Dual Nature of Matter

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 electromagn etic 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 o f 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.

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.

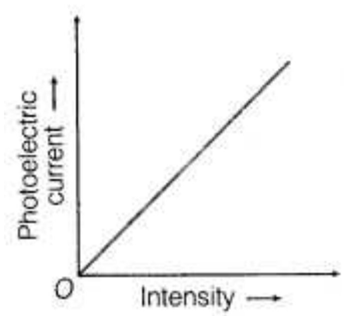
(v) Cut-off Potential : For a particular frequency of incident radiation, the minimum negative (retarding) potential V_0 given to plate for which the photoelectric current becomes zero, is called cut-off or stopping potential.

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

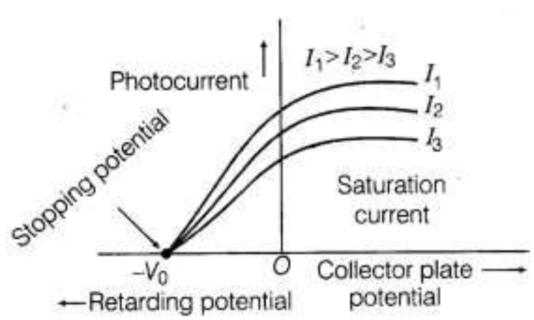
(vi) Cut-off Frequency : The minimum frequency of light which can emit photoelectrons from a material is called threshold frequency or cut-off frequency of that material.

(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.

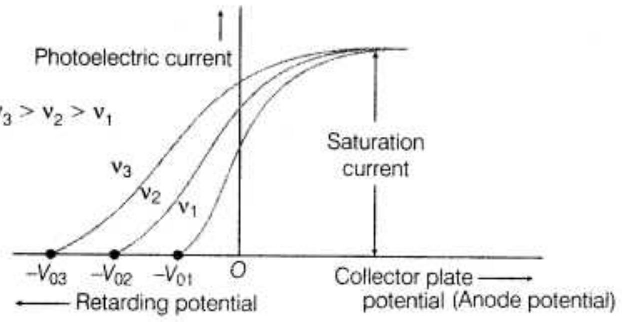
Effect of Intensity : Effect of intensity of Light on Photo current For a fixed frequency of incident radiation, the photoelectric current increases linearly with increase in intensity of incident light.



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.



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.



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 t he 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.

Einstein Photoelectric Equ ation: 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.

Relation between Stopping Potential (V_0) and Threshold Frequency (v_0)

We know that $hv = KE_{max} + W_0$

Where, W_0 = work function

$KE_{max} = hv - W_0$ and $W_0\ hv_0$

$KE_{max} = hv - hv_0 \Rightarrow KE_{max} = h(v - v_0)$

$$eV_0 = h(v - v_0) \Rightarrow V_0 \frac{h}{e}(v - v_0) \qquad [\because KE_{max} = eV_0]$$

$$v = \frac{c}{\lambda} \text{ and } v_0 = \frac{c}{\lambda_0}$$

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

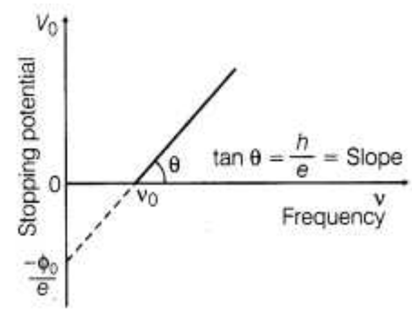
For photoelectric emission $\lambda < \lambda_0$ and $v > v_0$.

Important Graphs related to Photoelectric Effect

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

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

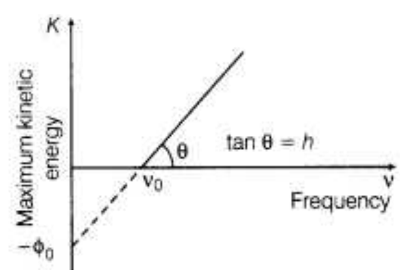
So, V0 $\propto$ v



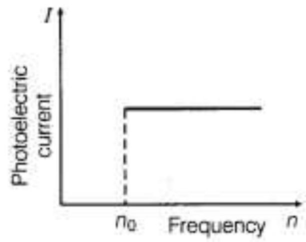
(ii) Frequency (v) and maximum kinetic energy graph

