Photonics

Lecture 2

Photoelectric Effect

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The electromagnetic spectrum

Light, radio waves , x-rays , γ-rays are all E.M radiation, The only difference between them is their frequency. E.M radiation is propagated through space as a transverse wave; the speed of propagation (c) is related to frequency by:

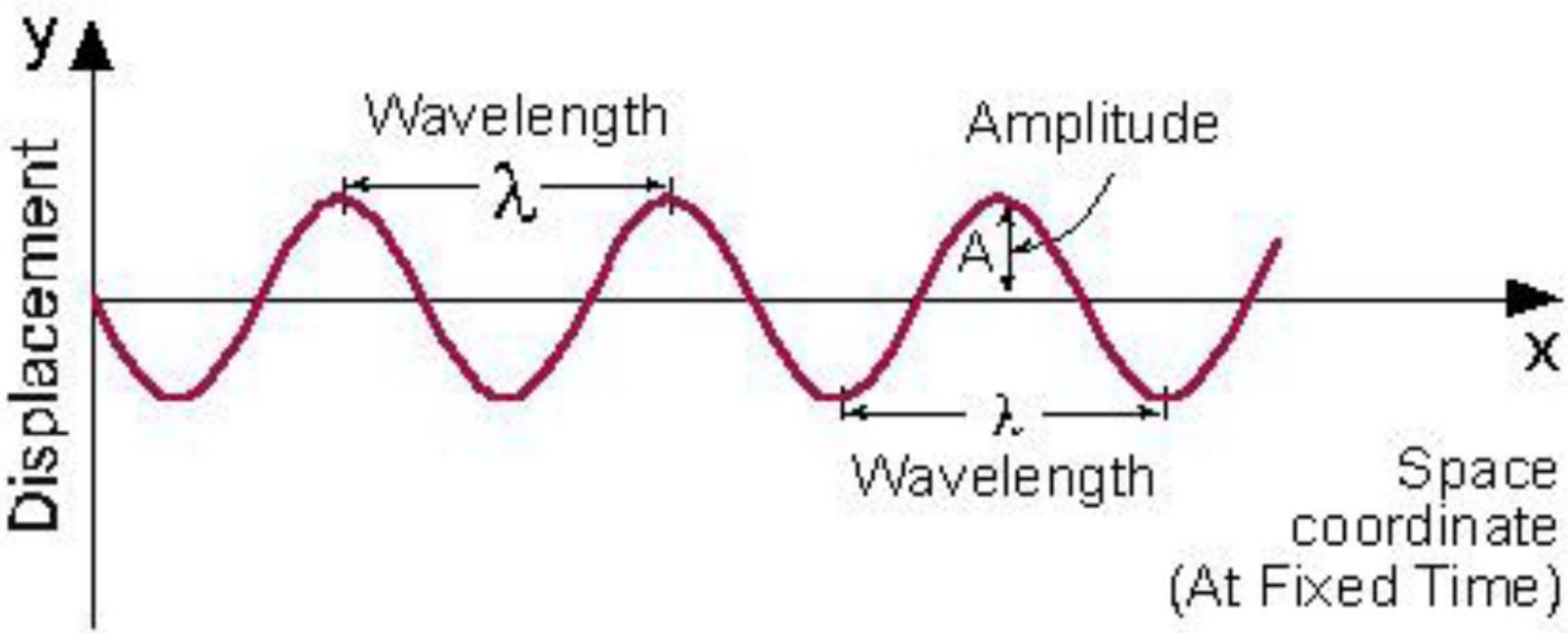
$c = \lambda * f$

λ = wavelength

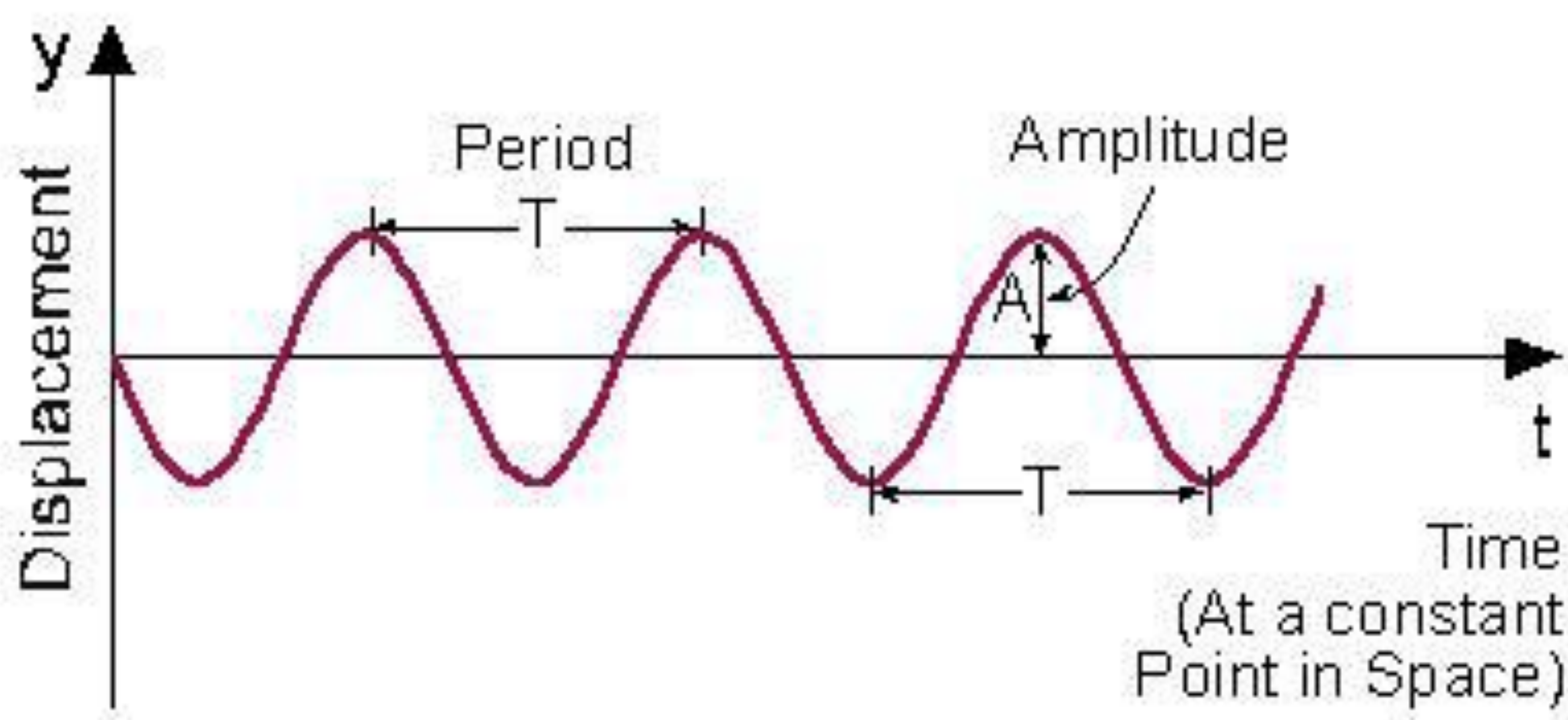
Wave Description: A wave can be described in two standard forms:

1. Displacement as a function of space when time is held constant.
2. Displacement as a function of time at a specific place in space.

