Short Answer Questions – II (PYQ)

Q. 1. Explain briefly the reasons why wave theory of light is not able to explain the observed features of photo-electric effect. [CBSE Delhi 2013; (AI) 2013; (F) 2010]

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

(i) According to wave theory, the light propagates in the form of wave fronts and the energy is distributed uniformly over the wave fronts. With increase of intensity of light, the amplitude of waves and the energy stored by waves will increase. These waves will then, provide more energy to electrons of metal; consequently, the energy of electrons will increase.

Thus, ***according to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light; but according to experimental observations, the kinetic energy of photoelectrons does not depend on the intensity of incident light.***

(ii) According to wave theory, the 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, but according to experimental observations, the light of frequency less than threshold frequency cannot emit electrons; whatever the intensity of incident light may be.

(iii) 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. But experimental observations show that the emission of electrons take place instantaneously after the light is incident on the metal; whatever the intensity of light may be.

Q. 2. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can explain on the basis of this equation.

The maximum kinetic energy of the photoelectrons gets doubled when the wavelength of light incident on the surface changes from λ_1 to λ_2. Derive the expressions for the threshold wavelength λ_0 and work function for the metal surface.
[CBSE (AI) 2010, Delhi 2015]

Ans. Einstein's photoelectric equation:

$$hv = hv_0 + eV_0$$

Where v = incident frequency, v_0 = threshold frequency, V_0 = stopping potential

i. Incident energy of photon is used in two ways (*a*) to liberate electron from the metal surface (*b*) rest of the energy appears as maximum energy of electron.
ii. Only one electron can absorb energy of one photon. Hence increasing intensity increases the number of electrons hence current.
iii. If incident energy is less than work function, no emission of electron will take place.
iv. Increasing v (incident frequency) will increase maximum kinetic energy of electrons but number of electrons emitted will remain same.

For wavelength λ_1

$$\frac{hc}{\lambda_1} = \varphi_0 + K = \varphi_0 + eV_0 \qquad \ldots(i) \text{ where } K = eV_0$$

For wavelength λ_2

$$\frac{hc}{\lambda_2} = \varphi_0 + 2\,eV_0 \qquad \ldots(ii) \text{ (because KE is doubled)}$$

From equation (i) and (ii), we get

$$\frac{hc}{\lambda_2} = \varphi_0 + 2\left(\frac{hc}{\lambda_1} - \varphi_0\right) = \varphi_0 + \frac{2\,hc}{\lambda_1} - 2\varphi_0$$

$$\Rightarrow \qquad \varphi_0 = \frac{2\,hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

For threshold wavelength λ_0 kinetic energy, $K = 0$, and work function $\varphi_0 = \frac{hc}{\lambda_0}$

$$\therefore \qquad \frac{hc}{\lambda_0} = \frac{2\,hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

$$\Rightarrow \qquad \frac{1}{\lambda_0} = \frac{2}{\lambda_1} - \frac{1}{\lambda_2} \quad \Rightarrow \quad \lambda_0 = \frac{\lambda_1 \lambda_2}{2\lambda_2 - \lambda_1}$$

Work function, $\varphi_0 = \dfrac{hc\,(2\lambda_2 - \lambda_1)}{\lambda_1 \lambda_2}$

Q. 3. Using photon picture of light, show how Einstein's photoelectric equation can be established. Write two features of photoelectric effect which cannot be explained by wave theory. [CBSE (AI) 2017]

Ans. In the photon picture, energy of the light is assumed to be in the form of photons each carrying energy.

When a photon of energy ‘hv’ falls on a metal surface, the energy of the photon is absorbed by the electrons and is used in the following two ways:

(i) A part of energy is used to overcome the surface barrier and come out of the metal surface. This part of energy is known as a work function and is expressed as $\varphi 0 = v0$.

(ii) The remaining part of energy is used in giving a velocity ‘v’ to the emitted photoelectron which is $\left(\frac{1}{2}\mathrm{mv}_{\max}^2\right)$.

(iii) According to the law of conservation of energy,

$$h\nu = \varphi_0 + \frac{1}{2}\mathrm{mv}_{\max}^2$$

$$\Rightarrow \qquad h\nu = h\nu_0 + \frac{1}{2}\mathrm{mv}_{\max}^2 \qquad \Rightarrow \qquad h\nu = h\nu_0 + \mathrm{KE}_{\max}$$

$$\Rightarrow \qquad KE_{\max} = h\nu = h\nu_0$$

$$\text{or} \qquad KE_{\max} = h\nu - \varphi_0$$

This equation is called Einstein photoelectric equation.

Features which cannot be explained by wave theory:

(i) The process of photoelectric emission is instantaneous in nature.

