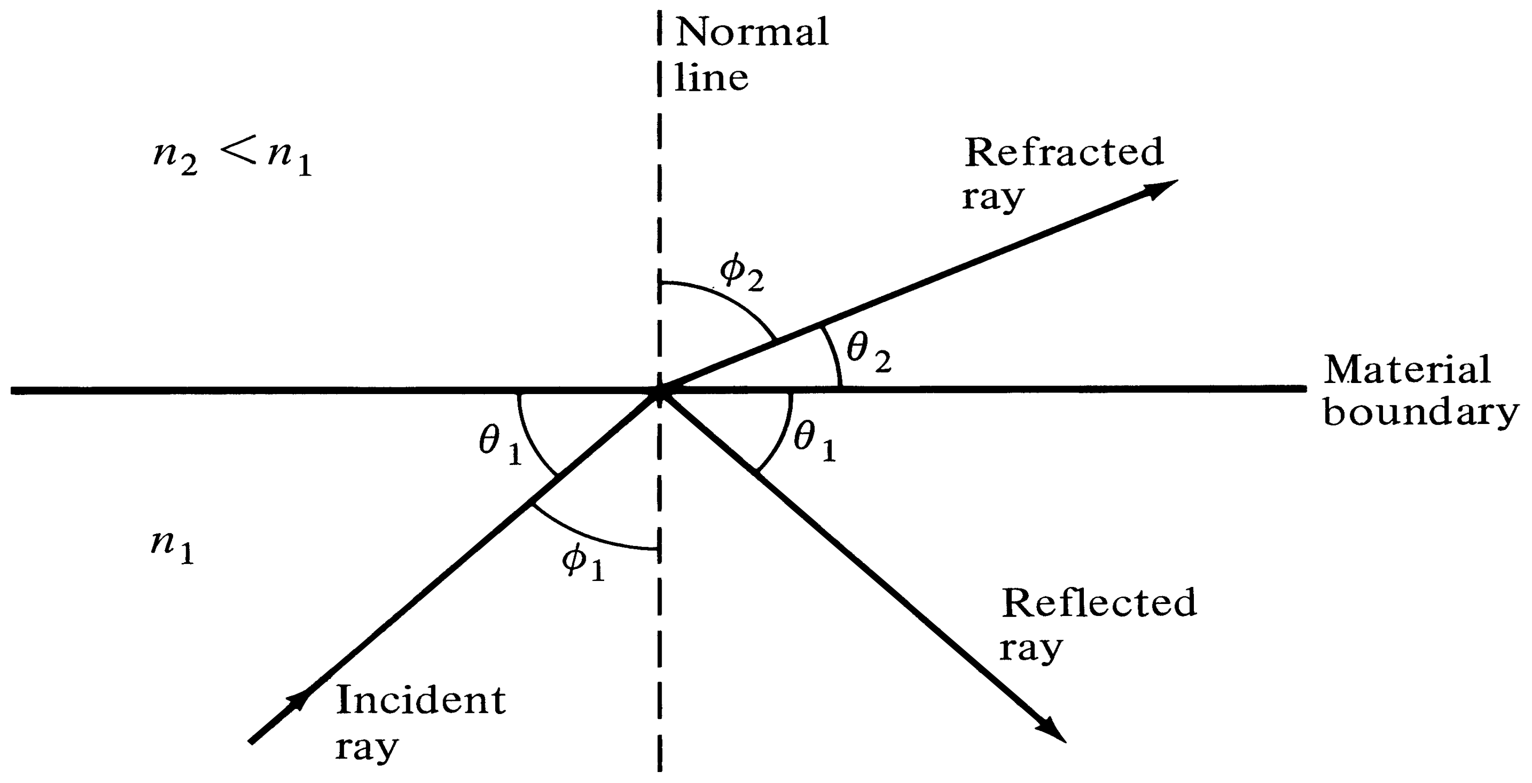
1. When a light ray encounters a boundary separating two media what happens?

