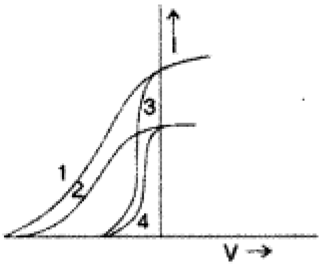
"DUAL NATURE OF RADIATION AND MATTER".

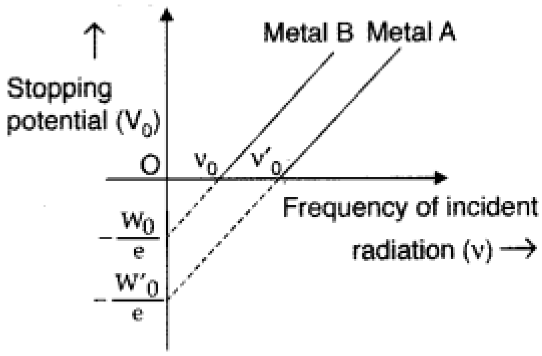
Worksheet: MODULE-2

Q.1] The given graph shows the variation of photo-electric current (I) versus applied voltage (V) for two different photosensitive materials and for two different intensities of the incident radiation. Identify the pairs of curves that correspond to different materials but same intensity of incident radiation.



Ans: The pairs (2, 4) and (1, 3) have same intensity but different material.

Q.2] The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer.



Ans: Metal 'A', because of higher threshold frequency for it.

Q.3] State one reason to explain why wave theory of light does not support photoelectric effect.

Answer:

One reason why wave theory of light does not support photoelectric effect is that the kinetic energy of photo electrons does not depend on the intensity of incident light.

Q.4] Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect, which can be explained on the basis of Einstein's photoelectric equation is $K_{max} = h\nu - \phi_0$.

(i) We find K_{max} depends linearly on V only. It is independent of intensity of radiation.

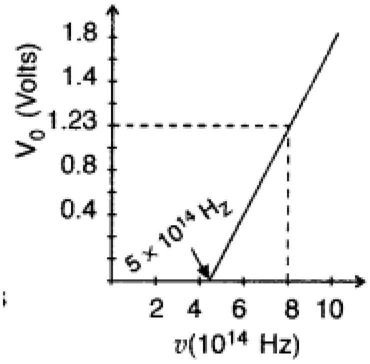
(*ii*) Since K_{max} must be positive.

$h\nu > \phi_0 \quad \Rightarrow \nu > \nu_0 \qquad (\because \phi_0 = h\nu_0)$

So greater the work function (ϕ_0), higher is the minimum frequency (threshold frequency) required to emit photo electron.

(ii) Greater the number of photons, greater is the number of photoelectrons. So, photoelectric current is proportional to intensity.

Q.5] Using the graph shown in the figure for stopping potential v/s the incident frequency of photons, calculate Planck's constant.



According to Einstein's photoelectric equation,

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

In the given graph :

Stopping potential, $V_0 = 1.23$ V

Change in frequency, $\Delta\nu = (8 \times 10^{14} - 5 \times 10^{14})$

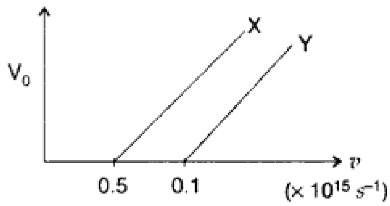
$= 3 \times 10^{14}$ Hz

$\therefore$ Slope of the line $= \frac{h}{e}$

$\because \quad \frac{h}{e} = \frac{V_0}{\Delta\nu} = \frac{1.23}{3 \times 10^{14}}, \quad \because e = 1.6 \times 10^{-19}$ C

$\therefore \quad h = \frac{1.23 \times 1.6 \times 10^{-19}}{3 \times 10^{14}}$ JS $= 6.6 \times 10^{-34}$ JS

Q.6] The following graph shows the variation of stopping potential V_0 with the frequency v of the incident radiation for two photosensitive metals X and Y:



(i) Which of the metals has larger threshold wavelength? Give reason.

(ii) Explain, giving reason, which metal gives out electrons, having larger kinetic energy, for the same wavelength of the incident radiation.

(iii) If the distance between the light source and metal X is halved, how will the kinetic energy of electrons emitted from it change? Give reason.

(*i*) $\lambda = \frac{C}{\nu}$

As $(\nu_0)X < (\nu_0)Y \quad \therefore (\lambda_0)X > (\lambda_0)Y$

$\therefore$ **Metal 'X' has larger threshold wavelength**

(*ii*) *According to Einstein's photoelectric equation :*

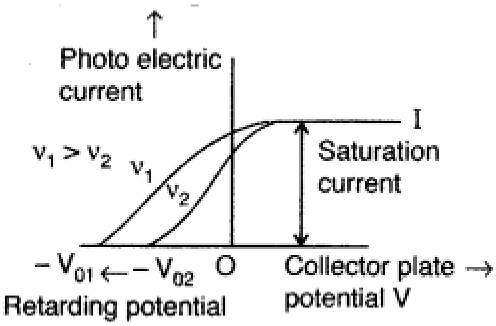
$$\frac{hC}{\lambda} = \frac{hC}{\lambda_0} + \text{K.E. of photoelectron}$$

For the same λ of incident radiation, L.H.S. is constant. So, metal X with higher value of λ_0 will emit photoelectrons of larger K.E.

(iii) Kinetic energy will not change. On reducing the distance only intensity of light changes, frequency remains same. K.E. of emitted photoelectrons depends on frequency.

Q.7] Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $v_1 > v_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer.

