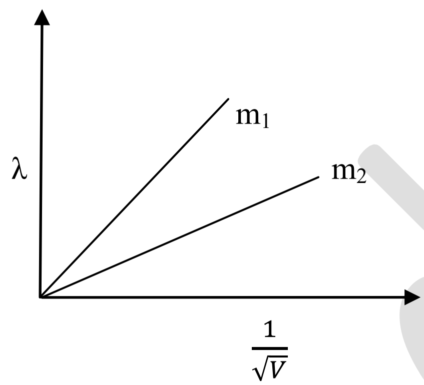
Dual Nature of Light

Board Questions (Answers)

Delhi 2016

Ans.1



Ans.2

1. There is no emission of photoelectrons (i.e. no current) if the frequency of the incident radiation is below a certain minimum value however large may be the intensity of the light.
2. Maximum kinetic energy of the photo electrons does not depend upon intensity of light.
3. Maximum kinetic energy of photoelectron increases with the frequency of the incident radiation.
4. The process of photoelectric emission is instantaneous.

(Any three)

Wave theory fails to explain why :

1. The photo electric emission is instantaneous.
2. There exists a threshold frequency for a given metal.
3. The maximum KE of photoelectrons is independent of the intensity of incident radiation.

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Ans.1 (i)

Given :

$V_p = V_\alpha$

$q_\alpha = 2q_p$

$m_\alpha = 4m_p$

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

For proton, $\lambda_p = \frac{h}{\sqrt{2m_p q_p V_p}}$

For α − particle, $\lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}$

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$$\frac{\lambda_p}{\lambda_\alpha} = \frac{\frac{h}{\sqrt{2m_p q_p V_p}}}{\frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}} = \frac{h}{\sqrt{2m_p q_p V_p}} \times \frac{\sqrt{2m_\alpha q_\alpha V_\alpha}}{h} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\frac{4m_p \times 2q_p V}{m_p q_p V}} = 2\sqrt{2}:1$$

$\therefore \lambda_p > \lambda_\alpha$ *for same acc. potential.*

(ii)

$K = qV$

For proton, $K_p = q_p V_p$

For $\alpha -$ *particle,* $K_\alpha = q_\alpha V_\alpha$

$$\frac{K_p}{K_\alpha} = \frac{q_p V_p}{q_\alpha V_\alpha} = \frac{q_p V}{2q_p V} = \frac{1}{2}$$

$K_p < K_\alpha$

Ans.2 Features of the photons:

(i) Photons are particles of light having energy E = hν and momentum p =*h/λ* .

(ii) Photons travel with the speed of light in vacuum, independent of the frame of reference.

Stopping Potential(V_0) : The minimum negative potential applied to the anode/ plate for which photoelectric current become zero.

Threshold frequency(ν_0) : The minimum (cut off) frequency of incident radiation, below which no emission of photoelectrons takes place. .

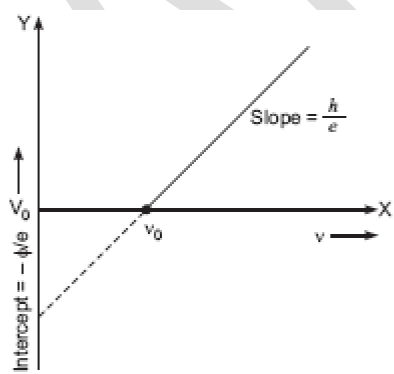
By Einstein's photo electric equation

$K_{max} = hc/\lambda - \phi = h\nu - h\nu_0$

$eV_0 = h\nu - h\nu_0$

$V_0 = (h/e)\,\nu - (h/e)\,\nu_0$

Clearly, $V_0 - \nu$ graph is a straight line.



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Ans.1 (i)

$$\lambda_\alpha = \lambda_p$$

$$\frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}} = \frac{h}{\sqrt{2m_p q_p V_p}}$$

$$m_p q_p V_p = 2m_\alpha q_\alpha V_\alpha$$

$$\frac{V_p}{V_\alpha} = \frac{m_\alpha q_\alpha}{m_p q_p} = \frac{(4m_p)(2q_p)}{m_p q_p} = \frac{8}{1}$$

$$V_p : V_\alpha = 8:1$$

(ii)

$$\lambda = \frac{h}{mv}$$

$$\lambda_\alpha = \lambda_p$$

$$\frac{h}{m_\alpha v_\alpha} = \frac{h}{m_p v_p}$$

$$\frac{v_p}{v_\alpha} = \frac{m_\alpha}{m_p} = \frac{(4m_p)}{m_p} = \frac{4}{1}$$

$$v_p : v_\alpha = 4:1$$

Ans.2

- $K_{max} = h(\nu - \nu_0)$
- Important features:

(i) Photoelectric emission does not take place for incident radiation below threshold frequency.

(ii) Above threshold frequency kinetic energy depends only on frequency of incident radiation

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

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

$$K_{\max} = \frac{hc}{\lambda_1} - \frac{hc}{\lambda_0} \rightarrow (i)$$

Also

$$2K_{\max} = \frac{hc}{\lambda_2} - \frac{hc}{\lambda_0} \rightarrow (ii)$$

Putting value of $K_{\max}$ *from* (i) *in* (ii)

$$2\left(\frac{hc}{\lambda_1} - \frac{hc}{\lambda_0}\right) = \frac{hc}{\lambda_2} - \frac{hc}{\lambda_0}$$

$$\frac{2hc}{\lambda_1}-\frac{2hc}{\lambda_0}=\frac{hc}{\lambda_2}-\frac{hc}{\lambda_0}$$
$$\frac{2hc}{\lambda_1}-\frac{hc}{\lambda_2}=\frac{2hc}{\lambda_0}-\frac{hc}{\lambda_0}$$
$$\left(\frac{2}{\lambda_1}-\frac{1}{\lambda_2}\right)=\frac{1}{\lambda_0}$$
$$\frac{(2\lambda_2-\lambda_1)}{\lambda_1\lambda_2}=\frac{1}{\lambda_0}$$
$$\lambda_0=\frac{\lambda_1\lambda_2}{(2\lambda_2-\lambda_1)}$$
$$Work\ \ function\ \phi_0=\frac{hc}{\lambda_0}=\frac{hc(2\lambda_2-\lambda_1)}{\lambda_1\lambda_2}$$

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Ans.1 **Stopping Potential:**

The minimum negative potential applied to the anode/ plate for which photoelectric current become zero.

