Very Short Answer Questions (PYQ)

Q. 1. Name the phenomenon which shows the quantum nature of electromagnetic radiation. [CBSE (AI) 2017]

Ans. "Photoelectric effect" shows the quantum nature of electromagnetic radiation.

Q. 2. Define intensity of radiation on the basis of photon picture of light. Write its SI unit. [CBSE (AI) 2014]

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

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

Q. 3. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based. [CBSE Delhi 2013]

Ans. Features of the photons:

(i) Photons are particles of light having energy E = hν and momentum p = $\frac{h}{\lambda}$, where h is Planck constant.

(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.

Q. 4. Define the term 'stopping potential' in relation to photoelectric effect. [CBSE (AI) 2011]

Ans. The minimum retarding (negative) potential of anode of a photoelectric tube for which photoelectric current stops or becomes zero is called the stopping potential.

Q. 5. Define the term 'threshold frequency' in relations to photoelectric effects. [CBSE (F) 2011]

Ans. Threshold frequency is defined as the minimum frequency of incident radiation which can cause photoelectric emission. It is different for different metal.

Q. 6. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain. [CBSE (F) 2014]

Ans. The photoelectric current increases proportionally with the increase in intensity of incident radiation. 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.

Q. 7. Write the expression for the de Broglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V.
[CBSE (AI) 2013]

Ans.

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

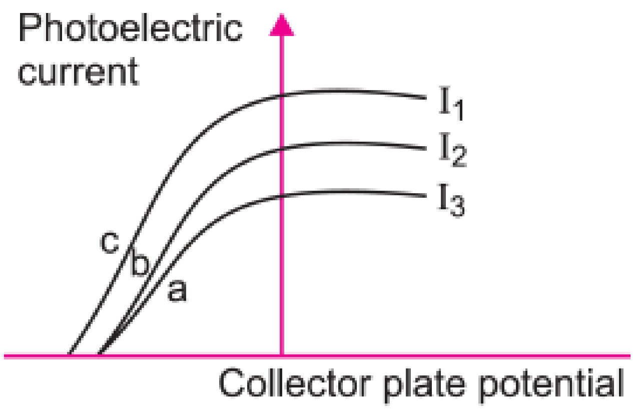
Hint: $W = K = \mathrm{qV} = \frac{p^2}{2m}$ or $p = \sqrt{2\,\mathrm{mqV}}$

Q. 8. State de-Broglie hypothesis. [CBSE Delhi 2012]

Ans. According to hypothesis of de Broglie "The atomic particles of matter moving with a given velocity, can display the wave like properties."

i.e., $\lambda = \frac{h}{\mathrm{mv}}$ (mathematically)

Q. 9. The figure shows a plot of three curves a, b, c showing the variation of photocurrent vs. collector plate potential for three different intensities I_1, I_2, and I_3 having frequencies v_1, v_2 and v_3 respectively incident on a photosensitive surface.



Point out the two curves for which the incident radiations have same frequency but different intensities. [CBSE Delhi 2009]

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

Q. 10. The stopping potential in an experiment on photoelectric effect is 1.5V. What is the maximum kinetic energy of the photoelectrons emitted? [CBSE (AI) 2009]

Ans.

$$K_{\max} = eV_s = e\,(1.5\text{V}) = 1.5 \text{ eV}$$

$$= 1.5 \times 1.6 \times 10^{-19} \text{ J}$$

$$= \mathbf{2.4 \times 10^{-19} \text{ J}}$$

Q. 11. The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential? [CBSE (AI) 2009]

Ans.

$$(E_k)_{\max} = eV_s$$

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

Q. 12. The stopping potential in an experiment on photoelectric effect is 2 V. What is the maximum kinetic energy of the photoelectrons emitted? [CBSE (AI) 2009]

Ans. Maximum kinetic energy, $(E_k)_{max} = eV_s$

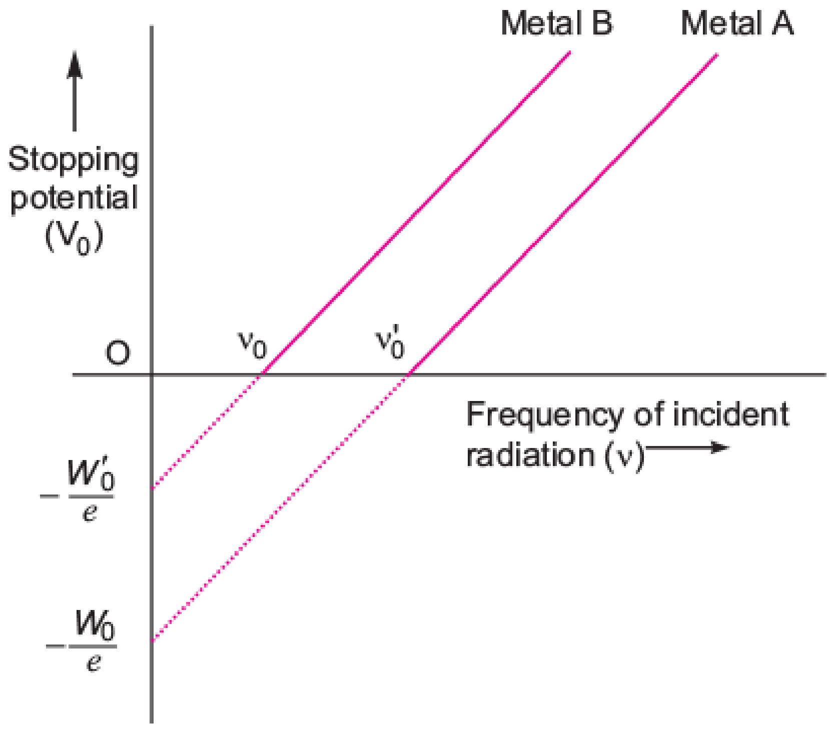
$= e(2\text{V}) =$ **2eV**

Q. 13. What is the stopping potential of a photocell, in which electrons with a maximum kinetic energy of 6 eV are emitted? [CBSE (AI) 2008]

Ans. $E_k = eV_0 \Rightarrow 6\text{eV} = eV_0 \Rightarrow V_0 = 6$ V

The stopping potential V_0 = 6 volt (Negative).

Q. 14. The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer. [CBSE (AI) 2014]



Ans. Metal A

Since work function $W = h\nu_0$

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

Aliter:

On stopping potential axis $-\frac{W'_0}{e} > -\frac{W_0}{e}$.

Hence work function W_0 of metal A is more.

