Date: 22/10/2021

Q1. Show the variation of photocurrent with collector plate potential for different intensities but same frequency of incident radiation.

Q2. Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation.

Q3. How does the maximum kinetic energy of electrons emitted vary with the work function of the metal?

Q4. Why no electron is emitted from a wooden table, when light from a bulb falls on it?

Q5. Red light, however bright it is, can't produce the emission of electrons from a clean zinc surface. But even weak ultraviolet radiation can do so. Why?

Q6. Show graphically how the maximum kinetic energy of electrons emitted from a photosensitive surface varies with the frequency of incident radiations?

Q7. (a) An X-ray tube produces a continuous spectrum of radiation with its short wavelength end at 0.66Å. What is the maximum energy of a photon in the radiation?

(b) From your answer to (a), guess what order of accelerating voltage (for electrons) is required in such a tube.

Q8. If a light wave of wavelength 4,950 Å is viewed as a continuous flow of photons, what is the energy of each photon in eV? Given that planck's constant, $h = 6.6 \times 10^{-34}$ J s, $c = 3 \times 10^8$ ms^{-1}.

Q9. Two monochromatic radiations, blue and violet, of the same intensity, are incident on a photosensitive surface and cause photoelectric emission. Would

(a) the number of electrons emitted per second and

(b) the maximum kinetic energy of the electrons, be equal in the two cases? Justify your answer.

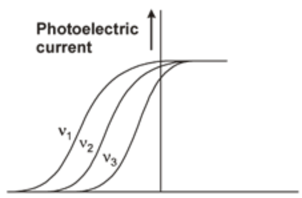
Q10. State the laws of photoelectric emission.

Q11. Draw suitable graphs to show the variation of photoelectric current with collector plate potential for

(a) a fixed frequency but different intensities, $I_1 > I_2 > I_3$.

(b) a fixed intensity but different frequencies, $\nu_1 > \nu_2 > \nu_3$.

Q12. The given graph shows variation of photoelectric current with collector plate potential for different frequencies of incident radiation.



(a) Which physical parameter is kept constant for the three curves?

(b) Which frequency (ν_1, ν_2 or ν_3) is the highest?

Q13. Plot a graph showing variation of stopping potential (V_0) with the frequency (ν) of the incident radiation for a given photosensitive material. Hence, state the significance of the threshold frequency in photoelectric emission.

Using the principle of energy conservation, write the equation relating the energy of incident photon, threshold frequency and the maximum kinetic energy of the emitted photoelectrons.

Q14. Calculate the energy of a photon, whose (a) frequency is 1,000 kHz, (b) wavelength is 5.890 Å, (c) wavelength is 1Å. Also express the energy of the photon in eV in each case. Given, 1 $eV = 1.6 \times 10^{-19}$ J, $h = 6.62 \times 10^{-34}$ J s and $c = 3 \times 10^8$ m s^{-1}.

Q15. (a) Determine the de-Broglie wavelength of a proton whose kinetic energy is equal to the rest mass energy of an electron. Mass of a proton 1836 times that of electron.

(b) In which region of electromagnetic spectrum does this wavelength lie?

Q16. Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Explain briefly how the de-Broglie relation was experimentally verified in case of electrons?

Q17. An electron and a proton are accelerated through the same potential. Which one of the two has (a) greater value of de-Broglie wavelength associate with it and (b) less momentum? Justify your answer.

Q18. An electron, an α-particle and a proton have the same de-Broglie wavelengths. Which of these particle has

(a) minimum kinetic energy,

(b) maximum kinetic energy and why? In what way has the wave nature of electron been exploited in electron microscope?

Q19. (a) Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electron.

(b) Express the de-Broglie wavelength associated with electrons in terms of the accelerating voltage V.

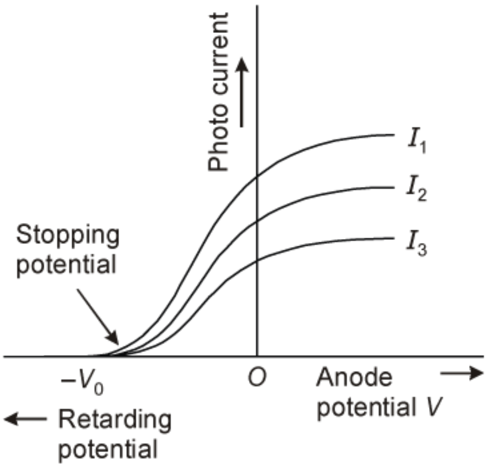
(c) An electron and a proton have the same kinetic energy. Which of the two will have larger wavelength and why?

Q20. (a) A particle is moving three times as far as an electron. The ratio of the de-Broglie wavelength of the particle to that of the electron is 1.813×10^{-4}. Calculate the particle's mass and identify the particle.

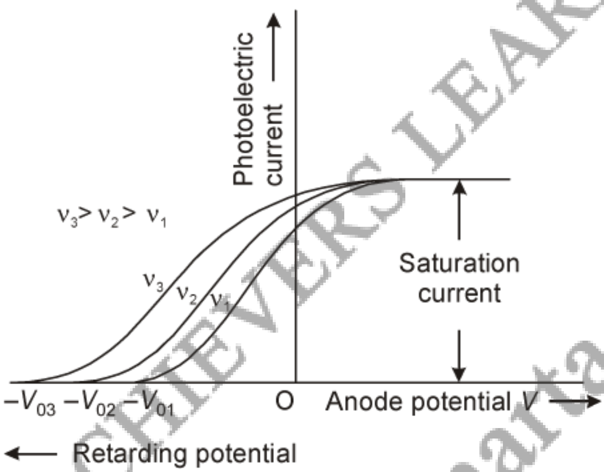
(b) An electron and a proton have the same kinetic energy. Which of the two will have larger de-Broglie wavelength? Give reason.

Date: 22/10/2021

S1. The variation of photocurrent with collector plate potential for different intensities at constant frequency is shown below.



S2. The variation of photocurrent with the collector plate potential for different plate frequencies is shown below.

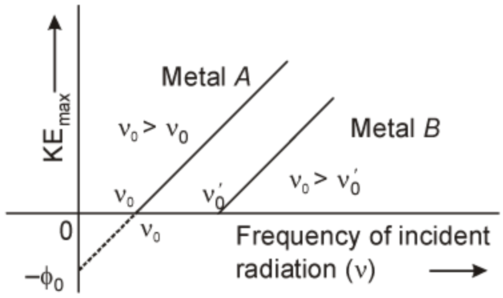


S3. The maximum kinetic energy of emitted electrons decreases, as the work function of the metal increases.

S4. The work function of wood is very large as compared to the energy possessed by visible light.

S5. It is because, the frequency of red light is less than the threshold frequency for zinc surface, while that of ultraviolet radiation is greater than the threshold frequency.

S6. The variation of maximum kinetic energy with frequencies of incident radiation is shown below.



S7. Given, $\lambda = 0.66$ Å $= 0.66 \times 10^{-10}$ m

$h = 6.62 \times 10^{-34}$ Js and $c = 3 \times 10^8$ m s^{-1}

(a) The maximum energy of photon is

$$E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{0.66 \times 10^{-10}}$$

$$= 3.01 \times 10^{-15} \text{ J}$$

$$= \frac{3.01 \times 10^{-15}}{1.6 \times 10^{-19}} = 18812.5 \text{ eV or } 18.81 \text{ KeV}$$

(b) To produce electrons of energy 18.81 KeV, accelerating potential of 18.81 kV *i.e.*, of the order of 20 kV is required

S8. Given, $h = 6.6 \times 10^{-34}$ J s ; c $= 3 \times 10^8$ m s^{-1}

and $\lambda = 4,950$ Å $= 4{,}950 \times 10^{-10}$ m

Energy of photon, E is given by,

We know, $E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4{,}950 \times 10^{-10}} = 4.0 \times 10^{-19}$ J [setting the value in equation]

$$= \frac{4.0 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV}$$

$= \textbf{2.5 eV}$

S9. The intensities for both the monochromatic radiation are same but their frequencies are different. It represents

(a) The number of elements (photo) ejected in two cases are same because it depends on number of incident photons.

(b) As, KE$_{max} = h\nu - \phi_0$

[Einstein photo electric current]

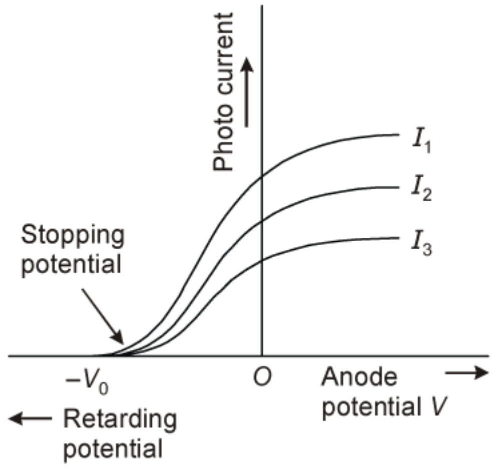
The KE$_{max}$ of violet radiation will be more.

S10. (a) The emission of photoelectrons takes place only when the frequency of the incident radiation is above a certain value, characteristic of that metal.

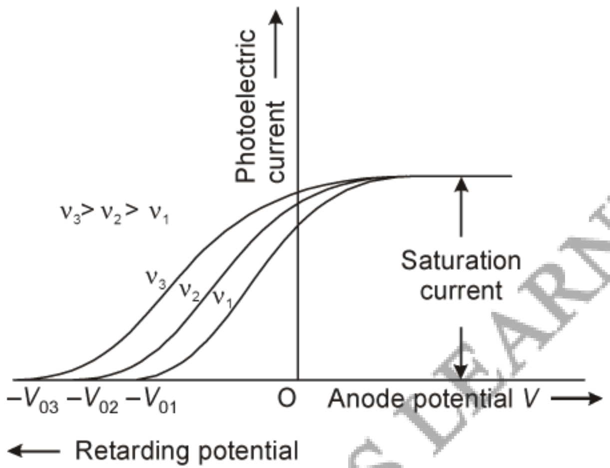
(b) The emission of photoelectrons starts as soon as light falls on metal surface.

(c) The number of photoelectrons emitted (photoelectric current) from a metal surface depends only on the intensity of the incident light and is independent of its frequency.

S11. (a)



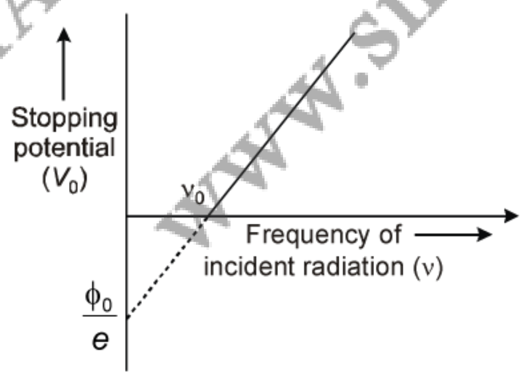
(b)



S12. (a) According to laws of photoelectric emission, the photoelectric current depends on the intensity of incident light. The constant saturation value of photoelectric current reveals that intensity of incident light is constant.

(b) Frequency ν_1 is the highest among ν_1, ν_2 and ν_3 because higher the cut-off potential, higher will be the frequency of incident light.

S13.



The graph showing the variation of stopping potential with the frequency is shown below.

ϕ_0 = Work-function of photosensitive material

e = Electronic charge

From Einstein's photo electric equation

$$(K.E.)_{max} = h\nu - h\nu_0 = h(\nu - \nu_0)$$

where, ν = frequency of incident radiation,

ν_0 = threshold frequency

From the equation, if $\nu < \nu_0$ then $(K.E.)_{max}$ is negative, which is not possible. For a given material, there exists a certain minimum frequency of the incident radiation below which no emission of photoelectrons take place, this is called threshold frequency i.e., photoelectric effect will take place only when $\nu > \nu_0$.

S14. The energy of a photon is given by

$$E = h\nu = \frac{hc}{\lambda}, \qquad \text{where } c \text{ is velocity of light.}$$

Here, $h = 6.62 \times 10^{-34}$ J s; $c = 3 \times 10^8$ m s^{-1};

$1\ eV = 1.6 \times 10^{-19}$ J;

(a) When $\nu = 1{,}000$ kHz $= 10^6$ Hz :

$\therefore$ $E = h\nu = 6.62 \times 10^{-34} \times 10^6 = \mathbf{6.62 \times 10^{-28}}$ **J**

$$= \frac{6.62 \times 10^{-28}}{1.6 \times 10^{-19}} = \mathbf{4.14 \times 10^{-9}\ eV}$$

(b) When $\lambda = 5{,}890$ Å $= 5{,}890 \times 10^{-10}$ m:

$$\therefore \quad E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{5{,}890 \times 10^{-10}}$$

$= \mathbf{3.37 \times 10^{-19}}$ **J**

$$= \frac{3.37 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.11\ eV$$

(c) When $\lambda = 1$Å $= 10^{-10}$ m

$$E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{10^{-10}}$$

$= \mathbf{1.99 \times 10^{-16}\ J}$

$$= \frac{1.99 \times 10^{-16}}{1.6 \times 10^{-19}} = 1243.8 \text{ eV}$$

S15. Rest mass energy of a particle can be calculated using Einstein's mass energy equivalence.

(a) de-Broglie matter wave equation is given by

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

$\because$ $p = \sqrt{2mK}$

where, m = mass of proton,

K = kinetic energy of proton.

According to the question, kinetic energy of proton,

$K = m_e c^2$

(Einstein's mass-energy relation)

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2m(m_e c^2)}}$$

$$\lambda = \frac{h}{c\sqrt{2m \cdot m_e}}$$

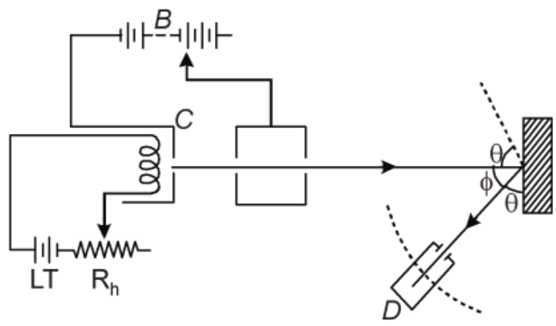
or $$\lambda = \frac{h}{c\sqrt{2 \times 1836 \times m_e \times m_e}} \quad (\because m = 1836 m_e)$$

$$\lambda = \frac{6.63 \times 10^{-34}}{1.414 \times (3 \times 10^8) \times 9.1 \times 10^{-31} \times 42.8}$$

$$\lambda = 4 \times 10^{-14} \text{ m}$$

(b) This region of electromagnetic spectrum is X-ray.

S16. The accelerated electron beam strikes to nickel crystal and get scattered in different directions. The intensity of scattered electron beam can be obtained by an electron detector.



It was found experimentally that sharp peak of intensity of electron beam is obtained at 54 V accelerating potential and 50° scattering angle. By geometry, angle of glancing θ is

$$\theta + \phi + \theta = 180°$$

$$2\theta = 180° - \phi$$

$$= 180 - 50$$
$$= 130°$$

$\Rightarrow$ $\theta = 65°$

For nickel crystal, $d = 0.91$ Å

By Bragg's law,

$$2d \sin\theta = 1 \times \lambda$$

For 1st diffraction maximum

$$\lambda = 2 \times 0.91 \times 10^{-10} \times \sin 65°$$

$$\lambda = 1.65 \text{ Å} \quad \text{... (i)}$$

But by de-Broglie equation

$$\lambda = \frac{12.27}{\sqrt{V}} \text{ Å} = \frac{12.27}{\sqrt{54}} = 1.66 \text{ Å} \quad \text{... (ii)}$$

Eqs (i) and (ii) are very close to each other. This explains that sharp peak due to the constructive interference of electron beam reflected by different layer of atom of crystal. Hence, waves nature of accelerated electron beam established experimentally by Davisson and Germer.

S17. (a) From de-Broglie equation

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

as, $p = \sqrt{2mK}$ and $k = qV$

$\Rightarrow$ $$\lambda = \frac{h}{\sqrt{2mqV}} \quad \text{... (i)}$$

where, signs are as usual for given accelerating potential.

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

Ratio of wavelength of electron and proton.

$$\frac{\lambda_e}{\lambda_p} = \sqrt{\left(\frac{m_p}{m_e}\right)\left(\frac{q_p}{q_e}\right)}$$

$\because$ Ratio of mass of proton and electron

$$\frac{m_p}{m_e} = 1836 \qquad \text{(constant)}$$

$$\frac{q_p}{q_e} = 1$$

(Both electron and proton have same charge)

$\Rightarrow$ $$\frac{\lambda_e}{\lambda_p} = \sqrt{1836 \times 1}$$

$$\lambda_e \approx 42.8\lambda_p \text{ nearly}$$

Electron have greater wavelength associated with it than that of proton.

(b) $\because$ $$\lambda = \frac{h}{p} \qquad \text{(de-Broglie equation)}$$

$\Rightarrow$ $$p = \frac{h}{\lambda}$$

$\Rightarrow$ $$p \propto \frac{1}{\lambda}$$

$\Rightarrow$ $$\frac{p_e}{p_p} = \frac{\lambda_p}{\lambda_e}$$

But from Eq (i)

$$\frac{\lambda_p}{\lambda_e} = \frac{1}{42.8}$$

$\Rightarrow$ $$\frac{p_e}{p_p} = \frac{\lambda_p}{\lambda_e} = \frac{1}{42.8}$$

Momentum of proton is nearly 42.8 times to that of momentum of electron.

S18. de-Broglie equation

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} \qquad \left(\because\ K = \frac{p^2}{2m}\right)$$

where, K is kinetic energy and m is mass of particle.

$$K = \frac{h^2}{2m\lambda^2} \qquad \text{(for same wavelength)}$$

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

$$\Rightarrow \qquad K_e : K_\alpha : K_p = \frac{1}{m_e} : \frac{1}{m_\alpha} : \frac{1}{m_p}$$

where m_e, m_p and m_α are masses of electron, proton and α-particle respectively.

Also, K_e, K_α and K_p are their respective kinetic energies.

$\because \qquad m_\alpha > m_p > m_e$

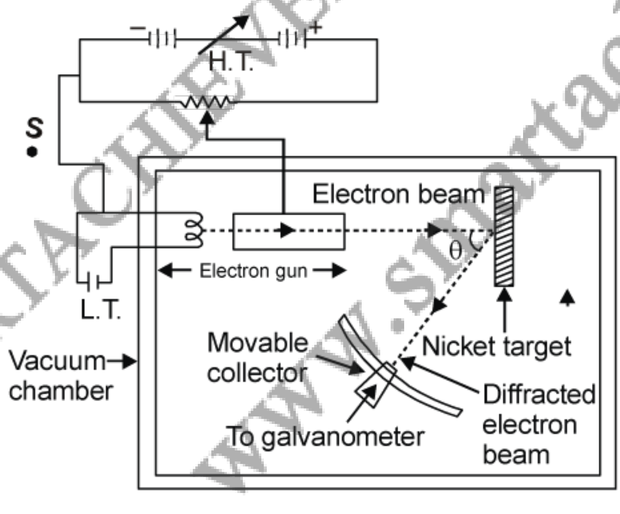
$\Rightarrow \qquad K_e > K_p > K_\alpha$

(a) α-particle posses minimum KE.

(b) Electron has maximum KE.

The magnifying power of an electron microscope is inversely related to wavelength of radiation used. Smaller wavelength of electron beam in comparison to visible light increases the magnifying power of microscope.

S19. (a)



(b) de-Broglie wavelength

$$\lambda = \frac{h}{\sqrt{2meV}} = \frac{12.27}{\sqrt{V}}$$

(c) Also, $\lambda = \frac{h}{\sqrt{2mK}}$

$\Rightarrow$ wavelength of the electron will larger because its mass is smaller.

S20. Given $v_{particle} = 3\ v_{electron}$ ... (i)

and $\lambda_{particle} = 1.813 \times 10^{-4}\ \lambda_{electron}$

(a) As $\lambda = \frac{h}{mv}$ (de-Broglie equation)

$$\Rightarrow \quad \frac{m_{particle}}{m_{electron}} = \frac{\lambda_{electron} \times v_{electron}}{\lambda_{particle} \times v_{particle}}$$

$\therefore$ $m_{particle} = 1839\ m_{electron}$ [From Eq. (i)]

$m_{particle} = 1839 \times 9.1 \times 10^{-31}$

$= 1.673 \times 10^{-27}$ kg

Particle is either a proton or a neutron.

(b) Now, $\lambda = \frac{h}{\sqrt{2mk}}$

Therefore, it is clear that de broglie wavelength of electron is more than that of proton or neutron.

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Q1. Two metals *A* and *B* have work functions 2 eV and 4 eV respectively. Which metal has a lower threshold wavelength for photoelectric effect?

Q2. Calculate the threshold frequency of photon for photoelectric emission from a metal of work function 0.1 eV.

Q3. Work function for a photosensitive surface of material is 3.3×10^{-19} J. What is its threshold frequency.

Q4. Define the term work function for photoelectric effect.

Q5. Define threshold wavelength for photoelectric effect.

Q6. What is photoelectric effect?

Q7. Define the term 'stopping potential' in relation to photoelectric effect.

Q8. The stopping potential in an experiment on photoelectric effect is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted?

Q9. If the intensity of incident radiation in a photocell is increased, how does the stopping potential vary?

Q10. Define 'intensity' of radiation in photon picture of light.

Q11. The photoelectric cut-off voltage in a certain experiment is 1.5 V. What is the maximum kinetic energy of photoelectrons emitted?

