Chapter 16

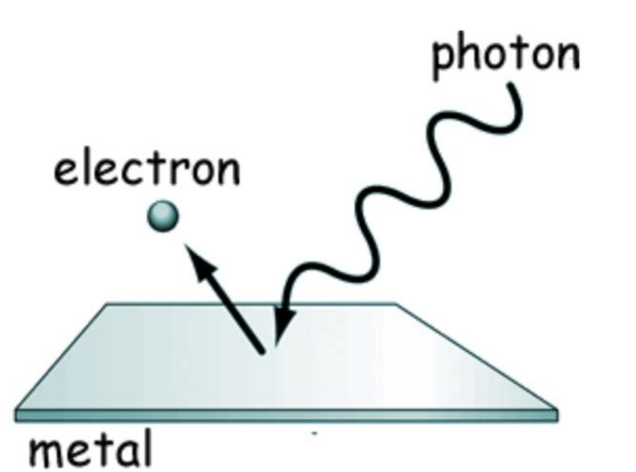
CORPUSCULAR ASPECT OF LIGHT

PHOTOELECTRIC EFFECT

I) What is photoelectric effect?

Is the emission of free electrons from the surface of a metal when illuminated by a suitable radiation.

The energy of the radiation must be greater than a certain value W_0



W_0 is called the **work function** of the metal or **extraction energy** or **ionization energy**.

It is the minimum energy needed to extract an electron from the surface of the metal.

Element	Work Function (eV)
Aluminum	4.3
Carbon	5.0
Copper	4.7
Gold	5.1
Nickel	5.1
Silicon	4.8
Silver	4.3
Sodium	2.7

II) Einstein's Postulate

Light is made up of very tiny massless particles (of zero charge) called photons. The energy of each photon is given by:

$$\boxed{E_{Ph} = h\nu = \frac{hc}{\lambda}}$$

Unit of E_{ph}

$$\boxed{\frac{(J.s)(m/s)}{m} = J}$$

Where:

ν is the frequency the photon in (Hz) or (s^{-1}).

λ is the wavelength of the photon in (m)

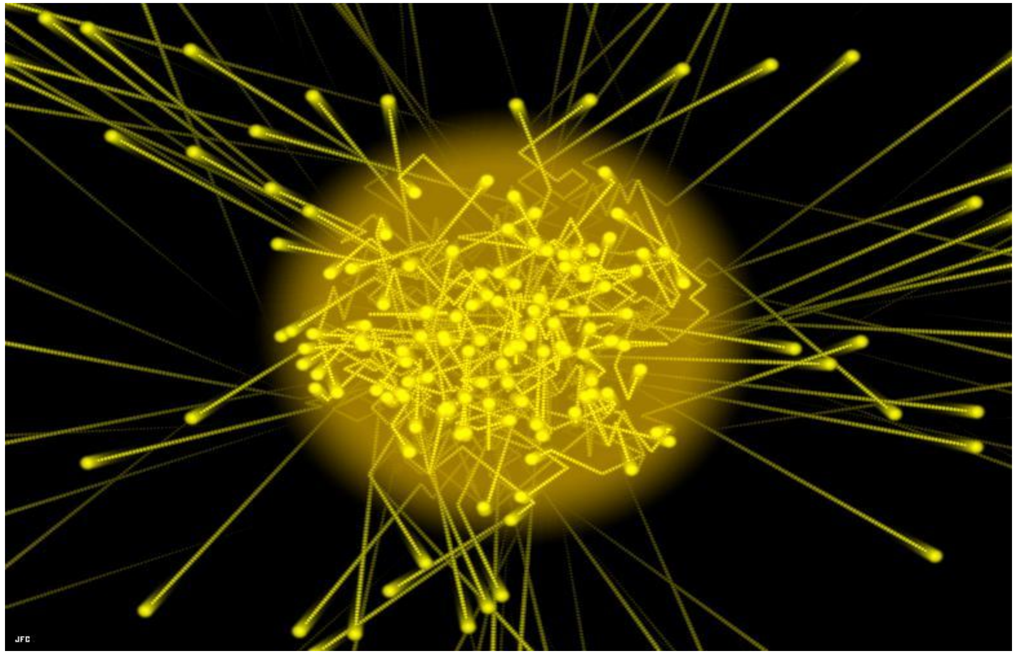
$h = 6.62 \times 10^{-34}$ J.s is Planck's constant.