Q. 15. An electron and a proton have the same kinetic energy. Which one of the two has the larger de Broglie wavelength and why? [CBSE (AI) 2012]

Ans. An electron has the larger wavelength.

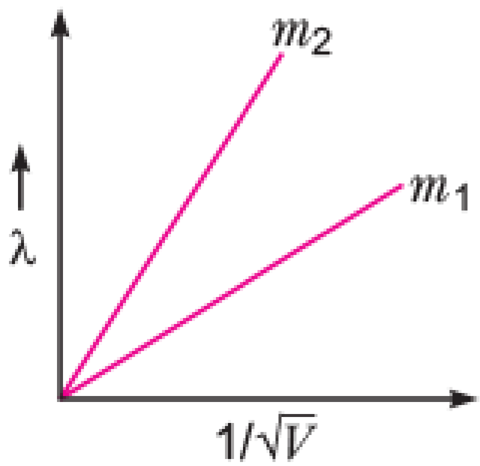
Reason: de-Broglie wavelength in terms of kinetic energy is $\lambda = \frac{h}{\sqrt{2\,mE_k}} \propto \frac{1}{\sqrt{m}}$ for the same kinetic energy.

As an electron has a smaller mass than a proton, an electron has larger de Broglie wavelength than a proton for the same kinetic energy.

Q. 16. Plot a graph showing variation of de-Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where V is accelerating potential for two particles A and B carrying same charge but of masses m_1, m_2 ($m_1 > m_2$). Which one of the two represents a particle of smaller mass and why? [CBSE Delhi 2016] [HOTS]

Ans.

$$\text{As, } \lambda = \frac{h}{\sqrt{2\,\mathrm{mqV}}} \qquad \text{or} \qquad \lambda = \left(\frac{h}{\sqrt{2q}} \cdot \frac{1}{\sqrt{m}}\right)\frac{1}{\sqrt{V}}$$



$$\text{or} \qquad \frac{\lambda}{\frac{1}{\sqrt{V}}} = \frac{h}{\sqrt{2q}} \cdot \frac{1}{\sqrt{m}}$$

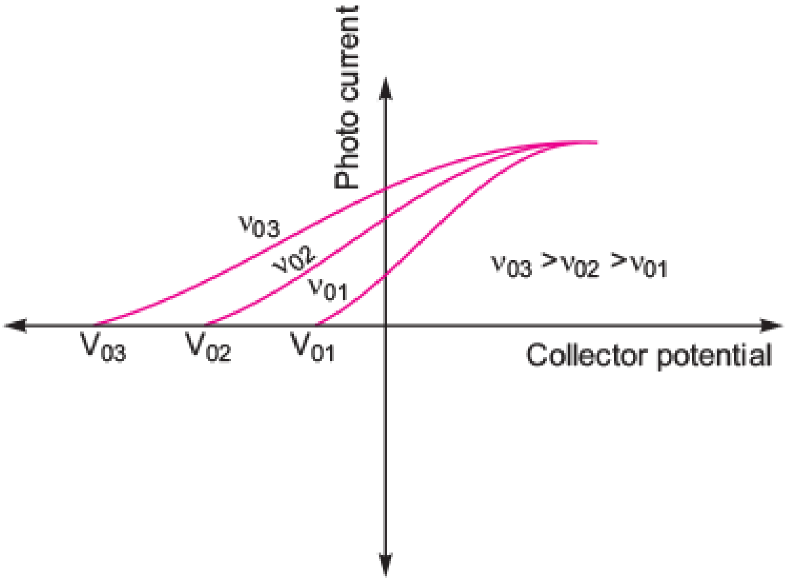
As the charge on two particles is same, we get

$$\text{Slope} \propto \frac{1}{\sqrt{m}}$$

Hence, particle with lower mass (m_2) will have greater slope.

Q. 17. Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation. [CBSE (F) 2011] [HOTS]

Ans.

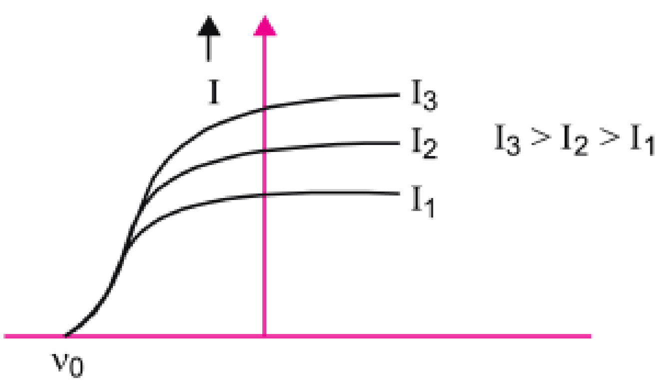


Q. 18. Answer the following questions:

(i) Draw a graph showing variation of photo-electric current (I) with anode potential (V) for different intensities of incident radiation. Name the characteristic of the incident radiation that is kept constant in this experiment.

(ii) If the potential difference used to accelerate electrons is doubled, by what factor does the de-Broglie wavelength associated with the electrons change? [CBSE (F) 2009]

Ans. (i) The frequency of incident radiation was kept constant.



(ii) de-Broglie wavelength,

$$\lambda = \frac{h}{\sqrt{2\,mqV}} \propto \frac{1}{\sqrt{V}}$$

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

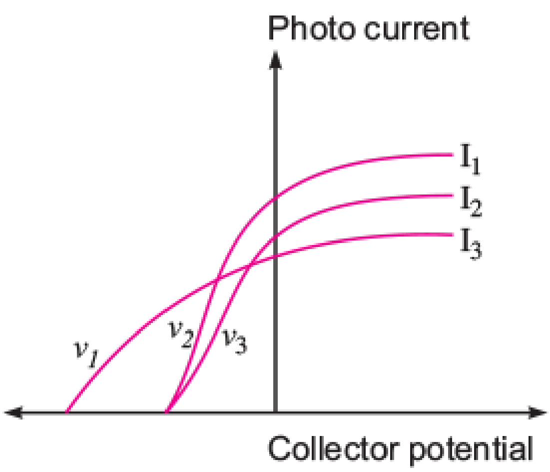
Q. 19. (a) Define the term 'intensity of radiation' in photon picture.

(b) Plot a graph showing the variation of photo current vs collector potential for three different intensities $I_1 > I_2 > I_3$, two of which (I_1 and I_2) have the same frequency v and the third has frequency v1 > v.

(c) Explain the nature of the curves on the basis of Einstein's equation.
[CBSE South 2016] [HOTS]

Ans. (a) The amount of light energy or photon energy incident per metre square per second is called intensity of radiation.

