12^{th} Standard Physics

Dual Nature of Radiation and Matter

1. Photoelectric Effect The phenomenon of emission of photoelectron from the surface of metal, when a light beam of suitable frequency is incident on it, is called photoelectric effect. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current.

Hertz' Observation The phenomenon of photo electric emission was discovered in 1887 by Heinrich Hertz during his electromagnetic wave experiment. In his experimental investigation on the production of electromagnetic waves by means of spark across the detector loop were enhanced when the emitter plate was illuminated by ultraviolet light from an arc lamp.

Lenard's Observation Lenard observed that when ultraviolet radiation were allowed to fall on emitter plate of an evacuated glass tube enclosing two electrodes, current flows. As soon as, the ultraviolet radiations were stopped, the current flows also stopped. These observations indicate that when ultraviolet radiations fall on the emitter plate, electrons are ejected from it which are attracted towards the positive plate by the electric field.

2. Terms Related to Photoelectric Effects

There are many terms related to photoelectric effects which are of follow:

(i) Free Electrons In metals, the electrons in the outer shells (valence electrons) are loosely bound to the atoms, hence they are free to move easily within the metal surface but cannot leave the metal surface. Such electrons are called free electrons.

(ii) Electron Emission The phenomenon of emission of electrons from the surface of a metal is called electron emission.

(iii) Photoelectric Emission It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.

(iv) Work Function The minimum amount of energy required to just eject an electron from the outer most surface of metal is known as work function of the metal.

Also, work function $W = h\nu_0 = \frac{hc}{\lambda_0}$

where, ν_0 and λ_0 are the threshold frequency and threshold wavelength, respectively.

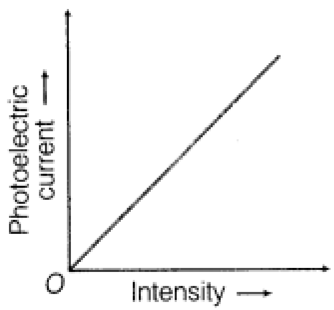
(v) Cut-off Potential For a particular frequency of incident radiation, the minimum negative (retarding) potential V_0 given to plate for which the photoelectric current becomes zero, is called cut-off or stopping potential.

$$KE_{max} = eV_0 \Rightarrow \frac{1}{2}mv_{max}^2 = eV_0$$

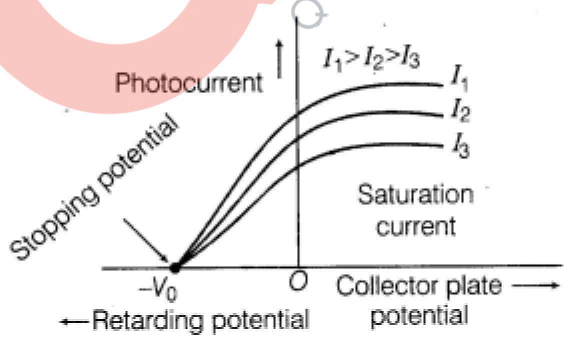
(vi) Cut-off Frequency The minimum frequency of light which can emit photoelectrons from a material is called threshold frequency or cut-off frequency of that material.

(vii) Cut-off Wavelength The maximum wavelength of light which can emit photoelectrons from a material is called threshold wavelength or cut-off wavelength of that material.

3. Effect of Intensity of Light on Photo current For a fixed frequency of incident radiation, the photoelectric current increases linearly with increase in intensity of incident light.



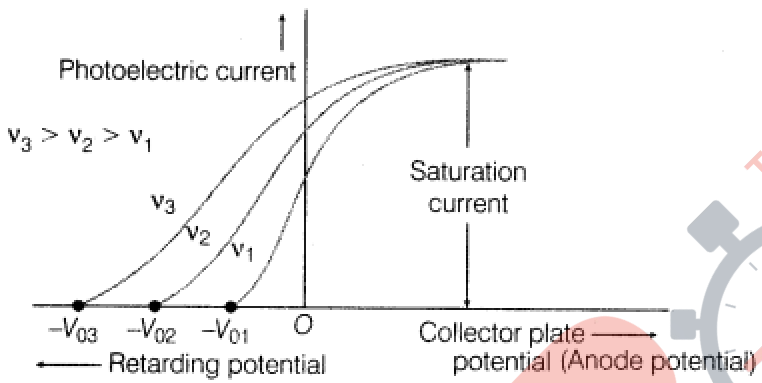
4. Effect of Potential on Photoelectric Current For a fixed frequency and intensity of incident light, the photoelectric current increases with increase in the potential applied to the collector. When all the photoelectrons reach the plate A, current becomes maximum it is known as saturation current.



NOTE Photoelectric current is zero whenever no electron even the fastest photoelectrons cannot reach the plate A. Hence, Maximum kinetic energy is given as $K_{max} = eV_0 = \frac{1}{2} mv_{max}^2$

where, m is the mass of photoelectron and v_{max} is the maximum velocity of emitted photoelectron.

5. Effect of Frequency of Incident Radiation on Stopping Potential We take radiations of different frequencies but of same intensity. For each radiation, we study the variation of photoelectric current against the potential difference between the plates.