Q12. Light of wavelength 3, 500 Å is incident on two metals A and B. Which metal will yield photoelectrons, if their work functions are 4.2 eV and 1.9 eV respectively?

Q13. Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. (a) What is the energy of a photon in the light beam? (b) How many photons per second, on an average, are emitted by the source?

Q14. The energy flux of sunlight reaching the surface of the Earth is 1.388×10^3 W/m^2. How many photons (nearly) per square metre are incident on the Earth per second? Assume that the photons in the sunlight have an average wavelength of 550 nm.

Q15. In an experiment on photoelectric effect, the slope of the cut-off voltage versus frequency of incident light is found to be 4.12×10^{-15} Vs. Calculate the value of Planck's constant.

Q16. What is the effect of (a) intensity and (b) frequency of incident light on photoelectric current? Explain.

Q17. Define photoelectric effect and threshold frequency

Q18. In the photoelectric effect, there is a cut-off frequency. How does the photon picture explain this fact?

Q19. If radiation of wavelength 5,000 Å is incident on a surface of work function 1.2 eV, find the value of stopping potential.

Q20. Calculate the maximum kinetic energy of electrons emitted from a photosensitive surface of work function 3.2 eV, for the incident radiation of wavelength 300 nm.

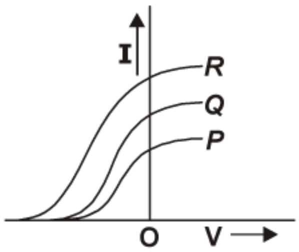
Q21. A source of light is placed at a distance of 50 cm from a photocell and the cut of potential is found to be V_0. If the distance between the light source and photocell is made 25 cm, what will be the new cut off potential? Justify your answer.

Q22. Draw suitable graphs to show the variation of photoelectric current with collector plate potential for

(a) a fixed frequency but different intensities $L_1 > L_2 > L_3$ of radiation.

(b) a fixed intensity but different frequencies $\nu_1 > \nu_2 > \nu_3$ of radiation.

Q23. Figure show a plot of three curves *P*, *Q* and *R* showing the variation of photocurrent (I) versus collector plate potential (V) for three different intensities I_1, I_2 and I_3 having frequency ν_1, ν_2 and ν_3 respectively incident on a photosensitive surface.



Point out the two curves for which the incident radiations have same frequency but different intensities.

Q24. Figure shows variation of stopping potential (V_0) with the frequency (ν) for two photosensitive materials M_1 and M_2.

(a) Why is the slope same for both lines?

(b) For which material will the emitted electrons have greater kinetic energy for the incident radiation of the same frequency? Justify your answer.

Q25. State Einstein's photoelectric equation and explain the terms involved.

Q26. Is it essential that each incident photon should eject a photoelectron? Explain.

Q27. Two metals *X* and *Y* have work functions 2 eV and 5 eV respectively. Which metal will emit electrons, when irradiated with light of wavelength 400 nm and Why?

Q28. Define the terms threshold frequency' and stopping potential' for photo-electric effect. Show graphically how the stopping potential for a given metal varies with frequency of the incident radiations. Mark threshold frequency on this graph.

Q29. Plot a graph showing the variation of stopping potential (V_0) with the frequency (ν) of the incident radiation for a given photosensitive material. Hence state the significance of the threshold frequency in photoelectric emission.

Q30. The threshold frequency of metal is ν_0. When the light of frequency $2\nu_0$ is incident on the metal plate, the maximum velocity of electrons is v_1. when the frequency of incident radiation is increased to 5 ν_0, the maximum velocity of electron emitted is v_2. Find the ratio of v_1 to v_2.

Q31. A metal has a work function of 2.0 eV. It is illuminated by monochromatic light of wavelength 500 nm. Calculate: (a) the threshold wavelength, (b) the maximum energy of photoelectrons, (c) the stopping potential. Given, Planck's constant, $h = 6.6 \times 10^{-34}$ J s, charge on electron, $e = 1.6 \times 10^{-19}$ C and 1 eV = 1.6×10^{-19} J.

Q32. Define the term: (a) work function, (b) threshold frequency and (c) stopping potential with reference to photoelectric effect.

Q33. The work function of caesium metal is 2.14 eV. When light of frequency 6×10^{14} Hz is incident on the metal surface, photoemission of electrons occurs. What is the

(a) maximum kinetic energy of the emitted electrons,

(b) stopping potential, and

(c) maximum speed of the emitted photoelectrons?

Q34. When light of wavelength 250 nm is incident on the cathode of a photocell, the stopping potential recorded is 4 V. If the wavelength of the incident light is increased to 300 nm, calculate the new stopping potential.

Q35 Light of wavelength 2,000 Å falls on an aluminium surface. In aluminium 4.2 eV are required to remove an electron. What is the kinetic energy in eV of (a) the fastest, (b) the slowest emitted photoelectrons? What is (c) the stopping potential (d) cut off wavelength for aluminium? Given, Planck's constant, $h = 6.6 \times 10^{-34}$ Js, $c = 3 \times 10^{8}$ m s^{-1}.

Q36. Find the frequency of light, which ejects electrons from a metal surface and such ejected electrons are fully stopped by retarding potential of 3 eV. The photoelectric effect begins in this metal at threshold frequency of 6×10^{14} s^{-1}. Find out $c = 3 \times 10^{8}$ m s^{-1} and $e = 1.6 \times 10^{-19}$ C.

Q37. Light of wavelength 5, 500Å falls on a sensitive plate with work function 1.7 eV. Find (a) energy of photon, (b) energy of photoelectron and (c) stopping potential.

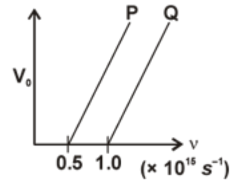
Q38. Define the term (a) 'cut-off voltage' and (b) threshold frequency, in relation to the phenomenon of photoelectric effect.

Q39. Find the de-Broglie wavelength of the wave associated with an atom in helium gas at a temperature of 27°C and pressure of 1 atm.
Compare the de-Broglie wavelength of the He-atom with mean separation d between the two atoms under these conditions.

Q40. Find the frequency of light, which ejects electrons from a metal surface fully stopped by a retarding potential of 3 V. The photoelectric effect begins in the metal at frequency of 6×10^{14} s^{-1}. Find the work function of this metal.

Q41. An electron and a proton are accelerated through the same potential. Which on of the two has (a) greater value of de Broglie wavelength associated with it and (b) less momentum? Justify your answer.

Q42. The following graph shows the variation of stopping potential V_0 with the frequency ν of the incident radiation for two photosensitive metals *P* and *Q*:

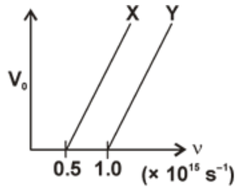


(a) Explain which metal has smaller threshold wavelength.

(b) Explain giving reason, which metal emits photo-electrons having smaller kinetic energy

(c) If the distance between the light source and metal *P* is doubled, how will the stopping potential change?

Q43. The following graph shows the variation of stopping potential V_0 with the frequency ν of the incident radiation for two photosensitive metal X and Y:



(a) Which of the metals has larger threshold wavelength? Give reason.

(b) Explain, giving reason, which metal gives out electron, having larger kinetic energy, for the same wavelength of the incident radiation.

(c) If the distance between the light source and metal X is halved, how will the kinetic energy of electrons emitted from it change ? Give reason.

Q44. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have the de Broglie wavelength λ_1, prove that $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$.

Q45. (a) Why photoelectric effect cannot be explained on the basis of wave nature of light? give reasons.

(b) Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based.

Q46. Define the term:

(a) (i) Work function, (ii) threshold frequency and (iii) stopping potential, with reference to photoelectric effect.

(b) Calculate the maximum kinetic energy of electrons emitted from a photosensitive surface of work function 3.2 eV, for the incident radiation of wavelength 300 nm.

Q47. Explain the term: ' stopping potential' and 'threshold frequency' in photoelectric emission. Draw a graph showing the variation of stopping potential with frequency of incident light in relation to photoelectric effect. Deduce an expression for the slope of this graph using Einstein's photoelectric equation.

Q48. Draw the graphs showing the variation of photoelectric current with anode potential of a photocell for (a) the same frequencies but different intensities $I_1 > I_2 > I_3$ of incident radiation, (b) the same intensity but different frequencies $\nu_1 > \nu_2 > \nu_3$ of incident radiation. Explain why the saturation current is independent of the anode potential.

Q49. A proton and an alpha particle are accelerated through the same potential. Which of the two has

(a) greater value of deBroglie wavelength associated with it and

(b) less kinetic energy?

Justify your answers.

Q50. An electron and a photon each have a wavelength 1.00 nm. Find
(a) their momenta, (b) the energy of the photon and (c) the kinetic energy of electron.

Q51. Write two characteristic features observed in photoelectric effect which supports the photon pictures of electromagnetic radiation. Draw a graph between the frequency of incident radiation (ν) and the maximum kinetic energy of the electrons emitted from the surface of photosensitive material State clearly how this graph can be used to determine (a) Planck's constant and (b) work function of the material?

Q52. Write Einstein's photoelectic equation and point out any two characteristic properties of photons on which this equation is based.
Briefly explain the three observed features which can be explained by this equation.

Date: 22/10/2021

S1. We know,

$$\phi_0 = \frac{hc}{\lambda_0} \quad \text{or} \quad \lambda_0 \propto \frac{1}{\phi_0}$$

It follows that for the metal *B*, which has greater value of work function *i.e.*, 4 eV, the threshold wavelength will be lower.

S2. Given, $\phi_0 = 0.1\,\text{eV} = 0.1 \times 1.6 \times 10^{-19} = 1.6 \times 10^{-20}\,\text{J}$

Therefore, threshold frequency,

$$\nu_0 = \frac{\phi_0}{h} = \frac{1.6 \times 10^{-20}}{6.62 \times 10^{-34}} = \mathbf{2.417 \times 10^{13}\,Hz}.$$

S3. Given, $\phi_0 = 3.3 \times 10^{-19}$; $h = 6.6 \times 10^{-34}$ J s

We know, threshold frequency,

$$\nu_0 = \frac{\phi_0}{h} = \frac{3.3 \times 10^{-19}}{6.6 \times 10^{-34}} = \mathbf{5 \times 10^{14}\,Hz}.$$

S4. The minimum amount of energy required to eject an electron from a surface (without imparting any kinetic energy) is called work function of the surface.

S5. The maximum wavelength of incident light for a metal surface, above which the incident light can't eject electrons from metal surface, is called threshold wavelength for that metal surface.

S6. The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls upon it, is known as the photoelectric effect.

S7. In experimental set up of photoelectric effect, the value of negative potential of anode at which photoelectric current in the circuit reduces to zero is called stopping potential or cut-off potential for the given frequency of the incident radiation.

S8. We know that at stopping potential no electron reaches the plate *i.e.*, energy of electrons is compensated by energy equivalent to stopping potential.

$$\text{K.E.}_{max} = eV_0$$

where, V_0 = cut-off potential

$$\text{K.E.}_{max} = 1.5\,\text{eV}.$$

S9. There is no effect on stopping potential.

S10. The intensity of radiation in photon picture of light defined as, the photon incident on unit area of a surface, in unit time.

S11. Photoelectric cut-off voltage, $V_0 = 1.5\,\text{V}$

The maximum kinetic energy of the emitted photoelectrons is given as:

$$K_e = eV_0$$

Where, e = Charge on an electron = $1.6 \times 10^{-19}\,\text{C}$

$\therefore$ $K_e = 1.6 \times 10^{-19} \times 1.5$

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

Therefore, the maximum kinetic energy of the photoelectrons emitted in the given experiment is $2.4 \times 10^{-19}\,\text{J}$.

S12. Given, $\lambda = 3{,}500\,\text{Å} = 3{,}500 \times 10^{-10}\,\text{m}$

The energy of the photon of incident light E is given by

$$E = \text{h}\nu = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{3{,}500 \times 10^{-10}} = 5.67 \times 10^{-19}\,\text{J} \qquad \left(\because \ \nu = \frac{c}{\lambda}\right)$$

$$= \frac{5.67 \times 10^{-19}}{1.6 \times 10^{-19}}\,\text{eV}$$

$$= \mathbf{3.543\ eV}.$$

The incident light will eject electrons from a metal surface if its energy is greater than the work function of that metal. Accordingly, metal B will yield photoelectrons.

S13. (a) Each photon has an energy

$$E = h\nu = (6.63 \times 10^{-34}\,\text{J s})(6.0 \times 10^{14}\,\text{Hz})$$
$$= 3.98 \times 10^{-19}\,\text{J}$$

(b) If N is the number of photons emitted by the source per second, the power P transmitted in the beam equals N times the energy per photon E, so that $P = NE$. Then

$$N = \frac{P}{E} = \frac{2.0 \times 10^{-3}\,\text{W}}{3.98 \times 10^{-19}\,\text{J}}$$
$$= 5.0 \times 10^{15} \text{ photons per second.}$$

S14. Energy flux of sunlight reaching the surface of Earth,

$$\Phi = 1.388 \times 103\,\text{W/m}^2$$

Hence, power of sunlight per square metre,

$$P = 1.388 \times 10^3 \text{ W}$$

Speed of light, $c = 3 \times 10^8$ m/s

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Average wavelength of photons present in sunlight,

$$\lambda = 550 \text{ nm} = 550 \times 10^{-9} \text{ m}$$

Number of photons per square metre incident on earth per second = n

Hence, the equation for power can be written as:

$$P = nE$$

$$\therefore \quad n = \frac{P}{E} = \frac{P\lambda}{hc}$$

$$= \frac{1.388 \times 10^3 \times 550 \times 10^{-9}}{6.626 \times 10^{-34} \times 3 \times 10^8}$$

$$= 3.84 \times 10^{21} \text{ photons/m}^2\text{/s}$$

Therefore, every second, 3.84×10^{21} photons are incident per square metre on Earth.

S15. The slope of the cut-off voltage (V) versus frequency (ν) of an incident light is given as:

$$\frac{V}{\nu} = 4.12 \times 10^{-15} \text{ Vs}$$

V is related to frequency by the equation:

$$h\nu = eV$$

Where, e = Charge on an electron

$= 1.6 \times 10^{-19}$ C

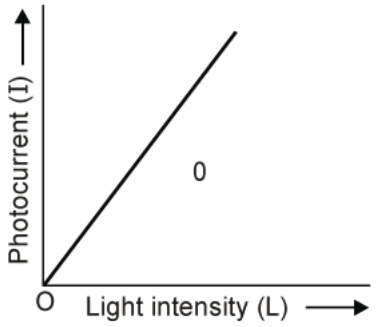
h = Planck's constant

$$\therefore \quad h = e \times \frac{V}{\nu}$$

$$= 1.6 \times 10^{-19} \times 4.12 \times 10^{-15} = 6.592 \times 10^{-34} \text{ Js}$$

Therefore, the value of Planck's constant is 6.592×10^{-34} Js.

S16. The number of photoelectrons emitted (photoelectric current) from a metal surface depends only on the intensity of the incident light and is independent of its frequency.



S17. **Photoelectric effect:** The phenomenon of ejection of electrons from a metal surface, when light of sufficiently high frequency falls upon it, is known as the photoelectric effect.

Threshold frequency: The emission of photoelectrons takes place only when the frequency of the incident radiation is above a certain value, characteristic of that metal. The critical value of frequency is known as the threshold frequency for the metal used to make the emitter.

S18. To eject an electron from a metal surface, a minimum amount of energy, called the work function of the metal, is required. Classically, if incident radiation is a wave its energy is shared by all the atoms in the metal surface and calculations show that it will take almost a year, when the requisite amount of energy may be accumulated by an electron. Hence, on classical picture, the photoelectric emission cannot be instantaneous.

When the incident radiation is assumed to be consisting of photons, a photon of frequency ν_0 or more can possess the energy needed to eject an electron. If frequency of incident photon is less than ν_0, no photoelectric emission will take place. In a way, ν_0 is a cut-off frequency. As said earlier, the photo-electric emission will take place only, if the frequency of incident photon is equal to or greater than ν_0, the threshold frequency.

S19. Here, work function,

$$\phi_0 = 1.2 \text{ eV} = 1.2 \times 1.6 \times 10^{-19} = 1.92 \times 10^{-19} \text{J}$$

Wavelength of the incident radiation,

$$\lambda = 5{,}000 \text{ Å} = 5{,}000 \times 10^{-10} \text{m}$$

If photoelectrons are emitted with maximum velocity v_{max}, then

$$\frac{1}{2}mv_{max}^2 = h\nu - \phi_0 = \frac{hc}{\lambda} - \phi_0$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{5{,}000 \times 10^{-10}} - 1.92 \times 10^{-19}$$

$$= 3.97 \times 10^{-19} - 1.92 \times 10^{-19} = 2.05 \times 10^{-19} \text{J}$$

If e is the charge on electron and V_0 is the stopping potential, than

$$eV_0 = \frac{1}{2} m v_{max}^2 = 2.05 \times 10^{-19}$$

or $$V_0 = \frac{2.05 \times 10^{-19}}{e} = \frac{2.05 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{1.28\ V}$$

S20. Here, work function,

$$\phi_0 = 3.2\ eV = 3.2 \times 1.6 \times 10^{-19} = 5.12 \times 10^{-19}\ J$$

Wavelength of the incident radiation,

$$\lambda = 300\ nm = 3 \times 10^{-7}\ m$$

The maximum kinetic energy of the emitted electrons,

$$\frac{1}{2} m v_{max}^2 = h\nu - \phi_0 = \frac{hc}{\lambda} - \phi_0$$

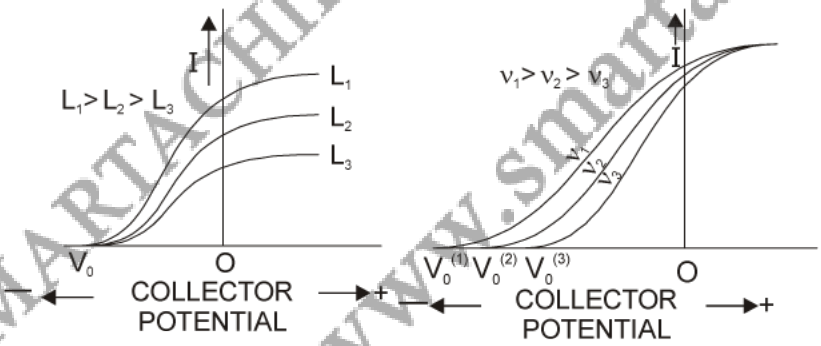
$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{3 \times 10^{-7}} - 5.12 \times 10^{-19}$$

$$= 6.62 \times 10^{-19} - 5.12 \times 10^{-19} = 1.5 \times 10^{-19}\ J$$

$$= \frac{1.5 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{0.9375\ eV}.$$

S21. On decreasing the distance of the source of light from the photocell from 50 cm to 25 cm, the intensity of light on the maximum kinetic energy of emitted photo-electrons, the stopping potential will remain *the same i.e.* V_0.

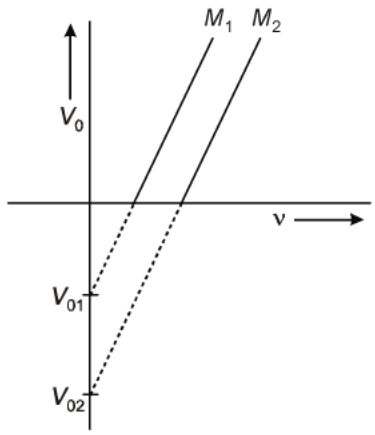
S22. (a) The variation of photoelectric current with collector plate potential for fixed frequency but different intensities $L_1 > L_2 > L_3$ of radiation is as shown in figure.



(b) The variation of photoelectric current with collector plate potential for a fixed intensity but different frequencies $v_1 > v_2 > v_3$ of radiation is as shown in figure.

S23. The curves *P* and *Q* correspond to the incident radiations having same frequency but different intensities.

S24. The slope of a straight line graph is equal to the ratio of value on *Y*-axis to *X*-axis.



(a) Slope of stopping potential with frequency of incident radiation gives the value of Planck's constant, this is the reason why the slope is same for both lines.

(b) The intercept of graph on stopping potential gives the value of stopping potential, which is higher for M_2.

So, for the photoelectrons to be emitted from material M_2, kinetic energy will also be higher.

S25. Einstein's photoelectric equation:

$$h\nu = h\nu_0 + \frac{1}{2}m v_{max}^2$$

Here, ν is frequency of the incident light, ν_0 is threshold frequency and v_{max} is the maximum velocity with which photoelectrons emitted.

S26. The photoelectric emission takes place, when the incident photon is absorbed by the electron in the atom. The energy equal to work function of metal is used up in ejecting the photoelectron and the difference appears as the kinetic energy of the electron. Since one photon can be absorbed by one electron, a photon can eject only one electron.

S27. Here, λ = 400 nm = 400 × 10^{-9} m

Therefore, energy of photon,

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

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{400 \times 10^{-9}} = 4.965 \times 10^{-19}\,\text{J}$$

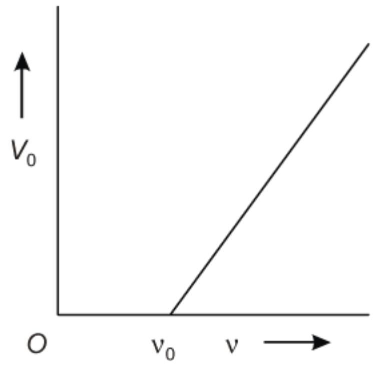
$$= \frac{4.965 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.1\,\text{eV}$$

Since work function of metal *X* is less than the energy of the incident light, photoelectrons will be emitted by this metal only.