(b)



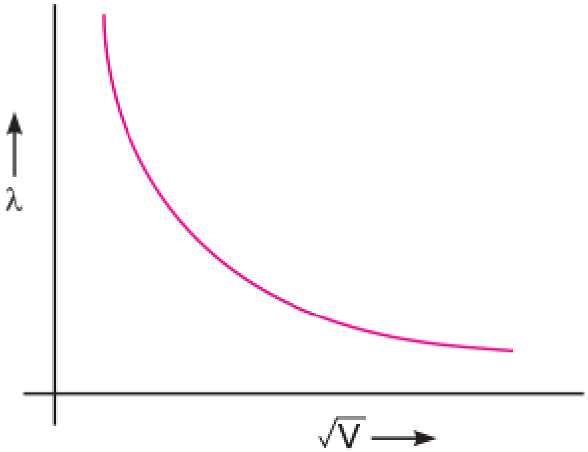
(c) As per Einstein's equation,

(i) The stopping potential is same for I_1 and I_2 as they have the same frequency.

(ii) The saturation currents are as shown in figure because $I_1 > I_2 > I_3$.

Q. 20. Show on a graph the variation of the de Broglie wavelength (λ) associated with an electron, with the square root of accelerating potential (V).
[CBSE (F) 2012] [HOTS]

Ans.



We know $\lambda = \frac{1.22}{\sqrt{V}}\ \mathring{A}$

$\therefore \quad \lambda\sqrt{V} = \text{constant}$

The nature of the graph between λ and $\sqrt{V}$ is hyperbola.

Very Short Answer Questions (OIQ)

Q. 1. What is a photon?

Ans. A photon is a bundle of energy of electromagnetic wave. For a frequency of wave v, energy of a photon E = hv.

Q. 2. Define work function for a given metallic surface.

Ans. The minimum energy required to free an electron from the metallic surface is called the work function of that surface.

Q. 3. The wavelength of electromagnetic radiation is doubled; how will the energy of a photon change?

Ans. $E = \frac{hc}{\lambda} \propto \frac{1}{\lambda}$

Clearly when wavelength λ is doubled, the energy of photon is halved.

Q. 4. If the intensity of radiation in a photocell is increased how does the stopping potential vary?

Ans. The stopping potential does not depend on the intensity of incident radiation; so stopping potential will remain unchanged.

Q. 5. How does the maximum kinetic energy of electrons emitted vary with the work function of the metal?

Ans. Maximum kinetic energy $E_k = hv - W$

Clearly, smaller the work function W, greater is the E_k This means that when work function of a metal increases, maximum kinetic energy of photoelectrons decreases.

Q. 6. The frequency v of incident radiation is greater than threshold frequency (v_0) in a photocell. How will the stopping potential vary if frequency (v) is increased, keeping other factors constant?

Ans. From Einstein's photoelectric equation, stopping potential V_0 is

$$eV_0 = h\nu - h\nu_0 \Rightarrow V_0 = \frac{h}{e}(\nu - \nu_0)$$

Given $v > v_0$, so with increase of frequency v, stopping potential increases.

Q. 7. Two metals A and B have work functions 4 eV and 10 eV respectively. Which metal has the higher threshold wavelength?

Ans.

Work function $W = h\nu_0 = \frac{hc}{\lambda_0}$

$$\Rightarrow \quad \lambda_0 \propto \frac{1}{W}$$

As $\quad W_A < W_B; \ (\lambda_0)_A > (\lambda_0)_B$

i.e., threshold wavelength of metal A is higher.

Q. 8. Two beams, one of red light and the other of blue light, of the same intensity are incident on a metallic surface to emit photoelectrons. Which one of the two beams emits electrons of greater kinetic energy?

Ans. The photon of blue light has higher energy as compared to red light; so blue light emits electrons of greater kinetic energy than that of red light.

Q. 9. Does the stopping potential in photoelectric emission depend upon

(i) The intensity of the incident radiation in a photocell?
(ii) The frequency of the incident radiation?

Ans. (i) No

(ii) Yes; stopping potential increases with increase of frequency.

Q. 10. Ultraviolet light is incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$). In which case will the kinetic energy of the emitted electrons be greater? Why?

Ans. From Einstein's photoelectric equation $hv = W + E_k$

$$E_k = hv - W$$

Clearly, smaller the work function, greater is the KE. As $W_1 > W_2$, KE for metal of work function W_2 will be greater.

Q. 11. Ultraviolet radiations of different frequencies v_1 and v_2, are incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) respectively. The kinetic energy of the emitted photoelectrons is same in both the cases. Which one of the two relations will be of the higher frequency?

Ans. According to Einstein's photoelectric equation, kinetic energy of photoelectrons, $E_k = hv - W$

As E_k is same, $hv_1 - W_1 = hv_2 - W_2$

$$\Rightarrow \quad h\nu_1 - h\nu_2 = W_1 - W_2 \quad \Rightarrow \quad \nu_1 - \nu_2 = \frac{W_1 - W_2}{h}$$

As $W_1 > W_2$, $v_1 > v_2$

That is, frequency of radiation v_1 is higher.

Q. 12. With what purpose was famous Davisson-Germer experiment with electrons performed?

Ans. Davisson-Germer experiment was performed to verify wave nature of electrons. It is the first experimental evidence for wave nature of matter.

Q. 13. If the potential difference used to accelerate electrons is tripled, by what factor does de Broglie wavelength of electrons beam change?

Ans. de Broglie wavelength of electrons accelerated through a potential difference of V volts is λ= $\frac{h}{\sqrt{2\,meV}}$

When accelerating voltage V is tripled, the de Broglie wavelength becomes $\frac{1}{\sqrt{3}}$ times.

Q. 14. de Broglie wavelength associated with an electron accelerated through a potential difference V is λ What will be the de Broglie wavelength when the accelerating potential is increased to 4 V?

Ans. $\frac{\gamma}{2}$

Reason: de Broglie wavelength associated with electron is

$$\lambda = \frac{h}{\sqrt{2\,\mathrm{meV}}} \quad \Rightarrow \quad \lambda \propto \frac{1}{\sqrt{V}}$$

Obviously when accelerating potential becomes 4 V, the de-Broglie wavelength reduces to half.

Q. 15. An electron, an alpha particle and a proton have the same kinetic energy. Which one of these particles has (i) the shortest and (ii) the largest, de Broglie wavelength?

Ans. de Broglie wavelength of particle of mass m in terms of kinetic energy (E_k) is λ = $\frac{h}{\sqrt{2\,\mathrm{mE}_k}} \propto \frac{1}{\sqrt{m}}$ for the same kinetic energy.