(ii) There exists a ‘threshold frequency’ for each photosensitive material.

(iii) Maximum kinetic energy of emitted electrons is independent of the intensity of incident light.

Q. 4. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (i) greater value of de Broglie wavelength associated with it and (ii) less kinetic energy? Give reasons to justify your answer.
[CBSE North 2016, Delhi 2014]

Ans.

i. de Broglie wavelength

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\mathrm{mqV}}}$$

For same V, $\lambda \, \alpha \frac{1}{\sqrt{\mathrm{mq}}}$

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{4m_p}{m_p} \cdot \frac{2e}{e}}$$

$$= \sqrt{8} = 2\sqrt{2}$$

Clearly, $\lambda_p > \lambda_\alpha$.

Hence, proton has a greater de-Broglie wavelength.

ii. Kinetic energy, $K = qV$

For same V, $K \, \alpha \, q$

$$\frac{K_p}{K_\alpha} = \frac{q_p}{q_\alpha} = \frac{e}{2e} = \frac{1}{2}$$

Clearly, $K_p < K_\alpha$.

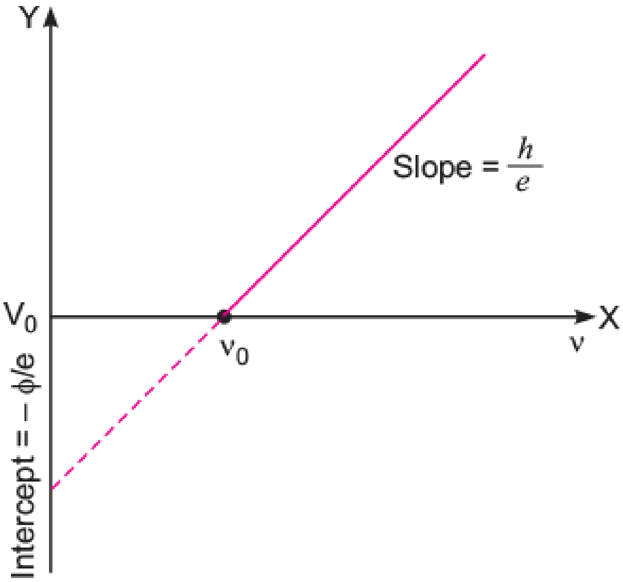
Hence, proton has less kinetic energy.

Q. 5. Define the terms (i) 'cut-off voltage' and (ii) 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. [CBSE (AI) 2012]

Ans. (i) Cut off or stopping potential is that minimum value of negative potential at anode which just stops the photo electric current.

(ii) For a given material, there is a minimum frequency of light below which no photo electric emission will take place, this frequency is called as threshold frequency.



By Einstein's photo electric equation

$$KE_{max} = \frac{hc}{\lambda} - \varphi = h\nu - h\nu_0$$

$$eV_0 = h\nu - h\nu_0$$

$$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0$$

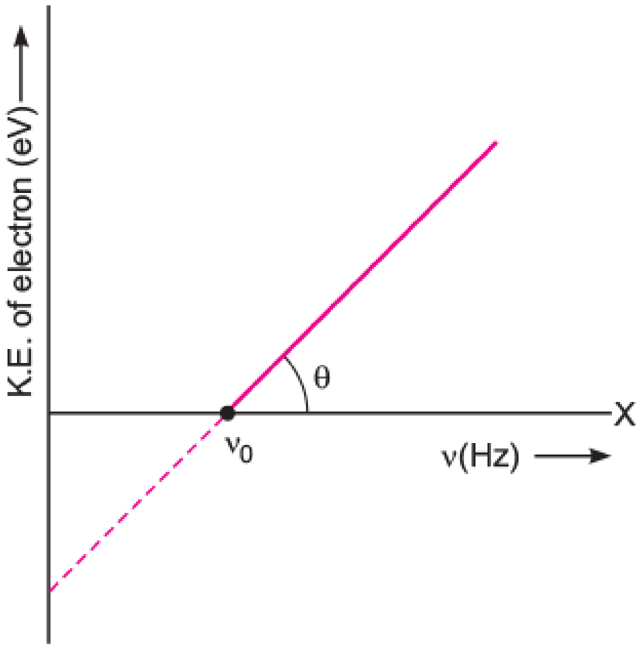
Clearly, $V_0 - \nu$ graph is a straight line.

Q. 6. Write two characteristic features observed in photoelectric effect which support the photon picture of electromagnetic radiation.