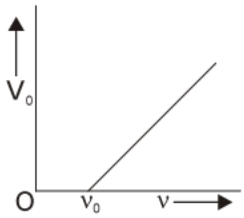
S28. **Threshold frequency:** The emission of photoelectrons takes place only when the frequency of the incident radiation is a certain critical value, characteristic of the metal. The critical value of frequency is known as the ***threshold frequency***.

Stopping potential: The value of negative potential of the collector, corresponding to which even the fatest photoelectrons are repelled back, is called ***stopping potential***.

The stopping potential increases with increase in frequency of the incident light.



S29. The graph between frequency of incident radiation and stopping potential is



The graph tells that the emission of photoelectrons does not take place, till the frequency of the incident light is above the threshold frequency (ν_0) for the metal.

S30. According to Einstein's photoelectric equation,

$$h\nu = h\,\nu_0 + \frac{1}{2}m\,v_{max}^2 \quad \text{... (i)}$$

When incident light is of frequency 2 ν_0:

Here, $\nu = 2\nu_0$ and $v_{max} = v_1$

Therefore, the equation (i) becomes

$$h(2\nu_0) = h\,\nu_0 + \frac{1}{2}m\,v_1^2$$

or $$\frac{1}{2}mv_1^{\,2} = h\,\nu_0$$

or $$v_1 = \sqrt{\frac{2\,h\nu_0}{m}} \quad \text{... (ii)}$$

When incident light it of frequency 5 ν_0:

Here, $\nu = 5\nu_0$ and $v_{max} = v_2$

Therefore, the equation (ii) becomes

$$h\,(5\,\nu_0) = h\,\nu_0 + \frac{1}{2}\,mv_2^2$$

or $\frac{1}{2}mv_2^{\ 2} = 4\,h\,\nu_0$

or $v_2 = \sqrt{\frac{8\,h\nu_0}{m}}$ ... (iii)

Dividing the equation (ii) by (iii), we have

$$\frac{v_1}{v_2} = \sqrt{\frac{2\,h\,\nu_0/m}{8\,h\,\nu_0/m}} = \frac{\mathbf{1}}{\mathbf{2}}$$

S31. Here, $h = 6.6 \times 10^{-34}$ J s ; $e = 1.6 \times 10^{-19}$ C;

$\phi_0 = 2.0$ eV $= 2.0 \times 1.6 \times 10^{-19} = 3.2 \times 10^{-19}$J;

$\lambda = 500$ nm $= 500 \times 10^{-9}$ m; 1eV $= 1.6 \times 10^{-19}$J

(a) If λ_0 is the threshold wavelength, then

$$\phi_0 = \frac{h\,c}{\lambda_0}$$

or $\lambda_0 = \frac{h\,c}{\phi_0} = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{3.2 \times 10^{-19}}$

$= 618.75 \times 10^{-9}$m = **618.75 nm**

(b) The maximum energy of the photoelectrons,

$$\frac{1}{2}mv_{max}^2 = h\nu - \phi_0 = \frac{hc}{\lambda} - \phi_0$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{500 \times 10^{-9}} - 3.2 \times 10^{-19}$$

$= 3.96 \times 10^{-19} - 3.2 \times 10^{-19}$

$= 0.76 \times 10^{-19}$ J

(c) The stopping potential given by

$$eV_0 = \frac{1}{2}mv_{max}^2 = 0.76 \times 10^{-19}$$

or $V_0 = \frac{0.76 \times 10^{-19}}{e} = \frac{0.76 \times 10^{-19}}{1.6 \times 10^{-19}}$ **= 0.475 V**.

S32. (a) **Work function:** The minimum amount of energy required to eject an electron from a surface (without imparting any kinetic energy) is called ***work function*** of the surface.

(b) **Threshold frequency:** The emission of photoelectrons takes place only when the frequency of the incident radiation is a certain critical value, characteristic of the metal. The critical value of frequency is known as the ***threshold frequency***.

(c) **Stopping potential:** The value of negative potential of the collector, corresponding to which even the fastest photoelectrons are repelled back, is called ***stopping potential***.

S33. Work function of caesium metal, $\phi_0 = 2.14$ eV

Frequency of light, $\nu = 6.0 \times 10^{14}$ Hz

(a) The maximum kinetic energy is given by the photoelectric effect as:

$$K = h\nu - \phi_0$$

Where, h = Planck's constant

$= 6.626 \times 10^{-34}$ Js

$$\therefore \quad K = \frac{6.626 \times 10^{34} \times 6 \times 10^{14}}{1.6 \times 10^{-19}} - 2.14$$

$$= 2.485 - 2.140 = 0.345 \text{ eV}$$

Hence, the maximum kinetic energy of the emitted electrons is 0.345 eV.

(b) For stopping potential V_0, we can write the equation for kinetic energy as:

$$K = eV_0$$

$$\therefore \quad V_0 = \frac{K}{e}$$

$$= \frac{0.345 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-19}} = 0.345 \text{ V}$$

Hence, the stopping potential of the material is 0.345 V.

(c) Maximum speed of the emitted photoelectrons = ν.

Hence, the relation for kinetic energy can be written as:

$$K = \frac{1}{2} mv^2$$

Where, m = Mass of an electron

$= 9.1 \times 10^{-31}$ kg

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

$$= \frac{2 \times 0.345 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}$$

$$= 0.1104 \times 10^{12}$$

$\therefore \qquad v = 3.323 \times 10^5$ m/s = 332.3 km/s.

Hence, the maximum speed of the emitted photoelectrons is 332.3 km/s.

S34. $$\frac{hc}{\lambda} = \phi_0 + e\,V_0$$

or $$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$\therefore$ $$\phi_0 = \frac{6.62 \times 10^{34} \times 3 \times 10^8}{250 \times 10^{-9}} - 1.6 \times 10^{-19} \times 4$$

$$= 7.944 \times 10^{-19} - 6.4 \times 10^{-19} = \mathbf{1.544 \times 10^{-19}\ J}.$$

Let V_0' be the stopping potential, when wavelength of incident light is increased to λ' (= 300 nm). Then,

$$e\,V_0' = \frac{h\,c}{\lambda'} - \phi_0$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9}} - 1.544 \times 10^{-19} = 5.076 \times 10^{-19}\ \text{J}$$

or $$V_0 = \frac{5.076 \times 10^{-19}}{e} = \frac{5.076 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{3.17\ V}$$

S35. (a) $$\frac{1}{2} m\,v_{\max}^2 = \frac{h\,c}{\lambda} - \phi_0$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{2{,}000 \times 10^{-10}} - 4.2 \times 1.6 \times 10^{-19}$$

$$= 9.9 \times 10^{-19} - 6.72 \times 10^{-19} = 3.18 \times 10^{-19}\ \text{J}$$

$$= \frac{3.18 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{1.9875\ eV}$$

(b) The slowest electrons emitted will have zero kinetic energy.

(c) V_0 = maximum K. E. (in eV) = **1.9875 V**

(d) $$\lambda_0 = \frac{hc}{\phi_0} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.2 \times 1.6 \times 10^{-19}}$$

$$= 2.946 \times 10^{-7}\ \text{m} = \mathbf{2{,}946\ Å}$$

S36. Here, $V_0 = 3\,\text{eV}$ and $\nu_0 = 6 \times 10^{-14}\ \text{s}^{-1}$

Now, $$\frac{1}{2} m v_{max}^2 = 3\ \text{eV} = 3 \times 1.6 \times 10^{-19}\ \text{s}^{-1}$$

$$= 4.8 \times 10^{-19} \text{J}$$

and $$\phi_0 = h\nu_0$$

$$= 6.62 \times 10^{-34} \times 6 \times 10^{14} = 3.97 \times 10^{-19}\ \text{J}$$

$$= \frac{3.97 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{2.48\ eV}$$

$$h\nu = h\,\nu_0 + \frac{1}{2} m v_{max}{}^2$$

$$= 3.97 \times 10^{-19} + 4.8 \times 10^{-19} = 8.77 \times 10^{-19}\ \text{J}$$

or $$\nu = \frac{8.77 \times 10^{-19}}{6.62 \times 10^{-34}} = \mathbf{13.25 \times 10^{14}\ s^{-1}}$$

S37. (a) $$E = \frac{h\,c}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{5{,}500 \times 10^{-10}}$$

$$= 3.61 \times 10^{-19} J$$

$$= \frac{3.61 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{2.256\ eV}$$

(b) $$\frac{1}{2} m v_{max}^2 = \frac{hc}{\lambda} - \phi_0 = 2.257 - 1.7$$

$$= \mathbf{0.556\ eV}$$

(c) V_0 = Maximum K.E. (in eV) = **0.556 V**

S38. (a) ***Cut of off Voltage:*** It is minimum negative potential given to anode at which photoelectric current becomes zero

(b) ***Threshold Frequency:*** Minimum frequency of incident radiation for a given photosensitive surface below which no emission of photoelectrons take places.

According to Einstein's photoelectric equation

$$h\nu = \phi_0 + eVs$$

$$eVs = h\nu - \phi_0$$

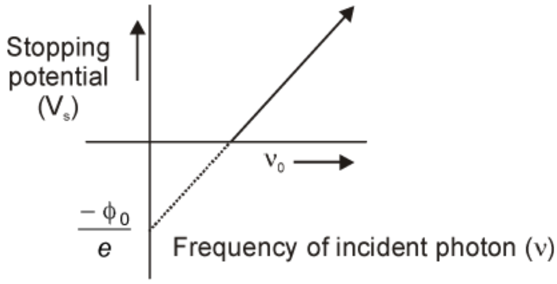
$$V_s = \frac{h}{e}\nu - \frac{\phi_0}{e}$$

This equation is of the form

$$y = mx + c$$

i.e. the equation of straight line.

Slope of the line is h/e and intercept is $-\dfrac{\phi_0}{e}$



Thus, with the help of graph we can find out the value of stopping potential and threshold frequency.

S39. Here, mass of the He-atom,

$$m = \frac{\text{atomic weight of He}}{\text{Avogadro number}} = \frac{4}{6.02 \times 10^{23}}$$

$$= 6.645 \times 10^{-24}\, g = 6.645 \times 10^{-27} \text{ kg}$$

It can be obtained that de Broglie wavelength of the He-atom,

$$\lambda = 0.73 \times 10^{-10}\, m = 0.73 \text{ Å}$$

If V is volume of the gas and d, the mean separation between two atoms in the gas, than

$$V = d^3 N,$$

Where N is Avogadro's number.

From the perfect gas equation,

$$P\,V = R\,T = (k\,N)T$$

or $$P \times d^3\,N = k\,N\,T$$

or $$d = \left(\frac{k\,T}{P}\right)^{1/3} = \left(\frac{1.38 \times 10^{-23} \times 300}{0.76 \times 13.6 \times 10^3 \times 9.8}\right)$$

$$= 34.45 \times 10^{-10} \text{ m } 34.45 \text{ Å}$$

$$\frac{d}{\lambda} = \frac{34.45}{0.73} \approx \mathbf{47}$$

i.e., the separation between the two He-atoms in the gas is much larger than the Broglie wavelength of the atom.

S40. We know, $h\nu = h\,\nu_0 + eV_0$

or $$\nu = \nu_0 + \frac{e\,V_0}{h}$$

or $$\nu = 6\times 10^{14} + \frac{1.6\times 10^{-19}\times 3}{6.62\times 10^{-34}}$$

$$= 6 \times 10^{14} + 7.25 \times 10^{14} = 13.25 \times 10^{14}\ s^{-1}$$

$$\phi_0 = h\nu_0 = 6.62 \times 10^{-34} \times 6 \times 10^{14} = 3.97 \times 10^{-19}\ J$$

$$= \frac{3.97\times 10^{-19}}{1.6\times 10^{-19}} = \mathbf{2.48\ eV}$$

S41. As a charge q is accelerated by a potential V,

We have, $W = qV = \frac{1}{2}m\nu^2 = \frac{p^2}{2m}$ as the work done on the charge becomes K. E.

$\therefore$ $$p = \sqrt{2mqV}$$

(a) Since, $\lambda = \frac{h}{p}, \frac{\lambda_p}{\lambda_e} = \sqrt{\frac{2m_e eV}{2m_p eV}} = \sqrt{\frac{m_e}{m_p}} < 1.$

So electron will have greater de Broglie wavelength.

(b) Since, $p \propto \sqrt{m}$ and $m_e < m_p$ momentum is less with electron.

S42. (a) $$\phi_0 = h\nu_0 = \frac{hc}{\lambda_0} \quad i.e. \quad \nu_0 \propto \frac{1}{\lambda_0}$$

As $\nu_{OP} < \nu_{OQ}$

$\lambda_{OP} > \lambda_{OQ}$

Metal 'Q' has smaller threshold wavelength

(b) $$h\nu = \phi_0 + \frac{1}{2}m\nu^2$$

For a given photon of frequency 'ν' work function is more for metal Q so it will emit photo-electrons having smaller kinetic energy.

(c) As stopping potential does not depend upon intensity, it will remain same.

S43. (a) $$\lambda = \frac{c}{v}$$

As $(v_0)x < (v_0)y$

$(\lambda_0)x > (\lambda_0)y$

Metal 'X' has larger wavelength.

(b) We know, $$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + K.E.$$

As the L.H.S. is constant, for lesser value of work function, K.E. of photoelectron will be more. So metal '*X*' will give out electrons of larger kinetic energy.

(c) Kinetic energy will not change. On reducing the distance only intensity of light changes, frequency remains same K. E. of emitted photoelectrons depend on frequency.

S44. Photoelectric equation.

$$h\nu = h\nu_0 + E_k$$

According to question

$$h\nu_0 \sim 0$$

Therefore, $$E_k = h\nu = \frac{h\nu}{\lambda} \quad ...(i)$$

de Broglie wavelength,

$$\lambda_1 = \frac{h}{m\nu} = \frac{h}{\sqrt{2mE_k}} \quad ... (ii)$$

Substituting the value of E_k from equation (*i*) in equation (ii), we have

$$\lambda_1 = \frac{h}{\sqrt{2m \times \frac{hc}{\lambda}}} = \sqrt{\frac{h\lambda}{2mc}}$$

$$\lambda = \left[\frac{2mc}{h}\right]\lambda_1^2$$

S45. (a) The photoelectric effect cannot be explained on the basis of wave nature of light because wave nature of radiation cannot explain the following

(i) The instantaneous ejection of photoelectrons.

(ii) The existence of threshold frequency for a metal surface.

(iii) The fact that kinetic energy of the emitted electrons is independent of the intensity of light and depends upon its frequency.

(b) Photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based on particle nature of light.

It basic features are

(i) In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.

(ii) Each photon has energy $E\left(=h\nu=\dfrac{hc}{\lambda}\right)$ and momentum $p\,(= h\nu/c = h/\lambda)$, where c is the speed of light, h is Planck's constant, v and λ are frequency and wavelength of radiation.

(iii) All photons of light of a particular frequency ν or wavelength λ have the same energy $E\left(=h\nu=\dfrac{hc}{\lambda}\right)$ and momentum $p\left(=\dfrac{h\nu}{c}=\dfrac{h}{\lambda}\right)$ whatever the intensity of radiation may be.

(iv) By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area, with each photon having the same energy. Thus, photon energy is independent of intensity of radiation.

(v) Photons are electrically neutral and are not deflected by electric end magnetic fields.

(vi) In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved. However number of photons may not be conserved.

(vii) The velocity of photon in different media is different which is due to change in its wavelength.

S46. (a) (i) Minimum energy required to make free an electron from a metal is called the work function of that metal.

(ii) The minimum frequency of incident light which can eject photoelectrons from a material is known as the threshold frequency of a plate.

(iii) Value of negative potential which can stop even the highest energy electrons coming towards it from cathode side is called stopping potential.

(b) Given $\lambda = 300 \times 10^{-9}$ m

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

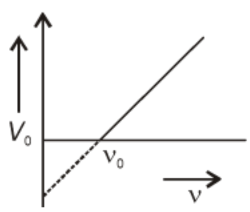
$$E = \frac{6.62\times10^{34}\times3\times10^{8}}{3\times10^{-7}}J = \frac{6.62\times10^{-19}}{1.6\times10^{-19}}eV$$

$\therefore$ $E = 4.1$ eV.

$$K.E. = h\nu - \phi_0 = 4.1 - 3.2 = 0.9 \text{ eV}.$$

S47. ***Stopping Potential:*** It is a minimum negative potential given to anode (metal plate) at which photoelectric current becomes zero.

Threshold Frequency: Minimum frequency of incident radiation for a given metal below which no emission of photoelectrons take place is know as threshold frequency.



Slope of line = $\dfrac{\Delta V}{\Delta \nu}$

From Einstein's photoelectric equation we get

$$eV = h\nu - \phi_0$$

We differentiate this with respect to ν

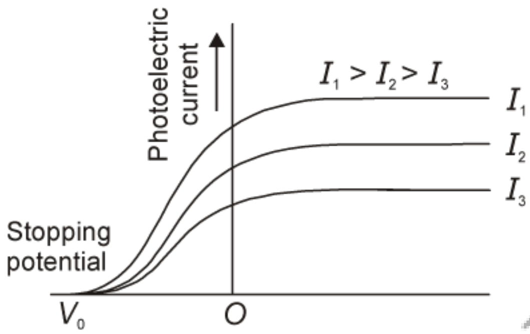
$$e\frac{dV}{d\nu} = h$$

or $$edV = hd\nu \Rightarrow dV/d\nu = h/e$$

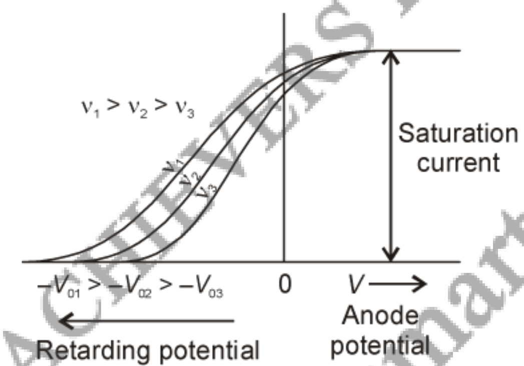
$\therefore$ Slope of the line = h/e

Here h is planck's constant.

S48. (a) Variation in photoelectric current with anode potential of a photocell for same frequency but different intensities $I_1 > I_2 > I_3$ of incident radiation.



(b) For same intensity but different frequencies $\nu_1 > \nu_2 > \nu_3$ of incident radiation.



Saturation current corresponds to the number of photoelectrons emitted by the cathode reaching the anode at a constant intensity of incident radiation. Anode potential cannot change saturation current.

S49. From de-Broglie matter wave equation,

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

But, $$p = \sqrt{2mK} \quad \text{and} \quad K = qV$$

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

Where, m = mass of charge particle

q = charge

V = potential difference

$\Rightarrow$ $\lambda \propto \frac{1}{\sqrt{mq}}$ (for same accelerating voltage)

(a) Ratio of wavelengths of proton and α-particles

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\left(\frac{m_\alpha}{m_p}\right)\left(\frac{q_\alpha}{q_p}\right)}$$

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

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{(4) \times 2} = 2\sqrt{2}$$

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

Proton have greater de-Broglie wavelength associated with it.

(b) $\because$ Kinetic energy, $K = qV$

$\Rightarrow$ $\frac{K_p}{K_\alpha} = \left(\frac{q_p}{q_\alpha}\right)$ (for same acelerating voltage)

$$\frac{K_p}{K_\alpha} = \frac{1}{2}$$

$\Rightarrow$ $K_p = \frac{1}{2}K_\alpha$

Proton have less KE.

S50. (a) For electron or photon, momentum

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{10^{-9}} = 6.63 \times 10^{-25}\text{m}$$

(b) $$E = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})\times(3\times10^{8})}{10^{-9}\times(1.6\times10^{-19})}$$

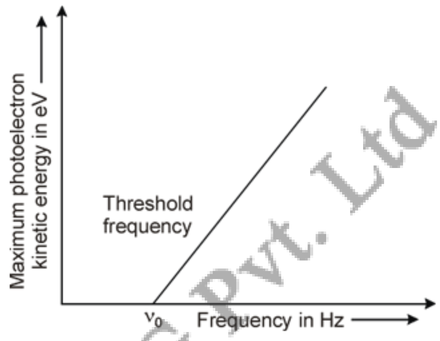
$$= 1243 \text{ eV}$$

(c) As, $$E_k = \frac{p^2}{2m} = \frac{(6.63\times10^{-25})^2}{2\times9.1\times10^{-31}} = 2.42\times10^{-19}$$

$$= 2.42\times10^{-19} \div (1.6\times10^{-19}) = \mathbf{1.52\ eV}.$$

S51. The two characteristics features observed in photoelectric effect which support the photon pictures of electromagnetic radiation.

(a) All photons of light of particular frequency ν or wavelength λ have the same energy, $E\left(=h\nu=\frac{hc}{\lambda}\right)$ and momentum, $p\left(=\frac{h}{\lambda}\right)$ whatever the intensity of radiation may be. The increase intensity of the radiation implies an increase in the number of photons crossing a given area per second.



(b) Photons are electrically neutral and not deflected by electric magnetic fields.

(i) Planck constant is given by slope of the curve *i.e.*, as,

Slope of graph = $\frac{h}{e}$

(ii) Work function is the minimum energy required by the electron to escape out of the metal surface thus,

$$\phi = h\nu_0$$

Here, ν_0 is the threshold frequency.