By Einstein's Equation

$$K = h\nu - \varnothing_0$$
$$eV_0 = h\nu - \varnothing_0$$
$$V_0 = \frac{h\nu}{e} - \frac{\varnothing_0}{e}$$

Threshold frequency: The minimum (cut off) frequency of incident radiation, below which no emission of photoelectrons takes place.

$$\varnothing_0 = h\nu_0$$

So, $\nu_0 = h/\varnothing_0$

Ans.2 (a)

1. There is no emission of photoelectrons (i.e. no current) if the frequency of the incident radiation is below a certain minimum value however large may be the intensity of the light.
2. The current becomes zero at a certain value of negative potential, applied at the anode , this is known as stopping potential.
3. Maximum kinetic energy of the photo electrons does not depend upon intensity of light.
4. Maximum kinetic energy of photoelectron increases with the frequency of the incident radiation.
5. The process of photoelectric emission is instantaneous.

(Any three)

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(b) It fails to explain why :

1. The photo electric emission is instantaneous.
2. There exists a threshold frequency for a given metal.
3. The maximum KE of photoelectrons is independent of the intensity of incident radiation.

Ans.3 (a) i) The energy of a photon is $h\nu$

ii) Each photon is completely absorbed by a single electron.

(b) $K = h\nu - \text{Ø}_0 = h\nu - h\nu_0 = h(\nu - \nu_0)$

(i) When incident frequency (ν) < Threshold frequency (ν_0), there will be no emission of electrons. Hence, frequency of incident radiation should be greater than threshold frequency.

(ii) $K = h\nu - \text{Ø}_0$

$eV_0 = h\nu - \text{Ø}_0$

$$V_0 = \frac{h\nu}{e} - \frac{\text{Ø}_0}{e}$$

At $\nu = \nu_0$, $K = eV_0 = 0$

V_0 is stopping potential

Ans.4 Intensity of radiation - It is defined as the number of photons (of given frequency) incident per unit area per unit time.

$$h\nu = \phi_0 + K_{\max}$$
$$\phi_0 = h\nu - K_{\max}$$
$$= \frac{hc}{\lambda} - eV$$
$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{2270\times10^{-10}} - 1.6\times10^{-19}\times1.3$$
$$= 8.7\times10^{-19} - 2.08\times10^{-19}$$
$$= 6.62\times10^{-19}\,J$$
$$= \frac{6.62\times10^{-19}}{1.6\times10^{-19}}\,eV = 4.2eV$$

For red light incident photon energy will be less than the work function, hence no emission of electrons.

Ans.5 Incident photon energy ($h\nu$) is used up in two ways:

(1) A part of this energy is used to remove the electrons.

(2) Remaining part of the energy imparts KE to the emitted electrons

$$h\nu = \phi_0 + K_{\max}$$
$$K_{\max} = h\nu - \phi_0 = h\nu - h\nu_0 = h(\nu - \nu_0)$$

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Explanation :

(i) Maximum KE depends on frequency and not on intensity.

(ii) There exists a threshold frequency below which no photoemission takes place.

(iii) Basic elementary process involved is absorption of photon by electron. This process is instantaneous.

Ans.6 (a) According to Einstein, packets of energy called photons, which are absorbed completely by electrons. This absorbed energy is used to eject the electron and also provide kinetic energy to the emitted electron.

(b)

$$(i)$$

$$\frac{1}{2}mV_{\max}^2 = h\nu - \varphi_0$$

$$mV_{\max}^2 = 2(h\nu - \varphi_0)$$

$$V_{\max}^2 = \left(\frac{2h}{m}\right)\nu - \left(\frac{2\varphi_0}{m}\right)$$

$$Slope = \frac{2h}{m} = \frac{l}{n}$$

$$\therefore h = \frac{ml}{2n}$$

$$(ii)$$

$$Intercept = \frac{2\varphi_0}{m} = l$$

$$\therefore \varphi_0 = \frac{ml}{2}$$

Ans.7 (a)

$Given:$

$\nu = 6\times10^{14}\,Hz$

$P = 2\times10^{-3}W$

$Now, P = nh\nu$

$$n = \frac{P}{h\nu} = \frac{2\times10^{-3}}{6.6\times10^{-34}\times6\times10^{14}} = 5\times10^{15}$$

(b)

$K.E = h\nu - \varphi_0$

$\because \varphi_y > \varphi_x$

$\therefore (K.E)_x > (K.E)_y$

Ans.8 (i) Anode current will increase with increase of intensity

More is intensity of light, more is the number of photons & so more number of electrons are emitted

(ii) No effect

Frequency of light affects the maximum K.E. of the emitted photoelectrons.

(iii) Anode current will increase with anode potential

More anode potential will accelerate the electrons more till it attains a saturation value and get them collected at the anode at a faster rate.

Ans.9

$$For\ photon, E = h\nu = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$

$$For\ electron, \lambda = \frac{h}{p}$$

$$\therefore \frac{h}{p} = \frac{hc}{E}$$

$$p = \frac{E}{c} = \frac{6\times10^{-17}}{3\times10^{8}} = 2\times10^{-25} kgm/s$$

Ans10 a) **Intensity of radiation**: It is the number of photons incident per unit area per unit time.

b) (i) Red Light

Reason: E = hν

$\nu_{red} < \nu_{blue}$

So, Energy of photon of red light < Energy of a photon of blue light

(ii) Blue Light

Reason: E = hν

$\nu_{blue} > \nu_{red}$

So, Energy of photon of blue light > Energy of a photon of blue light

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Ans.1

$$\lambda = \frac{h}{\sqrt{2mK}} = \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times3.4\times1.6\times10^{-19}}} = 6.6\times10^{-10} m$$

Ans.2 a) No, Electrons at different depths need different energies to come out.

b) No, The K.E. depends on the energy of each photon and not on the number of photons (intensity of light).

c) Number of photoelectrons emitted depends on the intensity of incident light.