2. What happens when light ray
   - falls from a medium with a greater refractive index to a medium of smaller refractive index?

Geometric View

- Reflection and refraction

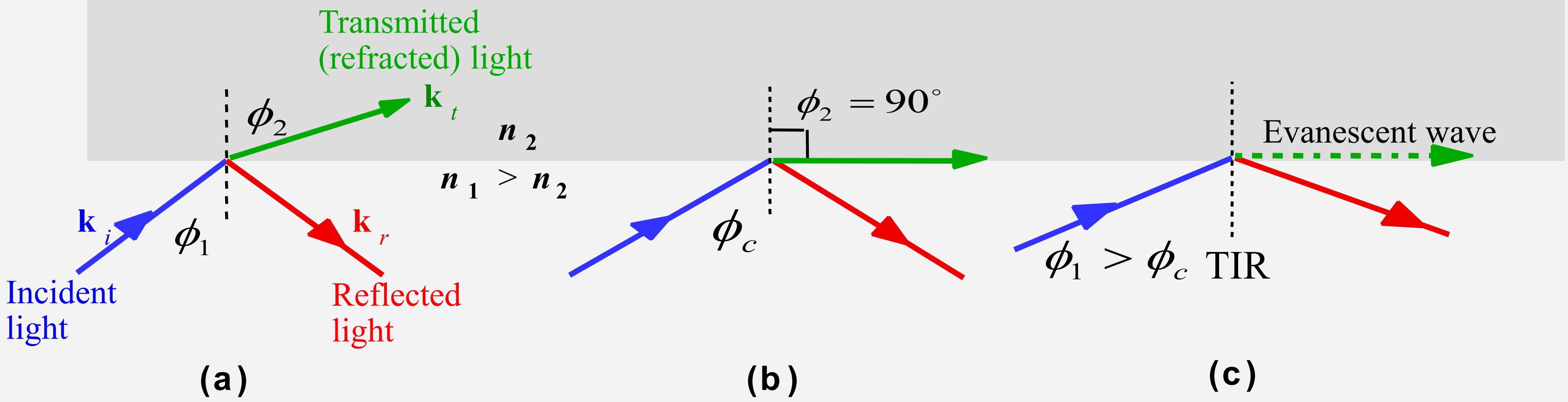
$$n_1 \sin\phi_1 = n_2 \sin\phi_2$$



Reflection and Refraction

- The angle, φ_1 between the incident ray and the normal to the surface is the
  - Angle of incidence
- As the angle of incidence φ_1
  - in the optically dense material becomes larger the refracted angle φ_2 approaches 90 degrees
- Beyond this point i.e. 90°
  - No refraction is possible and the light becomes
    - totally internally reflected