Draw a graph between the frequency of incident radiation (v) and the maximum kinetic energy of the electrons emitted from the surface of a photosensitive material. State clearly how this graph can be used to determine (i) Planck's constant and (ii) work function of the material. [CBSE Delhi 2017, (F) 2012]

Ans. (a) All photons of light of a particular frequency 'v' 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

$$h = \frac{\Delta(\mathrm{KE})}{\Delta \nu}$$

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

$\varphi = h\nu_0$, where ν_0 = Threshold frequency

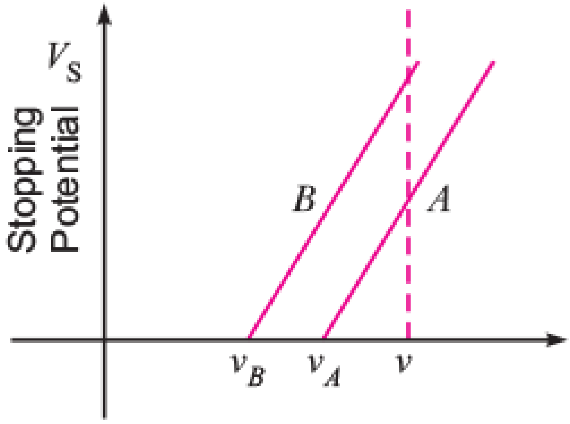
Q. 7. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $\nu_A > \nu_B$.

(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.
[CBSE Central 2016]

Ans. (i) From the graph for the same value of 'ν', stopping potential is more for material 'B'.

From Einstein's photoelectric equation



$$eV_0 = h\nu - h\nu_0$$

$$V_0 = \frac{h}{e}\nu - \frac{h}{e}\nu_0 = \frac{h}{e}(\nu - \nu_0)$$

$\therefore$ V_0 is higher for lower value of ν_0

ii. No, as slope is given by $\frac{h}{e}$ which is a universal constant.

Q. 8. Deduce de Broglie wavelength of electrons accelerated by a potential of V volt. Draw a schematic diagram of a localized wave describing the wave nature of moving electron. [CBSE (F) 2009, 2014]

Ans. Expression for de Broglie Wavelength associated with Accelerated Electrons:

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

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad \text{.......(i)}$$

Where m is mass and v is velocity of electron. If E_k is the kinetic energy of electron, then

$$E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{p}{m}\right)^2 = \frac{p^2}{2m} \quad \left(\text{since } p = mv \Rightarrow v = \frac{p}{m}\right)$$

$$p = \sqrt{2mE_K}$$

$\therefore$ Equation (i) gives $\lambda = \frac{h}{\sqrt{2mE_K}}$ ...(ii)

If V volt is accelerating potential of electron, then kinetic energy, $E_k = eV$

$\therefore$ Equation (ii) gives $\lambda = \frac{h}{\sqrt{2meV}}$ ...(iii)

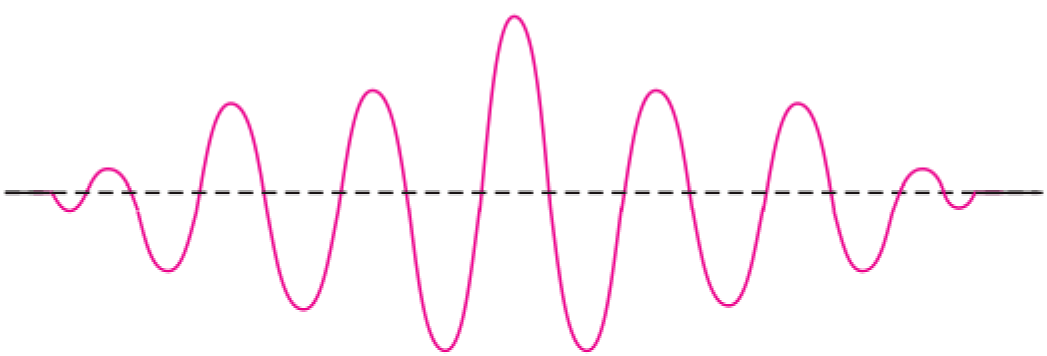
Substituting $m = 9.1 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C, $h = 6.62 \times 10^{-34}$ Js, we get

$$\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} V}} = \frac{12.27}{\sqrt{V}} \times 10^{-10}\, m$$

$$\lambda = \frac{12.27}{\sqrt{V}}\ \mathring{A}$$ ...

This is the required expression for de Broglie wavelength associated with electron accelerated to potential of V volt.

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



Q. 9. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has

(i) Greater value of de-Broglie wavelength associated with it, and
(ii) Less momentum?

Give reasons to justify your answer. [CBSE Delhi 2014]

Ans.

i. de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2\,mqV}}$

Here V is same for proton and deutron.