S52. Einstein's photoelectric equation,

$$\text{K.E.}_{max} = h\nu - \phi_0 \quad \text{... (i)}$$

where,

ν = frequency of incident light beam

ϕ_0 = work function of metal

K.E._{max} = maximum kinetic energy

$\because$ $\phi_0 = h\nu_0$

where, ν_0 is threshold frequency.

$\Rightarrow \qquad K.E._{max} = h\nu - h\nu_0$

$K.E._{max} = h(\nu - \nu_0) \qquad \ldots \text{(ii)}$

This equation is obtained by considering the particle nature of electromagnetic radiation.

Three salient features observed in photoelectric effect and their explanation on the basis of Einstein's photoelectric equation is given below.

Threshold frequency: For $K.E._{max} \geq 0$,

$\Rightarrow \qquad \nu \geq \nu_0 \qquad$ [From eq. (ii)]

i.e., the phenomenon of photoelectric effect takes place when incident frequency is greater or equal to a minimum frequency (threshold frequency) ν_0 fixed for given metal.

Two two characteristics properties of photons on which this equation is based are as follows.

(a) Photons have particle characteristics. It is emitted or absorbed in units called quanta of light.

(b) Photons have wave characteristics. It travels in space with particular frequency, a characteristics of waves.

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Q1. **Calculate the momentum of a photon having frequency 5×10^{13} Hz. Given that $h = 6.6 \times 10^{-34}$ J s and $c = 3 \times 10^{8}$ m s^{-1}.**

Q2. **The frequency (ν) of incident radiation is greater than threshold frequency (ν_0) in a photocell. How will the stopping potential vary, if frequency (ν) is increased, keeping other factors constant?**

Q3. **If the maximum kinetic energy of electrons emitted by a photo cell is 5 eV, what is the stopping potential?**

Q4. **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?**

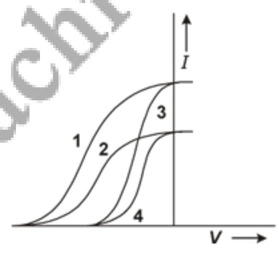
Q5. **If the frequency of the incident radiation is equal to the threshold frequency, what will be the value of the stopping potential?**

Q6. **The wavelength of electromagnetic radiation is doubled. What will happen to the energy of the photons?**

Q7. **Is photoelectric emission possible at all frequencies? Give reasons for your answer.**

Q8. **Show the graphically how the stopping potential for a given photosensitive surface varies with the frequency of the incident radiation.**

Q9. **The given graph shows the variation of photo electric current (I) versus applied voltage (V) for two difference photosensitive materials and for two different intensities of the incident radiations. Identify the pairs of curves that correspond to different materials but same intensity of incident radiation.**



Q10. **An electron, an alpha particle and a proton have the same kinetic energy, Which one of these particles has the largest de-Broglie wavelength?**

Q11. **Does the stopping potential in photoelectric emission depend upon**

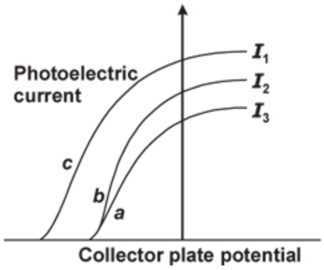
(a) **The intensity of the incident radiation in a photocell?**

(b) **The frequency of the incident radiation?**

Q12. **The maximum kinetic energy of a photoelectron is 3 eV. What is its stopping potential?**

Q13. 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 ν_1, ν_2 and ν_3 respectively incident on a photosensitive surface.

Point out the two curves for which the incident radiations have same frequency but different intensities.



Q14. How will the photoelectric current change on decreasing the wavelength of incident radiation for a given photosensitive material?

Q15. Light of wavelength 488 nm is produced by an argon laser which is used in the photoelectric effect. When light from this spectral line is incident on the emitter, the stopping (cut-off) potential of photoelectrons is 0.38 V. Find the work function of the material from which the emitter is made.

Q16. Light of frequency 7.21×10^{14} Hz is incident on a metal surface. Electrons with a maximum speed of 6.0×10^5 m/s are ejected from the surface. What is the threshold frequency for photoemission of electrons?

Q17. Monochromatic radiation of wavelength 640.2 nm (1 nm = 10^{-9} m) from a neon lamp irradiates photosensitive material made of caesium on tungsten. The stopping voltage is measured to be 0.54 V. The source is replaced by an iron source and its 427.2 nm line irradiates the same photo-cell. Predict the new stopping voltage.

Q18. The work function for the following metals is given:

Na: 2.75 eV; K: 2.30 eV; Mo: 4.17 eV; Ni: 5.15 eV.

Which of these metals will not give photoelectric emission for a radiation of wavelength 3300 Å from a He-Cd laser placed 1 m away from the photocell? What happens if the laser is brought nearer and placed 50 cm away?

Q19. The wavelength of a probe is roughly a measure of the size of a structure that it can probe in some detail. The quark structure of protons and neutrons appears at the minute length-scale of 10^{-15} m or less. This structure was first probed in early 1970's using high energy electron beams produced by a linear accelerator at Stanford, USA. Guess what might have been the order of energy of these electron beams. (Rest mass energy of electron = 0.511 MeV.)

Q20. Crystal diffraction experiments can be performed using X-rays, or electrons accelerated through appropriate voltage. Which probe has greater energy? (For quantitative comparison, take the wavelength of the probe equal to 1 Å, which is of the order of inter-atomic spacing in the lattice) ($m_e = 9.11 \times 10^{-31}$ kg).

Q21. The work function of caesium is 2.14 eV. Find (a) the threshold frequency for caesium, and (b) the wavelength of the incident light if the photocurrent is brought to zero by a stopping potential of 0.60 V.

Q22. Radiation of frequency 10^{15} Hz is incident on two photosensitive surface *P* and *Q*. Following observations are made:

(a) Surface *P*: Photoemission occurs but the photoelectrons have zero kinetic energy.

(b) Surface *Q*: Photoemission occurs and photo-electrons have some kinetic energy.

Which of these has a higher work function? If the incident frequency is slightly reduced, what will happen to photoelectrons emission in the two cases?

Q23. For a photosensitive surface, threshold wavelength is λ_0. Does photoemission occur, if the wavelength (λ) of the incident radiation is (a) more than λ_0, (b) less than λ_0? Justify your answer.

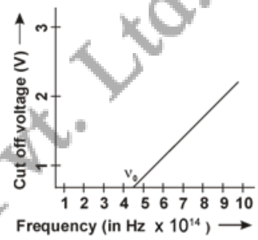
Q24. An electron, an α-particle, and a proton have the same kinetic energy. Which of these particles has the shortest de Broglie wavelength?

Q25. What is the de Broglie wavelength associated with (a) an electron moving with a speed of 5.4×10^6 m/s, and (b) a ball of mass 150 g travelling at 30.0 m/s?

Q26. For photoelectric effect in metal, figure shows the plot of cut off voltage versus frequency of incident radiation. Calculate

(a) the threshold frequency and

(b) the work function for the given metal.



Q27. Draw a graph to show the variation of stopping potential with frequency of radiations incident on a metal plate. How can the value of Planck's constant be determined from this graph?

Q28. Define the terms work function' and 'threshold frequency' for photoelectric effect. Show graphically how stopping potential for a given metal varies with frequency of incident radiation. What does the slope of this graph represent?

Q29. Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions ϕ_1 and ϕ_2 ($\phi_1 > \phi_2$). On what factors does the (a) slope and (b) intercept of the lines depends?

Q30. Draw a graph showing the variation of stopping potential with frequency of incident radiation in relation to photoelectric effect. Deduce an expression for the slope of this graph using Einstein's photoelectric equation.

Q31. The work function for a certain metal is 4.2 eV. will this metal give photoelectric emission for incident radiation of wavelength 330 nm? Given charge on electron, $e = 1.6 \times 10^{-19}$ C; velocity of light, $c = 3 \times 10^8$ m s^{-1} electron, $e = 1.6 \times 10^{-19}$ C ; velocity of light, $c = 3 \times 10^8$ ms^{-1} and Planck's constant, h =6.62×10^{-34} Js.

Q32. The wavelength of a spectral line is 4, 000 Å. Calculate its frequency and energy. Given, $c = 3 \times 10^8$ ms^{-1} and $h = 6.6 \times 10^{-34}$ Js.

Q33. The threshold frequency for a certain metal is 3.3×10^{14} Hz. If light of frequency 8.2×10^{14} Hz is incident on the metal, predict the cutoff voltage for the photoelectric emission.

Q34. Calculate the de-Broglie wavelength for electron and proton, if their speed is 10^5 ms^{-1}. Given, mass of an electron = 9.1×10^{-31} kg, mass of proton = 1.67×10^{-27} kg and planck's constant = 6.62×10^{-34} Js.

Q35. The photoelectric work function of a certain surface is 4 eV. What is the maximum velocity of the photoelectrons when light of frequency 10^{15} Hz strike on surface?
$h = 6.625 \times 10^{-34}$ Js, 1 eV = 1.602×10^{-19} J.

Q36. Plot graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work functions ϕ_1 and $\phi_2 (\phi_1 > \phi_2)$. On what factors does the
(a) slope and
(b) intercept of the lines depend?

Q37. Write Einstein's photoelectric equation. State clearly, the three salient features observed in photoelectric effect, which can be explained on the basis of above equation.

Q38. A particle of mass M at rest decays into two particles of masses m_1 and m_2 having non zero velocities. What is the ratio of the de-Broglie wavelengths of the two particles?

Q39. Calculate the kinetic energy of a photoelectron (in eV) emitted on shining light of wavelength 6.2×10^{-6} m on a metal surface. The work function of the metal is 3.1 eV.

Q40. Work function of sodium is 2.35 eV. What is the maximum wavelength of light that will cause photoelectrons to be emitted from the metal? What will be the maximum energy of the photoelectrons, if radiation of 1.000 Å falls on the metal surface ($h = 6.625 \times 10^{-34}$ J s).

Q41. Energy of photoelectrons emitted from a photosensitive surface is 1.56 eV. If its threshold wavelength is 2, 500 Å, find wavelength of the incident light. Take $h = 6.625 \times 10^{-34}$Js.

Q42. A 100 W sodium lamp radiates energy uniformly in all directions. The lamp is located at the centre of a large sphere that absorbs all the sodium light which is incident on it. The wavelength of the sodium light is 589 nm. (a) What is the energy per photon associated with the sodium light? (b) At what rate are the photons delivered to the sphere?

Q43. Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW.

(a) Find the energy and momentum of each photon in the light beam,

(b) How many photons per second, on the average, arrive at a target irradiated by this beam? (Assume the beam to have uniform cross-section which is less than the target area), and

(c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

Q44. When a surface is irradiated with a light of wavelength 4, 750 Å, a photocurrent appears which vanishes, if a retarding potential greater than 0.6 V is applied across the photo tube. When a different source of light is used, it is found that the critical retarding potential is changed to 1.1 V. Find the work function of the emitting surface and the wavelength of second sources. if the photoelectrons (after emission from the surface) are subjected to a magnetic field to 10 T, what changes will be observed in the above two retarding potentials?

Q45. The wavelength of light in the visible region is about 390 nm for violet colour, about 550 nm (average wavelength) for yellowgreen colour and about 760 nm for red colour.

(a) What are the energies of photons in (eV) at the (i) violet end, (ii) average wavelength, yellow-green colour, and (iii) red end of the visible spectrum? (Take $h = 6.63 \times 10^{-34}$ Js and 1 eV = 1.6×10^{-19} J.)

(b) From which of the photosensitive materials with work functions listed in Table 11.1 and using the results of (i), (ii) and (iii) of (a), can you build a photoelectric device that operates with visible light?

Q46. An electron and a photon each have a wavelength of 1.50 nm. Find (a) their momenta, (b) the energy of the photon and (c) kinetic energy of the electron.

Q47. Write Einstein's photoelectric equations. State clearly how this equation is obtained using the photon picture of electromagnetic radiation. Write the three salient features observed in photoelectric effect which can be explained using this equation.

Q48. If a photon and electron have the same de-Broglie wave-length of 0.5 Å, then find the ratio of the kinetic energy of photon to that of electron. Mass of electron = 9.1×10^{-31} kg.

Q49. Assume that the de-Broglie wave associated with an electron can form a standing wave between the atoms arranged in a one dimensional array with nodes at each of the atomic sites. It is found that one such standing wave is formed, if the distance *d* between the atoms of the array is 2 Å. A similar standing wave is again formed, if the distance *d* is increased to 2.5 Å, but not for any intermediate value of *d*. Find the energy of the electrons in eV and the least value of *d* for which the standing wave of the type described above can form.

Q50. Define the terms 'cut-off voltage' and 'threshold frequency' in relation to the phenomenon of photoelectric effect.

Using Einstein's photoelectric equation show how the cut-off voltage and threshold frquency for a given photosensitive material can be determined with the help of a suitable plot graph.

Q51. (a) The mass of a principle moving with velocity 5×10^6 m/s has de-Broglie wavelength associated with it to be 0.135 mm. Calculate its mass.

(b) In which region of the electromagnetic spectrum does this wavelength lie?

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S1. The momentum of photon is given by

$$p = \frac{h}{\lambda} = \frac{h}{c/v} = \frac{hv}{c}$$

$$= \frac{6.6 \times 10^{-34} \times 5 \times 10^{13}}{3 \times 10^{8}} = \mathbf{1.1 \times 10^{-28}\,kg\,m\,s^{-1}}.$$

S2. When the frequency is increased, the kinetic energy of the emitted photoelectrons will increase and hence the stopping potential will also increase.

S3. The stopping potential free electrons having maximum kinetic energy of 5 eV is 5 V.

S4. From Einstein's photoelectric equation, we have

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

Since frequency of blue light is greater than that of the red light, blue light emits electrons of greater kinetic energy.

S5. From Einstein's photoelectric equation, we have

$$h\nu = h\nu_0 + eV_0$$

When $\nu = \nu_0$,

we have $h\nu_0 = h\nu_0 + eV_0$

or $V_0 = 0.$

S6. The energy of photon is half.

Explanation:

We know $E = h\nu = \frac{hc}{\lambda}$ ... (i)

if λ is doubled $E' = \frac{hc}{2\lambda}$

$$\mathbf{E' = \frac{1}{2}E}.$$

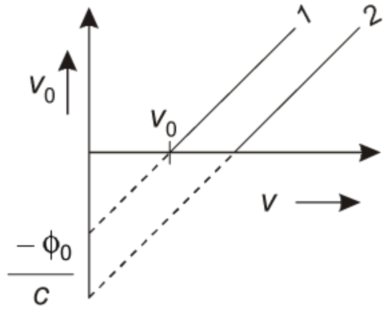
Therefore energy is half.

S7. No. The energy of incident photon must be greater than work function

$$h\nu > \phi_0$$

$$\nu > \frac{\phi_0}{h}. \text{ } i.e., \text{ threshold frequency}$$

S8.



S9. Curves 1 and 2 correspond to similar materials while curves 3 and 4 represent similar materials, since the value of stopping potential for the pair of curves (1 and 2) and (3 and 4) are the same. For given frequency of the incident radiation, the stopping potential is independent of its intensity.

So, the pairs of curves (1 and 3) and (2 and 4) correspond to different materials but same intensity of incident radiation.

S10. If λ is the de-Broglie wavelength of a particle having kinetic energy K, then

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

Out of the three, since mass of the electron is least, the de-Broglie wavelength of the electron is largest.

S11. (a) No. (b) Yes.

S12. Maximum kinetic energy of photoelectron

$$= 3\text{eV}$$

$\therefore$ Maximum KE $= eV_0$

where, V_0 = stopping potential

$$3eV = eV_0$$

$\therefore$ Stopping potential $V_0 = 3$ V

S13. The photoelectric current is directly proportional to the intensity of incident radiation. Energy of photoelectrons or cut-off potential depends on frequency of incident radiation.

Curves, *a* and *b* have got same cut-off potential, so for these two curves frequencies will be same.

S14. Decreasing the wavelength of radiation, the photoelectric current remains unchanged.

S15. Wavelength of light produced by the argon laser,

$$\lambda = 488 \text{ nm}$$
$$= 488 \times 10^{-9} \text{ m}$$

Stopping potential of the photoelectrons,

$$V_0 = 0.36 \text{ V}$$
$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\therefore \quad V_0 = \frac{0.38}{1.6 \times 10^{-19}}$$

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

Charge on an electron, $e = 1.6 \times 10^{-19}$ C

Speed of light, $c = 3 \times 10$ m/s

From Einstein's photoelectric equation, we have the relation involving the work function Φ_0 of the material of the emitter as:

$$eV_0 = \frac{hc}{\lambda} - \phi_0$$

$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 10^{-19} \times 488 \times 10^{-9}} - \frac{1.6 \times 10^{-19} \times 0.38}{1.6 \times 10^{-19}}$$

$$= 2.54 - 0.34 = 2.16 \text{ eV}$$

Therefore, the material with which the emitter is made has the work function of 2.16 eV.

S16. Frequency of the incident photon, $\nu = 488 \text{ nm} = 488 \times 10^{-9}$ m

Maximum speed of the electrons, $v = 6.0 \times 10^5$ m/s

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Mass of an electron, $m = 9.1 \times 10^{-31}$ kg

For threshold frequency ν_0, the relation for kinetic energy is written as:

$$\frac{1}{2} mv^2 = h(\nu - \nu_0)$$

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

$$= 7.21 \ 10^{14} - \frac{(9.1 \times 10^{-31}) \times (6 \times 10^5)^2}{2 \times (6.626 \times 10^{-34})}$$

$$= 7.21 \times 10^{14} - 2.472 \times 10^{14}$$
$$= 4.738 \times 10^{14}\,\text{Hz}$$

Therefore, the threshold frequency for the photoemission of electrons is 4.738×10^{14} Hz.

S17. Wavelength of the monochromatic radiation,

$$\lambda = 640.2\ \text{nm}$$
$$= 640.2 \times 10^{-9}\,\text{m}$$

Stopping potential of the neon lamp, $V_0 = 0.54\,\text{V}$

Charge on an electron, $e = 1.6 \times 10^{-19}\,\text{C}$

Planck's constant, $h = 6.6 \times 10^{-34}\,\text{C}$

Let ϕ_0 be the work function and ν be the frequency of emitted light.

We have the photo-energy relation from the photoelectric effect as:

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

$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{640.2 \times 10^{-9}} - 1.6 \times 10^{-19} \times 0.54$$

$$= 3.093 \times 10^{-19} - 0.864 \times 10^{-19}$$
$$= 2.229 \times 10^{-19}\,\text{J}$$

$$= \frac{2.229 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.39\ \text{eV}$$

Wavelength of the radiation emitted from an iron source,

$$\lambda' = 427.2\ \text{nm}$$
$$= 427.2 \times 10^{-9}\,\text{m}$$

Let V_0' be the new stopping potential. Hence, photo-energy is given as:

$$eV_0' = \frac{hc}{\lambda'} - \phi_0$$

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{427.2 \times 10^{-9}} - 2.229 \times 10^{-19}$$

$$= 4.63 \times 10^{-19} - 2.229 \times 10^{-19}$$
$$= 2.401 \times 10^{-19}\,\text{J}$$

$$= \frac{2.401 \times 10^{-19}}{1.6 \times 10^{-19}} = 1.5\ \text{eV}$$

Hence, the new stopping potential is 1.50 eV.

S18. Mo and Ni will not show photoelectric emission in both cases

Wavelength for a radiation, $\lambda = 3300\ \text{Å} = 3300 \times 10^{-10}$ m

Speed of light, $c = 3 \times 10^{8}$ m/s

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

The energy of incident radiation is given as:

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

$$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{3300 \times 10^{-10}} = 6 \times 10^{-19}\ \text{J}$$

$$= \frac{6 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.158\ \text{eV}$$

It can be observed that the energy of the incident radiation is greater than the work function of Na and K only. It is less for Mo and Ni. Hence, Mo and Ni will not show photoelectric emission.

If the source of light is brought near the photocells and placed 50 cm away from them, then the intensity of radiation will increase. This does not affect the energy of the radiation. Hence, the result will be the same as before. However, the photoelectrons emitted from Na and K will increase in proportion to intensity.

S19. Wavelength of a proton or a neutron, $\lambda \approx 10^{-15}$ m

Rest mass energy of an electron:

$$m_0 c^2 = 0.511\ \text{MeV}$$

$$= 0.511 \times 10^{6} \times 1.6 \times 10^{-19} \qquad [1\ \text{eV} = 1.6 \times 10^{-19}\ \text{J}]$$

$$= 0.8176 \times 10^{-13}\ \text{J}$$

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

Speed of light, $c = 3 \times 10^{8}$ m/s

The momentum of a proton or a neutron is given as:

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

$$= \frac{6.6 \times 10^{-34}}{10^{-15}} = 6.6 \times 10^{-19}\ \text{kg m/s}$$

The relativistic relation for energy (E) is given as:

$$E^2 = p^2c^2 + m_0^2c^4$$

$$= (6.6 \times 10^{-19} \times 3 \times 10^{8})^2 + (0.8176 \times 10^{-13})^2$$

$$= 392.04 \times 10^{-22} + 0.6685 \times 10^{-26}$$

$$\approx 392.04 \times 10^{-22}$$

$\therefore$ $E = 1.98 \times 10^{-10}$ J

$$= \frac{1.98 \times 10^{-10}}{1.6 \times 10^{-10}}$$

$$= 1.24 \times 10^{9}\text{ eV} = 1.24 \text{ BeV}$$

Thus, the electron energy emitted from the accelerator at Stanford, USA might be of the order of 1.24 BeV.