Anil Yadav

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Ans.1 (i)

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

$$V_p = V_d, q_p = q_d$$

$$So, \lambda \propto \frac{1}{\sqrt{m}}$$

$$Now, m_p < m_d$$

$$\therefore \lambda_p > \lambda_d \ \ for\ same\ acc.\ potential.$$

(ii)

$$momentum,\ p = \frac{h}{\lambda}$$

$$\because \lambda_p > \lambda_d$$

$$\therefore p_{proton} < p_{deutron}$$

(ii) We know that momentum = h/λ

As $\lambda_p > \lambda_d$

So, momentum of proton will be less than that of deutron.

Ans.2 (i)

$Given:$

$$\nu = 6.0 \times 10^{14}\,\text{Hz}$$

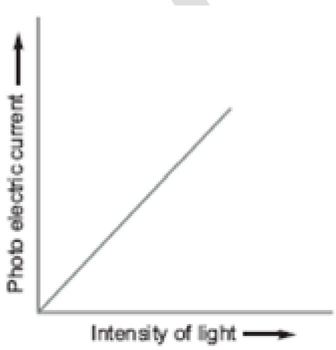
$$\text{P} = 2.0 \times 10^{-3}\,\text{W}$$

$$\text{h} = 6.6 \times 10^{-34}$$

$Power, P = nh\nu$ ($where\ n$ – number of photons per second)

$$n = \frac{P}{h\nu} = \frac{2.0 \times 10^{-3}}{6.6 \times 10^{-34} \times 6.0 \times 10^{14}} = 0.050\times10^{17} = 5\times10^{15}\,\text{photons per second}$$

(ii)



Ans.3 (i)

Given:

$V_p = V_\alpha$

$q_\alpha = 2q_p$

$m_\alpha = 4m_p$

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

$$For\ proton, \qquad \lambda_p = \frac{h}{\sqrt{2m_p q_p V_p}}$$

$$For\ \alpha - particle, \quad \lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}$$

$$\frac{\lambda_p}{\lambda_\alpha} = \frac{\dfrac{h}{\sqrt{2m_p q_p V_p}}}{\dfrac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}} = \frac{h}{\sqrt{2m_p q_p V_p}} \times \frac{\sqrt{2m_\alpha q_\alpha V_\alpha}}{h} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\frac{4m_p \times 2q_p V}{m_p q_p V}} = 2\sqrt{2}:1$$

$\therefore \lambda_p > \lambda_\alpha$ *for same acc. potential.*

(ii)

$K = qV$

$$For\ proton, \qquad K_p = q_p V_p$$

$$For\ \alpha - particle, \quad K_\alpha = q_\alpha V_\alpha$$

$$\frac{K_p}{K_\alpha} = \frac{q_p V_p}{q_\alpha V_\alpha} = \frac{q_p V}{2q_p V} = \frac{1}{2}$$

$K_p < K_\alpha$

Ans.4 (i)

Given:

$V_d = V_\alpha$

$q_\alpha = 2q_d$

$m_\alpha = 2m_d$

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

$$For\ deutron, \qquad \lambda_p = \frac{h}{\sqrt{2m_d q_d V_d}}$$

$$For\ \alpha - particle, \quad \lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}$$

$$\frac{\lambda_d}{\lambda_\alpha} = \frac{\dfrac{h}{\sqrt{2m_d q_d V_d}}}{\dfrac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}} = \frac{h}{\sqrt{2m_d q_d V_d}} \times \frac{\sqrt{2m_\alpha q_\alpha V_\alpha}}{h} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_d q_d V_d}} = \sqrt{\frac{2m_d \times 2q_d V}{m_d q_d V}} = 2:1$$

$\therefore \lambda_d > \lambda_\alpha$ *for same acc. potential.*

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(ii)

$K = qV$

$For\ deutron, \quad K_d = q_d V_d$

$For\ \alpha - particle,\ K_\alpha = q_\alpha V_\alpha$

$$\frac{K_d}{K_\alpha} = \frac{q_d V_d}{q_\alpha V_\alpha} = \frac{q_d V}{2q_d V} = \frac{1}{2}$$

$K_d < K_\alpha$

All India 2014

Ans.1 The amount of light energy incident per metre square per second is called intensity of radiation.

SI unit : W/m^2 or $J/s\text{-}m^2$

Ans.2 Metal A

Since work function $W = h\nu_0$

and $\nu'_0 > \nu_0$ so work function of metal A is more.

OR

On stopping potential axis $-\omega_0'/e > -\omega_0/e$.

Hence work function ω'_0 of metal A is more.

Ans.3 From the graph $\nu_0' > \nu_0$

So, the minimum frequency at which the photoemission starts is more for metal A.

Hence metal A has higher threshold frequency.

Foreign 2014

Ans.1 Larger the intensity of incident radiation, larger is the number of incident photons and hence larger is the number of electrons ejected from the photosensitive surface.

Ans.2 (a) **Davisson and Germer Experiment:** .

Apparatus: It consists of three parts

(i) Electron Gun **:** It gives a fine beam of electrons.(Energy (54 eV), wavelength **1.66** A^0)

(ii) Nickel Crystal **:** The electron beam was directed on nickel crystal (behaves as diffraction grating).

(iii) Electron Detector : It measures the intensity of electron beam diffracted from nickel crystal with a help of a sensitive galvanometer.

Method:

- The crystal is rotated in small steps to change the angle (α say) between incidence and scattered

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directions and the corresponding intensity (I) of scattered beam is measured.

- The variation of the intensity (I) of the scattered electrons with the angle of scattering α is obtained for different accelerating voltages.
- The experiment was performed by varying the accelerating voltage from 44 V to 68 V.
- It was noticed that a strong peak appeared in the intensity (I) of the scattered electron for an accelerating voltage of 54 V at a scattering angle $\alpha = 50°$.

$\therefore$ From Bragg's law

$2d \sin\theta = n\lambda$

$\therefore\ \lambda = 2d \sin\theta/n$

$=2 \times (0.914\ Å) \sin 65°/1 = 2 \times 0.914 \times 0.9063\ Å = 1.65\ Å$

The measured wavelength is in close agreement with the estimated de Broglie wavelength.

Thus the wave nature of electron is verified.