1. Displacement as a function of space, when time is "frozen" (held constant), as described in figure. In this description, the minimum distance between two adjacent points with the same phase is wavelength (υ). Note that the horizontal (x) axis is space coordinate.



2. Displacement as a function of time: in a specific place in space, as described in figure. In this description, the minimum distance between two adjacent points with the same phase is period (T). Note that the horizontal (x) axis is time coordinate



In vacuum the speed of light for any E.M radiation is equal to : **c= 3*108 m.s-1** In a transparent medium the velocity (c') is less than (c). This reduction is related to the refractive index of medium by:

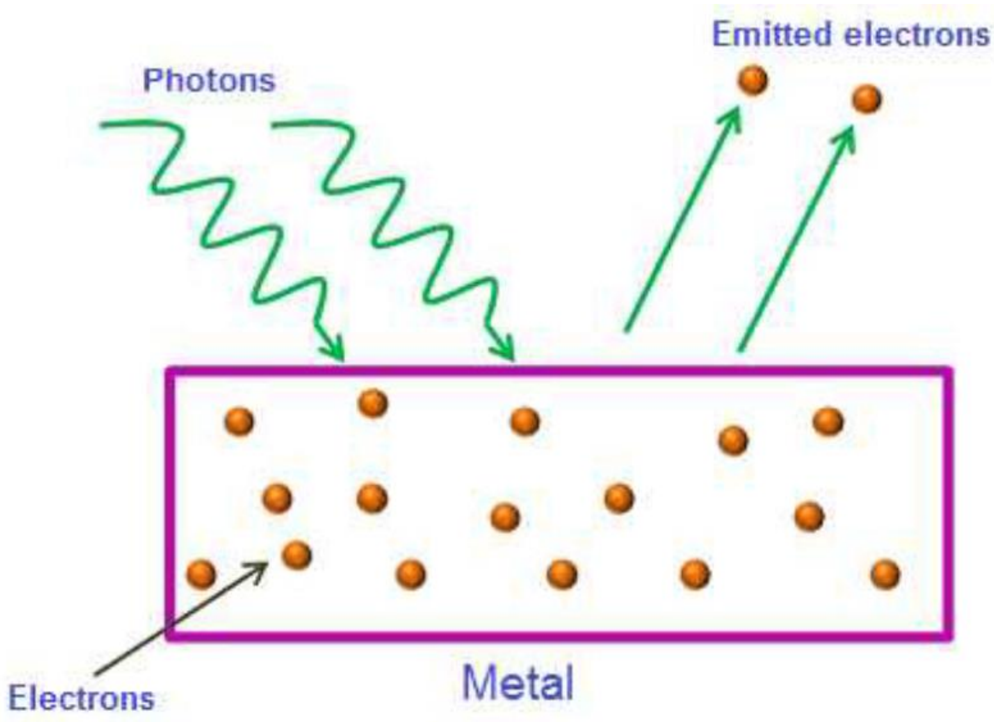
Refractive index of the medium (n) = (velocity in vacuum / velocity in medium) = c/c' so :