As mass of proton < mass of deutron and $q_p = q_d$

Therefore, $\lambda_p > \lambda_d$ for same accelerating potential.

ii. We know that momentum $= \frac{h}{\lambda}$

Therefore, $\lambda_p > \lambda_d$

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

Q. 10. A beam of monochromatic radiation is incident on a photosensitive surface. Answer the following questions giving reasons:

(i) Do the emitted photoelectrons have the same kinetic energy?

(ii) Does the kinetic energy of the emitted electrons depend on the intensity of incident radiation?

(iii) On what factors does the number of emitted photoelectrons depend? [CBSE (F) 2015]

Ans. In photoelectric effect, an electron absorbs a quantum of energy hv of radiation, which exceeds the work function, an electron is emitted with maximum kinetic energy,

$K_{max} = hv - W$

(i) No, all electrons are bound with different forces in different layers of the metal. So, more tightly bound electron will emerge with less kinetic energy. Hence, all electrons do not have same kinetic energy.

(ii) No, because an electron cannot emit out if quantum energy hv is less than the work function of the metal. The K.E. depends on energy of each photon.

(iii) Number of emitted photoelectrons depends on the intensity of the radiations provided the quantum energy hv is greater than the work function of the metal.

Q. 11. Why are de Broglie waves associated with a moving football not visible?

The wavelength 'λ' of a photon and the de Broglie wavelength of an electron have the same value. Show that the energy of photon is $\frac{2\gamma\, mc}{h}$ times the kinetic energy of electron, where m, c, h have their usual meanings. [CBSE (F) 2016]

Ans. Due to large mass of a football the de Broglie wavelength associated with a moving football is much smaller than its dimensions, so its wave nature is not visible.

de Broglie wavelength of electron $\lambda = \frac{h}{\mathrm{mv}} \Rightarrow v = \frac{h}{m\lambda}$ ....(i)

energy of photon $E = \frac{\mathrm{hc}}{\lambda}$ (because λ is same) ... (ii)

Ratio of energy of photon and kinetic energy of electrons

$$\frac{E}{E_k} = \frac{\mathrm{hc}/\lambda}{\frac{1}{2}\mathrm{mv}^2} = \frac{2\,\mathrm{hc}}{\lambda\,\mathrm{mv}^2}$$

Substituting value of v from (i), we get

$$\frac{E}{E_k} = \frac{2\,\mathrm{hc}}{\lambda m(h/m\lambda)^2} = \frac{2\lambda\,\mathrm{mc}}{h}$$

$\therefore$ Energy of photon $= \frac{2\lambda\,\mathrm{mc}}{h} \times$ kinetic energy of electron

Q. 12. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths. [CBSE Delhi 2017, (AI) 2010]

Ans.

de-Broglie wavelength $\lambda = \frac{h}{\sqrt{2\,\mathrm{mE}}} = \frac{h}{\sqrt{2\,\mathrm{mqV}}}$

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

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

$$\therefore \qquad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}}$$

But $\frac{m_\alpha}{m_p} = 4, \frac{q_\alpha}{q_p} = 2$

$$\therefore \qquad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{1}{4}\cdot\frac{1}{2}} = \frac{1}{\sqrt{8}} = \frac{1}{2\sqrt{2}}.$$

Q. 13. A proton and an α-particle have the same de-Broglie wavelength. Determine the ratio of (i) their accelerating potentials (ii) their speeds. [CBSE Delhi 2015]

Ans.

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\text{mqV}}}$

where, m = mass of charge particle, q = charge of particle, V = potential difference

i. $$\lambda^2 = \frac{h^2}{2\,\text{mqV}} \quad \Rightarrow \quad V = \frac{h^2}{2\,\text{mq}\,\lambda^2}$$

$\therefore$ $$\frac{V_p}{V_\alpha} = \frac{2m_\alpha q_\alpha}{2m_p q_p} = \frac{2\times 4m2q}{2\,\text{mq}} = \frac{8}{1}$$

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

ii. $$\lambda = \frac{h}{\text{mv}}, \lambda_p = \frac{h}{m_p v_p},\ \lambda_\alpha = \frac{h}{m_\alpha v_\alpha}$$

$$\lambda_p = \lambda_\alpha \quad \Rightarrow \quad \frac{h}{m_p v_p} = \frac{h}{m_\alpha v_\alpha}$$

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

Q. 14. An electron and a proton, each have de Broglie wavelength of 1.00 nm.

(i) Find the ratio of their momenta.