Total internal reflection, Critical angle



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

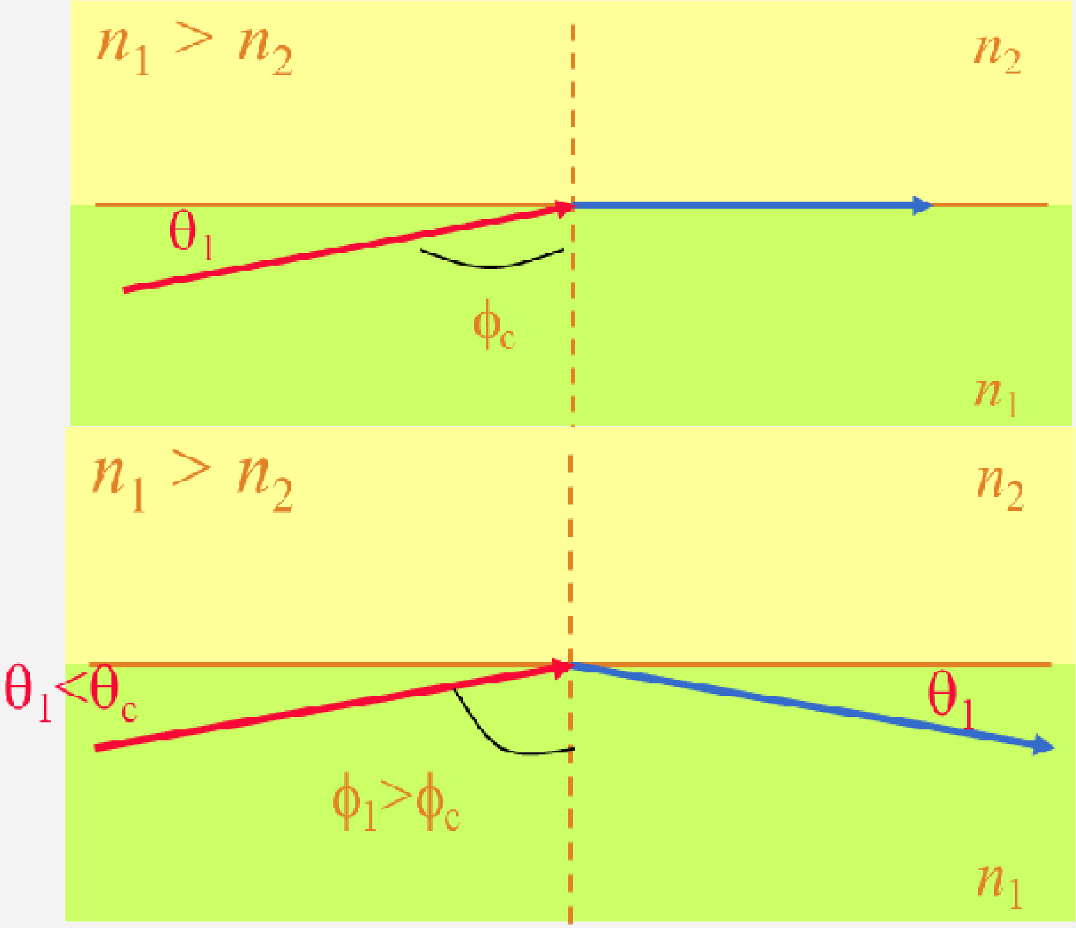
Total Internal Reflection

- As ϕ_1 **increases the refracted angle approaches 90 degrees**
- The incident angle
  $\phi_1 = \phi_c =$ **Critical Angle**
  $n_1 \sin \phi_1 = n_2$