Ans: Stopping potential is directly proportional to the frequency of incident radiation. The stopping potential is more negative for higher frequencies of incident radiation. Therefore, stopping potential is higher in v_1.



Q.8] Write Einstein's photoelectric equation. State clearly how this equation is obtained using the photon picture of electromagnetic radiation.

$$h\nu = \phi_0 + K_{max}$$

This is Einstein's photoelectric equation. Photoelectric emission is the result of interaction of two particles—one a photon of incident radiation and other an electron of photo sensitive metal. The free electrons are bound within the metal due to restraining forces on the surface. The minimum energy required to liberate an electron from the metal surface is called work function ϕ0 of the metal. Each photon interacts with one electron. The energy hv of the incident photon is used up in two parts:

(a) a part of the energy of the photon is used in liberating the electron from the metal surface, which is equal to the work function ϕ0 of the metal and

(b) the remaining energy of the photon is used in imparting K.E. of the ejected electron.

By the conservation of energy:

Energy of the inefficient photon = maximum K.E. of photoelectron + Work function

$$h\nu = \frac{1}{2}mv_{max}^2 + \phi_0$$

$$\Rightarrow K_{max} = \frac{1}{2}mv_{max}^2 = h\nu - \phi_0$$

$$= h\nu - h\nu_0 = h(\nu - \nu_0)$$

Q.9] Why photoelectric effect cannot be explained on the basis of wave nature of light? Give reasons.

(i) The maximum kinetic energy of the emitted electron should be directly proportional to the intensity of incident radiations but it is not observed experimentally. Also, maximum kinetic energy of the emitted electrons should not depend upon incident frequency according to wave theory, but it is not so.

(ii) According to wave theory, threshold frequency should not exist. Light of all frequencies should emit electrons provided intensity of light is sufficient for electrons to eject.

(iii) According to wave theory, photoelectric effect should not be instantaneous. Energy of wave cannot be transferred to a particular electron but will be distributed to all the electrons present in the illuminated portion. Hence, there has to be a time lag between incidence of radiation and emission of electrons.

Q.10] Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

Basic features of photon picture of electromagnetic radiation:

(i) Radiation behaves as if it is made of particles like photons. Each photon has energy E = hv and momentum p = h/λ.

(ii) Intensity of radiation can be understood in terms of number of photons falling per second on the surface. Photon energy depends only on frequency and is independent of intensity.

(iii) Photoelectric effect can be understood as the result of one to one collision between an electron and a photon.

(iv) When a photon of energy E = h v; is incident on a metal surface, a part of its energy is used in overcoming the work function and other part is used in imparting kinetic energy, so

KE = h (v – v_0).

Q.11] Write Einstein's photoelectric equation.

Einstein's photoelectric equation

$$hv = hv_0 + \frac{1}{2}mv^2_{max}$$

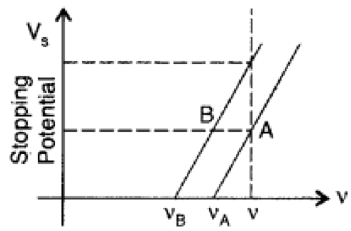
where
- v = frequency of incident radiation
- $\frac{1}{2}mv^2_{max}$ = maximum kinetic energy
- v_0 = threshold frequency

Q.12] Sketch the graph showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $v_A > v_B$.

(i) In which case is the stopping potential more and why?

(ii) Does the slope of the graph depend on the nature of the material used? Explain.

Graph :



(*i*) For material B, because from the graph for the same value of 'v', stopping potential is more for material 'B' $\left[V_0 = \frac{h}{e}(v - v_0)\right]$

∴ V_0 is higher for lower value of v_0

(*ii*) No, it does not depend on the nature of material used.

As slope is given by $\frac{h}{e}$ which is constant.

Q.14] The photon emitted during the de-excitation from the 1st excited level to the ground state of hydrogen atom is used to irradiate a photo cathode of a photocell, in which stopping potential of 5 V is used. Calculate the work function of the cathode used.

Given : $n_1 = 2$, $n_2 = 1$, $V_0 = 5V$, $eV_0 = 5eV$,

$(\phi_0) = ?$

Energy of photon (E) = (13.6) – (3.4) eV = 10.2 eV

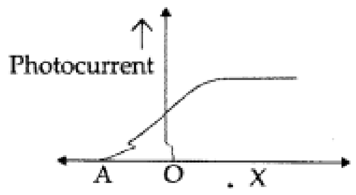
According to photoequation,

$E = eV_0 + \phi_0$

$\phi_0 = E - (eV_0) = (10.2) - (5)$

$\therefore$ $\boldsymbol{\phi_0 = 5.2 \text{ eV}}$

Q.15] The given graph shows the variation of photocurrent for a photosensitive metal:



(a) Identify the variable X on the horizontal axis.

(b) What does the point A on the horizontal axis represent?

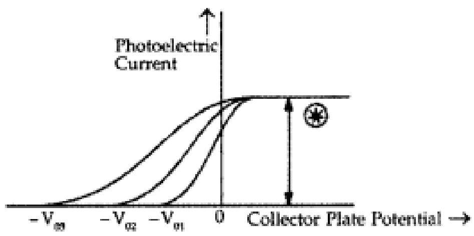
(c) Draw this graph for three different values of frequencies of incident radiation v1 v2 and v3 ($v_1 > v_2 > v_3$) for same intensity.

(d) Draw this graph for three different values of intensities of incident radiation I1 I2 and I3 ($I_1 > I_2 > I_3$) having same frequency.

(a) 'X' is a collector plate potential.

(b) 'A' represents the stopping potential.

(c) Graph for different frequencies:



(*d*) Graph for different intensites :