(i) Out of given particles, the mass of alpha particle is maximum, so **de Broglie wavelength associated with alpha particle is the shortest.**

(ii) As mass of electron is least, so electron has largest de-Broglie wavelength.

Q. 16. Why is the de Broglie wavelength associated with macroscopic objects (cricket ball, car, etc.) not observed in daily life?

Ans. de Broglie wavelength, λ = $\frac{h}{mv}$

As h is very small and for macroscopic objects the mass is very large; therefore, de Broglie wavelength associated is much smaller than the size of objects; hence de Broglie wavelength associated with them is not observable.

Q. 17. Which of the two: (i) light and (ii) moving material particle is concerned with de-Broglie hypothesis?

Ans. Moving material particle is concerned with de Broglie hypothesis.

Q. 18. How does de Broglie wavelength depend on the momentum of a particle?

Ans. $\lambda = \frac{h}{p} \propto \frac{1}{p}$

i.e., de Broglie wavelength varies inversely with the momentum of a particle.

Q. 19. A proton and a deuteron have the same velocity; what is the ratio of their de Broglie wavelengths?

Ans.

de Broglie wavelength $\lambda = \frac{h}{\mathrm{mv}} \propto \frac{1}{m}$ for the same velocity v.

$$\frac{\lambda_p}{\lambda_d} = \frac{m_d}{m_p} = \frac{2m_p}{m_p} = \frac{2}{1} = 2{:}1.$$

Q. 20. Which of the following moving with the same velocity has the longest de Broglie wavelength; electron, proton, deuteron, α-particle?

Ans.

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,\mathrm{mE}}} \propto \frac{1}{\sqrt{m}}$ for same energy E.

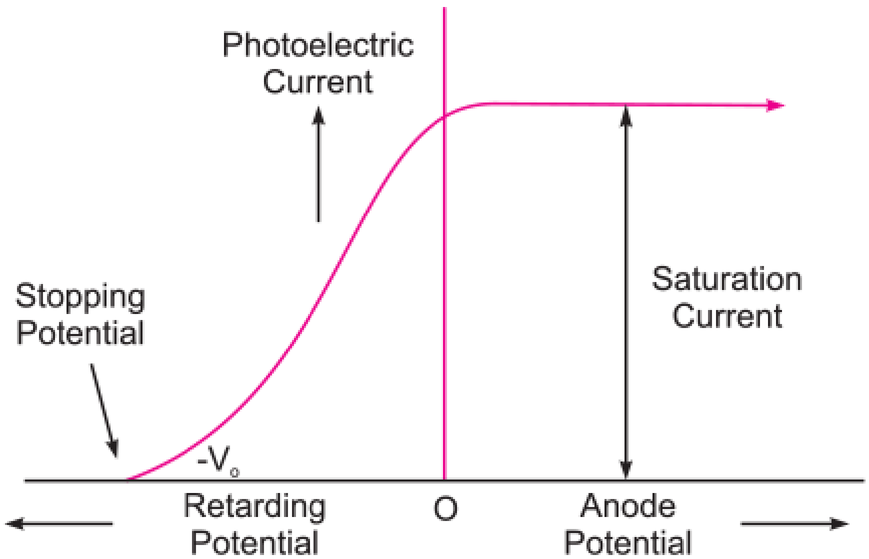
As the mass of electron is least, de Broglie wavelength of electron is the longest.

Q. 21. Answer the following questions:

(i) Draw a graph showing variation of photocurrent with anode potential for a particular intensity of incident radiation. Mark saturation current and stopping potential.

(ii) by how much would be 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?

Ans. (i)



Intercept of the graph with potential axis gives the stopping potential.

(ii) We have

$$hv_{in} = eV$$

$$\Rightarrow \quad \Delta V = \frac{h(\nu_1 - \nu_2)}{e}$$

$$= \frac{6.62\times10^{-15}\times(8\times10^{15} - 4\times10^{15})}{1.6\times10^{-19}}$$

$$= \frac{6.62\times4\times10^{15}\times10^{-34}}{1.6\times10^{19}} V$$

$$= \mathbf{16.55V}$$

Q. 22. There are materials which absorb photons of shorter wavelength and emit photons of longer wavelength. Can there be stable substances which absorb photons of larger wavelength and emit light of shorter wavelength? [NCERT Exemplar]

Ans. In the first case, energy given out is less than the energy supplied. In the second case, the material has to supply the energy as the emitted photon has more energy. This cannot happen for stable substances.

Q. 23. Do all the electrons that absorb a photon come out as photoelectrons? [NCERT Exemplar] [HOTS]

Ans. No, most electrons get scattered into the metal. Only a few come out of the surface of the metal.

Q. 24. Electrons are emitted from a photosensitive surface when it is illuminated by green light but electron emission does not take place by yellow light. Will the electrons be emitted when the surface is illuminated by (i) red light, and (ii) blue light?
[HOTS]

Ans. (i) No

(ii) Yes.

Reason: According to colour sequence VIBGYOR, the frequency of red light photons is less than threshold frequency of photo metal but frequency of blue light photons is more than threshold frequency of photo metal; so (i) electrons will not be emitted by red light and (ii) electrons will be emitted by blue light.

Q. 25. In a photoelectric effect, the yellow light is just able to emit electrons, will green light emit photoelectrons? What about red light? [HOTS]

Ans.

Energy of photon $E = \frac{hc}{\lambda} \propto \frac{1}{\lambda}$

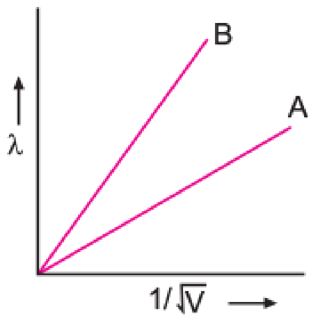
As $\lambda_{green} < \lambda_{yellow}$ so green light photon has more energy than yellow light photon, so green light will eject electron.

As $\lambda_{red} > \lambda_{yellow}$ so red light photon has lesser energy than yellow light photon, so red light will not be able to eject electrons.

Q. 26. Work function of aluminium is 4.2 eV. If two photons, each of energy 2.5 eV, are incident on its surface, will the emission of electrons take place? Justify your answer.
[HOTS]

Ans. In photoelectric effect, a single photon interacts with a single electron. As individual photon has energy (2.5 eV) which is less than work function, hence emission of electron will not take place.