(ii) Compare the kinetic energy of the proton with that of the electron.
[CBSE (F) 2013]

Ans. (i)

$$\lambda_e = \frac{h}{p_e} \text{ and } \lambda_p = \frac{h}{p_p},\ \lambda_e = \lambda_p = 1.00 \text{ nm}$$

So, $$\frac{\lambda_e}{\lambda_p} = \frac{p_p}{p_e} = \frac{1}{1} \quad \Rightarrow \quad \frac{p_p}{p_e} = \frac{1}{1} = 1:1$$

(ii)

From relation $K=\frac{1}{2}\mathrm{mv}^2=\frac{p^2}{2m}$

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

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

Since $m_e <<< m_p$. So $K_p <<< K_e$.

$$\frac{K_p}{K_e}=\frac{9.1\times10^{-31}}{1.67\times10^{-27}}=5.4\times10^{-4}$$

Q. 15. Write briefly the underlying principle used in Davison-Germer experiment to verify wave nature of electrons experimentally. What is the de-Broglie wavelength of an electron with kinetic energy (KE) 120 eV? [CBSE South 2016]

Ans. Principle: Diffraction effects are observed for beams of electrons scattered by the crystals.

$$\lambda=\frac{h}{p}=\frac{h}{\sqrt{2\,\mathrm{mE}_k}}=\frac{h}{\sqrt{2\,\mathrm{meV}}}$$

$$=\frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times120}}$$

$$\lambda = \mathbf{0.112\ nm}$$

Q. 16. A proton and an α-particle are accelerated through the same potential difference. Which one of the two has (i) greater de-Broglie wavelength, and (ii) less kinetic energy? Justify your answer. [CBSE North 2016]

Ans. (i) de-Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\mathrm{mqV}}}$$

For same V, $\lambda \propto \frac{1}{\sqrt{\mathrm{mq}}}$

$$\therefore \frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\frac{4m_p}{m_p} \cdot \frac{2e}{e}} = \sqrt{8} = 2\sqrt{2}$$

Clearly, $\lambda_p > \lambda_\alpha$.

Hence, proton has a greater de-Broglie wavelength.

ii. Kinetic energy, $K = qV$

For same V, $K \propto q$

$$\frac{K_p}{K_\alpha} = \frac{q_p}{q_\alpha} = \frac{e}{2e} = \frac{1}{2}$$

Clearly, $K_p < K_\alpha$.

Hence, proton has less kinetic energy.

Q. 17. Answer the following questions:

(1) Define the term ‘intensity of radiation’ in terms of photon picture of light.

(2) Two monochromatic beams, one red and the other blue, have the same intensity. In which case

(i) The number of photons per unit area per second is larger,

(ii) The maximum kinetic energy of the photoelectrons is more? Justify your answer. [CBSE Patna 2015]

Ans. (1) The number of photons incident normally per unit area per unit time is determined the intensity of radiations.

(2) (i) Red light, because the energy of red light is less than that of blue light

$(hv)_R < (hv)_B$

(ii) Blue light, because the energy of blue light is greater than that of red light

$(hv)_B > (hv)_R$

Q. 18. When an electron in hydrogen atom jumps from the third excited state to the ground state, how would the de Broglie wavelength associated with the electron change? Justify your answer. [CBSE Allahabad 2015]

Ans. de Broglie wavelength associated with a moving charge particle having a KE 'K' can be given as

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\mathrm{mK}}} \qquad ...(1) \qquad \left[K = \frac{1}{2}\mathrm{mv}^2 = \frac{p^2}{2m}\right]$$

The kinetic energy of the electron in any orbit of hydrogen atom can be given as

$$K = -\ E\ = -\left(\frac{13.6}{n^2}\ \mathrm{eV}\right) = \frac{13.6}{n^2}\ \mathrm{eV} \qquad ...(2)$$

Let K_1 and K_4 be the KE of the electron in ground state and third excited state, where n1 = 1 shows ground state and n_2 = 4 shows third excited state.

Using the concept of equation (1) & (2), we have

$$\frac{\lambda_1}{\lambda_4} = \sqrt{\frac{K_4}{K_1}} = \sqrt{\frac{n_1^2}{n_2^2}}$$

$$\frac{\lambda_1}{\lambda_4} = \sqrt{\frac{1^2}{4^2}} = \frac{1}{4}$$

$$\Rightarrow \qquad \lambda_1 = \frac{\lambda_4}{4}$$

i.e., the wavelength in the ground state will decrease.