Thus, the critical angle

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

- Beyond the critical angle, light ray becomes **totally internally reflected**

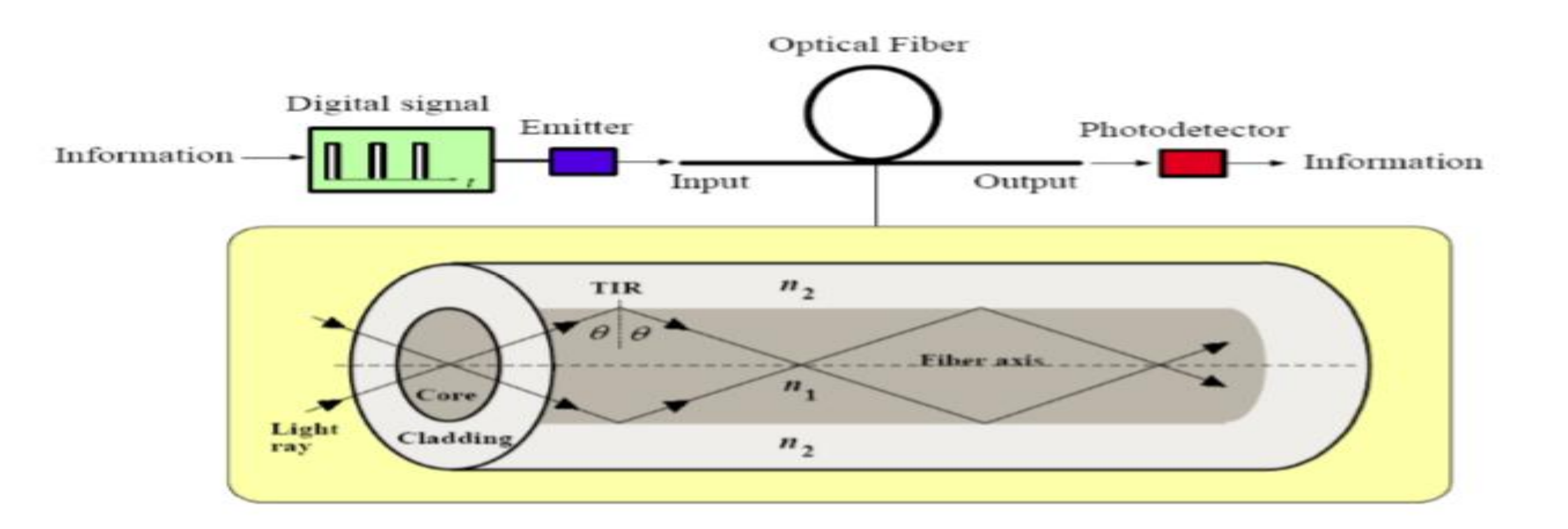


Geometric View – Concluding Remark

- When light travels
  - from a medium of higher refractive index to a medium of lower refractive index and it strikes the boundary at an angle more than the critical incident angle
    - All the light will be reflected back to the incident medium
      - This phenomenon is called total internal reflection

