ELECTRON PHOTON (GTB)

ILLUSTRATIVE EXAMPLES

(1) A metal whose work function is 4.2eV is irradiated by radiation whose wavelength is 2000 Å. Find the maximum kinetic energy of emitted electron.

Data : $\phi_o = 4.2 \text{ eV} = 6.72 \times 10^{-19}\text{J}$

$\lambda = 2000 \text{ A.U.} = 2 \times 10^{-7} \text{ m}$

$KE_{max} = ?$

Solution :

$$\therefore \frac{1}{2} m v_{max}^2 = h\upsilon - \phi_o$$

$$\therefore KE_{max} = h\upsilon - \phi_o$$

$$\therefore KE_{max} = \left(\frac{hc}{\lambda}\right) - (\phi_o)$$

$$\therefore KE_{max} = \left(\frac{6.63 \times 10^{-34} \text{ y } 3 \times 10^8}{2 \times 10^{-7}}\right) - (6.72 \times 10^{-19})$$

$$\therefore KE_{max} = \left(\frac{19.89}{2} \times 10^{-19}\right) - (6.72 \times 10^{-19})$$

$$\therefore KE_{max} = (9.945 - 6.72) \times 10^{-19}$$

$$\therefore KE_{max} = 3.225 \times 10^{-19}\text{J}$$

$$\therefore KE_{max} = 2.015 \text{ eV}$$

(2) If photoelectrons are to be emitted from potassium surface with speed of 6×10^5 m/s, what frequency of radiation must be used ? Threshold frequency for potassium is 4.22×10^{14} Hz.

Data : $v_{max} = 6 \times 10^5$ m/s

$\upsilon_0 = 4.22 \times 10^{14} \text{ H}_z$

$\upsilon = ?$

Solution :

$$\therefore KE_{max} = \frac{1}{2} m v_{max}^2 = h(\upsilon - \upsilon_o)$$

$$\therefore \upsilon = \frac{1}{2}\frac{m v_{max}^2}{h} + \upsilon_0$$

$$= \frac{1}{2}\frac{9.1 \times 10^{-31} \times (6 \times 10^5)^2}{6.63 \times 10^{-34}} + 4.22 \times 10^{14} \text{ H}_Z$$

$$= 2.47 \times 10^{14} + 4.22 \times 10^{14}$$

$$= 6.69 \times 10^{14} \text{ Hz}$$

(3) A photon of wavelength 3310 Å falls on a photocathode and an electron of energy 3×10^{-19} J is ejected. If the wavelength of the incident photon is changed to 5000 Å, the energy of the ejected electron is 9.72×10^{-20} J. Calculate the value of the Planck's constant and threshold wavelength of the photon.

Data :

$\lambda_1 = 3310\ \text{Å} = 3.31 \times 10^{-7}$ m

$KE_{max}(1) = 3 \times 10^{-19}$ J

$\lambda_2 = 5000\ \text{Å} = 5 \times 10^{-7}$ m

$KE_{max}(2) = 9.72 \times 10^{-20}\ J = 0.972 \times 10^{-19}$ J

$h = ?$

$\lambda_0 = ?$

Solution :

$$KE_{max}(1) = \frac{hc}{\lambda_1} - \phi_0$$

$$KE_{max}(2) = \frac{hc}{\lambda_2} - \phi_0$$

$$\therefore KE_{max}(1) - KE_{max}(2) = hc\left(\frac{1}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

$$3 \times 10^{-19} - 0.972 \times 10^{-19} = h \times 3 \times 10^8 \left(\frac{1}{3.31 \times 10^{-7}} - \frac{1}{5.00 \times 10^{-7}}\right)$$

$$2.028 \times 10^{-19} = h \times \frac{3 \times 10^8}{10^{-7}}\left(\frac{5.00 - 3.31}{3.31 \times 5.00}\right)$$

$$2.028 \times 10^{-19} = h \times 3 \times 10^{15}\left(\frac{1.69}{16.55}\right)$$

$$\therefore h = \frac{2.028 \times 10^{-19} \times 16.55}{3 \times 10^{15} \times 1.69}$$

$$= 6.62 \times 10^{-34}\ \text{Js}$$

$$KE_{max}(1) = \frac{hc}{\lambda_1} - \phi_0$$

$$\therefore \phi_0 = \frac{hc}{\lambda_1} - KE_{max}(1)$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3.31 \times 10^{-7}} - 3 \times 10^{-19}$$

$$= 6 \times 10^{-19} - 3 \times 10^{-19}$$

$$= 3 \times 10^{-19}\ \text{J}$$

$$\phi_0 = \frac{hc}{\lambda_0}$$

$$\therefore \lambda_0 = \frac{hc}{\phi_0} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3 \times 10^{-19}}$$

$$= 6.62 \times 10^{-7}$$

$$= 6620\ \text{Å}$$

(4) If the maximum kinetic energy of emitted electrons in photoelectric effect is 2 eV. Find the stopping potential and threshold wavelength, if the work function for metal is 4.2 eV.