Q. 27. Two lines A and B shown in the graph represent the de Broglie wavelength (λ) as a function of $\frac{1}{\sqrt{V}}$ (V is the accelerating potential) for two particles having the same charge. Which of the two represents the particle of smaller mass?
[HOTS]



Ans.

de Broglie wavelength $\lambda = \frac{h}{\sqrt{2\,\mathrm{mqV}}}$ or $\lambda = \frac{h}{\sqrt{2\,\mathrm{mq}}} \cdot \frac{1}{\sqrt{V}}$

The graph of λ versus $\frac{1}{\sqrt{V}}$ is a straight line of slope $\frac{h}{\sqrt{2\,\mathrm{mq}}} \propto \frac{1}{\sqrt{m}}$. The slope of line B is large, so **particle B has smaller mass**.

Q. 28. A photosensitive surface emits photoelectrons when red light falls on it. Will the surface emit photoelectrons when blue light is incident on it? Give reason.

Ans. According to photoelectric equation

$$h\nu_{\text{in}} = \varphi + K.E$$

$$\Rightarrow \quad \frac{\mathrm{hC}}{\lambda_{\text{in}}} = \varphi + K.E \qquad [\lambda_{\text{in}} = \text{Wavelength of incident light}]$$

Since, energy of blue light falling on the surface is more than red light, surface will emit photoelectrons.

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

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

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,

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

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

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

$$= \frac{2.0 \times 10^{-3}}{6.63 \times 10^{-34} \times 6 \times 10^{14}}$$

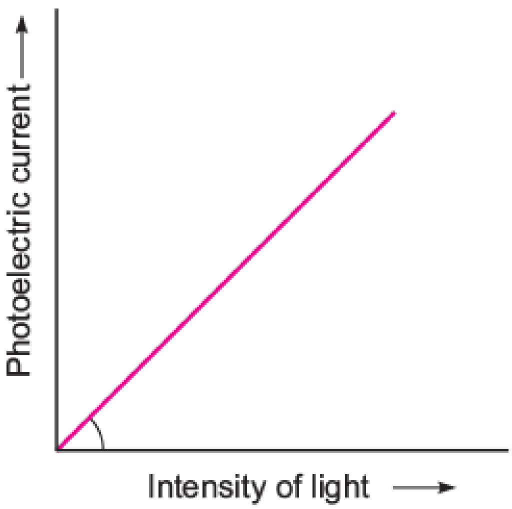
$$= 5 \times 10^{15} \text{ photons per second}$$

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

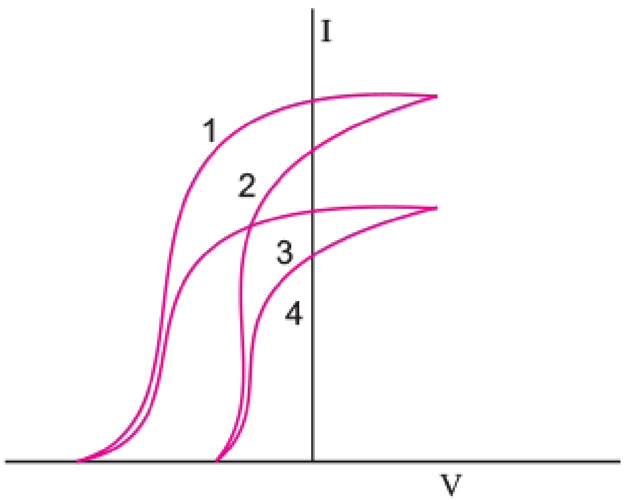
$$= \frac{hc}{e\lambda} \text{eV}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 3.3 \times 10^{-7}} \text{ eV} = 3.75 \text{ eV}$$

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.

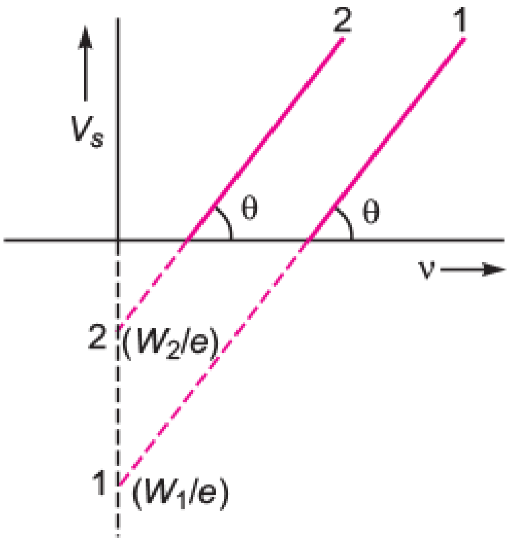
This is because the saturation currents are same and stopping potentials are different.

(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 (ν) 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

$$= \frac{hc}{\lambda} \quad \ldots(1)$$

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

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

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

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.

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

Kinetic energy, $E_k = \frac{(\text{mv})^2}{2m}$

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

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

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

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

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)

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

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

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

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]

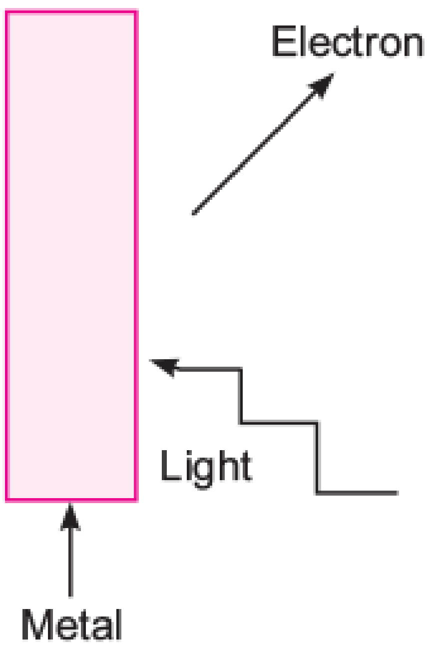
Ans. Total E is constant.

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

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

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

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

$$E_K = h\nu - W$$

If frequency is doubled, $E_K' = 2h\nu - W$

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

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

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 $\varphi_0 = \frac{hc}{\lambda_0}$

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

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

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

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 φ0 = v0.

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

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

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

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

$$\Rightarrow \quad KE_{\mathrm{max}} = hV = hV_0$$

$$\text{or} \quad KE_{\mathrm{max}} = hV - \varphi_0$$

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, $K_p < K_\alpha$.