Geometric View

- Total internal reflection
  - is what keeps light inside an optical fiber



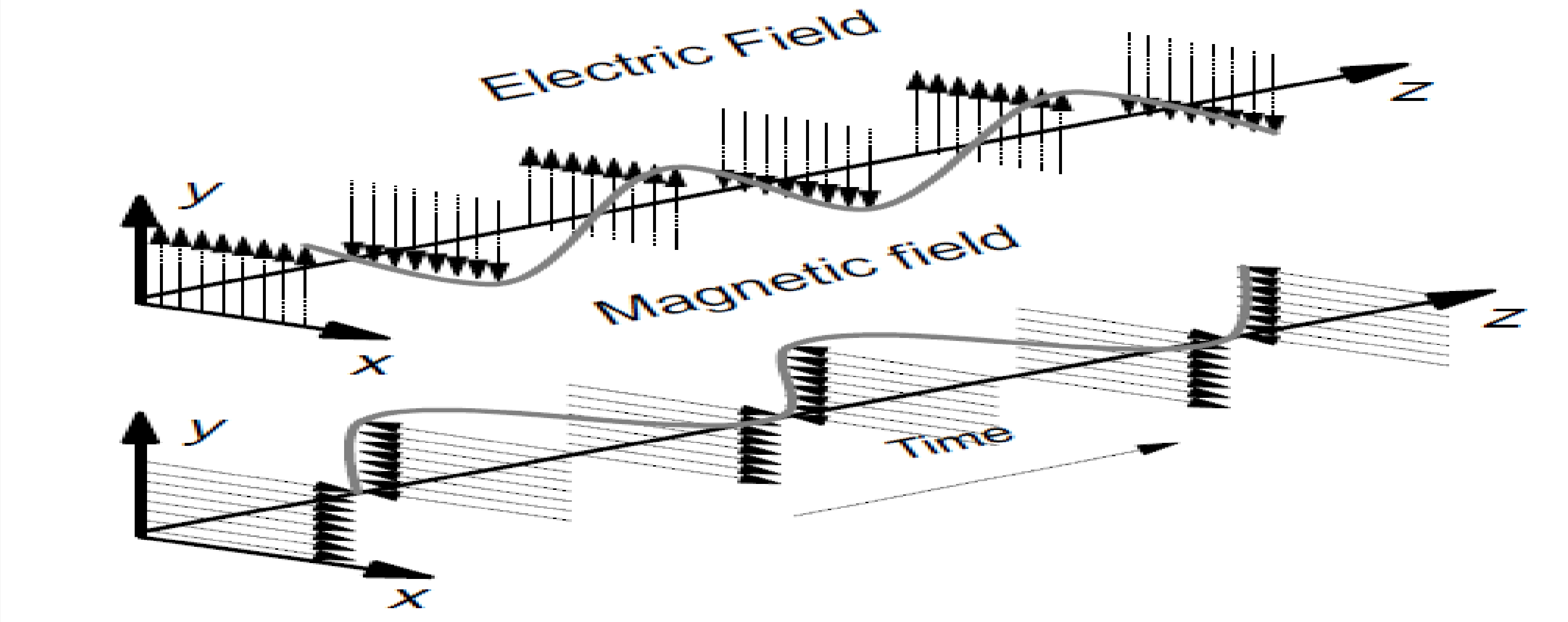
The wave view

James Clerk Maxwell

- His mathematical theory of electromagnetism led to the view that
  - light is of electromagnetic nature, propagating as a wave from the source to the receiver
- It is possible to
  - describe any optical phenomena by wave theory in which light is described by a wave function
- That optical signal is an
  - electromagnetic signal

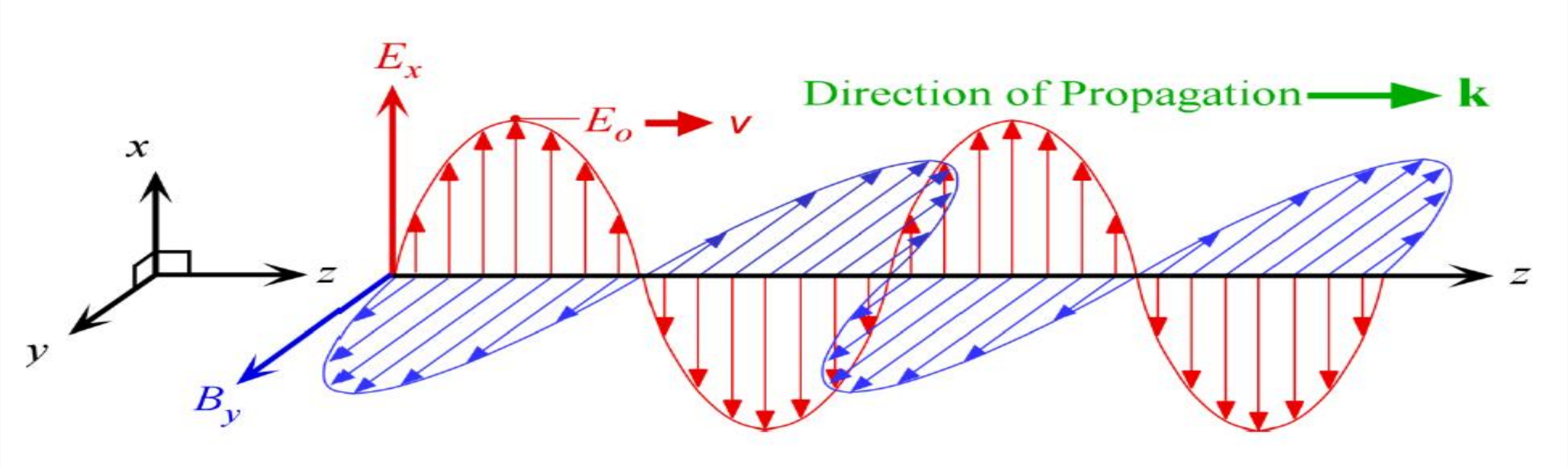
The wave view (electromagnetic theory)

