Particle Properties Of waves
Part 4
Photoelectric Effect

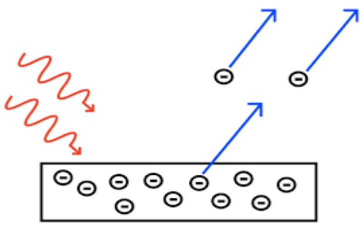
Einstein's Explanation Of Photoelectric Effect

- Inspired by Planck's quantization of EM radiation, Einstein in 1905 gave a theoretical explanation for the dependence of photoelectric emission on the frequency of the incident radiation.
- He assumed that light is made of corpuscles(particles) each carrying an energy hν, called photons.
- When a beam of light of frequency ν is incident on a metal, each photon transmits all its energy hν to an electron near the surface; in the process, the photon is entirely absorbed by the electron.

Work Function & Threshold Frequency

- Every metal has free electrons that move from one atom to another.
- The minimum energy required to dislodge the electron from the metal is called the work function (W) of that metal.
- Threshold Frequency : The minimum frequency required by the incident wave to dislodge the electron from the metal.
- Hence no electron can be emitted from the metal's surface unless hν > W

Incident light of energy



hν = W + K

- If ν_0 is the threshold frequency then work function, $\mathbf{W = h\nu_0}$

hν = W + K becomes

$$h\nu = h\nu_0 + K \text{ or } K = h(\nu - \nu_0)$$

- No electron can be ejected from the metal unless $\nu > \nu_0$ (since kinetic energy cannot be negative)
- The photoelectric effect cannot occur when $\nu < \nu_0$ regardless of the intensity of radiation.
- The ejected electrons acquire their kinetic energy from the excess energy **h** $(\nu - \nu_0)$ supplied by the incident radiation.

Review

- No emission below threshold .
- Threshold frequency depends on the properties of the metal.
- The number of electrons ejected increases with the intensity of the light.
- The kinetic energy of the ejected electrons depends on the frequency but not on the intensity of the beam.

Problems

1. How can we increase the number of electrons in photoelectric effect ?

A) By increasing the frequency

B) By decreasing the frequency

C) By increasing the intensity

D) By decreasing the intensity

Solution : C) By increasing the intensity

- The number of ejected electrons increases with the intensity of the light and hence the photoelectric effect.

2. The kinetic energy of the photoelectron depends on the

A) Wavelength of the incident wave.

B) Intensity of the incident wave

C) Amplitude of the incident wave.

D) None of the above.

Solution : A) Wavelength of the incident wave

- Kinetic energy is proportional to frequency $K \propto \nu$

Also we know $C = \nu\lambda$

$\nu = \frac{C}{\lambda}$ Which means $K = \frac{C}{\lambda}$

3. When an ultraviolet beam of wavelength λ= 80 nm falls on a lead surface, it produces photoelectrons with maximum energies 11.390 eV. Calculate the work function, the cut-off frequency, and the cut-off wavelength of lead.

Solution : Given

λ= 80 nm= 80×10^{-9} nm

KE = 11.390 ev

W = ?

ν_0 = ?

λ_0 = ?

Work function

By Photoelectric effect hν = W+ K

Also E = hν = $\frac{hc}{\lambda}$

hc = 1.24×10^{-6}ev

$\frac{hc}{\lambda}$ = W + K

W = $\frac{hc}{\lambda}$ - K

= $\frac{1.24\times10^{-6}}{80\times10^{-9}}$ - 11.390 ev

= 4.11 ev

Cut off frequency

W = hν_0= 4.11 ev

$\nu_0 = \frac{4.11\times1.6\times10^{-19}}{6.626\times10^{-34}Js}$

ν_0= 10^{15}Hz

Cut off wavelength

$\lambda_0 = \frac{c}{\nu_0}$

= $\frac{3\times10^{8}m/s}{10^{-15}Hz}$ =$3\times10^{-7} = 300$ nm

4. Threshold wavelength for photoelectric effect on sodium is 5000 A^0 . Its work function is

(a) 15 J

(b) 16×10^{-14} J

(c) $4\times10^{-19}J$

(d) $4\times110^{-81}J$

Solution : (c) $4\times10^{-19}J$

$$\lambda = 5000A^0 = 5000\times10^{10}m$$

$$W = \frac{hc}{\lambda_0} = \frac{6.626\times10^{-34}\times3\times10^8}{5000\times10^{-10}}$$

$$W = 4\times10^{-19}J$$

5. When light of wavelength 300 nm falls on a photoelectric emitter, photoelectrons are liberated. For another emitter, however light of 600 nm wavelength is sufficient for creating photoemission. What is the ratio of the work functions of two emitters?

(a) 1 : 2

(b) 2 : 1

(c) 4 : 1

(d) 1 : 4

Solution :

λ_1 = 300 nm

λ_2 = 600 nm

W_1 = ?

W_2 =?

$\frac{W_1}{W_2}$ = ?

Work function, $W = \frac{hC}{\lambda} \longrightarrow W \propto \frac{1}{\lambda}$

$$\frac{W_1}{W_2} = \frac{\lambda_2}{\lambda_1} = \frac{600}{300} = \frac{2}{1}$$

$W_1 : W_2 = 2 : 1$

6. The energy of a photon of light with wavelength $5000A^0$ is approximately 2.5 eV. This way the energy of an X-ray photon with wavelength $1A^0$ would be

(a) 2.5/5000 eV

(b) $2.5/(5000)^2$ eV

(c) 2.5×5000 eV

(d) $2.5\times5000)^2\ eV$

Solution : (c) 2.5×5000 eV

Given ; λ_1= $5000A^0$

E_1 = 2.5 eV

λ_2 = $1A^0$

E_2 = ?

As E= $\frac{hC}{\lambda}$ $\Longrightarrow$ E $\propto \frac{1}{\lambda}$

$\frac{E_1}{E_2} = \frac{\lambda_2}{\lambda_1}$

$E_2 = E_1 \frac{\lambda_2}{\lambda_1}$

$E_2 = \frac{2.5\times5000}{1} = 2.5\times5000$ eV

7. Threshold frequency of Potassium is $5\times10^{14}\ S^{-1}$. A light of frequency $1.6\times10^{15}S^{-1}$ Strikes the metal. Calculate the kinetic energy of ejected electron.

Solution :

$\nu_0 = 5\times10^{14}\ S^{-1}$

ν = $1.6\times10^{15}S^{-1}$

K= h (ν - ν_0)

= $6.626 \times 10^{-34}(1.6\times10^{15} - 5\times10^{14})$

= 72.6×10^{20}J

= 6.5 eV