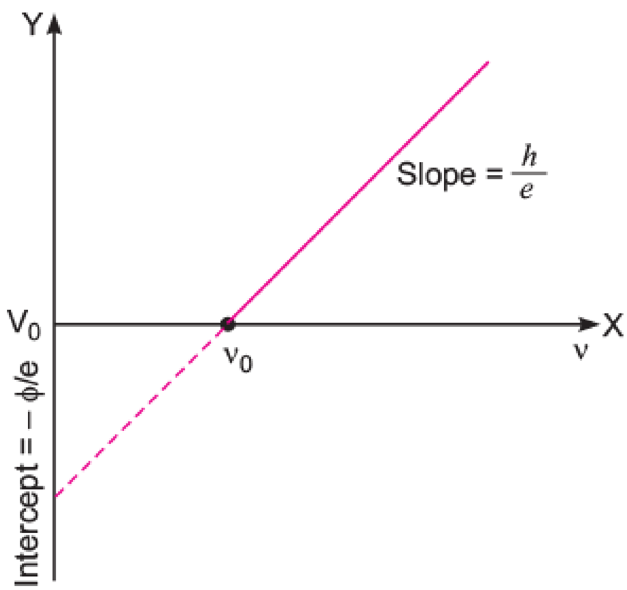
Hence, proton has less kinetic energy.

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

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

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

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

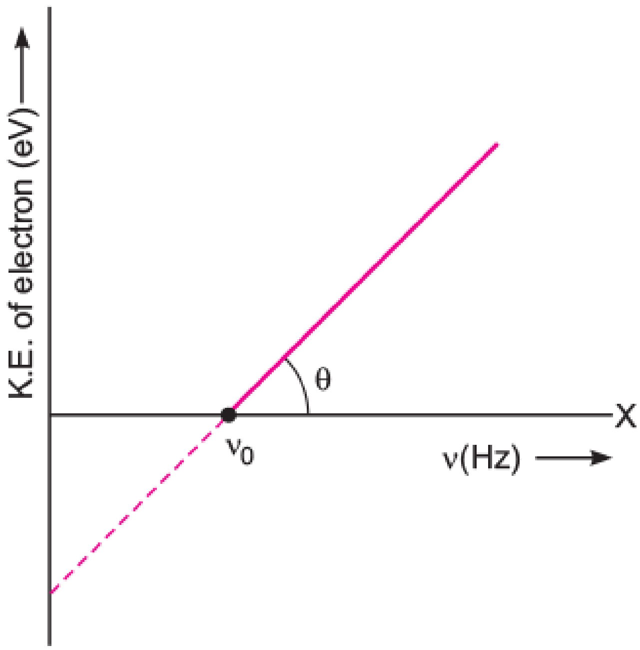
Clearly, $V_0 - \nu$ graph is a straight line.

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

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

(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

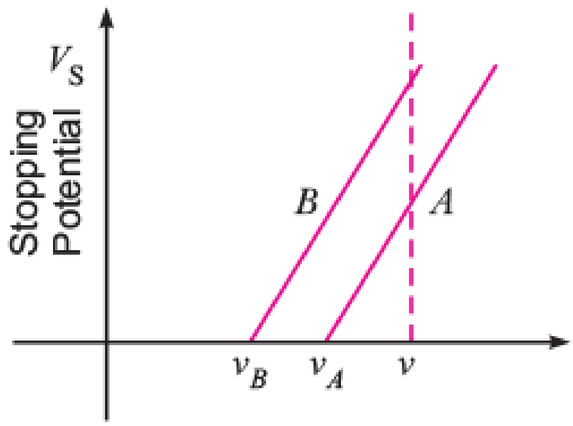
Q. 7. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials A and B having threshold frequencies $\nu_A > \nu_B$.

(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

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

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

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

$$p = \sqrt{2\,\text{mE}_K}$$

$\therefore$ Equation (i) gives $\lambda = \frac{h}{\sqrt{2\,\text{mE}_K}}$ ...(ii)

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

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

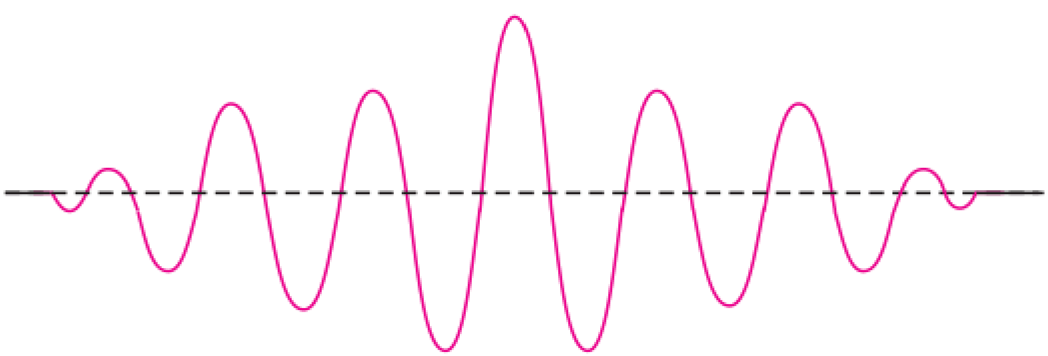
Substituting $m = 9.1 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C, $h = 6.62 \times 10^{-34}$ Js, we get

$$\lambda = \frac{6.62\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.6\times10^{-19}V}} = \frac{12.27}{\sqrt{V}} \times 10^{-10}\ m$$

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

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

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

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

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

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

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

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

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

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

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 $K = \frac{1}{2}\text{mv}^2 = \frac{p^2}{2m}$

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

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

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

$$\frac{K_p}{K_e} = \frac{9.1 \times 10^{-31}}{1.67 \times 10^{-27}} = 5.4 \times 10^{-4}$$

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.

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

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 120}}$$

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

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

$$\lambda_1 = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times2.18\times10^{-18}}}$$

$$= 9.33\times10^{-9} = 0.33\ \text{nm}$$

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

$$= \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times0.544\times10^{-18}}}$$

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

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

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

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

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

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

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

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

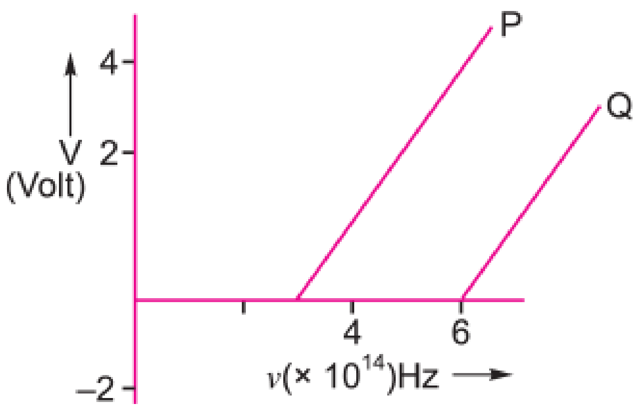
$$E = h\nu = \frac{hc}{e\lambda}\text{in eV}$$