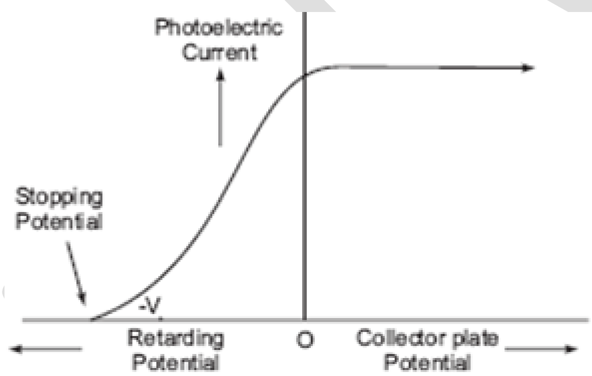
(b) de Broglie wavelength λ associated with electrons is given by

$\lambda = h/p = h/2mK$

But kinetic energy $K = eV$

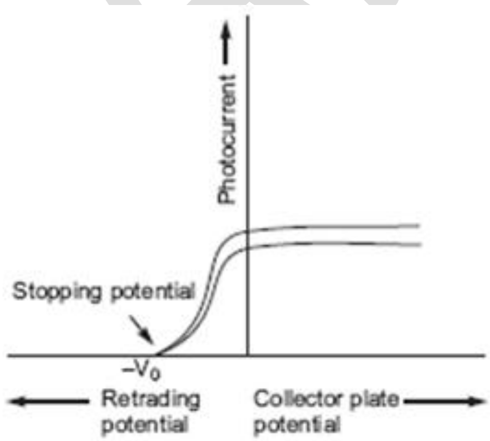
$\therefore\ \lambda = h/\sqrt{2meV}$.

Ans.3



Intercept of the graph with potential axis gives the stopping potential

Ans.4



Delhi 2013

Ans.1 Pairs of curves for different materials and same intensity radiations are graphs (1, 3) and (2, 4).

Reason: Stopping potential depends on (i) nature of material (ii) frequency of radiation.

Ans.2 (*a*) The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light due to the following reasons.

(i) Wave theory : kinetic energy of photoelectrons must depend on the intensity of incident light

Exp. observations: kinetic energy of photoelectrons does not depend on the intensity of incident light.

(ii) Wave theory : light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons

Exp. observations: light of frequency less than threshold frequency cannot emit electrons; whatever the intensity of incident light may be.

(iii)Wave theory : According to wave theory, the energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission.

The time for emission will be more for light of less intensity and vice versa.

Exp. observations: emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

(b) Features of the photons:

(i) Photons are particles of light having energy E = hν and momentum p =h/λ .

(ii) Photons travel with the speed of light in vacuum, independent of the frame of reference.

(iii)Intensity of light depends on the number of photons crossing unit area in a unit time.

(iv)Photons are electrically neutral as they are not deflected by electric and magnetic fields.

All India 2013

Ans.1 $\lambda = \dfrac{h}{\sqrt{2mqV}}$

Ans.2 If radiation of frequency (ν) greater than threshold frequency (ν0) irradiate the metal surface, electrons emitted out from the metal. So Einstein's photoelectric equation can be given as

$E = h\nu - \phi_0 = h(\nu - \nu_0)$

Characteristic properties of photons:

(i) Energy of photon is directly proportional to the frequency (or inversely proportional to the wavelength).

(ii) In photon-electron collision, total energy & momentum of the system of 2 constituents remain constant.

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(iii) In the interaction of photons with the free electrons, the entire energy of photon is absorbed.

Features of photoelectric effects

(i) **Explanation of intensity law:**

As one photon ejects one photoelectron so, number of photoelectrons emitted per second depends on number of photons falling on metal surface which in turn depends on intensity of light.

If intensity increases, photon number increases and hence photoelectrons (photocurrent) increases.

(ii) **Explanation of frequency law:**

If ν >ν, K.E α ν

i.e., When frequency of incident photon (ν) is greater than threshold frequency (ν_{0}), the kinetic energy of emitted electron only depends upon frequency of incident radiation.

(iii) **Explanation of no time lag law:**

The phenomenon of photoelectric emission has been conceived as an effect of elastic collision between photon and electron inside the metal. So, the absorption of energy by electron from photon takes place without any time lag.

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Foreign 2013

Ans.1 $Given:$

$\lambda = 2271 A^0$

$V_0 = -1.3V$

$\phi_0 = ?$

$Acc. to\ Einstein's\ photo-electric\ equation$

$$\phi_0 = h\nu - eV_0$$

$$= \frac{hc}{\lambda} - eV_0$$

$$= \frac{6.6\times10^{-34}\times3\times10^{8}}{2271\times10^{-10}} - 1.3\times1.6\times10^{-19}$$

$$= 8.71\times10^{-19} - 2.08\times10^{-19}$$

$$= 6.63\times10^{-19}\,J$$

$$= \frac{6.63\times10^{-19}}{1.6\times10^{-19}}\,eV = 4.2eV$$

$$Threshold\ \ frequency, \nu_0 = \frac{\phi_0}{h} = \frac{6.63\times10^{-19}}{6.63\times10^{-34}} = 10^{15}\,Hz$$

$$Frequency\,of\ red\ light, \nu_r = \frac{c}{\lambda_r} = \frac{3\times10^{8}}{6238\times10^{-10}} = 4.7\times10^{14}\,Hz$$

$$\because \nu_r < \nu_0\ so\ photocell\ won't\,respond\,to\,red\ light.$$

Ans.2 (i)

$$\lambda_e = \lambda_p$$

$$\frac{h}{p_e} = \frac{h}{p_p}$$

$$\frac{p_p}{p_e} = 1:1$$

(ii)

$$K = \frac{p^2}{2m}$$

$$For\ proton, K_p = \frac{p_p^2}{2m_p}$$

$$For\,electron, K_e = \frac{p_e^2}{2m_e}$$

$$\frac{K_p}{K_e} = \frac{\frac{p_p^2}{2m_p}}{\frac{p_e^2}{2m_e}} = \frac{p_p^2}{2m_p}\times\frac{2m_e}{p_e^2} = \frac{m_e}{m_p}$$

$$\because m_e << m_p\,, so\,K_p << K_e$$

Delhi 2012

Ans.1 "The atomic particles of matter moving with a given velocity, can display the wave like properties."

$$\lambda = \frac{h}{mv}$$

Ans.2 Einstein photo electric equation is $h\nu = \phi_0 + K_{max}$,

The energy ($h\nu$) carried by a photon of frequency ν is absorbed by electrons on the surface to

(i) overcome the work function of metal ϕ_0 .

(ii) impart maximum K.E. to the emitted electron (K_{max}.)