Q. 19. Determine the value of the de Broglie wavelength associated with the electron orbiting in the ground state of hydrogen atom (Given $E_n = -(13.6/n^2)$ eV

and Bohr radius r0 = 0.53 Å). How will the de Broglie wavelength change when it is in the first excited state? [CBSE Bhubaneshwar 2015]

Ans. In ground state, the kinetic energy of the electron is

$$K = -E = \frac{+13.6 \text{ eV}}{1^2} = 13.6 \times 1.6 \times 10^{-19} \ J = 2.18 \times 10^{-18} \ J$$

de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\text{mK}}}$

$$\lambda_1 = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 2.18 \times 10^{-18}}}$$

$$= 9.33 \times 10^{-9} = 0.33 \text{ nm}$$

Kinetic energy in the first excited state $(n = 2)$

$$K = - E = +\frac{13.6}{2^2} \text{ eV} = +3.4 \text{ eV} = 3.4 \times 1.6 \times 10^{-19} \ J = 0.54 \times 10^{-18} \ J$$

de Broglie wavelength, $\lambda_2 = \frac{h}{\sqrt{2\,\text{mK}}}$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 0.544 \times 10^{-18}}}$$

$$= 2 \times 0.33 \text{ nm} = \mathbf{0.66 \text{ nm}}$$

i.e., de Broglie wavelength will increase (or double).

Q. 20. Define the term 'intensity of radiation' in photon picture of light.

Ultraviolet light of wavelength 2270 Å from 100 W mercury source irradiates a photo cell made of a given metal. If the stopping potential is –1.3 V, estimate the work function of the metal. How would the photocell respond to a high intensity (~ 10^5 Wm^{-2}) red light of wavelength 6300 Å produced by a laser?
[CBSE Bhubaneshwar 2015]

Ans. The intensity of light of certain frequency (or wavelength) is defined as the number if photons passing through unit area in unit time.

For a given wavelength, (λ) of light

$$\frac{hc}{\lambda} = W + K$$

$$= W + eV_s \text{ (where } V_s \text{ is stopping potential)}$$

$$\frac{6.63\times10^{-34}\times3\times10^{8}}{2270\times10^{-10}} = W + 1.6\times10^{-19}\times(-1.3\,\text{eV})$$

$$\therefore \qquad W = \left(\frac{6.63\times10^{-34}\times3\times10^{8}}{2270\times10^{10}\times1.6\times10^{-19}} - 1.3\right)\text{eV}$$

$$W = 4.2 \text{ eV}$$

The wavelength of red light 6300 Å >> 2270 Å. So, the energy of red light must be

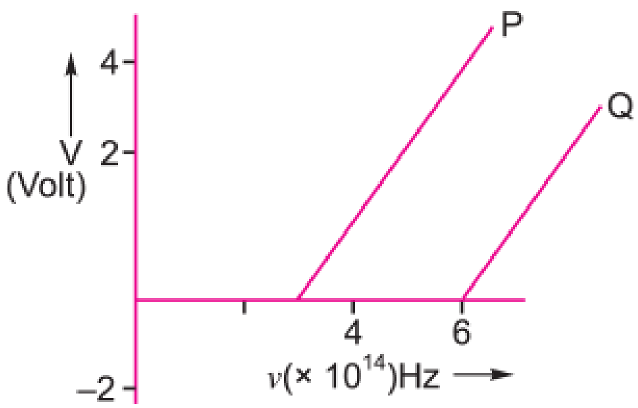
$$E = h\nu = \frac{hc}{e\lambda}\text{in eV}$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times6300\times10^{-10}}$$

$$= \frac{6.63\times3}{1.6\times63}\times10 = \frac{198.9}{1.6\times63}\text{eV} = 1.973 \text{ eV}$$

The energy of red light is very less than its work function, even intensity is very high. Hence no emission of electron is possible.

Q. 21. In the study of a photoelectric effect the graph between the stopping potential V and frequency v of the incident radiation on two different metals P and Q is shown below:



(i) Which one of the two metals has higher threshold frequency?

(ii) Determine the work function of the metal which has greater value.

(iii) Find the maximum kinetic energy of electron emitted by light of frequency 8 × 10^{14} Hz for this metal. [CBSE Delhi 2017]

Ans. (i) Threshold frequency of *P* is 3 × 10^{14} Hz.

Threshold frequency of *Q* is 6 × 10^{14} Hz.

Clearly *Q* has higher threshold frequency.