- It has electric and magnetic fields that are orthogonal to each other

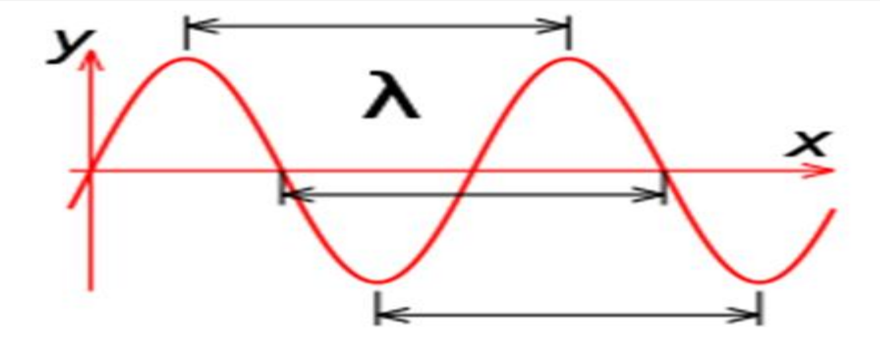


The wave view

- Electromagnetic radiation
    - propagates in the form of two mutually coupled vector waves
        - Electric field wave and magnetic field wave



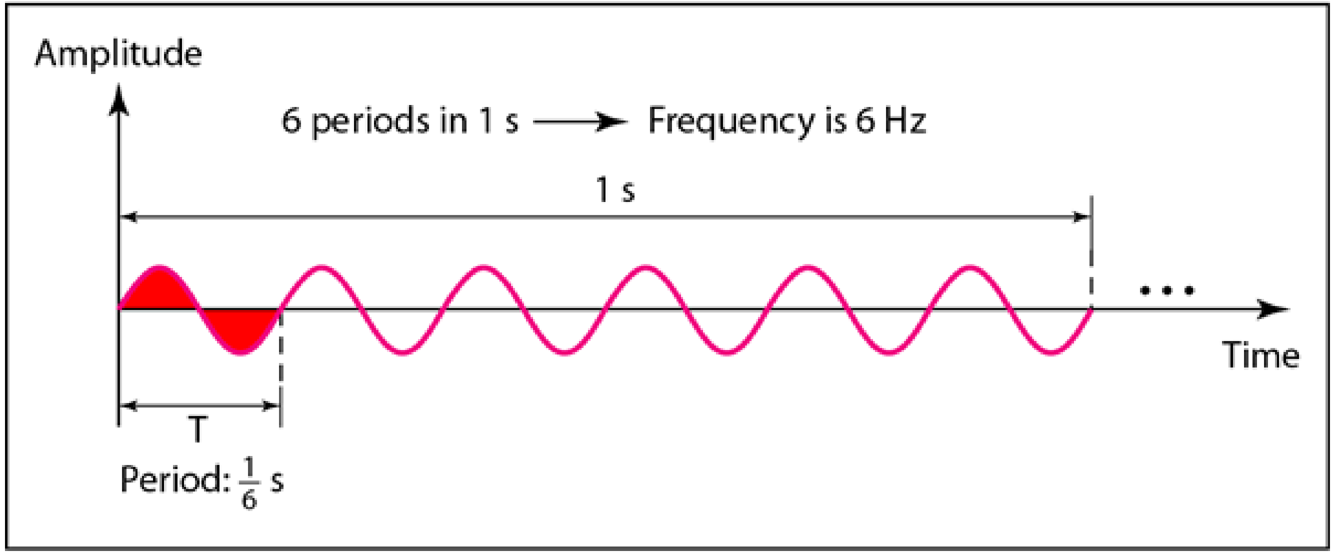
The wave view



- Light as an electromagnetic wave
  - develops in both TIME and SPACE
- Its development in
  - space is described by WAVELENGTH (λnm)
    - The distance between two identical points of two successive cycles of wave

The wave view

- Its development in
  - time is quantified by a PERIOD
    - The time it takes a wave's two identical points to pass in sequence the same location



A signal with a frequency of 6 Hz

The wave view

- The wavelength and the period
  - of the light wave are related through the wave velocity
    - which is equal to the wavelength divided by the period

$$\upsilon = \frac{\lambda}{T}$$

- This results in an important formula

$$\lambda . f = c$$

The Quantum View (stream of photons)

- The wave and geometric views of light
  - adequately account for all phenomena involving the transmission of light
- However
  - in dealing with the interaction of light and matter, as occurs in emission and absorption of light both views are not appropriate