6. Laws of Photoelectric Emission

(i) For a given material and a given frequency of incident radiation, the photoelectric current number of photoelectrons ejected per second is directly proportional to the intensity of the incident light.

(ii) For a given material and frequency of incident radiation, saturation current is found to be proportional to the intensity of incident radiation, whereas the stopping potential is independent of its intensity.

(iii) For a given material, there exists a certain minimum frequency of the incident radiation below which no emissions of photoelectrons takes place. This frequency is called threshold frequency.

Above the threshold frequency, the maximum kinetic energy of the emitted photoelectron or equivalent stopping potential is independent of intensity of incident light but depends only upon the frequency (or wavelength) of the incident light.

(iv) The photoelectric emission is an instantaneous process. The time lag between the incidence of radiations and emission of photoelectron is very small, less than even 10^{-9} s.

7. Einstein Photoelectric Equation Energy Quantum of Radiation, Kmax = hv – Φ_0 where, hv = energy of photon and Φ = work-function

NOTE: According to Planck's quantum theory, light radiations consist of tiny packets of energy called quanta. One quantum of light radiation is called a photon which travels with the speed of light.

8. Relation between Stopping Potential (V_0) and Threshold Frequency (ν_0)

We know that $h\nu = KE_{max} + W_0$

where, W_0 = work function

$$KE_{max} = h\nu - W_0 \quad \text{also,} \quad W_0 = h\nu_0$$

$$KE_{max} = h\nu - h\nu_0 \Rightarrow KE_{max} = h(\nu - \nu_0)$$

$$eV_0 = h(\nu - \nu_0) \Rightarrow V_0 = \frac{h}{e}(\nu - \nu_0) \qquad [\because KE_{max} = eV_0]$$

$$\nu = \frac{c}{\lambda} \text{ and } \nu_0 = \frac{c}{\lambda_0}$$

$$V_0 = \frac{h}{e}\left[\frac{c}{\lambda} - \frac{c}{\lambda_0}\right] \Rightarrow V_0 = \left(\frac{hc}{e}\right)\left[\frac{1}{\lambda} - \frac{1}{\lambda_0}\right]$$

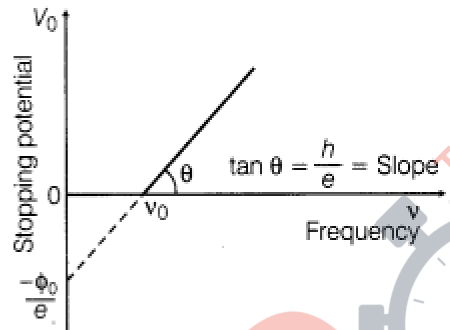
For photoelectric emission $\lambda < \lambda_0$ and $\nu > \nu_0$.

9. Important Graphs related to Photoelectric Effect

(*i*) Graph between frequency (ν) and stopping potential V_0, we know that

$$eV_0 = h\nu - \phi_0 \Rightarrow V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

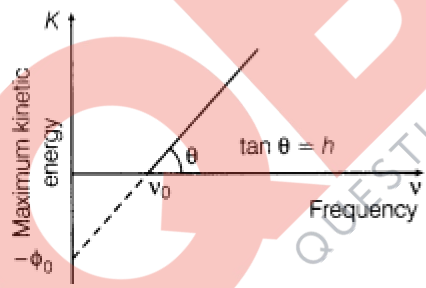
So, $V_0 \propto \nu$



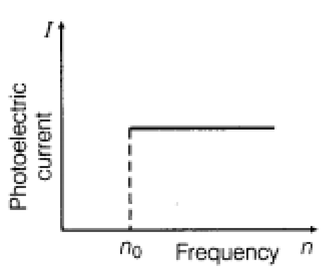
(*ii*) Frequency (ν) and maximum kinetic energy graph

$$KE_{max} = h\nu - \phi_0$$

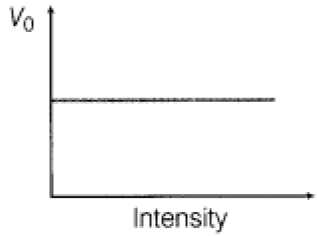
So, $$KE_{max} \propto \nu$$



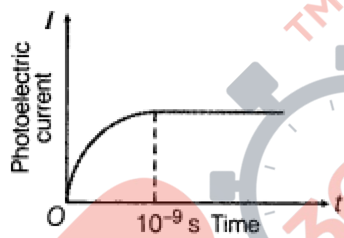
(iii) Frequency (v) and photoelectric current (I) graph. This graph shows that the photoelectric current (I) is independent of frequency of the incident light till intensity remains constant.



(iv) Intensity and stopping potential (V_0) graph



(v) Photoelectric current (I) and time lag (t) graph is given by



10. (i) $1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}$, $1\ \text{MeV} = 1.6 \times 10^{-13}\ \text{J}$,

(ii) Energy of a photon $= E = h\nu = \frac{hc}{\lambda} = \frac{1242\ \text{eV-nm}}{\lambda\ (\text{in nm})}$