S20. An X-ray probe has a greater energy than an electron probe for the same wavelength.

Wavelength of light emitted from the probe,

$$\lambda = 1 \text{ Å} = 10^{-10}\text{ m}$$

Mass of an electron $m_e = 9.11 \times 10^{-31}$ kg

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

Charge on an electron, $e = 1.6 \times 10^{-19}$ C

The kinetic energy of the electron is given as:

$$E = \frac{1}{2} m_e v^2$$

$$m_e v = \sqrt{2Em_e}$$

Where, v = Velocity of the electron

$m_e v$ = Momentum (p) of the electron

According to the de Broglie principle, the de Broglie wavelength is given as:

$$\lambda = \frac{h}{p} = \frac{h}{m_e v} = \frac{h}{\sqrt{2Em_e}}$$

$\therefore$

$$E = \frac{h^2}{2\lambda^2 m_e}$$

$$= \frac{(6.6 \times 10^{-34})^2}{2 \times (10^{-10})^2 \times 9.11 \times 10^{-31}} = 2.39 \times 10^{-17}\text{ J}$$

$$= \frac{2.39 \times 10^{-17}}{1.6 \times 10^{-19}} = 149.375 \text{ eV}$$

Energy of a photon, $E' = h\nu = h\frac{c}{\lambda}$

$$E' = \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{10^{-10} \times 1.6 \times 10^{-19}}$$

$$= 12.375 \times 10^{3}\text{ eV} = 12.375 \text{ keV}$$

Hence, a photon has a greater energy than an electron for the same wavelength.

S21. (a) For the cut-off or threshold frequency, the energy $h\nu_0$ of the incident radiation must be equal to work function ϕ_0, so that

$$\nu_0 = \frac{\phi_0}{h} = \frac{2.74 \text{ eV}}{6.63 \times 10^{-34} \text{ Js}}$$

$$= \frac{2.14 \times 1.6 \times 10^{-19} \text{ J}}{6.63 \times 10^{-34} \text{ Js}} = 5.16 \times 10^{14} \text{ Hz.}$$

Thus, for frequencies less than this threshold frequency, no photoelectrons are ejected.

(b) Photocurrent reduces to zero, when maximum kinetic energy of the emitted photoelectrons equals the potential energy eV_0 by the retarding potential V_0. Einstein's Photoelectric equation is

$$eV_0 = h\nu - \phi_0 = \frac{hc}{\lambda} - \phi_0$$

or, $$\lambda = hc/(eV_0 + \phi_0)$$

$$= \frac{(6.63 \times 10^{-34} \text{ Js}) \times (3 \times 10^8 \text{ m/s})}{(0.60 \text{ eV} + 2.14 \text{ eV})}$$

$$= \frac{19.89 \times 10^{-26} \text{ Jm}}{(2.74 \text{ eV})}$$

$$\lambda = \frac{19.89 \times 10^{-26}}{2.74 \times 1.6 \times 10^{-19} \text{ J}} = 454 \text{ nm.}$$

S22. From Einstein's Photoelectric equation, we may write

$$\phi_0 = h\nu - \frac{1}{2} mv_{max}^2$$

For surface P, kinetic energy of photoelectrons is zero; while for plate Q, the photoelectrons have some kinetic energy, It follows that work function of surface P is greater than that of surface Q.

If the incident frequency is slightly reduced, the energy of incident photon will become less than the work function for surface P. Hence, photoelectric emission will not take place in case of surface P.

S23. In terms of wavelength of the incident radiation, Einstein's photoelectric equation is

$$\frac{h\nu}{\lambda} = \frac{hc}{\lambda_0} + \frac{1}{2} m v_{max}^2$$

(a) When $\lambda > \lambda_0$, $\frac{1}{2} m v_{max}^2$ is negative.

Hence, photo-emission will not occur, if $\lambda > \lambda_0$.

(b) When $\lambda < \lambda_0$, $\frac{1}{2} m v_{max}^2$ is positive.

Therefore, when $\lambda < \lambda_0$, photoemission will occur.

S24. For a particle, de Broglie wavelength, $\lambda = h/p$

Kinetic energy, $K = p^2/2m \Rightarrow P = \sqrt{2mK}$

Then, $\lambda = h/\sqrt{2mK}$

For the same kinetic energy K, the de Broglie wavelength associated with the particle is inversely proportional to the square root of their masses. A proton (^1_1H) is 1836 times massive than an electron and an α-particle (^4_2He) four times that of a proton.

Hence, α-particle has the shortest de Broglie wavelength.

S25. (a) **For the electron:** Mass $m = 9.11 \times 10^{-31}$ kg, speed $v = 5.4 \times 10^6$ m/s.

Then, momentum $p = m\,v = 9.11 \times 10^{-31}$ (kg) $\times 5.4 \times 10^6$ (m/s)

$p = 4.92 \times 10^{-24}$ kg m/s

de Broglie wavelength, $\lambda = h/p$

$$= \frac{6.63 \times 10^{-34} \text{ Js}}{4.92 \times 10^{-24} \text{ kg m/s}}$$

$\lambda = 0.135$ nm

(b) **For the ball:** Mass $m' = 0.150$ kg, speed $v' = 30.0$ m/s.

Then momentum $p' = m'v' = 0.150$ (kg) $\times$ 30.0 (m/s)

$p' = 4.50$ kg m/s

de Broglie wavelength $\lambda' = h/p'$

$$= \frac{6.63 \times 10^{\pm 34} \text{ Js}}{4.50 \times \text{kg m/s}}$$

$\lambda' = 1.47 \times 10^{-34}$ m

The de Broglie wavelength of electron is comparable with X-ray wavelengths. However, for the ball it is about 10^{-19} times the size of the proton, quite beyond experimental measurement.

S26. (a) The threshold frequency (ν_0) is equal to the intercept made by the graph on the frequency-axis. Thus,

$\nu_0 = 4.5 \times 10^{14}$ HZ

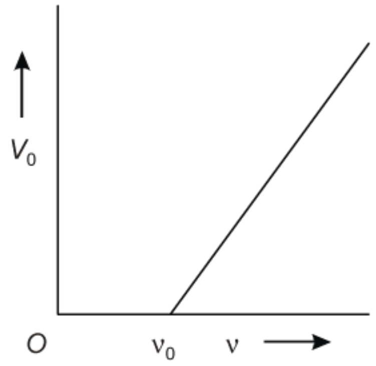
(b) Work function of the metal,

$\phi_0 = h\,\nu_0$

$= 6.62 \times 10^{-34} \times 4.5 \times 10^{14} = 2.98 \times 10^{-19}$ J

$$= \frac{2.98 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{1.86\ eV}.$$

S27. The graph between the radiation of stopping potential (or cut off voltage) and the frequency of the incident radiation is as shown in figure.



To find h : Now, Einstein's photoelectric equation:

$$h\nu - h\,\nu_0 = \frac{1}{2} m\, v_{max}^2$$

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

Where V_0 is the stopping potential. Therefore,

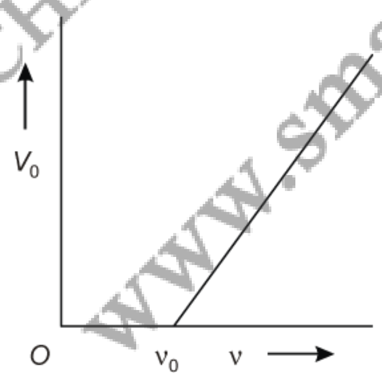
$$h = \frac{eV_0}{(\nu - \nu_0)}$$

From the graph, corresponding to a certain value of stopping potential, the value of frequency ν can be noted. Also noting the value of ν_0, the value of Planck's constant can be found.

S28. **Work function:** The minimum amount of energy required to eject an electron from a surface (without imparting any kinetic energy) is called ***work function*** of the surface.

Threshold frequency: The emission of photoelectrons takes place only when the frequency of the incident radiation is a certain critical value, characteristic of the metal. The critical value of frequency is known as the ***threshold frequency***.

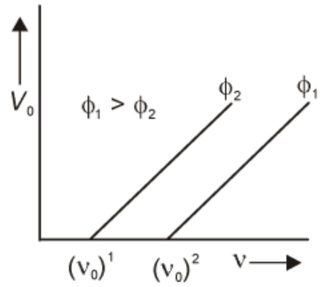
For graph between the stopping potential and frequency of incident radiation, as shown in figure.



Slope of the graph = h/e

S29. The graph showing the variation of stopping potential with the frequency of incident radiation for two different materials having work functions ϕ_1 and ϕ_2 is as shown in figure.

From Einstein's photoelectric equation, we have



$$h\nu = h\nu_0 + \frac{1}{2}mv_{max}^2 = h\nu_0 + eV_0$$

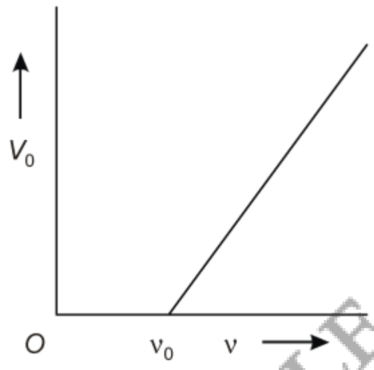
$$V_0 = \frac{h\nu}{e} - \frac{h\nu_0}{e}$$

Since ν is plotted along X-axis and V_0 along Y-axis; it represents a straight line.

(a) The slope of V_0 versus ν graph = h/e *i.e.*, it is a constant quantity and does not depend on the nature of the metal surface.

(b) The intercept on the ν-axis = $h\nu_0/e$ *i.e.*, it depends on the work function of the metal surface.

S30. Graph as shown in below



From Einstein's photoelectric equation, we have

$$h\nu = h\nu_0 + \frac{1}{2}mv_{max}^2 = h\nu_0 + eV_0$$

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

Since ν is plotted along X-axis and V_0 along Y-axis; comparing the equation (i) with the equation of a straight line, we have slope of V_0 versus ν graph = h/e

S31. Here, $\lambda = 330 \text{ nm} = 330 \times 10^{-9}$ m

The energy of photon of incident radiation

$$= \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{330 \times 10^{-9}} = 6.02 \times 10^{-19} \text{ J}$$

$$= \frac{6.02 \times 10^{-19}}{1.6 \times 10^{-19}} = 3.76\ eV$$

Since energy of photon of incident light is less than the work function (4.2 eV) of the metal, photoelectric emission will not take place.

S32.

$$\nu = \frac{c}{\lambda} = \frac{3\times10^{8}}{4{,}000\times10^{-10}} = 7.5 \times 10^{14}\ \text{Hz}$$

$$E = h\nu = 6.6 \times 10^{-34} \times 7.5 \times 10^{14} = 4.95 \times 10^{-19}\ \text{J}$$

$$= \frac{4.95\times10^{-19}}{1.6\times10^{-19}} = \mathbf{3.094\ eV}.$$

S33. Threshold frequency of the metal, $\nu_0 = 3.3 \times 10^{14}$ Hz

Frequency of light incident on the metal, $\nu = 8.2 \times 10^{14}$ Hz

Charge on an electron, $e = 1.6 \times 10^{-19}$ C

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Cut-off voltage for the photoelectric emission from the metal = V_0

The equation for the cut-off energy is given as:

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

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

$$= \frac{6.626\times10^{-34}\times(8.2\times10^{14} - 3.3\times10^{14})}{1.6\times10^{-19}}$$

$$= 2.0292\ \text{V}$$

Therefore, the cut-off voltage for the photoelectric emission is 2.0292 V.

S34. Here, $h = 6.62 \times 10^{-34}$ J s

de-Broglie wavelength electron:

Here, $m_e = 9.1 \times 10^{-31}\ kg$; $v_e = 10^5$ m s^{-1}

$$\therefore \quad \lambda_e = \frac{h}{m_e v_e} = \frac{6.62\times10^{-34}}{9.1\times10^{-31}\times10^{5}} = 7.27 \times 10^{-9}\ \text{m}$$

de-Broglie wavelength of proton:

Here, $m_p = 1.67 \times 10^{-27}$ kg ; v = 10^5 m s^{-1}

$$\lambda_p = \frac{h}{m_e v_e} = \frac{6.62\times10^{-34}}{1.67\times10^{-27}\times10^{5}} = \mathbf{3.96 \times 10^{-12} m}$$

S35.

$$\frac{1}{2} m v_{\max}^2 = h\nu - \phi_0$$

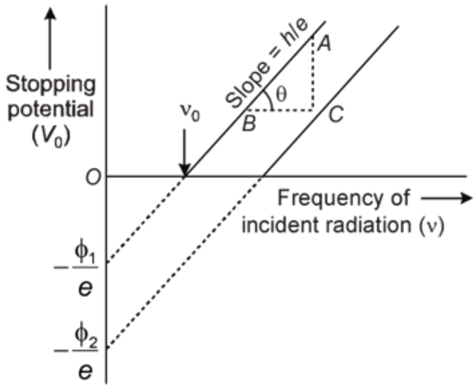
$= 6.625 \times 10^{-34} \times 10^{15} - 4 \times 1.602 \times 10^{-19}$

$= 6.625 \times 10^{-19} - 6.404 \times 10^{-19} = 0.217 \times 10^{-19}$ J

$\therefore \quad v_{max} = \sqrt{\dfrac{2 \times 0.217 \times 10^{-19}}{m}} = \sqrt{\dfrac{2 \times 0.217 \times 10^{-19}}{9.1 \times 10^{-31}}}$

$= \mathbf{2.18 \times 10^5\ m\ s^{-1}}$

S36. The variation of stopping potential with frequency of incident radiation is shown below.



(a) The slope of stopping potential versus frequency of incident radiation gives the ratio of Planck's constant (*h*) and electronic charge (*e*).

(b) Intercept on the frequency axis gives the value of threshold frequency ν_0.

Intercept on the potential axis = $-\dfrac{h\nu_0}{e}$

S37. Einstein's photoelectric equation,

$$KE_{max} = h\nu - \phi_0 \quad \text{... (i)}$$

where, ν = frequency of incident light beam

ϕ_0 = work function of metal

KE_{max} = maximum kinetic energy

$\because \quad \phi_0 = h\nu_0$

where, ν_0 is threshold frequency.

$\Rightarrow \quad KE_{max} = h\nu - h\nu_0$

$$KE_{max} = h(\nu - \nu_0) \quad \text{... (ii)}$$

This equation is obtained by considering the particle nature of electromagnetic radiation.

Three salient features observed in photoelectric effect and their explanation on the basis of Einstein's photoelectric equation is given below.

(a) ***Threshold frequency:*** For $KE_{max} \geq 0$,

$\Rightarrow \quad \nu \geq \nu_0$ [From eq. (ii)] *i.e.*, the phenomenon of photoelectric effect takes place when incident frequency is greater or equal to a minimum frequency (threshold frequency) ν_0 fixed for given metal.

(b) ***K.E.$_{max}$ of photoelectron:*** When incident frequency is greater than threshold frequency then KE_{max} of photoelectron is directly proportional to $(\nu - \nu_0)$ as

$$KE_{max} = h(\nu - \nu_0) \qquad \text{[From Eq. (ii)]}$$

$$\Rightarrow \quad KE_{max} \propto (\nu - \nu_0)$$

(c) ***Effect of intensity of light:*** The number of photon incident per unit time per unit area increases with the increase of intensity of incident light. More number of photons

facilitate ejection of more number of photoelectrons from metal surface leads to further increase of photocurrent till its saturation value is reached.

S38. Suppose that the particle of mass M (at rest) decays into two particles of masses m_1 and m_2, which start moving with velocities v_1 and v_2 respectively. Then, according to the principle of conservation of momentum,

$$m_1 v_1 + m_2 v_2 = M \times 0 \quad \text{or} \quad m_1 v_1 = -m_2 v_2$$

or
$$|m_1 v_1| = |m_2 v_2|$$

Now, de-Broglie wavelength of a particle,

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

Since $|m_1 v_1| = |m_2 v_2|$, the two particles will have equal de-Broglie wavelengths *i.e.*

$$\lambda_1/\lambda_2 = \mathbf{1}.$$

S39.
$$\frac{1}{2} mv_{max}^2 = \frac{hc}{\lambda} - \phi_0$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^8}{6.2 \times 10^{-6} \times 1.6 \times 10^{-19}} - 3.1$$

$$= \mathbf{3.1\ eV}.$$

S40.
$$\lambda_0 = \frac{hc}{\phi_0} = \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{2.35 \times 1.6 \times 10^{-19}} = 5.286 \times 10^{-7}\ \text{m} = 5286\ \text{Å}$$

$$\frac{1}{2} mv_{max}^2 = \frac{hc}{\lambda} - \phi_0$$

$$= \frac{6.625 \times 10^{-34} \times 3 \times 10^8}{1{,}000 \times 10^{-10} \times 1.6 \times 10^{-19}} - 2.35$$

$$= 12.42 - 2.35 = \mathbf{10.07\ eV}$$

S41. Here, $\frac{1}{2}m\,v_{max}{}^{2}$ = 1.56 eV = $1.56 \times 1.6 \times 10^{-19}$ J

λ_0 = 2,500 × 10^{-10} m and $h = 6.62 \times 10^{-34}$ J s

From Einstein's photoelectric equation, we have

$$\frac{h\,c}{\lambda} = \frac{h\,c}{\lambda_0} + \frac{1}{2}m\,v_{max}^2$$

or

$$\frac{1}{\lambda} = \frac{1}{\lambda_0} + \frac{\frac{1}{2}m\,v_{max}^2}{h\,c}$$

$$= \frac{1}{2{,}500 \times 10^{-10}} + \frac{1.56 \times 1.6 \times 10^{-19}}{6.625 \times 10^{-34} \times 3 \times 10^{8}}$$

$$= 4 \times 10^{6} + 1.256 \times 10^{6} = 5.526 \times 10^{6}$$

$\lambda = 1.903 \times 10^{-7}$ m = **1,903Å**

S42. Power of the sodium lamp, $P = 100$ W

Wavelength of the emitted sodium light,

$$\lambda = 589 \text{ nm} = 589 \times 10^{-9} \text{ m}$$

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Speed of light, $c = 3 \times 10^{8}$ m/s

(a) The energy per photon associated with the sodium light is given as:

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{589 \times 10^{-9}} = 3.37 \times 10^{-19} \text{ J}$$

$$= \frac{3.37 \times 10^{-19}}{1.6 \times 10^{-19}} = 2.11 \text{ eV}$$ [1 eV = 1.6×10^{-19} J]

(b) Number of photons delivered to the sphere = n

The equation for power can be written as:

$$P = nE$$

$\therefore$ $$n = \frac{P}{E}$$

$$= \frac{100}{3.37 \times 10^{-19}} = 2.96 \times 10^{20} \text{ Photon/s}$$

Therefore, every second, 2.96×10^{20} photons are delivered to the sphere.

S43. Wavelength of the monochromatic light, $\lambda = 632.8 \text{ nm} = 632.8 \times 10^{-9} \text{ m}$

Power emitted by the laser, $P = 9.42 \text{ mW} = 9.42 \times 10^{-3} \text{ W}$

Planck's constant, $h = 6.626 \times 10^{-34} \text{ Js}$

Speed of light, $c = 3 \times 10^{8} \text{ m/s}$

Mass of a hydrogen atom, $m = 1.66 \times 10^{-27} \text{ kg}$

(a) The energy of each photon is given as:

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

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} = 3.141 \times 10^{-19} \text{ J}$$

The momentum of each photon is given as:

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

$$= \frac{6.626 \times 10^{-34}}{632.8} = 1.047 \times 10^{-27} \text{ kg ms}^{-1}$$

(b) Number of photons arriving per second, at a target irradiated by the beam = n. Assume that the beam has a uniform cross-section that is less than the target area. Hence, the equation for power can be written as:

$$P = nE$$

$$\therefore \quad n = \frac{P}{E}$$

$$= \frac{9.42 \times 10^{-3}}{3.141 \times 10^{-19}} \approx 3 \times 10^{16} \text{ Photon/s}$$

(c) Momentum of the hydrogen atom is the same as the momentum of the photon,

$$P = 1.047 \times 10^{-27} \text{ kg ms}^{-1}$$

Momentum is given as:

$$P = mv$$

Where, v = Speed of the hydrogen atom

$$\therefore \quad v = \frac{p}{m}$$

$$= \frac{1.047 \times 10^{-27}}{1.66 \times 10^{-27}} = 0.621 \text{ m/s.}$$

S44. Now,

$$\frac{hc}{\lambda} = \phi_0 + eV_0$$

or

$$\phi_0 = \frac{hc}{\lambda} - eV_0$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{4{,}750 \times 10^{-10}} - 1.6 \times 10^{-19} \times 0.6$$

$$= 4.01 \times 10^{-19} - 0.96 \times 10^{-19} = 3.05 \times 10^{-19}\ \text{J}$$

$$= \frac{3.05 \times 10^{-19}}{1.6 \times 10^{-19}} = \mathbf{1.9\ eV}$$

Let λ' be the wavelength of the second source. Then,

$$\frac{hc}{\lambda'} = \phi_0 + eV_0 = 3.05 \times 10^{-19} + 1.6 + 10^{-19} \times 1.1$$

$\therefore$

$$\lambda' = \frac{hc}{4.81 \times 10^{-19}}$$

$$= \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{4.81 \times 10^{-19}} = 4.129 \times 10^{-7}\ \text{m}$$

$$= \mathbf{4{,}129\ Å}$$

There is no effect of magnetic field on photoelectric emission.