The Quantum View (stream of photons)

- Instead
  - we must turn to the quantum view
- Quantum (Theory) view
  - That optical signal consists of discrete units called PHOTONS
    - That is, light energy is always emitted or absorbed in discrete units called photons

The Quantum View (stream of photons)

- A photon
  - can be thought of as an elementary particle that carries a quantum of energy, E_p and travels with the speed of light c

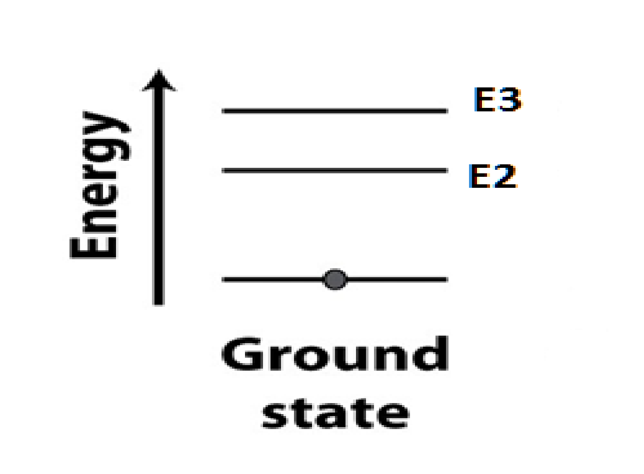
$$E_P = hf = \frac{hc}{\lambda}$$

where

- $h = 6.625 \times 10^{-34}$ J.s is Planck's constant
- f is the photon's frequency

The Quantum View (stream of photons)

- Energy level Diagram
  - All matter consists of atoms and an atom possesses discrete values of energy
  - Thus, an atom’s energy is quantized



The Quantum View (stream of photons)

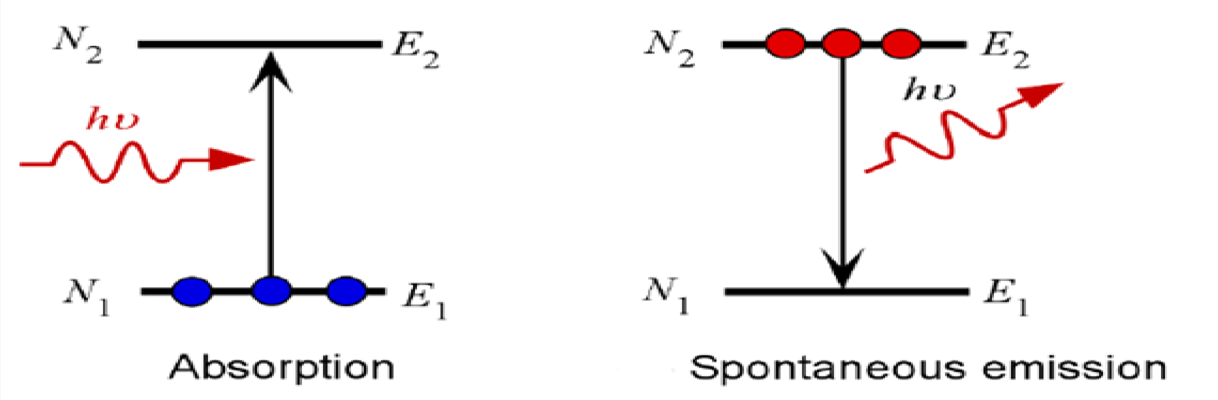
- A photon
  - When an atom jumps from E3 to E2, there is an energy gap between these two levels

$$\Delta E = E3 - E2$$

  - This difference will be released as a quantum of energy which is called a photon

The Quantum View (stream of photons)

- When light is
  - incident on an atom, a photon can transfer its energy to an electron within this atom, thereby exciting it to a higher energy level
    - The energy absorbed by the electron must be exactly equal to that required to excite the electron to higher energy level



- Conversely,
  - an electron in an excited state can drop to a lower state by emitting a photon

THANK YOU

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