Data : $K.E._{max} = 2$ eV

$K.E._{max} = 3.2 \times 10^{-19}$J

$\phi_o = 4.2\ \text{eV} = 6.72 \times 10^{-19}$J

$V_o = ?$

$\lambda_o = ?$

Solution :

$$K.E._{max} = eV_o$$

$$\therefore V_o = \frac{KE_{max}}{e} = \frac{3.2 \times 10^{-19}}{1.6 \times 10^{-19}} = 2\ \text{V}$$

$$\phi_o = h\upsilon_o = \frac{hc}{\lambda_0}$$

$$\therefore \lambda_o = \frac{hc}{\phi_0} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6.72 \times 10^{-79}}$$

$$\therefore \lambda_o = \frac{hc}{\phi_0} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6.72 \times 10^{-19}}$$

$$\therefore \lambda_o = 2960\ \text{Å}$$

(5) Light of wavelength 3000 Å falls on a metal surface having work function 2.3 eV. Calculate the maximum velocity of the ejected electrons.

Data : $\lambda = 3000\ \text{Å} = 3 \times 10^{-7}$m

$\phi_o = 2.3\ \text{eV} = 3.68 \times 10^{-19}$J

$v_{max} = ?$

Solution :

$$\frac{1}{2} m v_{max}^2 = h\upsilon - \phi_o$$

$$KE_{max} = \frac{hc}{\lambda} - \phi_o$$

$$KE_{max} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{3 \times 10^{-7}} - 3.68 \times 10^{-19}$$

$$\therefore KE_{max} = 6.63 \times 10^{-19} - 3.68 \times 10^{-19}$$

$$\therefore KE_{max} = (6.63 - 3.68) \times 10^{-19}$$

$$\therefore KE_{max} = 2.95 \times 10^{-19} J$$

$$\therefore \frac{1}{2} m v_{max}^2 = KE_{max}$$

$$\therefore v_{max} = \sqrt{\frac{2 KE_{max}}{m}} = \sqrt{\frac{2 \times 2.95 \times 10^{-19}}{9.1 \times 10^{-31}}}$$

$$\therefore v_{max} = 8.052 \times 10^5 m/s$$

(6) The photoelectric work function for a metal surface is 2.4 eV. If the light of wavelength 5000 Å is incident on the surface of metal, find threshold frequency and incident frequency. Will there be an emission of photoelectrons or not ?

Data : $\phi_o = 2.4 eV$

$\phi_o = 3.84 \times 10^{-19} J$

$\lambda = 5000 Å = 5 \times 10^{-7} m$

$\upsilon = ?$

$\upsilon_o = ?$

Solution :

$$\upsilon = \frac{c}{\lambda} = \frac{3 \times 10^8}{5 \times 10^{-7}} = 6 \times 10^{14} Hz$$

$$\upsilon_o = \frac{\phi_0}{h} = \frac{3.84 \times 10^{-19}}{6.63 \text{ y } 10^{-34}} = 5.792 \times 10^{14} Hz$$

As $\upsilon > \upsilon_o$, photoelectric emission is possible.

THEORY QUESTIONS

(1) What is photoelectric effect? State and explain its characteristics.

(2) With neat labelled circuit diagram, describe the experiment to study the characteristics of photoelectric effect.

(3) Define threshold frequency and photoeelectric work function.

(4) What is the effect of intensity on the stopping potential in photoelectric emission ?

(5) State Einstein's equation of photoelectric effect and explain the characteristics of the effect on the basis of this equation.

(6) Describe construction and working of photoelectric cell.

(7) Explain any two applications of photoelectric cell.

PROBLEMS FOR PRACTICE

(1) The energy required to remove electron from sodium is 2.3 eV. Does sodium show photoelectric effect for orange light of wavelength 6800 Å ?
(Ans: sodium does not show photoelectric effect)

(2) Find the maximum kinetic energy of electrons ejected from a certain material if material's work function is 2.3 eV and the frequency of the incident radiation is 3.0×10^{15} Hz.
(Ans : 10.13 eV)

(3) The work function for potassium and caesium is 2.25 eV and 2.14 eV respectively. Will the photoelectric effect occur for either of these elements (a) with incident light of wavelength 5650 Å and (b) with light of wavelength 5180 Å ?
(Ans: Caesium only, both potassium and caesium.)

(4) The work function of tungsten is 4.50 eV. Calculate the speed of fastest electron ejected from tungsten surface when light whose photon energy is 5.80 eV shines on the surface.

(**Ans** : 676 km/s)

(5) If the work function for certain metal is 1.8 eV,

(a) What is the stopping potential for electrons ejected from metal when light of 4000 Å shines on the metal ?

(b) What is the maximum speed of the ejected electrons ?

(**Ans** : 1.31 V, 678 km/s)

(6) The work function of caesium is 2.14 eV. Find a) the threshold frequency for caesium and (b) the wavelength of the incident light if photocurrent is brought to zero by stopping potential of 0.60 V.

(**Ans** : 5.164×10^{14} Hz, 4537 Å)

(7) When a surface is irradiated with light of wavelength 4950Å, a photocurrent appears which vanishes if a retarding potential greater than 0.6 V is applied across the phototube. When different source of light is used, it is found that the critical retarding potential is changed to 1.1 V. Find the work function of the emitting surface and the wavelength of the second source.

(**Ans. :** 1.911eV, 4128Å)

(8) The work function for the surface of aluminium is 4.2 eV. How much potential difference will be required to stop the emission of maximum energy electrons emitted by light of 2000 Å wavelength ? What will be the wavelength of that incident light for which stopping potential will be zero ?

(**Ans. :** 2.016 V, 2959 Å)