S45. (a) Energy of the incident photon, $E = h\nu = hc/\lambda$

$$E = (6.63 \times 10^{-34}\ \text{J s})\ (3 \times 10^{8}\ \text{m/s})/\lambda$$

$$= \frac{1.989 \times 10^{-25}\ \text{Jm}}{\lambda}$$

(i) For violet light, λ_1 = 390 nm (lower wavelength end)

Incident photon energy, $E_1 = \dfrac{1.989 \times 10^{-25}\ \text{Jm}}{390 \times 10^{-9}\ \text{m}} = 5.10 \times 10^{-19}\ \text{J}$

$$= \frac{5.10 \times 10^{-19}\ \text{J}}{1.6 \times 10^{-19}\ \text{J/eV}} = 3.19\ \text{eV}$$

(ii) For yellow-green light, λ_2 = 550 nm (average wavelength)

Incident photon energy, $E_2 = \dfrac{1.989 \times 10^{-25}\ \text{Jm}}{550 \times 10^{-9}\ \text{m}}$

$$= 3.62 \times 10^{-19}\ \text{J} = 2.26\ \text{eV}$$

(iii) For red light, λ_3 = 760 nm (higher wavelength end)

Incident photon energy, $E_3 = \dfrac{1.989 \times 10^{-25} \text{ Jm}}{760 \times 10^{-9} \text{ m}}$

$= 2.62 \times 10^{-19}$ J = 1.64 eV

(b) For a photoelectric device to operate, we require incident light energy E to be equal to or greater than the work function ϕ_0 of the material. Thus, the photoelectric device will operate with violet light (with E = 3.19 eV) photosensitive material Na (with ϕ_0 = 2.75 eV), K (with ϕ_0 = 2.30 eV) and Cs (with ϕ_0 = 2.14 eV). It will also operate with yellow-green light (with E = 2.26 eV) for Cs (with ϕ_0 = 2.14 eV) only. However, it will not operate with red light (with E = 1.64 eV) for any of these photosensitive materials.

S46. (a) Momentum of electron

= Momentum of photon

$$p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{1.50 \times 10^{-9}}$$

$$= 4.42 \times 10^{-25} \text{ kgms}^{-1}$$

(b) Energy of photon,

$$E_n = \frac{hc}{\lambda} = 1.326 \times 10^{-16} \text{ J}$$

(c) Kinetic energy of electron

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

$$E_k = \frac{(4.42 \times 10^{-25})^2}{2 \times 9.11 \times 10^{-31}} J$$

$$= \frac{1.953 \times 10^{-49}}{2 \times 9.11 \times 10^{-31}} = \mathbf{1.0723 \times 10^{-19} \text{ J}}.$$

S47. Einstein's photoelectric equation is

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

According to photon picture of electromagnetic radiation, if hν is the energy carried by a photon of frequency 'ν' it gets absorbed to

(a) overcome the work function of metal (ϕ_0)

(b) to impart maximum kinetic energy to the emitted electron (K_{max}).

Three Salient Features:

(a) Cut-off potential of the emitted electrons is proportional to 'ν'

(b) Maximum kinetic energy of emitted electron is independent of the intensity of incident radiation.

(c) Above threshold frequency emission of photoelectrons is instantaneous.

S48. Let m be the mass and v, the velocity of the electron. Then,

$$k = \frac{1}{2} m v^2$$

If λ is de Broglie wave length of the electron, then

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

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

$\therefore$ $$K = \frac{m^2 v^2}{2m} = \frac{h^2}{2m\lambda^2}$$

The rest mass energy of photon is zero. Therefore, energy of photon refers to kinetic energy of photon. Since de Broglie wave length of photon is also λ, kinetic energy of the photon is given by

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

$\therefore$ $$\frac{K'}{K} = \frac{hc}{\lambda} \times \frac{2m\lambda^2}{h^2} = \frac{2mc\lambda}{h}$$

Here, $h = 6.62 \times 10^{-34}$ J s, m = 9.1×10^{-31} kg,
$c = 3 \times 10^8$ m s^{-1} and $\lambda = 0.5$ Å $= 0.5 \times 10^{-10}$ m

$$\frac{K'}{K} = \frac{2 \times 9.1 \times 10^{-31} \times 3 \times 10^8 \times 0.5 \times 10^{-10}}{6.6 \times 10^{-34}} = \mathbf{41.4}$$

S49. When the standing wave is formed in a distance 2 Å:

Suppose that in the distance 2 Å, n loops of the standing wave are formed. Then,

$$n \times (\lambda/2) = 2\text{Å}$$

When the standing wave is formed in a distance 2.5 Å:

Now, in the distance 2.5 Å, $(n+1)$ loops of the standing wave will be formed. Therefore,

$$(n+1) \times (\lambda / 2) = 2.5\ \text{Å}$$

Subtracting the equation (i) from (ii), we have

$$(n + 1) \times (\lambda/2) - n \times (\lambda/2) = 2.5 - 2$$

or $$\lambda = 2 \times 0.5 = 1\ \text{Å} = 10^{-10}\ \text{m}$$

Now, de-Broglie wavelength of the electrons given by

$$\lambda = \frac{h}{\sqrt{2\,m\,E}}$$

or $$E = \frac{h^2}{2\,m\,\lambda^2} = \frac{(6.62 \times 10^{-34})}{2 \times 9.1 \times 10^{-31} \times (10^{-10})^2}$$

$$= 2.41 \times 10^{-17}\text{J} = \frac{2.41 \times 10^{-17}}{1.6 \times 10^{-19}} = \mathbf{150.63\ eV}$$

S50. ***Cut-off voltage:*** The minimum negative voltage (v_0) applied an anode plate with respect to the cathode for which photocurrent in the circuit reduces to zero.

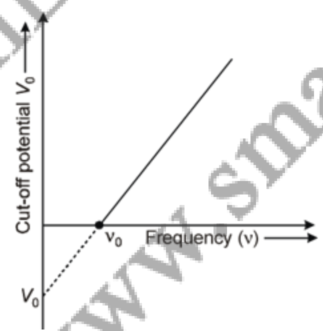
Threshold frequency: The minimum frequency of incident radiation which is required for photoelectric effect or the ejection of photoelectrons from metal surface.

Einstein's equation,

$$h\nu = h\nu_0 + \text{K.E.}_{max} = h\nu_0 + eV_0$$

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

The variation of cut-off potential with frequency of incident radiation is shown below.



From this graph, we can calculate the value of threshold frequency (point of intersection of frequency axis) and stopping potential (point of intersection on potential axis).

S51. (a) From de Broglie matter wave equation,

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

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

Here, $\lambda = 0.135 \times 10^{-9}$ m,

$v = 5 \times 10^{6}$ m/s

$$\therefore \quad m = \frac{6.63 \times 10^{-34}}{0.135 \times 10^{-9} \times 5 \times 10^{6}}$$

$$= 9.82 \times 10^{-31} \text{ kg}$$

(b) This wavelength 0.135 nm falls in the region of X-ray of electromagnetic spectrum.

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Q1. What is the de Broglie wavelength associated with an electron, accelerated through a potential differnece of 100 volts?

Q2. The energy and momentum of an electron are related to the frequency and wavelength of the associated matter wave by the relations:

$$E = h\nu, \quad p = \frac{h}{\lambda}$$

But while the value of λ is physically significant, the value of ν (and therefore, the value of the phase speed $\nu\lambda$) has no physical significance. Why?

Q3. Every metal has a definite work function. Why do all photoelectrons not come out with the same energy if incident radiation is monochromatic? Why is there an energy distribution of photoelectrons?

Q4. Why should gases be insulators at ordinary pressures and start conducting at very low pressures?

Q5. What is so special about the combination e/m? Why do we not simply talk of e and m separately?

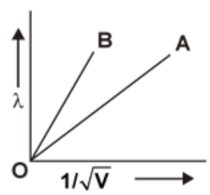
Q6. Quarks inside protons and neutrons are thought to carry fractional charges [(+ 2/3)e; (– 1/3)e]. Why do they not show up in Millikan's oil-drop experiment?

Q7. An electron and alpha particle have the same de-Broglie wavelength associated with them. How are their kinetic energies related to each other?

Q8. What happens to the wavelength of a photon after it collides with an electron?

Q9. At what angle of incidence should a light beam strike a glass slab of refractive index $\sqrt{3}$, such that the reflected and the refracted rays are perpendicular to each other?

Q10. Two lines, *A* and *B*, in the plot given below show the variation of de-Broglie wavelength, λ versus $1/\sqrt{V}$, where *V* is the accelerating potential difference, for two particles carrying the same charge. Which one of two represents a particle of smaller mass?



Q11. de-Broglie wavelength associated with an electron accelerated through a potential difference *V* is λ. What will be its wavelength when the accelerating potential is increased to 4 V?

Q12. Calculate the de-Broglie wavelength for electron moving with speed of $6 \times 10^5\ m\,s^{-1}$.

Q13. Calculate the momentum of electrons; if their wavelength is 2 Å. Given that Planck's constant, $h = 6.626 \times 10^{-34}$ J s; mass of electron, $m = 9.1 \times 10^{-31}$ kg.

Q14. Why was Davisson and Germer experiment with electrons performed?

Q15. Show graphically how the stopping potential for a given photosensitive surface varies with frequency of incident radiations?

Q16. For a given photosensitive material and with a source of constant frequency of incident radiation. How does the photocurrent vary with the intensity of incident light?

Q17. Ultraviolet radiations of different frequencies ν_1 and ν_2 are incident on two photosensitive materials having work functions ϕ_1 and ϕ_2 ($\phi_1 > \phi_2$) respectively. The kinetic energy of the emitted electrons is same in both the cases. Which one of the two radiations will be at the higher frequency?

Q18. 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.

Q19. The stopping potential in an experiment on photoelectric effect is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted?

Q20. 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: (a) red light, and (b) blue light?

Q21. An electron and alpha particle have the same kinetic energy. How are the de-Broglie wavelength associated with them related?

Q22. How will the photoelectric current change on decreasing the wavelngth of incident radiation for a given photosensitive material?

Q23. Light of intensity 10^{-5} W m^{-2} falls on a sodium photo-cell of surface area 2 cm^2. Assuming that the top 5 layers of sodium absorb the incident energy, estimate time required for photoelectric emission in the wave-picture of radiation. The work function for the metal is given to be about 2 eV. What is the implication of your answer?

Q24. In an accelerator experiment on high-energy collisions of electrons with positrons, a certain event is interpreted as annihilation of an electron-positron pair of total energy 10.2 *BeV* into two γ-rays of equal energy. What is the wavelength associated with each γ-ray? (1 *BeV* = 10^9 eV)

Q25. An electron gun with its collector at a potential of 100 V fires out electrons in a spherical bulb containing hydrogen gas at low pressure (~ 10^{-2} mm of Hg). A magnetic field of 2.83×10^{-4} T curves the path of the electrons in a circular orbit of radius 12.0 cm. (The path can be viewed because the gas ions in the path focus the beam by attracting electrons, and emitting light by electron capture; this method is known as the 'fine beam tube' method. Determine e/m from the data.

Q26. Show that the wavelength of electromagnetic radiation is equal to the de Broglie wavelength of its quantum (photon).

Q27. What is the de Broglie wavelength of a nitrogen molecule in air at 300 K? Assume that the molecule is moving with the root-mean square speed of molecules at this temperature. (Atomic mass of nitrogen = 14.0076 u)

Q28. Find the (a) maximum frequency, and (b) minimum wavelength of X-rays produced by 30 kV electrons.

Q29. Calculate the (a) momentum, and (b) de Broglie wavelength of the electrons accelerated through a potential difference of 56 V.

Q30. Obtain de-Broglie wavelength of an electron of kinetic energy 150 eV. Given mass of electron, $m = 9.1 \times 10^{-31}$ kg; charge on electron, $e = 1.6 \times 10^{-19}$ C and Planck's constant, $h = 6.62 \times 10^{-34}$ Js.

Q31. X-rays of wavelength λ fall on an 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 $\sqrt{h\lambda/(2mc)}$

Q32. A particle is moving three times as fast as an electron. The ratio of the de Broglie wavelength of the particle to that of the electron is 1.813×10^{-4}. Calculate the particle's mass and identify the particle.

Q33. Compute the typical de Broglie wavelength of an electron in a metal at 27 °C and compare it with the mean separation between two electrons in a metal which is given to be about 2×10^{-10} m.

[*Note:* Exercises 11.35 and 11.36 reveal that while the wave-packets associated with gaseous molecules under ordinary conditions are non-overlapping, the electron wave-packets in a metal strongly overlap with one another. This suggests that whereas molecules in an ordinary gas can be distinguished apart, electrons in a metal cannot be distinguished apart from one another. This indistinguishibility has many fundamental implications which you will explore in more advanced Physics courses.]

Q34. A proton and an α-particle are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths.

Q35. Show graphically, the variation of the de-Broglie wavelength (λ) with the potential (V) through which an electron is accelerated from rest.

Q36. 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?

Q37. An electron and a photon have the same de-Broglie wavelength. Which one of these have higher kinetic energy?

Q38. An electron and a proton are moving with the same speed. Which will have more wavelength?

Q39. An electron and a photon each have a wave-length of 4 nm. Find (a) their moment, (b) the energy of the photon and (c) the kinetic energy of the electron.

Q40. Calculate the momentum of electrons; if their wavelength is 2 Å. Given that Planck's constant, $h = 6.626 \times 10^{-34}$ Js; mass of electron, $m = 9.1 \times 10^{-31}$ kg.

Q41. Briefly explain the dual nature of radiation.
What do you understand by the phrase dual nature of radiation?

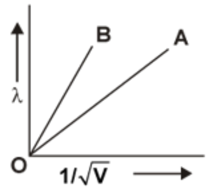
Q42. State de-Broglie hypothesis.

Q43. Find de-Broglie wavelength of an electron, if it has accelerated through a potential deference of 5 kV. Given mass of electron, $m = 9.1 \times 10^{-31}$ kg; Charge on electron $e = 1.6 \times 10^{-19}$ C and Planck's constant, $h = 6.62 \times 10^{-34}$ Js.

Q44. The two lines marked *A* and *B* in figure show a plot of de-Broglie wavelength (λ) as a function of $1/\sqrt{V}$ (V is the accelerating potential) for two nuclei $_1H^2$ and $_1H^3$.

(a) What does the slope of the lines represent?

(b) Identify, which lines correspond to these nuclei?



Q45. An electron and a photon each have a de-Broglie wavelength of 1 nm. Write the ratio of their linear moments. Compare the energy of the photon with the kinetic energy of the electron.

Q46. An electron and alpha particle have the same de-Broglie wavelength associated with them. How are their kinetic energies related to each other?

Q47. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photo-electrons emitted from this surface have de-Broglie wavelength λ_1, prove that

$$\lambda = \frac{2mc}{h}\lambda_1^2$$

Q48. An electron in a hydrogen-like atom is in excited state. It has a total energy of – 3.4 eV. Calculate (a) the kinetic energy and (b) the de-Broglie wavelength of the electron. Given that Planck's constant, $h = 6.62 \times 10^{-34}$ J s.

Q49. Calculate de-Broglie wavelength of an electron beam accelerated through a potential difference of 60 V.

Q50. What is the (i) de Broglie wavelength and (ii) momentum of an electron with kinetic energy of 120 eV.

Q51. Calculate de-Broglie wavelength of a beam of electrons, accelerated through a potential a difference of 10 kV.

Q52. The wavelength of light from the spectral emission line of sodium is 589 nm. Find the kinetic energy at which (a) an electron, and (b) a neutron, would have the same de Broglie wavelength.

Q53. What is the (a) momentum, (b) speed, and (c) de Broglie wavelength of an electron with kinetic energy of 120 eV.

Q54. What is the de Broglie wavelength of (a) a bullet of mass 0.040 kg travelling at the speed of 1.0 km/s, (b) a ball of mass 0.060 kg moving at a speed of 1.0 m/s, and (c) a dust particle of mass 1.0 × 10"9 kg drifting with a speed of 2.2 m/s?

Q55. (a) For what kinetic energy of a neutron will the associated de Broglie wavelength be 1.40×10^{-10} m?

(b) Also find the de Broglie wavelength of a neutron, in thermal equilibrium with matter, having an average kinetic energy of (3/2) *kT* at 300 K.

Q56. (a) Estimate the speed with which electrons emitted from a heated emitter of an evacuated tube impinge on the collector maintained at a potential difference of 500 V with respect to the emitter. Ignore the small initial speeds of the electrons. The *specific charge* of the electron, *i.e.*, its e/m is given to be 1.76×10^{11} C kg^{-1}.

(b) Use the same formula you employ in (a) to obtain electron speed for an collector potential of 10 MV. Do you see what is wrong? In what way is the formula to be modified?

Q57. (a) A monoenergetic electron beam with electron speed of 5.20×10^{6} m s^{-1} is subject to a magnetic field of 1.30×10^{-4} T normal to the beam velocity. What is the radius of the circle traced by the beam, given e/m for electron equals 1.76×10^{11} C kg^{-1}.

(b) Is the formula you employ in (a) valid for calculating radius of the path of a 20 MeV electron beam? If not, in what way is it modified?

[*Note:* Exercises 11.20(b) and 11.21(b) take you to relativistic mechanics which is beyond the scope of this book. They have been inserted here simply to emphasise the point that the formulas you use in part (a) of the exercises are not valid at very high speeds or energies. See answers at the end to know what 'very high speed or energy' means.]

Q58. Estimating the following two numbers should be interesting. The first number will tell you why radio engineers do not need to worry much about photons! The second number tells you why our eye can never 'count photons', even in barely detectable light.

(a) The number of photons emitted per second by a Medium wave transmitter of 10 kW power, emitting radiowaves of wavelength 500 m.

(b) The number of photons entering the pupil of our eye per second corresponding to the minimum intensity of white light that we humans can perceive (~ 10^{-10} W m^{-2}). Take the area of the pupil to be about 0.4 cm^2, and the average frequency of white light to be about 6×10^{14} Hz.

Q59. Obtain the de Broglie wavelength of a neutron of kinetic energy 150 eV. As you have seen in Exercise 11.31, an electron beam of this energy is suitable for crystal diffraction experiments. Would a neutron beam of the same energy be equally suitable? Explain. ($m_n = 1.675 \times 10^{-27}$ kg)

Obtain the de Broglie wavelength associated with thermal neutrons at room temperature (27 °C). Hence explain why a fast neutron beam needs to be thermalised with the environment before it can be used for neutron diffraction experiments.

Q60. An electron and a photon each have a wavelength of 2 nm. Find
(a) their moment
(b) the energy of the photon
(c) the kinetic energy of the electron.

Q61. Find the de-Broglie wavelength of the wave associated with an electron in a metal at 27°C and compare the de-Broglie wavelength of the electron with mean separation *d* between the two electrons, which is given to be about 2 Å.

Q62. A particle is moving with a speed three times as that of an electron. if the ratio of de-Broglie wavelength of the wave associated with the particle to that with the electron is 1.813×10^{-4}, find the mass of the particle. Can you identity the particle? Given that mass of the electron = 9.1×10^{-31} kg.

Q63. Find the typical de Broglie wavelength associated with a He atom in helium gas at room temperature (27 °C) and 1 atm pressure; and compare it with the mean separation between two atoms under these conditions.

Q64. (a) Ultraviolet light of wavelength 2271 Å from a 100 W mercury source is incident on a photocell made of molybdenum metal. If the stopping potential is 1.3 V, estimate the work function of the metal.

(b) How would the photocell respond to high intensity (10^5 Wm^{-2}) red light of wavelength 6328 Å produced by He-Ne laser?

Q65. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (a) greater value of de Broglie wavelength associated with it, and (b) less kinetic energy? Justify your answers.

Q66. (a) Determine the de Broglie wavelength of a proton whose kinetic energy is equal to of a proton 1836 times that of electron.

(b) In which region of electromagnetic spectrum does this wavelength lie?

Q67. Sketch a graph between frequency of incident radiations and stopping potential for a given photosensitive material. What information can be obtained from the value of the intercept on the potential axis?

Q68. Sketch the graphs showing the variation of stopping potential with frequency of incident radiations for two photosensitive materials *A* and *B* having threshold frequencies $\nu_0 > \nu_0'$ respectively.

(a) Which of the two metals, *A* or *B* has higher work function?

(b) What information do you get from the slope of the graphs?

(c) What does the value of the intercept of graph '*A*' on the potential axis represent?

Q69. Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Express the de Broglie wavelength associated with electron in terms of the accelerating voltage *V*. An electron and a proton have the same kinetic energy. Which of the two will have larger wavelength and why?

Q70. Define the terms 'Threshold frequency' and 'stopping potential' in the study of photoelectric emission. Explain briefly the reasons why wave theory of light is not able to explain the observed features in photoelectric effect?

Q71. Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $\nu_2 > \nu_1$ of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer.

Q72. When a surface 1 cm thick is illuminated with light of wavelength λ, the stopping potential is V_0, but when the same surface is illuminated by light of wavelength 3λ, the stopping potential is $\frac{V_0}{6}$. Find threshold wavelength metallic surface.

