Short Answer Questions – I (PYQ)

Q. 1. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. [CBSE (AI) 2013]

Ans. If radiation of frequency (v) greater than threshold frequency (v_0) irradiate the metal surface, electrons emitted out from the metal. So Einstein's photoelectric equation can be given as

$$K_{\max} = \frac{1}{2}\mathrm{mv}_{\max}^2 = h\nu - h\nu_0$$

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 and momentum of the system of two constituents remains constant.

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

Q. 2. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation. [CBSE Delhi 2016]

Ans. The three characteristic features which cannot be explained by wave theory are:

(i) Kinetic energy of emitted electrons is found to be independent of the intensity of incident light.

(ii) There is no emission of electrons if frequency of incident light is below a certain frequency (threshold frequency).

(iii) Photoelectric effect is an instantaneous process.

Q. 3. A proton and an electron have same velocity. Which one has greater de Broglie wavelength and why? [CBSE (AI) 2012]

Ans. de Broglie wavelength (λ) is given as $\lambda = \frac{h}{mv}$

Given $v_p = v_e$

Where v_p = velocity of proton and v_e = velocity of electron

Since $m_p > m_e$

From the given relation

$\lambda \propto \frac{1}{m}$, hence $\lambda_p < \lambda_e$

Thus, electron has greater de Broglie wavelength, if accelerated with same speed.

Q. 4. When the electron orbiting in hydrogen atom in its ground state moves to the third excited state, show how the de Broglie wavelength associated with it would be affected. [CBSE Ajmer 2015]

Ans. We know,

de Broglie wavelength,

$$\lambda = \frac{h}{p} = \frac{h}{\mathrm{mv}} \quad \Rightarrow \quad \lambda \propto \frac{1}{v}$$

Also $\qquad v \propto \frac{1}{n}$

$\therefore \qquad \lambda \propto n$

$\therefore$ de Broglie wavelength will increase.

Q. 5. What is meant by work function of a metal? How does the value of work function influence the kinetic energy of electrons liberated during photoelectron emission?
[CBSE Delhi 2013; (AI) 2013]

Ans. Work Function: The minimum energy required to free an electron from metallic surface is called the work function.

Smaller the work function, larger the kinetic energy of emitted electron.

Q. 6. Monochromatic light of frequency 6×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. How many photons per second on an average are emitted by the source? [CBSE Guwahati 2015]

Ans.

Power of radiation, $P = \frac{\mathrm{nh}\,\nu}{t} = \mathrm{Nh}\,\nu$, where N is number of photons per sec.

or $$N = \frac{P}{h\nu}$$

$$= \frac{2.0\times10^{-3}}{6.63\times10^{-34}\times6\times10^{14}}$$

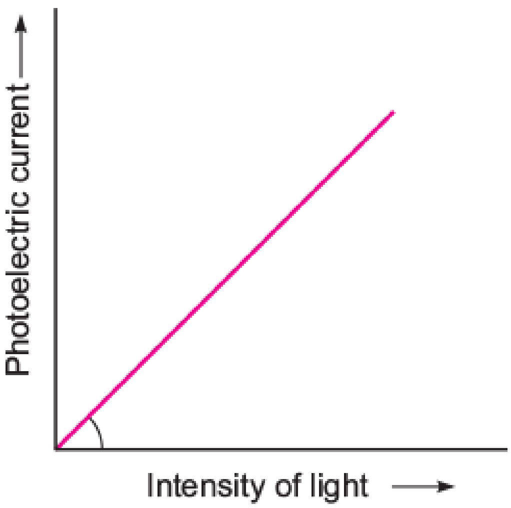
$$= 5 \times 10^{15} \text{ photons per second}$$

Q. 7. Plot a graph showing the variation of photoelectric current with intensity of light. The work function for the following metals is given:

Na: 2.75 eV and Mo: 4.175 eV.

Which of these will not give photoelectron emission from a radiation of wavelength 3300 Å from a laser beam? What happens if the source of laser beam is brought closer? [CBSE (F) 2016]

Ans.