$KE_{max} = hv - \phi_0$

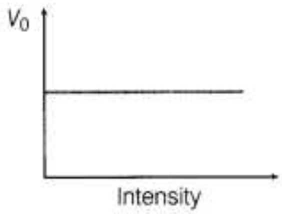
So, $KE_{max} = hv \propto v$



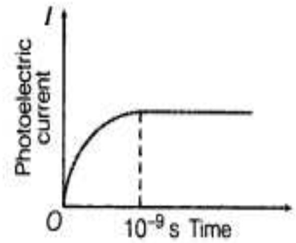
(iii) Frequency (v) and photoelectric current (I) graph. This graph shows that the photoelectric current (I) is independent of frequency of the incident light till intensity remains constant.



(iv) Intensity and stopping potential (V_0) graph



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



Note:

(i) 1 eV = 1.6×10^{-19}J, 1 MeV = 1.6×10^{-13}J,

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

Multiple Choice Questions

1. De-Broglie equation states the:
(a) dual nature (b) particle nature
(c) wave nature (d) None of these

2. Protons and alpha particles have the same de-Broglie wavelength. What is same for both of them?
(a) Energy (b) Time period
(c) Frequency (d) Momentum

3. Kinetic energy of emitted electrons depends upon:
(a) frequency
(b) intensity
(c) nature of atmosphere surrounding the electrons
(d) none of these

4. The ratio of specific charge of an alpha particle to the proton is:
(a) 1 : 2 (b) 2 : 1
(c) 4 : 1 (d) 1 : 4

5. In Thomson's experiment number of parabola gives:
(a) the no. of electrons present in element
(b) the no. of proton present in element
(c) the no. of neutrons present in element
(d) the no. of isotopes of the element present

6. The work function of photoelectric material is 3.3 eV. The threshold frequency will be equal to:
(a) 8×10^{14} Hz (b) 8×10^{10} Hz
(c) 5×10^{10} Hz (d) 4×10^{14} Hz

7. The strength of photoelectric current depends upon:
(a) angle of incident radiation
(b) frequency of incident radiation
(c) intensity of incident radiation
(d) distance between anode and cathode

8. The momentum of an electron that emits a wavelength of 2 Å. will be:
(a) 6.4×10^{-36} kgms^{-1}
(b) 3.3×10^{-24} kgms^{-1}
(c) 3.3×10^{-34} kgms^{-1}
(d) None of these

9. Name the scientists who first studied the passage of electricity through fluids to establish the electrical nature of matter.
(a) Millikan (b) Planck
(c) Faraday (d) Boyle

10. Millikan's oil drop experiment makes use of
(a) Stokes' law
(b) Boyle's law
(c) Gas equation
(d) Bernoulli's theorem

11. X-rays are -
(a) deflected by an electric field
(b) deflected by a magnetic field
(c) deflected by both electric and magnetic fields
(d) not deflected by electric and magnetic fields

12. In photo electric emission, for alkali metals the threshold frequency lies in the:
(a) visible region
(b) ultraviolet region
(c) infrared region
(d) far end of the infrared region

13 Which of the following radiations cannot eject photo electrons?
(a) ultraviolet
(b) infrared
(c) visible
(d) X-rays

14. What is the de -Broglie wavelength of an electron accelerated from rest through a potential difference of 100 volts?
(a) 12.3 Å (b) 1.23 Å
(c) 0.123 Å (d) None of these

15. The de -Broglie wavelength of particle of mass 1 mg moving with a velocity of 1 ms^{-1}, in terms of Planck's constant h, is given by (in meter):
(a) 10^5 h (b) 10^6 h
(c) 10^{-3} h (d) 10^3 h

16. Evidence of the wave nature of light c annot be obtained from:
(a) diffraction
(b) interference
(c) Doppler effect
(d) reflection

ANSWERS and SOLUTIONS

1. (a) dual nature
2. (d) Momentum
3. (a) frequency
4. (a) 1 : 2
5. (d) the no. of isotopes of the element present
6. (a) 8×10^{14} Hz
7. (b) frequency of incident radiation
8. (b) 3.3×10^{-24} $kgms^{-1}$
9. (c) Faraday
10. (a) Stokes' law
11. (d) not deflected by electric and magnetic fields
12. (d) visible region
13. (b) infrared
14. (b) 1.23 Å
15. (b) 10^6 h
16. (d) reflection

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