Q73. A mercury lamp is a convenient source for studying frequency dependence of photoelectric emission, since it gives a number of spectral lines ranging from the UV to the red end of the visible spectrum. In our experiment with rubidium photo-cell, the following lines from a mercury source were used:

$$\lambda_1 = 3650 \text{ Å}, \quad \lambda_2 = 4047 \text{ Å}, \quad \lambda_3 = 4358 \text{ Å}, \quad \lambda_4 = 5461 \text{ Å}, \quad \lambda_5 = 6907 \text{ Å},$$

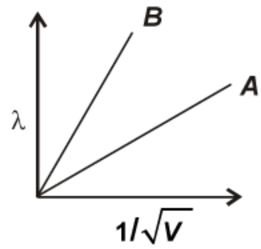
The stopping voltages, respectively, were measured to be:

$$V_{01} = 1.28\text{ V}, \quad V_{02} = 0.95\text{ V}, \quad V_{03} = 0.74\text{ V}, \quad V_{04} = 0.16\text{ V}, \quad V_{05} = 0\text{ V}$$

Determine the value of Planck's constant *h*, the threshold frequency and work function for the material.

[*Note:* You will notice that to get *h* from the data, you will need to know *e* (which you can take to be 1.6×10^{-19} C). Experiments of this kind on Na, Li, K, etc. were performed by Millikan, who, using his own value of *e* (from the oil-drop experiment) confirmed Einstein's photoelectric equation and at the same time gave an independent estimate of the value of *h*.]

Q74. Obtain the expression for the wavelength of de Broglie wave associated with an electron accelerated from rest through a potential difference *V*. The two lines *A* and *B* shown in difference *V*. The two lines *A* and *B* shown in the graph plot de Broglie wavelength (λ) as a function of $1/\sqrt{V}$ (*V* is the accelerating potential) fro two particles having the same charge. Which of the two represents the particle of heavier mass?



Q75. (a) Ultraviolet light of wavelength 2271 Å from a 100 W mercury source is incident on a photocell made of molybednum metal. If the stopping potential is 1.3 V, estimate the work function of the metal.

(b) How would the photocell respond to high intensity? (10^5 W/m^2) red light of wavelength 6328 Å produced by a He-Ne laser?

Q76. Derive the expression for the de Broglie wavelength of an electron moving under a potential difference of *V* volt.

Describe Davisson and Germer experiment to establish the wave nature of electrons. Draw a labelled diagram of the apparatus used.

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S1. Accelerating potential $V = 100$ V. The de Broglie wavelength λ is

$$\lambda = h/p = \frac{1.227}{\sqrt{V}} \text{ nm}$$

$$\lambda = \frac{1.227}{\sqrt{100}} \text{ nm} = 0.123 \text{ nm}$$

The de Broglie wavelength associated with an electron in this case is of the order of X-ray wavelengths.

S2. The absolute value of energy of a particle is arbitrary within the additive constant. Hence, wavelength (λ) is significant, but the frequency (ν) associated with an electron has no direct physical significance.

Therefore, the product $\nu\lambda$ (phase speed) has no physical significance.

Group speed is given as:

$$\nu_G = \frac{d\nu}{dk}$$

$$= \frac{d\nu}{d\left(\frac{1}{\lambda}\right)} = \frac{dE}{dp} = \frac{d\left(\frac{p^2}{2m}\right)}{dp} = \frac{p}{m}$$

This quantity has a physical meaning.

S3. The work function of a metal is the minimum energy required for a conduction electron to get out of the metal surface. All the electrons in an atom do not have the same energy level. When a ray having some photon energy is incident on a metal surface, the electrons come out from different levels with different energies. Hence, these emitted electrons show different energy distributions.

S4. At atmospheric pressure, the ions of gases have no chance of reaching their respective electrons because of collision and recombination with other gas molecules. Hence, gases are insulators at atmospheric pressure. At low pressures, ions have a chance of reaching their respective electrodes and constitute a current. Hence, they conduct electricity at these pressures.

S5. These relations include e (electric charge), v (velocity), m (mass), V (potential), r (radius), and B (magnetic field). These relations give the value of velocity of an electron as $\left(v = \sqrt{2V\left(\frac{e}{m}\right)}\right)$ and $\left(v = Br\left(\frac{e}{m}\right)\right)$ respectively.

It can be observed from these relations that the dynamics of an electron is determined not by e and m separately, but by the ratio e/m.

S6. Quarks inside protons and neutrons carry fractional charges. This is because nuclear force increases extremely if they are pulled apart. Therefore, fractional charges may exist in nature; observable charges are still the integral multiple of an electrical charge.

The basic relations for electric field and magnetic field are $\left(eV = \frac{1}{2}mv^2\right)$ and $\left(eBv = \frac{mv^2}{r}\right)$ respectively.

Here, V = potential through which e^- is accelerated.

S7.

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

de-Broglie wavelength, $\lambda = \frac{h}{p}$

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

We have,

$$\frac{h}{\sqrt{2m_e E_{ke}}} = \frac{h}{\sqrt{2m_\alpha E_{k\alpha}}}$$

$$\frac{m_e}{m_\alpha} = \frac{E_{k\alpha}}{E_{ke}}$$

As $m_\alpha > m_e$

$$E_{ke} > E_{k\alpha}.$$

S8. Wavelength of a photon increases.

S9. $\mu = \tan i_p$ under the given condition. Therefore, $i_p = \tan^{-1}(\sqrt{3}) = \pi/3$ radian.

S10. As,

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

$$\frac{\lambda}{1/\sqrt{V}} = \frac{h}{\sqrt{2me}}$$

i.e., slope $\propto \frac{1}{\sqrt{m}}$

Thus, $m_B < m_A$.

S11. $\lambda = \dfrac{12.27}{\sqrt{V}}$ Å .

Thus, on increasing accelerating potential to 4 V, de-Broglie wavelength will reduce to half.

S12. Given, $v = 6 \times 10^5\,\text{m s}^{-1}$. Taking mass of electron = 9.1×10^{-31} Kg

The de-Broglie wavelength associated with the electron is given by

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

Taking $h = 6.626 \times 10^{-34}$ J s and $m = 9.1 \times 10^{-31}$ kg, we have

$$\lambda = \frac{6.62 \times 10^{-34}}{9.1 \times 10^{-31} \times 6 \times 10^5} = 12.12 \times 10^{-10}\,\text{m} = \mathbf{12.12\,Å}.$$

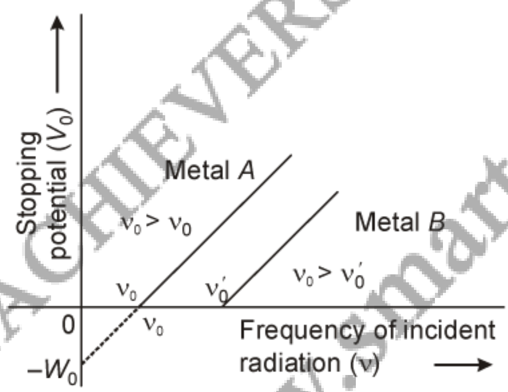
S13. Here, $\lambda = 2\,Å = 2 \times 10^{-10}$ m; $h = 6.626 \times 10^{-34}$ J s; $m = 9.1 \times 10^{-31}$ kg

Momentum of the electron,

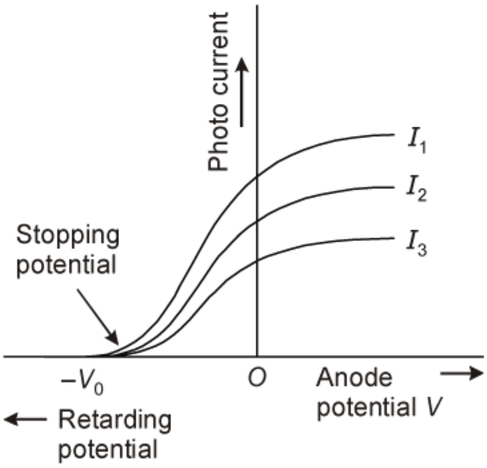
$$p = \frac{h}{\lambda} = \frac{6.626 \times 10^{-34}}{2 \times 10^{-10}} = \mathbf{3.313 \times 10^{-24}\,kg\,m\,s^{-1}},$$

S14. Davisson and Germer experiment was performed to demonstrate the wave nature of electrons.

S15. The variation of stopping potential with frequencies of incident radiations is shown below.



S16. The variation of photocurrent with collector plate potential for different intensities at constant frequency is shown below.



S17. K.E. of photo electrons, K.E. = $h\nu - \phi$

Here, kinetic energies of electrons in both the cases is same.

$$\therefore \qquad (K.E.)_1 = (K.E.)_2$$

$$(h\nu_1 - \phi_1) = (h\nu_2 - \phi_2)$$

Here, $\phi_1 > \phi_2$

$$\nu_1 > \nu_2$$

S18. The charged particle as a mass m and charge q. The kinetic energy of the particle is equal to the work done on it by the electric field.

$$K = qV$$

$$\Rightarrow \qquad \frac{1}{2}mv^2 = qV$$

$$\Rightarrow \qquad \frac{p^2}{2m} = qV \quad \Rightarrow \quad p = \sqrt{2mqV}$$

As, $\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2mqV}}$

S19. K.E. of the electron $e^- = 1.5\,\text{eV}$.

S20. (a) No. (b) Yes.

S21. $\lambda \propto \dfrac{1}{\sqrt{m}}$ and $m_\alpha > m_e$, So, $\lambda_\alpha < \lambda_e$.

S22. It remains same.

S23. Intensity of incident light, $I = 10^{-5}\,\text{W m}^{-2}$

Surface area of a sodium photocell, $A = 2\ \text{cm}^2 = 2 \times 10^{-4}\ \text{m}^2$

Incident power of the light, $P = I \times A$

$= 10^{-5} \times 2 \times 10^{-4}$

$= 2 \times 10^{-9}\,W$

Work function of the metal, $\phi_0 = 2\,eV$

$= 2 \times 1.6 \times 10^{-19}$

$= 3.2 \times 10^{-19}\,J$

Number of layers of sodium that absorbs the incident energy, $n = 5$

We know that the effective atomic area of a sodium atom, A_e is $10^{-20}\,m^2$.

Hence, the number of conduction electrons in n layers is given as:

$$n' = n \times \frac{A}{A_e}$$

$$= 5 \times \frac{2 \times 10^{-4}}{10^{-20}} = 10^{17}$$

The incident power is uniformly absorbed by all the electrons continuously. Hence, the amount of energy absorbed per second per electron is:

$$E = \frac{P}{n'}$$

$$= \frac{2 \times 10^{-9}}{10^{17}} = 2 \times 10^{-26}\ J/s$$

Time required for photoelectric emission:

$$t = \frac{\phi_0}{E}$$

$$= \frac{3.2 \times 10^{-19}}{2 \times 10^{-26}} = 1.6 \times 10^{7}\ s \approx 0.507\ \text{Years}$$

The time required for the photoelectric emission is nearly half a year, which is not practical. Hence, the wave picture is in disagreement with the given experiment.

S24. Total energy of two γ-rays:

$E = 10.2\ BeV$

$= 10.2 \times 10^{9}\ eV$

$= 10.2 \times 10^{9} \times 1.6 \times 10^{-10}\ J$

Hence, the energy of each γ-ray:

$$E' = \frac{E}{2}$$

$$= \frac{10.2 \times 1.6 \times 10^{-10}}{2} = 8.16 \times 10^{-10}\ \text{J}$$

Planck's constant, $h = 6.626 \times 10^{-34}$ Js

Speed of light, $c = 3 \times 10^{8}$ m/s

Energy is related to wavelength as:

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

$$\therefore \quad \lambda = \frac{hc}{E'}$$

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{8.16 \times 10^{-10}} = 2.436 \times 10^{-16}\ \text{m}$$

Therefore, the wavelength associated with each γ-ray is 2.436×10^{-16} m.

S25. Potential of an anode, V = 100 V

Magnetic field experienced by the electrons, $B = 2.83 \times 10^{-4}$ T

Radius of the circular orbit r = 12.0 cm = 12.0×10^{-2} m

Mass of each electron = m

Charge on each electron = e

Velocity of each electron = v

The energy of each electron is equal to its kinetic energy, *i.e.*,

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

$$v^2 = \frac{2eV}{m} \quad \text{... (i)}$$

It is the magnetic field, due to its bending nature, that provides the centripetal force $\left(F = \frac{mv^2}{r}\right)$ for the beam. Hence, we can write:

Centripetal force = Magnetic force

$$\frac{mv^2}{r} = evB$$

$$eB = \frac{mv}{r}$$

$$v = \frac{eBr}{m} \qquad \dots \text{(ii)}$$

Putting the value of v in Eq. (i), we get:

$$\frac{2eV}{m} = \frac{e^2B^2r^2}{m^2}$$

$$\frac{e}{m} = \frac{2eV}{B^2m^2}$$

$$= \frac{2 \times 100}{(2.83 \times 10^{-4})^2 \times (12 \times 10^{-2})^2} = 1.73 \times 10^{11}\ \text{C Kg}^{-1}$$

Therefore, the specific charge ratio (e/m) is $1.73 \times 10^{11}\ \text{C Kg}^{-1}$.

S26. The momentum of a photon having energy ($h\nu$) is given as:

$$p = \frac{h\nu}{c} = \frac{h}{\lambda}$$

$$\lambda = \frac{h}{p} \qquad \dots \text{(i)}$$

Where, λ = Wavelength of the electromagnetic radiation

c = Speed of light

h = Planck's constant

De Broglie wavelength of the photon is given as:

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

But $p = mv$

$$\therefore \quad \lambda = \frac{h}{p} \qquad \dots \text{(ii)}$$

Where, m = Mass of the photon

v = Velocity of the photon

Hence, it can be inferred from equations (i) and (ii) that the wavelength of the electromagnetic radiation is equal to the de Broglie wavelength of the photon.

S27. Temperature of the nitrogen molecule, T = 300 K

Atomic mass of nitrogen = 14.0076 u

Hence, mass of the nitrogen molecule, $m = 2 \times 14.0076 = 28.0152$ u

But 1 u = 1.66×10^{-27} kg

$\therefore$ $m = 28.0152 \times 1.66 \times 10^{-27}$ kg

Planck's constant, $h = 6.63 \times 10^{-34}$ Js

Boltzmann constant, $k = 1.38 \times 10^{-23}\ \text{J K}^{-1}$

We have the expression that relates mean kinetic energy $\left(\frac{3}{2}kT\right)$ of the nitrogen molecule with the root mean square speed ($v_{r.m.s.}$) as:

$$\frac{1}{2}mv_{r.m.s}^2 = \frac{3}{2}kT \qquad [K = \text{Boltzman constant}]$$

$$v_{r.m.s.} = \sqrt{\frac{3kT}{m}}$$

Hence, the de Broglie wavelength of the nitrogen molecule is given as:

$$\lambda = \frac{h}{mv_{r.m.s}} = \frac{h}{\sqrt{3mkT}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{3 \times 28.0152 \times 1.66 \times 10^{-27} \times 1.38 \times 10^{-23} \times 300}}$$

$$= 0.028 \times 10^{-9}\,\text{m} = 0.028\,\text{nm}$$

Therefore, the de Broglie wavelength of the nitrogen molecule is 0.028 nm.

S28. Potential of the electrons, $V = 30\,\text{kV} = 3 \times 10^4\,\text{V}$

Hence, energy of the electrons, $E = 3 \times 10^4\,\text{eV}$

Where, e = Charge on an electron

$= 1.6 \times 10^{-19}\,\text{C}$

(a) Maximum frequency produced by the X-rays = ν

The energy of the electrons is given by the relation:

$$E = h\nu$$

Where, h = Planck's constant

$= 6.626 \times 10^{-34}\,\text{Js}$

$$\therefore \quad \nu = \frac{E}{h}$$

$$= \frac{1.6 \times 10^{-19} \times 3 \times 10^4}{6.626 \times 10^{-34}}$$

$$= 7.24 \times 10^{18}\,\text{Hz}$$

Hence, the maximum frequency of X-rays produced is 7.24×10^{18} Hz.

(b) The minimum wavelength produced by the X-rays is given as:

$$\lambda = \frac{c}{\nu}$$

$$= \frac{3 \times 10^8}{7.24 \times 10^{18}}$$

$$= 4.14 \times 10^{-11}\ \text{m} = 0.0414\ \text{nm}$$

Hence, the minimum wavelength of X-rays produced is 0.0414 nm.

S29. Potential difference, $V = 56$ V

Planck's constant, $h = 6.6 \times 10^{-19}$ Js

Mass of an electron, $m = 9.1 \times 10^{-31}$ kg

Charge on an electron, $e = 1.6 \times 10^{-19}$ C

(a) At equilibrium, the kinetic energy of each electron is equal to the stopping potential, *i.e.*, we can write the relation for velocity (v) of each electron as:

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

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

$$\therefore \quad v = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 56}{9.1 \times 10^{-31}}}$$

$$= \sqrt{19.69 \times 10^{12}} = 4.44 \times 10^6\ \text{m/s}$$

The momentum of each accelerated electron is given as:

$$p = mv$$

$$= 9.1 \times 10^{-31} \times 4.44 \times 10^6$$

$$= 4.04 \times 10^{-24}\ \text{kg m s}^{-1}$$

Therefore, the momentum of each electron is 4.04×10^{-24} kg m s^{-1}.

(b) De Broglie wavelength of an electron accelerating through a potential V, is given by the relation:

$$\lambda = \frac{12.27}{\sqrt{V}}\ \text{Å}$$

$$= \frac{12.27}{\sqrt{56}} \times 10^{-19}\ \text{m} = 0.1639\ \text{nm}$$

Therefore, the de Broglie wavelength of each electron is 0.1639 nm.

S30. Here, $h = 6.62 \times 10^{-34}$ Js; $m = 9.1 \times 10^{-31}$ kg

and $\lambda = \frac{h}{\sqrt{2\,m\,E}}$

$$\therefore \quad \lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 150 \times 1.6 \times 10^{-19}}} = \frac{6.62 \times 10^{-34}}{66.1 \text{ x } 10^{-25}} = 10^{-10}\text{m} = \mathbf{1Å}.$$

S31. According to Einstein's photoelectric equation,

$$\frac{hc}{\lambda} = \phi_0 + \frac{1}{2}mv^2$$

Since work function of the surface is negligible, the above equation becomes

$$\frac{hc}{\lambda} = \frac{1}{2}mv^2$$

or $$mv = \sqrt{\frac{2mhc}{\lambda}}$$

If λ' is de-Broglie wavelength of the emitted electrons, then

$$\lambda' = \frac{h}{mv} = h\Big/\sqrt{\frac{2mhc}{\lambda}} = \sqrt{\frac{h\lambda}{2mc}}$$

S32. de Broglie wavelength of a moving particle, having mass m and velocity v:

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

Mass, $m = h/\lambda v$

For an electron, Mass $m_e = h/\lambda_e v_e$

Now, we have $v/v_e = 3$ and $\lambda/\lambda_e = 1.813 \times 10^{-4}$

Then, mass of the particle, $m = m_e\left(\frac{\lambda_e}{\lambda}\right)\left(\frac{v_e}{v}\right)$

$$m = (9.11 \times 10^{-31}\text{ kg}) \times (1/3) \times (1/1.813 \times 10^{-4})$$

$$m = 1.675 \times 10^{-27}\text{ kg.}$$

Thus, the particle, with this mass could be a proton or a neutron.

S33. Temperature, $T = 27°\text{C} = 27 + 273 = 300$ K

Mean separation between two electrons, $r = 2 \times 10^{-10}$ m

De Broglie wavelength of an electron is given as:

$$\lambda = \frac{h}{\sqrt{3mkT}}$$

Where, h = Planck's constant = 6.6×10^{-34} Js

m = Mass of an electron = 9.11×10^{-31} kg

k = Boltzmann constant = 1.38×10^{-23} J mol^{-1} K^{-1}

$\therefore$ $$\lambda = \frac{6.6 \times 10^{-34}}{\sqrt{3 \times 9.11 \times 10^{-31} \times 1.38 \times 10^{-23} \times 300}}$$

$= 6.2 \times 10^{-9}$ m

Hence, the de Broglie wavelength is much greater than the given inter-electron separation.

S34. The de-Broglie wavelength associated with a proton having charge *e* and accelerated through a potential difference V is given by

$$\lambda = \frac{h}{\sqrt{2meV}} \qquad \text{... (i)}$$

Suppose that an α-particle possesses the de-Broglie wavelength λ', when accelerated through the same potential difference *V*. If *e′* and *m′* are the values of charge and mass of the α-particle, then

$$\lambda' = \frac{h}{\sqrt{2m'e'V}} \qquad \text{... (ii)}$$

Dividing the equation (i) by (ii), we have

$$\frac{\lambda}{\lambda'} = \frac{h}{\sqrt{2m'e'V}} \times \frac{\sqrt{2m'e'V}}{h} = \sqrt{\frac{m'e'}{me}}$$

Here, m′ = 4*m* and e′ = 2e

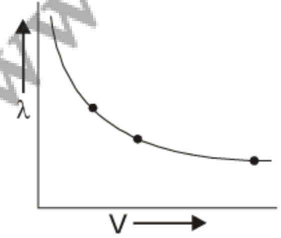
$$\frac{\lambda}{\lambda'} = \sqrt{\frac{4m \times 2e}{me}} = \sqrt{8}$$

S35. The de-Broglie wavelength associated with an electron accelerated through a potential difference *V* is given by

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

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

The variation of the de-Broglie wavelength (λ) with the potential (*V*) will be as shown in figure.



S36. The de-Broglie wavelength associated with an electron accelerated through a potential difference *V* is given by

$$\lambda = \frac{h}{\sqrt{2\,m\,e\,V}}$$

Here, $V = 100$ V

$\therefore$
$$\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 100}}$$

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

This wavelength corresponds to X-ray region of electromagnetic spectrum.