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

Three salient features are:

(i) Cut-off potential of the emitted electrons is proportional to ν.

(ii) Photo electric emission of electrons is possible only when $v > v_0$

(iii) Max. *K.E.* is independent of intensity of incident radiations.

All India 2012

Ans.1 $$\lambda = \frac{h}{\sqrt{2mqV}} = \frac{h}{\sqrt{2mK}}$$

$$As\ K_p = K_e = K$$

$$\lambda \propto \frac{1}{\sqrt{m}}$$

$$\because m_p > m_e$$

$$\therefore \lambda_p < \lambda_e$$

Ans.2 Stopping Potential(V_0) : The minimum negative potential applied to the anode/ plate for which photoelectric current become zero.

Threshold frequency(ν_0) : The minimum (cut off) frequency of incident radiation, below which no emission of photoelectrons takes place. .

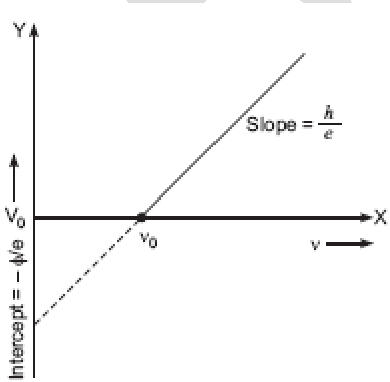
By Einstein's photo electric equation

$K_{max} = hc/\lambda - \phi = h\nu - h\nu_0$

$eV_0 = h\nu - h\nu_0$

$V_0 = (h/e)\ \nu - (h/e)\ \nu_0$

Clearly, $V_0 - \nu$ graph is a straight line.



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Ans.3

$$\lambda = \frac{h}{mv}$$

$$As\, v_p = v_e$$

$$\lambda \propto \frac{1}{m}$$

$$\because m_p > m_e$$

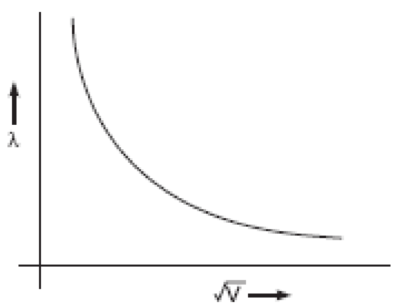
$$\therefore \lambda_p < \lambda_e$$

Foreign 2012

Ans.1

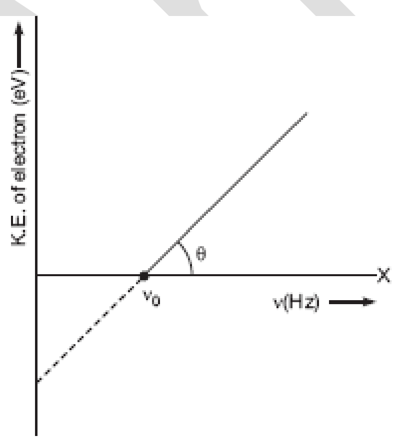
$$\lambda = \frac{1.22}{\sqrt{V}} A^0$$

$$\lambda \propto \frac{1}{\sqrt{V}}$$



Ans.2 a) All photons of light of a particular frequency 'ν' have same energy and momentum whatever the intensity of radiation may be.

b) Photons are electrically neutral and are not affected by presence of electric and magnetic fields.



(*i*) From this graph, the Planck constant can be calculated by the slope of the current $h = \Delta KE / \Delta \nu$

(*ii*) Work function is the minimum energy required to eject the photo-electron from the metal surface.

$$\phi = h\nu_0$$

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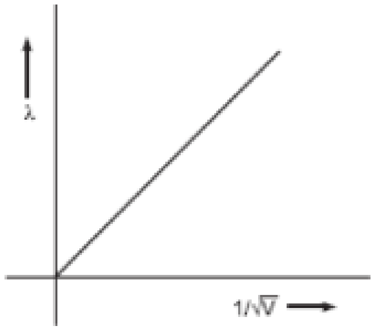
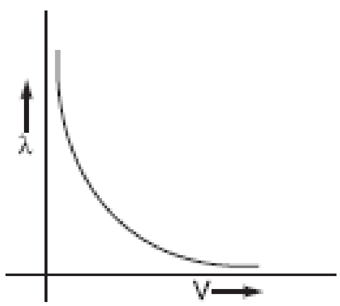
Ans.3 $\lambda \propto \frac{1}{\sqrt{V}}$



Ans.4 $\lambda = \frac{h}{\sqrt{2mK}}$

Delhi 2011

Ans.1 λ ∝ 1/*V*, so graph is shown in figure below.



Ans.2 (i)

$$\lambda_e = \lambda_{photon}$$

$$\frac{h}{p_e} = \frac{h}{p_p}$$

$$p_p = p_e = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{10^{-9}} = 6.63\times10^{-25}\ kgms^{-1}$$

(ii)

$$E_{photon} = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{10^{-9}} = 19.89\times10^{-17}\,J = \frac{19.89\times10^{-17}}{1.6\times10^{-19}}eV = 1.24KeV$$

(iii)

$$K_{elec} = \frac{p^2}{2m_e} = \frac{\left(6.63\times10^{-25}\right)^2}{2\times9.1\times10^{-31}} = 2.4\times10^{-19}\,J = \frac{2.4\times10^{-19}}{1.6\times10^{-19}}eV = 1.51KeV$$

Anil Yadav

Ans.3 (i)

$$\lambda_e = \lambda_{photon}$$

$$\frac{h}{p_e} = \frac{h}{p_p}$$

$$p_p = p_e = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{1.5\times10^{-9}} = 4.42\times10^{-25}\ kgms^{-1}$$

(ii)

$$E_{photon} = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.5\times10^{-9}} = 13.26\times10^{-17}\ J = \frac{13.26\times10^{-17}}{1.6\times10^{-19}}\ eV = 828.7eV$$

(iii)

$$K_{elec} = \frac{p^2}{2m_e} = \frac{\left(4.42\times10^{-25}\right)^2}{2\times9.1\times10^{-31}} = 1.07\times10^{-19}\ J = \frac{1.07\times10^{-19}}{1.6\times10^{-19}}\ eV = 0.67eV$$