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

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

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

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

$$\therefore \quad K_{max} = \mathbf{0.83 \ eV}$$

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

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

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.*,

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

According to de Broglie hypothesis

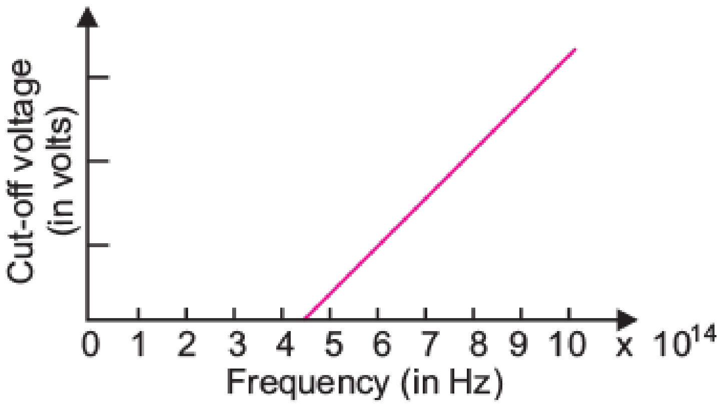
$$\lambda = \frac{h}{\text{mv}} \qquad \text{...}(iii)$$

Substituting this value in (ii), we get

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

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,

$v_0 = 4.5 \times 10^{14}$ Hz

(ii) Work function, $W = hv_0$

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

$$= \frac{6.6 \times 10^{-34} \times 4.5 \times 10^{14}}{1.6 \times 10^{-19}} \text{eV} = 1.85 \text{ eV}$$

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,

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

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

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 $h\nu = h\nu_0 + \frac{1}{2}mv^2$

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

$$h2f_0 = hf_0 + \frac{1}{2}mv_1^2 \quad \Rightarrow \quad \frac{1}{2}mv_1^2 = hf_0 \qquad \ldots(i)$$

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

$\therefore$

$$h(5f_0) = hf_0 + \frac{1}{2}mv_2^2 \quad \Rightarrow \quad \frac{1}{2}mv_2^2 = 4hf_0 \qquad \ldots(ii)$$

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

$$hv = W + E_k$$

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

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

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

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

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

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

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

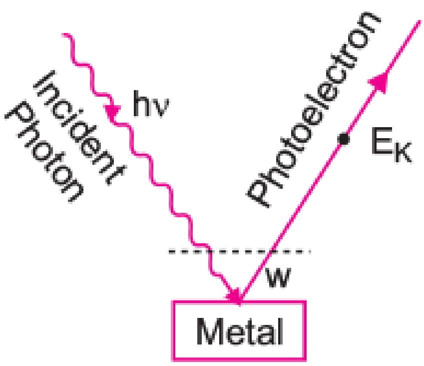
$$= \sqrt{\frac{1}{4}} \times \sqrt{2} = \frac{1}{\sqrt{2}}$$

Long Answer Questions

Q. 1. Derive Einstein's photoelectric equation $\frac{1}{2}mv^2 = hv - hv_0$.

Ans. Einstein's Explanation of Photoelectric Effect: Einstein's Photoelectric Equation

Einstein explained photoelectric effect on the basis of quantum theory. The main points are



1. Light is propagated in the form of bundles of energy. Each bundle of energy is called a **quantum** or **photon** and has energy *hv* where *h* = Planck's constant and *v* = frequency of light.
2. The photoelectric effect is due to collision of a photon of incident light and a bound electron of the metallic cathode.
3. When a photon of incident light falls on the metallic surface, it is completely absorbed. Before being absorbed it penetrates through a distance of nearly 10^{-8} m (or 100 Å). The absorbed photon transfers its whole energy to a single electron. The energy of photon goes in two parts: a part of energy is used in releasing the electron from the metal surface (*i.e.*, in overcoming work function) and the remaining part appears in the form of kinetic energy of the same electron.

If *v* be the frequency of incident light, the energy of photon = *hv*. If *W* be the work function of metal and E_K the maximum kinetic energy of photoelectron, then according to Einstein's explanation.

$hv = W + E_K$ or $E_K = hv - W$ ...(*i*)

This is called **Einstein's photoelectric equation.**

If v_0 be the threshold frequency, then if frequency of incident light is less then v_0 no electron will be emitted and if the frequency of incident light be v_0 then $E_K = 0$; so from equation (*i*)

$$0 = h\nu_0 - W \quad \text{or} \quad W = h\nu_0$$

If λ_0 be the threshold wavelength, then $\nu_0 = \frac{c}{\lambda_0}$,

where c is the speed of light in vacuum

$\therefore$ Work function $W = h\nu_0 = \frac{hc}{\lambda_0}$ ...(*ii*)

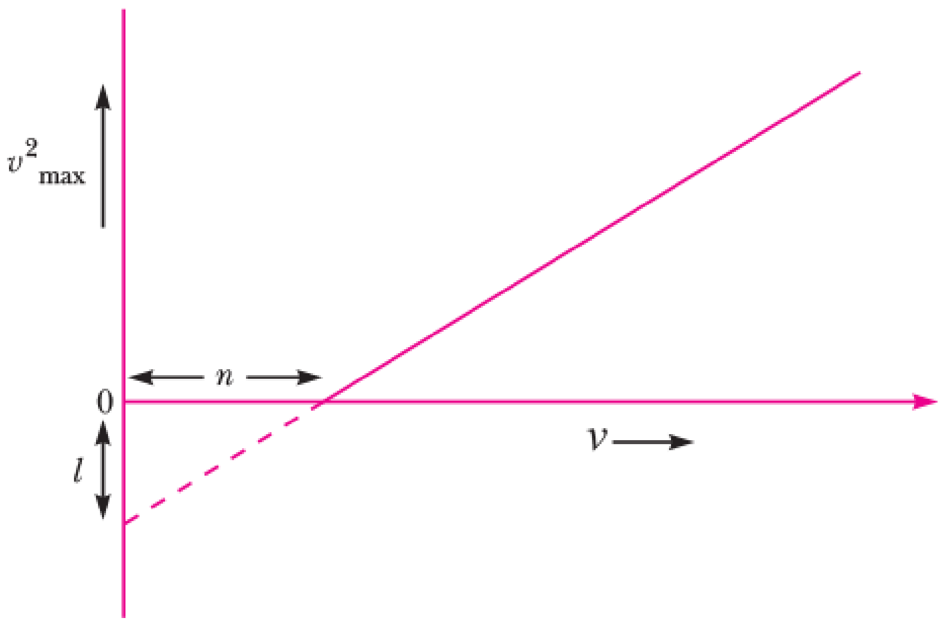
Substituting this value in equation (*i*), we get

$$E_K = h\nu - h\nu_0 \Rightarrow \frac{1}{2}mv^2 = h\nu - h\nu_0 \quad ...(iii)$$

This is another form of Einstein's photoelectric equation.