$c = 3 \times 10^{8}$ m/s is the speed of light in vacuum.

The SI unit of E_{ph} is **Joule (J)**

Another unit is the **electron-volt (eV)**

$1eV = 1.6 \times 10^{-19}$ J



An Artist's Drawing of Photons

Example:

Calculate, in $\boldsymbol{J}$ and in $\boldsymbol{eV}$, the energy of a violet photon of wavelength $\lambda_V = 400nm\ and$ that of a red photon of wavelength $\lambda_R = 750nm$. Conclude.

Given: $h = 6.62 \times 10^{-34} J.s$ $\quad c = 3 \times 10^{8} m/s$

$1\ eV = 1.6 \times 10^{-19} J$

The energy of the violet photon is:

$$E_V = \frac{hc}{\lambda_V} = \frac{6.62\times10^{-34}\times3\times10^{8}}{400\times10^{-9}} = 4.965 \times 10^{-19} J = \frac{4.965\times10^{-19}}{1.6\times10^{-19}}\text{eV} = 3.1\text{eV}$$

The energy of the red photon is:

$$E_R = \frac{hc}{\lambda_R} = \frac{6.62\times10^{-34}\times3\times10^{8}}{750\times10^{-9}} = 2.648 \times 10^{-19} J = \frac{2.648\times10^{-19}}{1.6\times10^{-19}}\text{eV} = 1.655\text{eV}$$

Conclusion: As λ increases, the energy of the photon decreases and vice versa.

III) Threshold frequency and wavelength:

When the energy of the photon is exactly equal to $W_0 \Rightarrow$ the frequency of this photon is called the **threshold frequency ν_0** and its wavelength is called the **threshold wavelength λ_0.**

$$E_{Ph} = W_0$$

$$\Rightarrow h\nu_0 = W_0$$

$$OR \frac{hc}{\lambda_0} = W_0$$

W_0 is minimum $\Rightarrow \nu_0$ is minimum

W_0 is minimum $\Rightarrow \lambda_0$ is maximum

Threshold frequency ν_0: is the minimum frequency (of the incident radiation) needed to extract an election from the surface of the metal.

Threshold wavelength λ_0: is the maximum wavelength (of the incident radiation) needed to extract an election from the surface of the metal.

material	Aluminum	Carbon	copper	Gold	Nickel	Silicon	Silver	Sodium
Threshold Wavelength λ_0 (nm)	288.6	248	264	243	243	300	290	460

Example:

Can a red photon of wavelength λ = 750nm extract an electron from the surface of sodium of threshold wavelength λ_0 = 460 nm? Justify your answer.

1st Method	2nd Method	3rd Method
The threshold wavelength of sodium is λ_0 = 460nm. It is the maximum wavelength of the radiation that can extract electrons form the surface of sodium. Since λ = 750nm > λ_0 then the red photon cannot extract an electron from the surface of sodium	$\lambda > \lambda_0$ $\Rightarrow \frac{1}{\lambda} < \frac{1}{\lambda_0}$ $\Rightarrow \frac{hc}{\lambda} < \frac{hc}{\lambda_0}$ $\Rightarrow E_{ph}$ $< W_0$ ⇒ the red photon cannot extract an electron from the surface of sodium	The energy of the red photon is: $E_{ph} = \frac{hc}{\lambda}$ $= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{750 \times 10^{-9}}$ $= 2.648 \times 10^{-19} J$ $= \frac{2.648 \times 10^{-19} J}{1.6 \times 10^{-19}}$ $= 1.655 eV$ The work function of sodium is: $W_0 = \frac{hc}{\lambda_0} = 4.317 \times 10^{-19} J$ $= \frac{4.317 \times 10^{-19} J}{1.6 \times 10^{-19}} = 2.7 eV$ Since $E_{ph} < W_0$ ⇒ the red photon cannot extract an electron from the surface of sodium

- If $E_{ph} < W_0 \Rightarrow$ No electrons are extracted from the surface of the metal.