Ans.4 (i)

$$\lambda_e = \lambda_{photon}$$

$$\frac{h}{p_e} = \frac{h}{p_p}$$

$$p_p = p_e = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{2\times10^{-9}} = 3.315\times10^{-25}\ kgms^{-1}$$

(ii)

$$E_{photon} = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{2\times10^{-9}} = 9.945\times10^{-17}\ J = \frac{9.945\times10^{-17}}{1.6\times10^{-19}}\ eV = 0.62KeV$$

(iii)

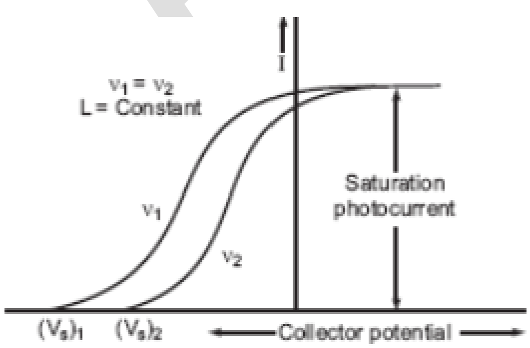
$$K_{elec} = \frac{p^2}{2m_e} = \frac{\left(3.315\times10^{-25}\right)^2}{2\times9.1\times10^{-31}} = 0.604\times10^{-19}\ J = \frac{0.604\times10^{-19}}{1.6\times10^{-19}}\ eV = 0.38eV$$

All India 2011

Ans.1 The minimum negative potential of anode of a photoelectric tube for which photoelectric current becomes zero is called the stopping potential.

Ans.2 The plots are shown in fig. The stopping potential (Vs) is higher for radiations of frequency ν_1.

Stopping potential is directly proportional to the frequency of incident radiation.



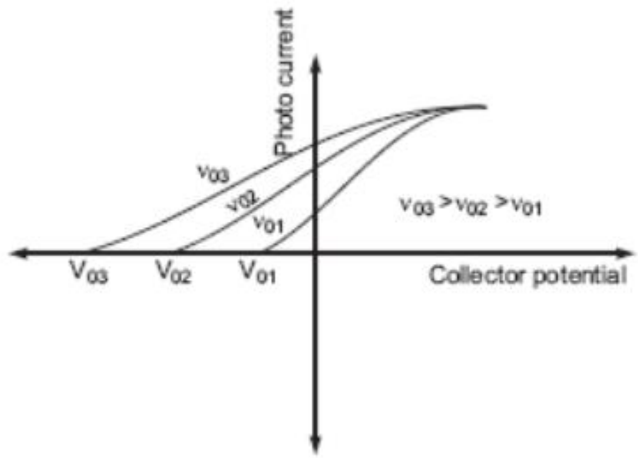
Foreign 2011

Ans.1 For a given metal, there exists a certain minimum frequency of incident radiation below which no emission of photoelectrons takes place. This frequency is called Threshold frequency.

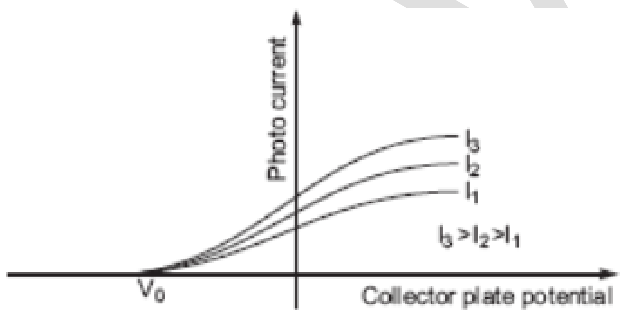
OR

Threshold frequency is defined as the minimum frequency of incident radiation which can cause photoelectric emission.

Ans.2



Ans.3



Ans.4

$$
\begin{aligned}
&Given: \\
&\lambda = 2000A^0 \\
&\phi_0 = 4.2eV \\
&K = ? \\
&Acc.to\ Einstein's\ photo-electric\ equation \\
&\phi_0 = h\nu + K \\
&\therefore K = \frac{hc}{\lambda} - \phi_0 \\
&\quad = \frac{6.6\times10^{-34}\times3\times10^{8}}{2000\times10^{-10}} - 4.2\times1.6\times10^{-19} \\
&\quad = 9.9\times10^{-19} - 6.72\times10^{-19} \\
&\quad = 3.18\times10^{-19}\,J \\
&\quad = \frac{3.18\times10^{-19}}{1.6\times10^{-19}}eV = 1.98eV \approx 2eV
\end{aligned}
$$

Anil Yadav

(*i*) The energy of the emitted electrons does not depend upon intensity of incident light, hence the energy remains unchanged.

(*ii*) For this surface, electrons will not be emitted as the energy of incident light (6·2 eV) is less than the work function (6·5 eV) of the surface.

Delhi 2010

Ans.1 $Given:$

$V = 100V$

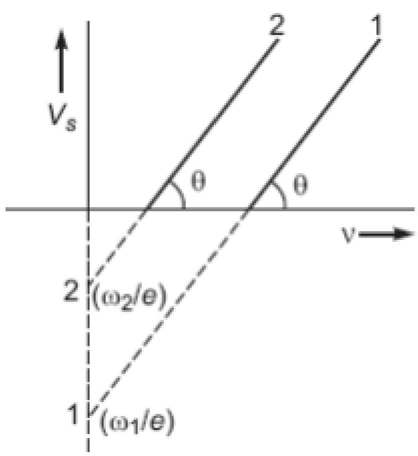
$m_e = 9.1\times10^{-31}kg$

$q_e = 1.6\times10^{-19}C$

$$\lambda = \frac{h}{\sqrt{2mqV}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times100}} = 1.227\times10^{-10}m = 1.227A^0$$

This wavelength corresponds to X – ray region of e – m spectrum.

Ans.2



(i) Slope of graph (tanθ =h/e) depends on h and e.

(ii) Intercept of lines depend on work function(ω)

Ans.3 $Given:$

$V = 144V$

$m_e = 9.1\times10^{-31}kg$

$q_e = 1.6\times10^{-19}C$

$$\lambda = \frac{h}{\sqrt{2mqV}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times144}} = 1\times10^{-10}m = 1A^0$$

This wavelength corresponds to X – ray region of e – m spectrum.