Energy of photon $E = \frac{\mathrm{hc}}{\lambda}$ Joule

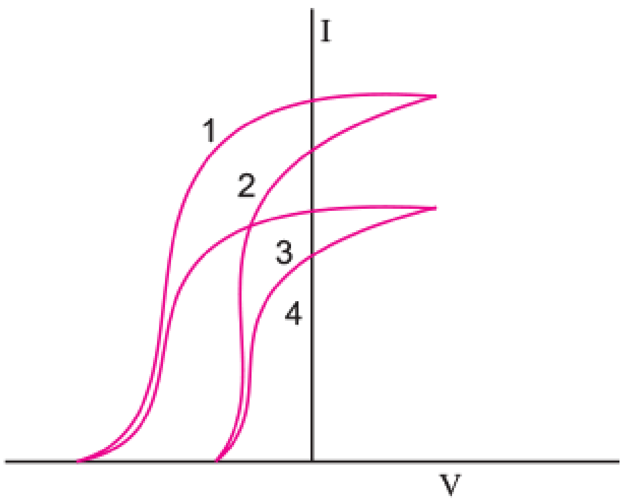
$$= \frac{\mathrm{hc}}{e\lambda}\mathrm{eV}$$

$$= \frac{6.63\times10^{-34}\times3\times10^{8}}{1.6\times10^{-19}\times3.3\times10^{-7}}\ \mathrm{eV} = 3.75\ \mathrm{eV}$$

Since W_0 of M_0 is greater than E, $\therefore M_0$ will not give photoemission.

There will be no effect of bringing source closer in the case of M_0. In case of Na, photocurrent will increase.

Q. 8. The given graph shows the variation of photo-electric current (I) with the applied voltage (V) for two different materials and for two different intensities of the incident radiations. Identify and explain using Einstein's photo electric equation for the pair of curves that correspond to



(i) Different materials but same intensity of incident radiation,

(ii) Different intensities but same materials. [CBSE East 2016]

Ans. (i) (a) 1 and 2 correspond to same intensity but different material.

(b) 3 and 4 correspond to same intensity but different material.

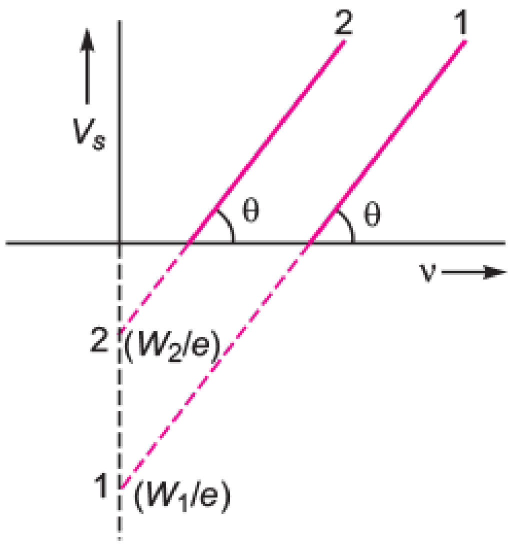
This is because the saturation currents are same and stopping potentials are different.

(ii) (a) 1 and 3 correspond to different intensity but same material.

(b) 2 and 4 correspond to different intensity but same material.

This is because the stopping potentials are same but saturation currents are different.

Q. 9. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). On what factors does the (i) slope and (ii) intercept of the lines depend? [CBSE Delhi 2010]



Ans. The graph of stopping potential V_s and frequency (v) for two photosensitive materials 1 and 2 is shown in fig.

(i) Slope of graph tan θ = $\frac{h}{e}$ = universal constant.

(ii) Intercept of lines depend on the work function.

Q. 10. An electron is accelerated through a potential difference of 100 V. What is the de Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond? [CBSE Delhi 2010]

Ans.

$$\text{de Broglie wavelength, } \lambda \left(= \frac{h}{p}\right) = \frac{h}{\sqrt{2\,\text{meV}}}$$

$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}\times100}}$$

$$= 1.227\times10^{-10}\text{ m} = \mathbf{1.227\ \text{Å}}$$

This wavelength belongs to X-ray spectrum.