- If $E_{ph} = W_0 \Rightarrow$ electrons are ejected from the surface of the metal with zero KE

IV) Einstein Formula:

- If $E_{ph} > W_0 \Rightarrow$, then:

$$\boxed{E_{Ph} = W_0 + KE_{electron}}$$

$$\Rightarrow h\nu = h\nu_0 + KE_{electron}$$

$$\Rightarrow \frac{hc}{\lambda} = \frac{hc}{\lambda_0} + \frac{1}{2}m_e v^2$$

$$\boxed{m_e = 9.1 \times 10^{-31} kg}$$

Notes:

- The energy exchange between metal and radiation is quantized.
- The photon that extracts an electron from the surface of the metal is called effective photon. **Not all incident photons are effective.**
- Each effective photon gives its energy to only one electron $\Rightarrow$ the number of extracted electrons is equal to the number of effective photons ($N_{electrons} = N_{effective}$)
- The quantum efficiency of a metal is:

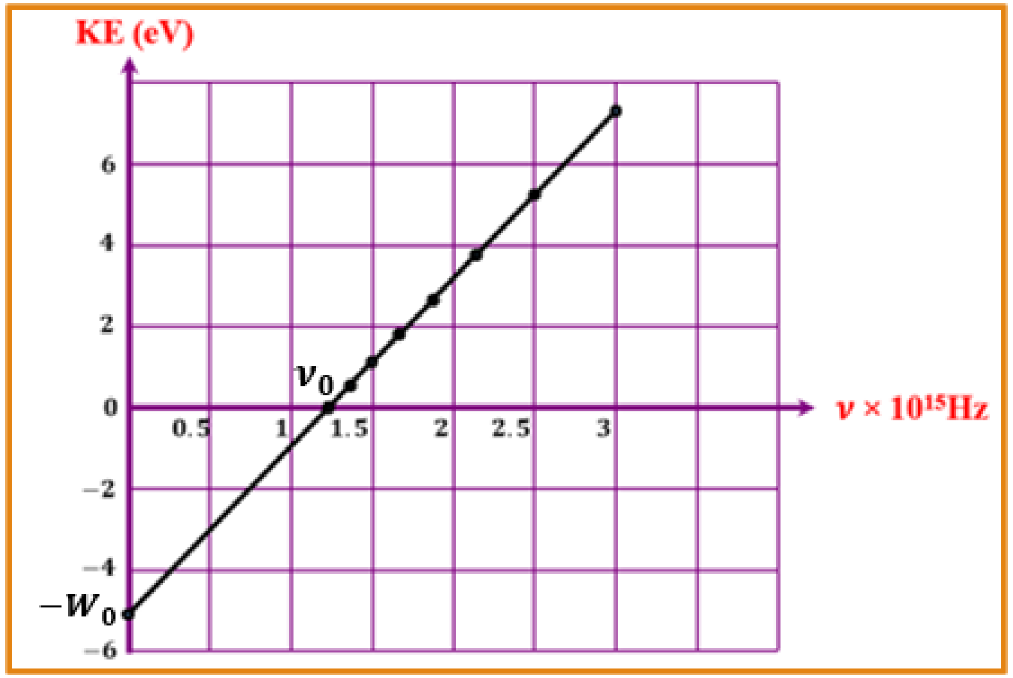
$$\boxed{\mathbf{r} = \frac{\text{Numberofeffectivephotons}}{\text{Numberofincidentphotons}} = \frac{N_{eff.}}{N_{incid.}}}$$

- Increasing the energy of photon does not increase the number of extracted electrons but it increases the K.E of the extracted electrons.
- Increasing the intensity of light, increases the number of extracted electrons.
- If the power P of a source of light and its wavelength λ are given, calculate the number of photons emitted form this source during time t.

$$\mathbf{P} = \frac{\mathbf{Energyofallthephotons}}{\mathbf{time}} = \frac{N \times Energyofonephoton}{time}$$

$$\Rightarrow P = \frac{Nhc}{\lambda t} \Rightarrow N = \frac{P\lambda t}{hc}$$

- Graph of KE versus frequency ν:



Using Einstein relation:

$$E_{ph} = W_0 + KE$$

$$KE = E_{ph} - W_0$$

$$\Rightarrow KE = h\nu - W_0 \text{ of the form } y = ax + b$$

⇒The variation of KE versus ν is a straight line not passing through the origin of positive slope.

The slope of this st. line is: $slope = h = \frac{KE_2 - KE_1}{\nu_2 - \nu_1}$