Ans.4 $Given:$

$V = 64V$

$m_e = 9.1\times10^{-31}kg$

$q_e = 1.6\times10^{-19}C$

$$\lambda = \frac{h}{\sqrt{2mqV}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times64}} = 1.53\times10^{-10}m = 1.53A^0$$

This wavelength corresponds to X – ray region of e – m spectrum.

All India 2010

Ans.1 $Given:$

$V_\alpha = V_p$

$q_\alpha = 2q_p$

$m_\alpha = 4m_p$

For proton, $\lambda_p = \dfrac{h}{\sqrt{2m_p q_p V_p}}$

For α *– particle,* $\lambda_\alpha = \dfrac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}$

$$\frac{\lambda_p}{\lambda_\alpha} = \frac{\dfrac{h}{\sqrt{2m_p q_p V_p}}}{\dfrac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}} = \frac{h}{\sqrt{2m_p q_p V_p}} \times \frac{\sqrt{2m_\alpha q_\alpha V_\alpha}}{h} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\frac{4m_p \times 2q_p V}{m_p q_p V}} = 2\sqrt{2}:1$$

$\therefore \lambda_\alpha : \lambda_p = 1:2\sqrt{2}$

Ans.2 Einstein's photoelectric equation is $E = h\nu - \varnothing_0 = h(\nu - \nu_0)$

(i) **Explanation of intensity law:**

As one photon ejects one photoelectron so, number of photoelectrons emitted per second depends on number of photons falling on metal surface which in turn depends on intensity of light.

If intensity increases, photon number increases and hence photoelectrons (photocurrent) increases.

(ii) **Explanation of frequency law:**

If $\nu > \nu$, K.E α ν

i.e., When frequency of incident photon (ν) is greater than threshold frequency (ν_0), the kinetic energy of emitted electron only depends upon frequency of incident radiation.

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(iii) **Explanation of no time lag law:**

The phenomenon of photoelectric emission has been conceived as an effect of elastic collision between photon and electron inside the metal. So, the absorption of energy by electron from photon takes place without any time lag.

Foreign 2010

Ans.1
- Davisson-Germer experiment shows wave nature of electrons.
- Diffraction of electron beam.

Ans.2 **Threshold Frequency (ν_0):** The minimum frequency of incident light which is just capable of ejecting electrons from a metal is called the threshold frequency.

Stopping Potential (V_0)**:** The minimum retarding potential applied to anode of a photoelectric tube at which photoelectric current is zero.

The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light due to the following reasons.

(i) Wave theory : K.E energy of photoelectrons must depend on the intensity of incident light

Experimental observations : K.E of photoelectrons doesn't depend on the intensity of incident light.

(ii) Wave theory : Light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons.

Experimental observations : Light of frequency less than threshold frequency cannot emit electrons; whatever the intensity of incident light may be.

(iii)Wave theory : Energy transferred by light waves will not go to a particular electron, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission.

Experimental observations : Emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

Anil Yadav

Delhi 2009

Ans.1 (i)

$Given:$

$V_p = V_\alpha,\ q_\alpha = 2q_p$

$m_\alpha = 4m_p$

$$\lambda = \frac{h}{\sqrt{2mqV}}$$

$$For\ proton,\qquad \lambda_p = \frac{h}{\sqrt{2m_p q_p V_p}}$$

$$For\ \alpha-particle,\ \lambda_\alpha = \frac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}$$

$$\frac{\lambda_p}{\lambda_\alpha} = \frac{\dfrac{h}{\sqrt{2m_p q_p V_p}}}{\dfrac{h}{\sqrt{2m_\alpha q_\alpha V_\alpha}}} = \frac{h}{\sqrt{2m_p q_p V_p}} \times \frac{\sqrt{2m_\alpha q_\alpha V_\alpha}}{h} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\frac{4m_p \times 2q_p V}{m_p q_p V}} = 2\sqrt{2}:1$$

$\therefore \lambda_p > \lambda_\alpha$ $for\ same\ acc.\ potential.$

(ii)

$K = qV$

$$For\ proton,\qquad K_p = q_p V_p$$

$$For\ \alpha-particle,\ K_\alpha = q_\alpha V_\alpha$$

$$\frac{K_p}{K_\alpha} = \frac{q_p V_p}{q_\alpha V_\alpha} = \frac{q_p V}{2q_p V} = \frac{1}{2}$$

$K_p < K_\alpha$

Ans.2 (i)

$Given:$

$V_e = V_p$

$q_e = q_p$

$$For\ proton,\qquad \lambda_p = \frac{h}{\sqrt{2m_p q_p V_p}}$$

$$For\ electron,\qquad \lambda_e = \frac{h}{\sqrt{2m_e q_e V_e}}$$

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$$\frac{\lambda_p}{\lambda_e} = \frac{\frac{h}{\sqrt{2m_p q_p V_p}}}{\frac{h}{\sqrt{2m_e q_e V_e}}} = \frac{h}{\sqrt{2m_p q_p V_p}} \times \frac{\sqrt{2m_e q_e V_e}}{h} = \sqrt{\frac{m_e q_e V_e}{m_p q_p V_p}} = \sqrt{\frac{m_e}{m_p}}$$

$$\because \lambda \propto \frac{1}{\sqrt{m}} \quad and \;\; m_e < m_p$$

$$\therefore \lambda_e > \lambda_p$$

(ii)

$$As, \lambda = \frac{h}{p}$$

$$so, \;\; p = \frac{h}{\lambda} \quad or \quad p \propto \frac{1}{\lambda}$$

$$As \;\; \lambda_e > \lambda_p$$

$$\therefore \;\; p_e < p_p$$

Ans.3 Curves *a* and *b* have different intensities but same stopping potential, so curves '*a*' and '*b'* have same frequency but different intensities.

All India 2009

Ans.1 $K_{max} = eV_0 = e\,(1.5V) = 1.5\text{ eV} = 1.5 \times 1.6 \times 10^{-19}\text{ J} = \mathbf{2.4 \times 10^{-19}\ J}$

Ans.2 $(E_k)_{max} = eV$

Stopping potential, $V = (E_k)_{max}/e = 3\text{ eV}/e = \mathbf{3\ V}$

Ans.3 Maximum kinetic energy, $(E_k)_{max} = eV_0 = e\,(2\text{ V}) = 2\text{ eV} = 2 \times 1.6 \times 10^{-19}\text{ J} = \mathbf{3.2 \times 10^{-19}\ J}$

Foreign 2009

Ans.1 Consider an electron of mass 'm' and charge 'e'.Let 'v' be the velocity acquired by a the electron when accelerated from rest through a potential difference of 'V' volts.