Q. 11. An electromagnetic wave of wavelength λ_1 is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this

surface have the de-Broglie wavelength prove that $\lambda = \left(\frac{2\,mc}{h}\right)\lambda_1^2$ **[CBSE Delhi 2008]**

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

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

$$\ldots(1)$$

de Broglie wavelength, $\lambda_1 = \frac{h}{\sqrt{2\,mE_k}}$ or $\lambda_1^2 = \frac{h^2}{2\,mE_k}$

Using (1), we get

$$\lambda_1^2 = \frac{h2}{2m\left(\frac{hc}{\lambda}\right)} \quad \Rightarrow \quad \lambda = \left(\frac{2\,mc}{h}\right)\lambda_1^2$$

Short Answer Questions – I (OIQ)

Q. 1. The de Broglie wavelengths, associated with a proton and a neutron, are found to be equal. Which of the two has a higher value for kinetic energy?

Ans.

$\lambda = \frac{h}{\sqrt{2\,mE}}$, where E is kinetic energy, λ are equal, mE are equal

$$m_p E_p = m_n E_n \quad \Rightarrow \quad E_p = \frac{m_n}{m_p} E_n$$

As mass of proton is slightly less than the mass of neutron $\frac{mn}{mp}$ is slightly greater than 1; so kinetic energy of proton is slightly higher than that of neutron.

Q. 2. For a photosensitive surface, threshold wavelength is λ0. Does photoemission occur if the wavelength of radiation is (i) more than λ0 and (ii) less than λ_0 ? Justify your answer.

Ans. Energy of a photon E = $\frac{hc}{\lambda}$ For emission of photoelectrons energy of a photon **≥** work function or wavelength of incident photon λ should be less than threshold wavelength **λ_0 (i.e., $\lambda < \lambda_0$).**

Q. 3. Red light however bright it is, cannot produce the emission of electrons from a clean zinc surface, but even weak ultraviolet radiation can do so; why?

Ans. The photoemission of electrons does not depend on the intensity but it depends on the frequency and hence on the energy of photon of incident light. If the energy of photon is greater than the work function, the photoemission of electrons results however weak the incident radiation may be. The energy of **photon of red light** is less than the work function of zinc, so red light cannot emit photoelectrons.

The energy of photon of ultraviolet light is greater than the work function of zinc, so ultraviolet light can emit photoelectrons.

Q. 4. There are two sources of light A and B. The wavelength of light emitted from A is from 8000 Å to 11000 Å, while that from B is from 3000 Å to 6000 Å. The intensity of A is 4 times that of B. But when light of A falls on metal, photoelectrons are not emitted whereas light of B can eject photoelectrons from the same metal. Explain its reason.

Ans. The photoelectrons from a metallic surface are emitted only when the energy of incident photons is equal to or more than work function of metal. In other words the wavelength of incident photon must be equal to or less than the threshold wavelength. In this case the threshold wavelength is less than 8000 Å. Hence source A cannot eject photoelectrons while B can eject photoelectrons.

Q. 5. If the intensity of light falling on a metal plate is doubled, what will be the effect on photocurrent and maximum kinetic energy of emitted photoelectrons?

Ans. As photocurrent is proportional to intensity of incident light, the photocurrent will be doubled; but the maximum kinetic energy of emitted photoelectrons does not depend upon the intensity of incident light; hence the maximum kinetic energy remains unchanged.

Q. 6. Work function of sodium is 2.3 eV. Does sodium show photoelectric emission for light of wavelength 6800 Å?

Ans. The threshold wavelength of sodium

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

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{2.3 \times 1.6 \times 10^{-19}} = 5380 \times 10^{-10} m = 5380\ \mathring{A}$$

As given wavelength λ = 6800 Å < threshold wavelength λ_0 = 5380 Å, no photoelectric emission will take place.

Q. 7. An electron and a proton possess equal kinetic energy. Which of these has the greater de Broglie wavelength?

Ans.

de Broglie wavelength, $\lambda = \frac{h}{\sqrt{2\,\mathrm{m}\mathrm{E}_K}}$

For given kinetic energy E_K, $\lambda \propto \frac{1}{\sqrt{m}}$

If λ_e , λ_p are de Broglie wavelengths of electron and proton and m_e , m_p the masses of electron and proton respectively, then

$$\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}}$$

As $m_p > m_e$, it follows $\lambda_e > \lambda_p$, *i.e.*, de Broglie wavelength of electron is greater.

Q. 8. An electron and alpha particle have the same kinetic energy. How are the de Broglie wavelengths associated with them related?