c'=c/n

Photoelectric Effect

The photoelectric effect is the emission of electrons when electromagnetic radiation, such as light, hits a material. Electrons emitted in this manner are called photoelectrons, figure. As the frequency of the photon was increased, the energy of the electron increased. For a single photon absorption process, a certain minimum amount of energy is required before current flow occurs.

This minimum depends on the material and is called the work function or threshold energy. If the photon energy exceeds the threshold energy value, then current flow results. Clearly, there is a cut off frequency, νc, above which current flow will occur, with is a corresponding cut-off wavelength, λc. Solar cells use the photoelectric effect principle



Example

A certain material has threshold energy of 3.48 eV. What is the minimum wavelength of radiation required to illuminate the material before current flow starts? If the wavelength of light corresponds exactly to 3.48 eV of photon energy, this is where the photoelectric effect starts happening.

$$E_p = 3.48\ \text{eV} = 5.57 \times 10^{-19}\ \text{J}$$

$$\lambda = \frac{hc}{E_p}$$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{5.57 \times 10^{-19}} =$$

$\lambda = 357$ nm

Unless radiation of 357 nm wavelength or lower is used, there will be no photo electricity using this material.

Energy of a Photon

Photon energy is the energy carried by a single photon. The amount of energy is directly proportional to the photon's electromagnetic frequency and thus, equivalently, is inversely proportional to the wavelength. The higher the photon's frequency, the higher its energy. Equivalently, the longer the photon's wavelength, the lower its energy. The photon energy is given by:

$E_p = h\gamma = hc/\lambda$ ……….(4)

Where: Ep represents the energy of a photon of wavelength λ, or frequency ν. In this equation, h is known as Planck's constant. Its value is 6.625 x 10-34 J.s.

Photon energy units

a. Joule unite: when the wavelength is expressed in meters or the frequency in Hertz, the photon energy gives in Joules (J.)

The energy of a quantum of light depends on its frequency.

$$E = h*f = h * \upsilon$$

Where: h= planck's constant = $6.63*10^{-34}$ J.s

E in joules & f in $Hz = s^{-1}$

$$E\ (\text{joule}) = hc/\lambda = (6.63*10^{-34} * 3*10^{8}) / \lambda\ (\text{joules})$$

But: $1\ ev = 1.6*10^{-19}\ J$

So : $E\ \text{in}\ (ev) = (6.63*10^{-34} * 3*10^{8}) / (\lambda * 1.6*10^{-19})\ ev$

$$=(1.243*10^{-6})/\lambda\ ev$$

Example (4)

Calculate the photon energy of the output of a He-Ne laser (λ=632.8 nm) and a CO2 laser (λ=10.6 μm).

$$E_p = \frac{hc}{\lambda}$$

$$E_p = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}}$$

= 3.14 x 10-19 J for the He-Ne laser photon.

$$Ep = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{10.6 \times 10^{-6}}$$

= 1.88 x 10-20 J for CO2 laser photon.

b. Electron volts (eV) unite: An eV is the energy expended in moving an electron
through a one-volt potential difference. The relationship between Joules and eV is as
follows:

$$1\ eV = 1.602 \times 10^{-19}\ J$$

Photon energy transfer

The rate at which energy is transferred is referred to as power

$$\text{Power} = \frac{\text{Energy}}{\text{Time}}$$

$$\text{or} \quad P = \frac{E}{t}$$

Where P represents power, E the energy, and *t* the time of energy transfer. We know that the fundamental measurement unit in the metric system for energy is Joule. The fundamental unit of measuring time is second (s.) Based on these units, the measuring unit for power is Watt (W.) One watt of power is expended if 1 Joule of energy is transferred in 1 second. Thus, a Watt is a Joule per second.