Gain in K.E. of electron $= \frac{1}{2}mv^2$

Work done on electron =eV

So, $\frac{1}{2}mv^2 = eV$

$$v = \sqrt{\frac{2eV}{m}}$$

Now, $\lambda = \dfrac{h}{mv} = \dfrac{h}{\sqrt{2meV}}$

OR

Expression for de Broglie Wavelength associated with Accelerated Electrons

The de Broglie wavelength associated with electrons of momentum p is given by

$\lambda = h/p = h/mv \quad ...(i)$

If E_k is the kinetic energy of electron, then

$EK = \frac{1}{2} mv^2 = p^2/2m$

So $p = \sqrt{2mE_k}$

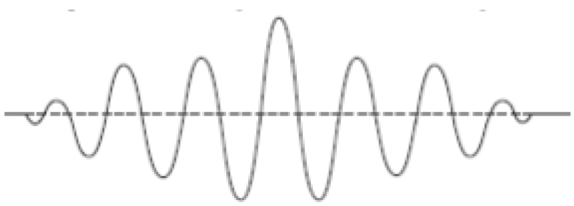
Equation (i) gives $\lambda = h/\sqrt{2mE_k}$

If V volt is accelerating potential of electron, then Kinetic energy,

$E_K = eV$

Equation (ii) gives $\lambda = h/\sqrt{2meV}$

The diagram of wave packet describing the motion of a moving electron is shown.

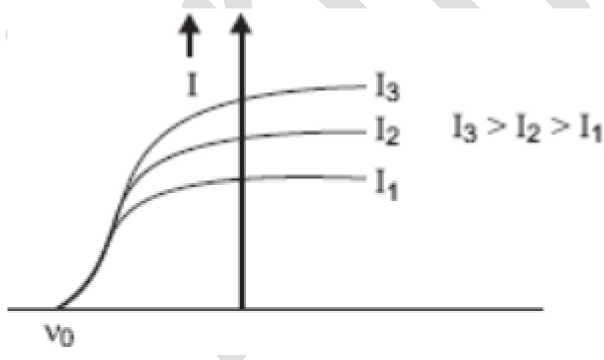


Ans.2 (i) The slope of stopping potential (V_0) versus frequency (ν) is equal to (h/e) which is universal constant, so slope is same for both lines.

(ii) K.E. = $h\nu - h\nu_0$

As threshold frequency ν_0 is lesser for M_1, so K.E. will be greater for M_1 for same frequency ν.

Ans.3 (a)



The frequency of incident radiation was kept constant.

(b) de-Broglie wavelength, $\lambda = h/\sqrt{2meV} \propto 1/\sqrt{V}$

If potential difference V is doubled, the de-Broglie wavelength is decreased to $1/\sqrt{2}$ times.

Ans.4 (i) Intensity of incident radiations

(ii) ν_1

Delhi 2008

Ans.1

$$Given:$$

$$\lambda_e = \lambda_\alpha$$

$$For\,\alpha - particle, \qquad \lambda_\alpha = \frac{h}{\sqrt{2m_\alpha K_p}}$$

$$For\,electron, \qquad \lambda_e = \frac{h}{\sqrt{2m_e K_e}}$$

$$\lambda_\alpha = \lambda_e$$

$$\frac{h}{\sqrt{2m_\alpha K_\alpha}} = \frac{h}{\sqrt{2m_e K_e}}$$

$$m_\alpha K_\alpha = m_e K_e$$

$$\frac{K_\alpha}{K_e} = \frac{m_e}{m_\alpha}$$

Ans.2

$$E = h\nu = \frac{hc}{\lambda}$$

$$According\ \ to\,question$$

$$de - Broglie\,wavelength, \quad \lambda_1 = \frac{h}{\sqrt{2mE}}$$

$$Squaring\,both\,sides$$

$$\lambda_1^2 = \frac{h^2}{2mE} = \frac{h^2}{2m \times \frac{hc}{\lambda}}$$

$$\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$$

Anil Yadav

Ans.3 Given :

$$K_e = K_\alpha$$

For α – particle, $\lambda_\alpha = \dfrac{h}{\sqrt{2m_\alpha K_\alpha}}$

For electron, $\lambda_e = \dfrac{h}{\sqrt{2m_e K_e}}$

$$\frac{\lambda_\alpha}{\lambda_e} = \frac{\dfrac{h}{\sqrt{2m_\alpha K_\alpha}}}{\dfrac{h}{\sqrt{2m_e K_e}}} = \frac{h}{\sqrt{2m_\alpha K_\alpha}} \times \frac{\sqrt{2m_e K_e}}{h} = \sqrt{\frac{m_e}{m_\alpha}}$$

$$\frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_e}} = \sqrt{\frac{4m_p}{m_e}} = \sqrt{\frac{4\times1.6\times10^{-27}}{9.1\times10^{-31}}} = 86.5$$

$$\lambda_e = 86.5 \ \ \lambda_\alpha$$

Ans.4 Given :

$$\lambda_e = \lambda_p$$

For proton, $\lambda_p = \dfrac{h}{\sqrt{2m_p K_p}}$

For electron, $\lambda_e = \dfrac{h}{\sqrt{2m_e K_e}}$

$$\lambda_p = \lambda_e$$

$$\frac{h}{\sqrt{2m_p K_p}} = \frac{h}{\sqrt{2m_e K_e}}$$

$$m_p K_p = m_e K_e$$

$$\frac{K_e}{K_p} = \frac{m_p}{m_e} \approx 1840$$

$$K_e = 1840 \times K_p$$

All India 2008

Ans.1 On doubling the distance between the light source and the cathode of the cell, the intensity of light incident on the photocell becomes one-fourth. As stopping potential does not depend on intensity, the stopping potential remains unchanged.

Ans.2 $E_k = eV_0$

$6\ eV = eV_0$

$V_0 = 6\text{V}$

AnilYadav

The stopping potential V_0 = **6 volt (negative)**.

Ans.3 $Ek = eV0$

$5\ eV = eV_0$

$V_0 = 5V$

The stopping potential V_0 = **5 volt (negative)**.

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