Ans.

$$p = \frac{h}{\lambda} \quad \Rightarrow \quad \mathrm{mv} = \frac{h}{\lambda} \qquad \Rightarrow \quad \lambda = \frac{h}{\mathrm{mv}}$$

Kinetic energy, $E_k = \dfrac{(\mathrm{mv})^2}{2m}$

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

$$\lambda \propto \frac{h}{\sqrt{\mathrm{mE}_k}}$$

Since $m_\alpha > m_e$

$$\frac{\lambda_e}{\lambda_\alpha} = \frac{\sqrt{m_\alpha}}{\sqrt{m_e}} = \sqrt{\frac{4m_p}{m_e}} \quad \Rightarrow \quad \frac{\lambda_e}{\lambda_\alpha} = \sqrt{1872 \times 4}$$

$\Rightarrow$ $\lambda_e = 86.5 \times \lambda_\alpha$

Q. 9. An electron and photon have same energy 100 eV. Which has greater associated wavelength?

Ans.

de Broglie wavelength associated with electron

$$\lambda_e = \frac{h}{\sqrt{2\,\mathrm{mE}_e}} \quad \Rightarrow \quad E_e = \frac{h^2}{2m\,\lambda_e^2} \qquad \ldots(i)$$

Also wavelength of photon of energy E_{ph} is

$$E_{\mathrm{ph}} = \frac{\mathrm{hc}}{\lambda_{\mathrm{ph}}} \quad \Rightarrow \quad E_{\mathrm{ph}}^2 = \frac{h^2c^2}{\lambda_{\mathrm{ph}}^2} \qquad \ldots(ii)$$

Given $E_e = E_{ph} = E$ (say) $= 100$ eV $\ldots(iii)$

Dividing (ii) by (i) and using (iii), we get

$$E = \frac{h^2c^2/\lambda_{\mathrm{ph}}^2}{h^2/2m\,\lambda_e^2} \quad \text{or} \quad E = \frac{2\,\mathrm{mc}^2\,\lambda_e^2}{\lambda_{\mathrm{ph}}^2}$$

$$\therefore \qquad \frac{\lambda_e}{\lambda_{\mathrm{ph}}} = \sqrt{\frac{E}{2\,\mathrm{mc}^2}}$$

As $E = 100$ eV $2mc^2 \cong 1$ MeV

$$\therefore \qquad E << 2mc^2 \quad \Rightarrow \quad \lambda_e < \lambda_{ph}$$

That is, wavelength associated with photon is greater as compared to electron of same energy.

Q. 10. By how much would the stopping potential for a given photosensitive surface go up if the frequency of the incident radiations were to be increased from 4×10^{15} Hz to 8×10^{15} Hz?

Given $h = 6.4\times10^{-34}$ J-s, $e = 1.6\times10^{-19}$ C and $c = 3\times10^{8}$ ms^{-1}.

Ans.

Stopping potential V_S is given by

$$eV_S = h\nu - W \Rightarrow V_S = \frac{h}{e}\nu - \frac{W}{e}$$

When $\nu_1 = 4\times10^{15}$ Hz, $Vs = Vs_1$ (say)

When $\nu_2 = 8\times10^{15}$ Hz, $Vs = Vs_2$ (say)

$$\therefore \qquad V_{S_1} = \frac{h}{e}\nu_1 - \frac{W}{e} \quad \text{and} \quad V_{S_2} = \frac{h}{e}\nu_2 - \frac{W}{e}$$

Subtracting $V_{S_2} - V_{S_1} = \frac{h}{e}(\nu_2 - \nu_1)$

$$= \frac{6.4\times10^{-34}}{1.6\times10^{-19}}(8\times10^{15} - 4\times10^{15}) = 16 \text{ volt}.$$

Q. 11. Calculate the de Broglie wavelength of a neutron of kinetic energy 150 eV.

Mass of neutron = 1.67×10^{-27} kg

Ans.

de Broglie wavelength $\lambda = \frac{h}{\sqrt{2\,mE_K}}$

Here $E_K = 150 \text{ eV} = 150\times1.6\times10^{-19} \text{ J} = 2.4\times10^{-17} \text{ J}$

$$\therefore \qquad \lambda = \frac{6.63\times10^{-34}}{\sqrt{[2\times1.67\times10^{-27}\times2.4\times10^{-17}]}}m = 0.02335 \text{ Å}$$