(ii) Work function of metal Q, $\varphi_0 = h\nu_0$

$= (6.6 \times 10^{-34}) \times 6 \times 10^{14}$ J

$$= \frac{39.6 \times 10^{-20}}{1.6 \times 10^{-19}} \text{eV} = 2.5 \text{ eV}$$

(iii) Maximum kinetic energy, $K_{max} = h\nu - h\nu_0$

$= h(\nu - \nu_0)$

$= 6.6 \times 10^{-34} (8 \times 10^{14} - 6 \times 10^{14})$

$= 6.6 \times 10^{-34} \times 2 \times 10^{14}$ J

$$= \frac{6.6 \times 10^{-34} \times 2 \times 10^{14}}{1.6 \times 10^{-19}} \text{eV}$$

$$\therefore \qquad K_{max} = \mathbf{0.83 \text{ eV}}$$

Short Answer Questions – II (OIQ)

Q. 1. Two monochromatic beams A and B of equal intensity I, hit a screen. The number of photons hitting the screen by beam A is twice that by beam B. Then what inference can you make about their frequencies? [NCERT Exemplar]

Ans. Let no. of photons falling per second of beam A = n_A

No. of photons falling per second of beam B = n_B

Energy of beam *A* = $h\nu_A$

Energy of beam $B = h\nu_B$

According to question, $I = n_A \nu_A = n_B \nu_B$

$$\frac{n_A}{n_B} = \frac{\nu_B}{\nu_A} \quad \text{or}\ , \ \frac{2n_B}{n_B} = \frac{\nu_B}{\nu_A} \Rightarrow \nu_B = 2\nu_A$$

The frequency of beam B is twice that of A.

Q. 2. How did de Broglie hypothesis lead to Bohr's quantum condition of atomic orbits?

Ans. According to Bohr's quantum condition "Only those atomic orbits are allowed as stationary orbits in which angular momentum of an electron is the integral multiple of $\frac{h}{2\pi}$.

If m is the mass, v velocity and r radius of orbit, then angular momentum of electron L= mvr.

According to Bohr's quantum condition

$$\mathrm{mvr} = n\frac{h}{2\pi} \qquad ...(i)$$

According to de Broglie quantum condition only those atomic orbits are allowed as stationary orbits in which circumference of electron-orbit is the integral multiple of de Broglie wavelength associated with electron, *i.e.*,

$$2\pi r = n\lambda \qquad ...(ii)$$

According to de Broglie hypothesis

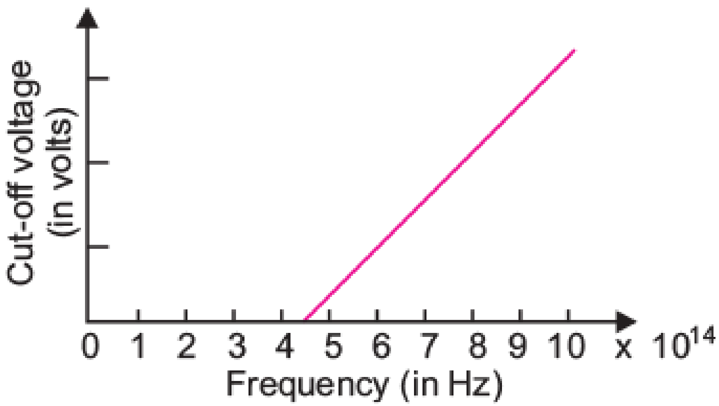
$$\lambda = \frac{h}{\mathrm{mv}} \qquad ...(iii)$$

Substituting this value in (ii), we get

$$2\pi r = n\left(\frac{h}{\mathrm{mv}}\right) \Rightarrow \mathrm{mvr} = n\frac{h}{2\pi}$$

This is Bohr's quantum condition.

Q. 3. For photoelectric effect in sodium, the figure shows the plot of cut-off voltage versus frequency of incident radiation. Calculate



(i) Threshold frequency

(ii) Work function for sodium.

Ans. (i) The threshold frequency is the frequency of incident light at which kinetic energy of ejected photoelectron is zero.

∴ From fig. threshold frequency,

$$\nu_0 = 4.5\times10^{14} \text{ Hz}$$

(ii) Work function, $W = h\nu_0$

$$= 6.6\times10^{-34} \times 4.5 \times 10^{14} \text{ joule}$$

$$= \frac{6.6\times10^{-34}\times4.5\times10^{14}}{1.6\times10^{-19}} \text{eV} = 1.85 \text{ eV}$$

Q. 4. A monochromatic light source of power 5mW emits 8×10^{15} photons per second. This light ejects photo electrons from a metal surface. The stopping potential for this set up is 2V. Calculate the work function of the metal.
[CBSE Sample Paper 2016]

Ans.