Q. 2.Give a brief description of the basic elementary process involved in the photoelectric emission in Einstein's picture.

When a photosensitive material is irradiated with the light of frequency v, the maximum speed of electrons is given by v_{max}. A plot of v_{2max} is found to vary with frequency v as shown in the figure.



Use Einstein's photoelectric equation to find the expressions for

(i) Planck's constant and

(ii) Work function of the given photosensitive material, in terms of the parameters l, n and mass m of the electron.

Ans.

a. Refer to Q. 1 above.

b. i. v_1^2 **and** v_2^2 are the velocities of the emitted electrons for radiations of frequencies $v_1 > v$ and $v_2 > v$ respectively. So,

$$h\nu_1 = h\nu + \frac{1}{2}\mathrm{mv}_1^2 \qquad \ldots(i)$$

and $$h\nu_2 = h\nu + \frac{1}{2}\mathrm{mv}_2^2 \qquad \ldots(ii)$$

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

$$h(\nu_2 - \nu_1) = \frac{1}{2}m(v_2^2 - v_1^2)$$

$$\therefore \qquad h = \frac{\frac{1}{2}m(v_2^2 - v_1^2)}{(\nu_2 - \nu_1)}$$

Slope of $v_{\max}^2$ vs frequency graph is

$$\tan\theta = \frac{v_2^2 - v_1^2}{(\nu_2 - \nu_1)}$$

$$\therefore \qquad h = \frac{1}{2}m \;.\; \tan\theta$$

From graph $\tan\theta = \frac{l}{n}$

So, $$h = \frac{1}{2}\; m\; \left(\frac{l}{n}\right) \qquad \ldots(iii)$$

ii. From graph, the work function of the material is

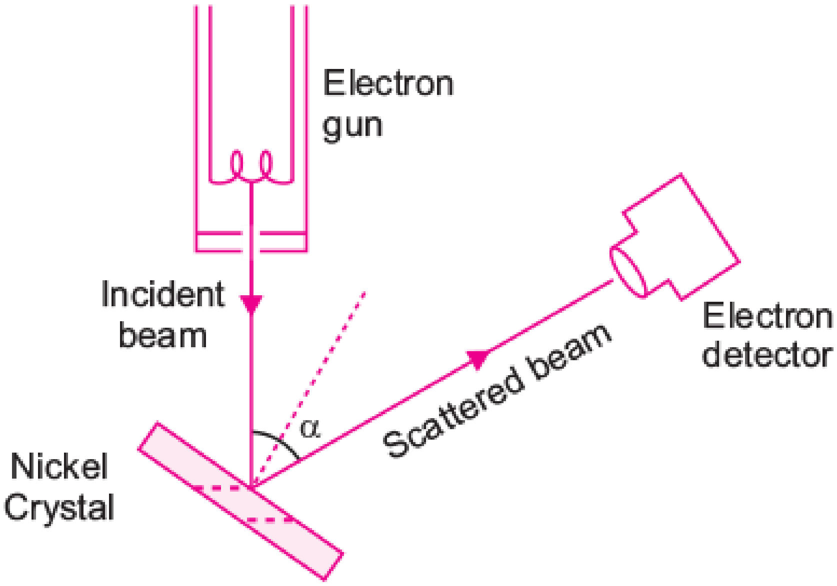
$$w = hn \qquad \ldots(iv)$$

From equations (iii) and (iv), we get

$$w = \frac{1}{2}m\left(\frac{l}{n}\right) \times n = \frac{1}{2}\mathrm{ml}$$

Q. 3. Describe Davisson and Germer’s experiment to demonstrate the wave nature of electrons. Draw a labelled diagram of apparatus used. [CBSE (F) 2014]

Ans. Davisson and Germer Experiment: In 1927 Davisson and Germer performed a diffraction experiment with electron beam in analogy with X-ray diffraction to observe the wave nature of matter.



Apparatus: It consists of three parts:

(i) Electron Gun: It gives a fine beam of electrons. de Broglie used electron beam of energy 54 eV. de Broglie wavelength associated with this beam

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

Here m = mass of electron = 9.1×10^{-31} kg

E_K = Kinetic energy of electron = 54 eV

$= 54 \times 1.6 \times 10^{-19}$ joule $= 86.4 \times 10^{-19}$ joule

$$\therefore \quad \lambda = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 86.4 \times 10^{-19}}}$$

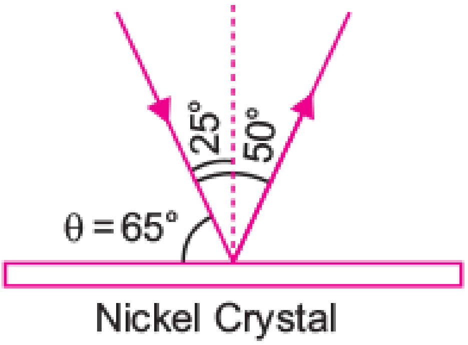
$= 1.66 \times 10^{-10}$ m $=$ **1.66 Å**

(i) Nickel Crystal: The electron beam was directed on nickel crystal against its (iii) face. The smallest separation between nickel atoms is 0.914 Å. Nickel crystal behaves as diffraction grating.

(ii) Electron Detector: It measures the intensity of electron beam diffracted from nickel crystal. It may be an ionisation chamber fitted with a sensitive galvanometer. The energy of electron beam, the angle of incidence of beam on nickel crystal and the position of detector can all be varied.

Method: The crystal is rotated in small steps to change the angle (α say) between incidence and scattered 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 α = 50°



∴ From Bragg's law

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

Here $n = 1$, $d = 0.914$ Å, $\theta = 65^\circ$

$$\therefore \qquad \lambda = \frac{2d\sin\theta}{n}$$

$$= \frac{2\times(0.914\ \mathring{A})\sin 65^\circ}{1}$$

$$= 2\times 0.914 \times 0.9063\ \mathring{A} = 1.65\ \mathring{A}$$

The measured wavelength is in close agreement with the estimated de Broglie wavelength. Thus the wave nature of electron is verified. Later on G.P. Thomson demonstrated the wave nature of fast electrons. Due to their work Davission and G.P. Thomson were awarded Nobel prize in 1937.

Later on experiments showed that **not only electrons but all material particles in motion (e.g., neutrons, α-particles, protons etc.) show wave nature.**