Q. 12. There are two sources of light, each emitting with a power 100W. One emits X-rays of wavelength 1 nm and the other visible light at 500 nm. Find the ratio of number of photons of X-rays the photons of visible light of the given wavelength. [NCERT Exemplar]

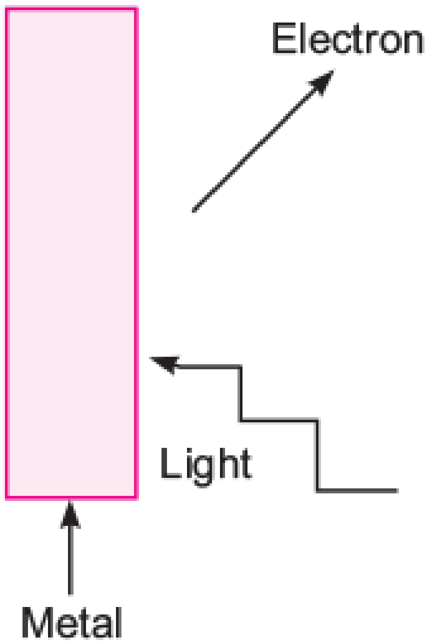
Ans. Total E is constant.

Let n_1 and n_2 be the number of photons of X-rays and visible region.

$$n_1 E_1 = n_2\ E_2 \qquad \Rightarrow \qquad n_1 \frac{\text{hc}}{\lambda_1} = n_2 \frac{\text{hc}}{\lambda_2}$$

$$\frac{n_1}{n_2} = \frac{\lambda_1}{\lambda_2} \qquad \Rightarrow \qquad \frac{n_1}{n_2} = \frac{1}{500}$$

Q. 13. Consider Fig. for photoemission.



How would you reconcile with momentum-conservation? No light (Photons) have momentum in a different direction than the emitted electrons. [NCERT Exemplar]

Ans. The momentum is transferred to the metal. At the microscopic level, atoms absorb the photon and its momentum is transferred mainly to the nucleus and electrons. The excited electron is emitted. Conservation of momentum needs to be accounted for the momentum transferred to the nucleus and electrons.

Q. 14. Electrons are emitted from the surface when green light is incident on it, but no electrons are ejected when yellow light is incident on it. Do you expect electrons to be ejected when surface is exposed to

(i) Red light and

(ii) Blue light?

Ans. (i) The wavelength of red light is longer than threshold wavelength, hence no electron will be emitted with red light.

(ii) The wavelength of blue light is smaller than threshold wavelength, hence electrons will be ejected.

Q. 15. Are matter waves electromagnetic?

Ans. Matter waves are not electromagnetic. The reason is that electromagnetic waves are produced by accelerated charges while matter waves or de Broglie waves are associated with neutral particles. In fact de Broglie waves are the probability waves; they tell the probability of location of particle in a certain region of space.

Q. 16. If the frequency of light falling on a metal is doubled, what will be the effect on photocurrent and the maximum kinetic energy of emitted photoelectrons?

Ans. The photocurrent does not depend on the frequency of incident radiation, hence the photocurrent remains unchanged. The maximum kinetic energy increases with increase of frequency, given by

$$E_K = hv - W$$

If frequency is doubled, $E_K' = 2hv - W$

$$\therefore \qquad \frac{E_K'}{E_K} = \frac{2h\nu - W}{h\nu - W} = \frac{2h\nu - 2W + W}{h\nu - W} = 2 + \frac{W}{h\nu - W} > 2$$

i.e., maximum kinetic energy will increase to slightly more than double value.

Q. 17. X-rays of wavelength 'λ' fall on a photosensitive surface, emitting electrons. Assuming that the work function of the surface can be neglected, prove that the de Broglie wavelength of electrons emitted will be $\sqrt{\frac{h\gamma}{2mc}}$.

Ans.

K.E. of electrons, E_k = energy of X-ray photon $= \frac{hc}{\lambda}$

$\therefore$ de Broglie wavelength, $\lambda_B = \frac{h}{\sqrt{2\,mE_k}}$.

But $E_k = \frac{hc}{\lambda}$ $\therefore$ $\lambda_B = \frac{h}{\sqrt{2m\left(\frac{hc}{\lambda}\right)}} = \sqrt{\frac{h\lambda}{2\,mc}}$