$P = 5\times10^{-3}$ W, $n = 8 \times 10^{15}$ photons per second

Energy of each photon,

$$E = \frac{p}{n} = \frac{5\times10^{-3}}{8\times10^{15}} = 6.25 \times 10^{-19} J = \frac{6.25\times10^{-19} J}{1.6\times10^{-19}} \mathrm{eV}$$

$$E = 3.9 \text{ eV}$$

Work function, $W_0 = E - V_0$

$$= (3.9 - 2) \text{ eV} = 1.9 \text{ eV}$$

Q. 5. Define the term work function of a metal. The threshold frequency of a metal is f_0. When the light of frequency $2f_0$ is incident on the metal plate, the maximum velocity of electrons emitted is v_1 When the frequency of the incident radiation is increased to $5f_0$ the maximum velocity of electrons emitted is v_2. Find the ratio of v_1 to v_2.

Ans. Work function: The work function of a metal is defined as the minimum energy required to free an electron from its surface binding.

Einstein's photoelectric equation is $h\nu = h\nu_0 + \frac{1}{2}\mathrm{mv}^2$

In first case $V = 2f_0$, $V_0 = f_0$, $v\ v_1$

$$h2f_0 = \mathrm{hf}_0 + \frac{1}{2}\mathrm{mv}_1^2 \quad \Rightarrow \quad \frac{1}{2}\mathrm{mv}_1^2 = \mathrm{hf}_0 \qquad \ldots(i)$$

In second case, $V = 5f_0$, $V_0 = f_0$, $v = v_2$

$\therefore$

$$h(5f_0) = \mathrm{hf}_0 + \frac{1}{2}\mathrm{mv}_2^2 \quad \Rightarrow \quad \frac{1}{2}\mathrm{mv}_2^2 = 4\,\mathrm{hf}_0 \qquad \ldots(ii)$$

Dividing $\left(\frac{v_1}{v_2}\right)^2 = \frac{1}{4} \Rightarrow \frac{v_1}{v_2} = \frac{1}{2}.$

Q. 6. Radiations of frequency 10^{15} Hz are incident on two photosensitive surfaces A and B. Following observations are recorded:

Surface A: No photoemission takes place.

Surface B: Photoemission takes place but photoelectrons have zero energy.

Explain the above observations on the basis of Einstein's photoelectric equation. How will the observation with surface B change when wavelength of incident light is decreased?

Ans. Einstein's Photoelectric Equation is

$$hv = W + E_k$$

$$\Rightarrow \qquad E_k = h_v - W \qquad \text{or} \qquad E_k = hv - hv_0 \qquad \ldots(i)$$

Where W is work function of metal, v is frequency of incident light and v_0 is threshold frequency.

Surface A: As no photoemission takes place; energy of incident photon is less than the work function.

In other words, the frequency $v = 10^{15}$ Hz of incident light is less than the threshold frequency (v_0).

Surface B: As photoemission takes place with zero kinetic energy of photolectrons (*i.e.*, $E_k = 0$), then equation (1) gives $W = hv$ or $v_0 = v$.

i.e., energy of incident photon is equal to work function. In other words, threshold frequency of metal is equal to frequency of incident photon *i.e.*, $v_0 = 10^{15}$ Hz. When wavelength of incident light is decreased, the energy of incident photon becomes more than the work function, so photoelectrons emitted will have finite kinetic energy given by

Q. 7. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photoelectrons emitted from the surface have the same de Broglie wavelength λB, prove that λ = $\left(\frac{2\,mc}{h}\right)\lambda_B^2$.

Ans. Kinetic energy of electrons, E_k = energy of photon of e.m. wave

$$= \frac{hc}{\lambda} \quad \ldots(i)$$

de Broglie wavelength, $\lambda_B = \frac{h}{\sqrt{2\,mE_k}}$ or $\lambda_B^2 = \frac{h^2}{2\,mE_k}$

Using (i), we get

$$\lambda_B^2 = \frac{h^2}{2m\left(\frac{hc}{\lambda}\right)} \quad \Rightarrow \quad \lambda = \left(\frac{2\,mc}{h}\right)\lambda_B^2$$

Q. 8. A proton and an α-particle move perpendicular to a magnetic field. Find the ratio of radii of the circular paths described by them when both (i) have equal momenta, and (ii) were accelerated through the same potential difference.

Ans.

We know that $r = \frac{mv}{Bq}$

i. For equal momenta $\frac{r_p}{r_\alpha} = \frac{q_\alpha}{q_p} = 2$

ii. Since $K.E = \frac{p^2}{2m} = qV$

$$P = \sqrt{2\,mqV}$$

$$r = \frac{\sqrt{2\,qVm}}{Bq} = \sqrt{\frac{2\,mV}{qB^2}}$$

$$\frac{r_p}{r_\alpha} = \sqrt{\frac{m_p}{q_p}} \times \sqrt{\frac{q_\alpha}{m_\alpha}}$$

$$= \sqrt{\frac{1}{4}} \times \sqrt{2} = \frac{1}{\sqrt{2}}$$