S37. Let λ be the de-Broglie wavelength of the electron and the photon. If m and v are the mass and velocity of the electron, then de-Broglie wavelength of the electron,

$$\lambda = \frac{h}{m\,v}$$

The photon has got zero rest mass. Therefore, energy of the photon is totally kinetic nature. Since the wavelength of the photon is same as that of the electron, the kinetic energy of the photon having wavelength λ,

$$E_1 = \frac{h\,c}{\lambda} = \frac{h\,c}{h\,/\,m\,v}$$

or
$$E_1 = m\,v\,c$$

Now, the kinetic energy of the electron,

$$E_2 = \frac{1}{2}m\,v^2 = m\,v \times (v\,/\,2)$$

Since $c > v/2$, since $C > v$, from the results (i) and (ii), it follows that

$$E_1 > E_2$$

i.e., kinetic energy of the photon is greater than that of the electron.

As it moves with the speed c, it is faster than electron.

S38. According to de-Broglie reaction:

$$\lambda = \frac{h}{m\,v}$$

$\therefore$
$$\lambda_e = \frac{h}{m_e\,v_e} \quad \text{and} \quad \lambda_p = \frac{h}{m_p\,v_p}$$

or
$$v_e = \frac{h}{m_e\,\lambda_e} \quad \text{and} \quad v_p = \frac{h}{m_p\,\lambda_p}$$

Since $v_e = v_p$, we have

$$\frac{h}{m_e \lambda_e} = \frac{h}{m_p \lambda_p} \quad \text{or} \quad m_e\lambda_e = m_p\lambda_p$$

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

As $m_p > m_e$, it follows that $\lambda_e > \lambda_p$.

S39. Here, wavelength of the electron and the photon,

$$\lambda = 4 \text{ nm} = 4 \times 10^{-9} \text{ m}$$

(a) Momentum of the electron and the photon,

$$p = \frac{h}{\lambda} = \frac{6.62 \times 10^{-34}}{4 \times 10^{-9}} = \mathbf{1.67 \times 10^{-25} \ kg\, ms^{-1}}$$

(b) Energy of the photon.

$$E = \frac{hc}{\lambda} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{4 \times 10^{-9}} = 4.97 \times 10^{-17} \text{ J}$$

(c) Kinetic energy of the electron,

$$E_k = \frac{p^2}{2m} = \frac{\left(1.67 \times 10^{-25}\right)^2}{2 \times 9.1 \times 10^{-31}} = 1.05 \times 10^{-20} \text{ J}$$

S40. Here, $\lambda = 2 \text{ Å} = 2 \times 10^{-10}$ m; $h = 6.626 \times 10^{-34}$ Js;

$m = 9.1 \times 10^{-31}$ kg

Momentum of the electron,

$$p = \frac{h}{\lambda} = \frac{6.626 \times 10^{-34}}{2 \times 10^{-10}}$$

$$= 3.313 \times 10^{-24} \text{ kg m s}^{-1}$$

S41. The phenomena such as interference, diffraction and polarisation can only be explained on the basis of wave nature of the radiation. On the other hand, the phenomena such as photoelectric effect and Compton effect can be explained by considering particle nature of radiation.

If was, therefore, concluded that the radiation has dual nature.

S42. The following observations led de-Broglie to the duality hypothesis for matter:

(a) The whole energy in this universe is in the form of matter and electromagnetic radiation.

(b) The nature loves symmetry. As the radiation has got dual nature, matter should also posses dual nature.

S43. Here, $h = 6.62 \times 10^{-34}$ Js; $m = 9.1 \times 10^{-31}$ kg

and $V = 5$ kV $= 5 \times 10^3$ V

Now, $$\lambda = \frac{h}{\sqrt{2\,m\,e\mathrm{V}}}$$

Taking $e = 1.6 \times 10^{-19}$ C,

we have

$$\therefore \quad \lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 5 \times 10^3}}$$

$$= 0.1735 \times 10^{-10}\, m = \mathbf{0.1735\,Å}$$

S44. In terms of accelerating potential *V*, the de-Broglie wavelength of a charged particle is given by

$$\lambda = \frac{h}{\sqrt{2\,m\,e\,V}}$$

where *e* is charge and *m*, mass of the particle.

The equation (i) represents a straight line, whose slope is $h/\sqrt{2\,m\,e}$

(a) The slope of the line is inversely proportional to $\sqrt{m}$.

(b) Since the slope of line *A* is lesser, it represents the particle of heavier mass.

S45. Now, $$p = \frac{h}{\lambda}$$

Since the electron and photon have the same de-Broglie wavelength of 1 nm, both the particles will have the same momentum. Hence, the ratio of their momenta will be 1.

For comparison of the energy of the photon with the kinetic energy of the electron,
It will be found that the ratio of their energies is 824.75.

S46. If λ is the de-Broglie wavelength of a particle having kinetic energy *K*, then

$$\lambda = \frac{h}{\sqrt{2\,m\,K}}$$

$$\therefore \quad \lambda = \frac{h}{\sqrt{2\,m_e\,K_e}}$$

and $$\lambda_\alpha = \frac{h}{\sqrt{2\,m_\alpha\,K_\alpha}}$$

Since $\lambda_e = \lambda_\alpha$, we have

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

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

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

S47. Since the photosensitive surface of negligible work function,

K.E. of emitted electron = energy of the incident photon

i.e. $$\frac{1}{2} m v^2 = h\nu$$

or $$\frac{p^2}{2m} = \frac{hc}{\lambda}$$

or $$p = \sqrt{\frac{2mhc}{\lambda}}$$

Therefore, de-Broglie wavelength of the emitted photoelectrons,

$$\lambda_1 = \frac{h}{p} = h \times \sqrt{\frac{\lambda}{2mhc}}$$

or $$\lambda = \boldsymbol{\frac{2mc}{h}\lambda_1^2}$$

S48. (a) The kinetic energy = –(total energy)

$$= (-3.4 \text{ eV}) = \mathbf{3.4\ eV}$$

(b) Now, $$\lambda = \frac{h}{\sqrt{2mE}}$$

Here, $h = 6.62 \times 10^{-34}$ Js and $E = 3.4$ eV $= 3.4 \times 1.6 \times 10^{-19}$ J

Taking mass of the electron as $m = 9.1 \times 10^{-31}$ kg, we have

$$\lambda = \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 3.4 \times 1.6 \times 10^{-19}}}$$

$$= 6.653 \times 10^{-10} \text{ m} = \mathbf{6.663\ Å}$$

S49.

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

$$= \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 60}}$$

$= 1.584 \times 10^{-10}$m = **1.584 Å**

S50. (a) $$\lambda = \frac{hc}{E} = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{120 \times 1.6 \times 10^{-19}} = \mathbf{1.12\ Å}$$

(b) Now, $$p = \frac{h}{\lambda} = \frac{6.62 \times 10^{-34}}{1.12 \times 10^{-10}} = 5.91 \times 10^{-24} \text{ kg ms}^{-1}$$

S51. $$\lambda = \frac{h}{\sqrt{2\,m\,e\,V}}$$

$$= \frac{6.62 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 10^{4}}}$$

= **0.123 Å**.

S52. Wavelength of light of a sodium line,

$$\lambda = 589 \text{ nm} = 589 \times 10^{-9} \text{ m}$$

Mass of an electron, $m_e = 9.1 \times 10^{-31}$ kg

Mass of a neutron, $m_n = 1.66 \times 10^{-27}$ kg

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

For the kinetic energy K, of an electron accelerating with a velocity v, we have the relation:

$$K = \frac{1}{2} mv^2 \quad \text{... (i)}$$

We have the relation for de Broglie wavelength as:

$$\lambda = \frac{h}{m_e v}$$

$$\therefore \quad v^2 = \frac{h^2}{\lambda^2 m_e^2} \quad \text{... (ii)}$$

Substituting Eq. (ii) in Eq. (i), we get the relation:

$$K = \frac{1}{2} \frac{m_e h^2}{\lambda^2 m_e^2} = \frac{h^2}{2\lambda^2 m_e} \quad \text{... (iii)}$$

$$= \frac{(6.6 \times 10^{-34})^2}{2 \times (589 \times 10^{-9})^2 \times 9.1 \times 10^{-31}}$$

$$\approx 69.10^{-25}\,J$$

$$= \frac{6.9 \times 10^{-25}}{1.6 \times 10^{-19}} = 4.31 \times 10^{-6}\,eV = 4.31\,\mu eV$$

Hence, the kinetic energy of the electron is 6.9×10^{-25} J or 4.31 μeV.

Using Eq. (3), we can write the relation for the kinetic energy of the neutron as:

$$\frac{h^2}{2\lambda^2 m_n} = \frac{(6.6 \times 10^{-34})^2}{2 \times (589 \times 10^{-9})^2 \times 1.66 \times 10^{-27}}$$

$$= 3.78 \times 10^{-28}\,J$$

$$= \frac{3.78 \times 10^{-28}}{1.6 \times 10^{-19}}$$

$$= 3.78 \times 10^{-28}\,eV = 2.36\,meV$$

Hence, the kinetic energy of the neutron is 3.78×10^{-28} J or 2.36 neV.

S53. Kinetic energy of the electron, $E_k = 120$ eV

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

Mass of an electron, $m = 9.1 \times 10^{-31}$ kg

Charge on an electron, $e = 1.6 \times 10^{-19}$ C

(a) For the electron, we can write the relation for kinetic energy as:

$$E_k = \frac{1}{2} mv^2$$

Where, v = Speed of the electron

$$\therefore \quad v^2 = \sqrt{\frac{2E_k}{m}}$$

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

$$= \sqrt{42.198 \times 10^{12}} = 6.496 \times 10^6\,m/s$$

Momentum of the electron, $p = mv$

$$= 9.1 \times 10^{-31} \times 6.496 \times 10^6$$

$$= 5.91 \times 10^{-24}\,kg\,m\,s^{-1}$$

Therefore, the momentum of the electron is 5.91×10^{-24} kg m s^{-1}

(b) Speed of the electron, $v = 6.496 \times 10^6$ m/s

(c) De Broglie wavelength of an electron having a momentum p, is given as:

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

$$= \frac{6.6 \times 10^{-34}}{5.91 \times 10^{-24}} = 1.116 \times 10^{-10} \text{ m}$$

$$= 0.112 \text{ nm}$$

Therefore, the de Broglie wavelength of the electron is 0.112 nm.

S54. (a) Mass of the bullet, $m = 0.040$ kg

Speed of the bullet, $v = 1.0$ km/s = 1000 m/s

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

De Broglie wavelength of the bullet is given by the relation:

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{0.040 \times 1000} = 1.65 \times 10^{-35} \text{ m}$$

(b) Mass of the ball, $m = 0.060$ kg

Speed of the ball, $v = 1.0$ m/s

De Broglie wavelength of the ball is given by the relation:

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{0.060 \times 1} = 1.1 \times 10^{-32} \text{ m}$$

(c) Mass of the dust particle, $m = 1 \times 10^{-9}$ kg

Speed of the dust particle, $v = 2.2$ m/s

De Broglie wavelength of the dust particle is given by the relation:

$$\lambda = \frac{h}{mv} = \frac{6.6 \times 10^{-34}}{2.2 \times 1 \times 10^{-9}} = 3.0 \times 10^{-25} \text{ m.}$$

S55. De Broglie wavelength of the neutron, $\lambda = 1.40 \times 10^{-10}$ m

Mass of a neutron, $m_n = 1.66 \times 10^{-27}$ kg

Planck's constant, $h = 6.6 \times 10^{-34}$ Js

(a) Kinetic energy (K) and velocity (v) are related as:

$$K = \frac{1}{2} m_n v^2 \qquad \text{… (i)}$$

De Broglie wavelength (λ) and velocity (v) are related as:

$$\lambda = \frac{h}{m_n v} \qquad \text{… (ii)}$$

Using Eq. (ii) in Eq. (i), we get:

$$K = \frac{1}{2}\frac{m_n h^2}{\lambda^2 m_n^2} = \frac{h^2}{2\lambda^2 m_n}$$

$$= \frac{(6.63\times10^{-34})^2}{2\times(1.40\times10^{-10})^2\times1.66\times10^{-27}}$$

$$= 6.75\times10^{-21}\text{ J}$$

$$= \frac{6.75\times10^{-21}}{1.6\times10^{-19}} = 4.219\times10^{-2}\text{ eV}$$

Hence, the kinetic energy of the neutron is 6.75×10^{-21} J or 4.219×10^{-2} eV.

(b) Temperature of the neutron, $T = 300$ K

Boltzmann constant, $k = 1.38\times10^{-23}$ kg m^2 s^{-2} K^{-1}

Average kinetic energy of the neutron:

$$K' = \frac{3}{2}kT$$

$$= \frac{3}{2}\times1.38\times10^{-23}\times300 = 6.21\times10^{-21}\text{ J}$$

The relation for the de Broglie wavelength is given as:

$$\lambda' = \frac{h}{\sqrt{2K'm_n}}$$

Where, $m_n = 1.66\times10^{-27}$ kg

$h = 6.6\times10^{-34}$ Js

$K' = 6.75\times10^{-21}$ J

$\therefore$
$$\lambda' = \frac{6.63\times10^{-34}}{\sqrt{2\times6.21\times10^{-21}\times1.66\times10^{-27}}}$$

$$= 1.46\times10^{-10}\text{ m} = 0.146\text{ nm}$$

Therefore, the de Broglie wavelength of the neutron is 0.146 nm.

S56. (a) Potential difference across the evacuated tube, $V = 500$ V

Specific charge of an electron, $e/m = 1.76\times10^{11}$ C kg^{-1}

The speed of each emitted electron is given by the relation for kinetic energy as:

$$\text{KE} = \frac{1}{2}mv^2 = eV$$

$\therefore$ $$v = \left(\frac{2eV}{m}\right)^{\frac{1}{2}} = \left(2V \times \frac{e}{m}\right)^{\frac{1}{2}}$$

$$= (2 \times 500 \times 1.76 \times 10^{11})^{\frac{1}{2}} = 1.327 \times 10^{7} \text{ m/s}$$

Therefore, the speed of each emitted electron is 1.327×10^7 m/s.

(b) Potential of the anode, $V = 10$ MV $= 10 \times 10^6$ V

The speed of each electron is given as:

$$v = \left(2V \times \frac{e}{m}\right)^{\frac{1}{2}}$$

$$= (2 \times 10^{7} \times 1.76 \times 10^{11})^{\frac{1}{2}}$$

$$= 1.88 \times 10^{9} \text{ m/s}$$

This result is wrong because nothing can move faster than light. In the above formula, the expression ($mv^2/2$) for energy can only be used in the non-relativistic limit, *i.e.*, for $v << c$.

For very high speed problems, relativistic equations must be considered for solving them. In the relativistic limit, the total energy is given as:

$$E = mc^2$$

Where, m = Relativistic mass

$$= m_0\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

m_0 = Mass of the particle at rest

Kinetic energy is given as:

$$K = mc^2 - m_0 c^2$$

S57. (a) Speed of an electron, $v = 5.20 \times 10^6$ m/s

Magnetic field experienced by the electron,

$$B = 1.30 \times 10^{-4} \text{ T}$$

Specific charge of an electron, $e/m = 1.76 \times 10^{11}$ C kg^{-1}

Where, e = Charge on the electron = 1.6×10^{-19} C

m = Mass of the electron = 9.1×10^{-31} kg^{-1}

The force exerted on the electron is given as:

$$F = e\,|\vec{v} \times \vec{B}|$$

$$= evB \sin\theta$$

θ = Angle between the magnetic field and the beam velocity

The magnetic field is normal to the direction of beam.

$\therefore$ $$\theta = 90°$$

$$F = evB \quad \text{... (i)}$$

The beam traces a circular path of radius, r. It is the magnetic field, due to its bending nature, that provides the centripetal force $\left(F = \frac{mv^2}{r}\right)$ for the beam.

Hence, Eq (i) reduces to:

$$evB = \frac{mv^2}{r}$$

$\therefore$ $$r = \frac{mv}{eB} = \frac{v}{\left(\frac{e}{m}\right)B}$$

$$= \frac{5.20 \times 10^6}{(1.76 \times 10^{11}) \times 1.30 \times 10^{-4}} = 0.227 \text{ m} = 22.7 \text{ cm}$$

Therefore, the radius of the circular path is 22.7 cm.

(b) Energy of the electron beam, E = 20 MeV

The energy of the electron is given as:

$$E = \frac{1}{2}mv^2$$

$\therefore$ $$v = \left(\frac{2E}{m}\right)^{\frac{1}{2}}$$

$$= \sqrt{\frac{2 \times 20 \times 10^6 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 2.652 \times 10^9 \text{ m/s}$$

This result is incorrect because nothing can move faster than light. In the above formula, the expression ($mv^2/2$) for energy can only be used in the non-relativistic limit, *i.e.*, for $v << c$.

When very high speeds are concerned, the relativistic domain comes into consideration.

In the relativistic domain, mass is given as:

$$m = m_0\left[1 - \frac{v^2}{c^2}\right]^{\frac{1}{2}}$$

Where, m_0 = Mass of the particle at rest

Hence, the radius of the circular path is given as:

$$r = mv/eB$$

$$= \frac{m_0 v}{eB\sqrt{\frac{c^2 - v^2}{c^2}}}.$$

S58. (a) Power of the medium wave transmitter,

$$P = 10 \text{ kW} = 10^4 \text{ W} = 10^4 \text{ J/s}$$

Hence, energy emitted by the transmitter per second, $E = 10^4$

Wavelength of the radio wave, $\lambda = 500$ m

The energy of the wave is given as:

$$E_1 = \frac{hc}{\lambda}$$

Where, h = Planck's constant = 6.6×10^{-34} Js

c = Speed of light = 3×10^8 m/s

$$\therefore \quad E_1 = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{500} = 3.96 \times 10^{-28} \text{ J}.$$

Let n be the number of photons emitted by the transmitter.

$$\therefore \quad nE_1 = E$$

$$n = \frac{E}{E_1}$$

$$= \frac{10^4}{3.96 \times 10^{-28}} = 2.525 \times 10^{31}$$

$$\approx 3 \times 10^{31}.$$

(b) The energy (E_1) of a radio photon is very less, but the number of photons (n) emitted per second in a radio wave is very large.

The existence of a minimum quantum of energy can be ignored and the total energy of a radio wave can be treated as being continuous.

Intensity of light perceived by the human eye,

$$I = 10^{-10} \text{ W m}^{-2}$$

Area of a pupil, $A = 0.4 \text{ cm}^2 = 0.4 \times 10^{-4} \text{ m}^2$

Frequency of white light, $\nu = 6 \times 10^{14}$ Hz

The energy emitted by a photon is given as:

$$E = h\nu$$

Where, h = Planck's constant = 6.6×10^{-34} Js

$\therefore \quad E = 6.6 \times 10^{-34} \times 6 \times 10^{14}$

$= 3.96 \times 10^{-19}$ J

Let n be the total number of photons falling per second, per unit area of the pupil.

The total energy per unit for

$$E = n \times 3.96 \times 10^{-19} \text{ Js}^{-1} \text{ m}^{-2}$$

The energy per unit area per second is the intensity of light.

$\therefore \quad E = I$

$$n \times 3.96 \times 10^{-19} = 10^{-10}$$

$$= 2.52 \times 10^{8} \text{ m}^2 \text{ s}^{-1}$$

The total number of photons entering the pupil per second is given as:

$$n_A = n \times A$$

$$= 2.52 \times 10^{8} \times 0.4 \times 10^{-4}$$

$$= 1.008 \times 10^{4} \text{ s}^{-1}$$

This number is not as large as the one found in problem **(a)**, but it is large enough for the human eye to never see the individual photons.

S59. De Broglie wavelength = 2.327×10^{-12} m; neutron is not suitable for the diffraction experiment

Kinetic energy of the neutron, $K = 150$ eV

$= 150 \times 1.6 \times 10^{-19}$

$= 2.4 \times 10^{-17}$ J

Mass of a neutron, $m_n = 1.675 \times 10^{-27}$ kg

The kinetic energy of the neutron is given by the relation:

$$K = \frac{1}{2} m_n v^2$$

$$m_n v = \sqrt{2Km_n}$$

Where, v = Velocity of the neutron

$m_n v$ = Momentum of the neutron

De-Broglie wavelength of the neutron is given as:

$$\lambda = \frac{h}{m_n v} = \frac{h}{\sqrt{2Km_n}}$$

It is clear that wavelength is inversely proportional to the square root of mass.

Hence, wavelength decreases with increase in mass and vice versa.

$$\therefore \quad \lambda = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 2.4 \times 10^{-17} \times 1.675 \times 10^{-27}}} = 2.327 \times 10^{-12} \text{ m}$$

It is given in the previous problem that the inter-atomic spacing of a crystal is about 1 Å, *i.e.*, 10^{-10} m. Hence, the inter-atomic spacing is about a hundred times greater. Hence, a neutron beam of energy

150 eV is not suitable for diffraction experiments.

De Broglie wavelength = 1.447×10^{-10} m

Room temperature, T = 27°C = 27 + 273 = 300 K

The average kinetic energy of the neutron is given as:

$$E = \frac{3}{2}kT$$

Where, k = Boltzmann constant

$= 1.38 \times 10^{-23}$ J mol^{-1} K^{-1}

The wavelength of the neutron is given as:

$$\lambda = \frac{h}{\sqrt{2m_n E}} = \frac{h}{\sqrt{3m_n kT}}$$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{3 \times 1.675 \times 10^{-27} \times 1.38 \times 10^{-23} \times 300}} = 1.447 \times 10^{-10}\ \text{m}$$

This wavelength is comparable to the inter-atomic spacing of a crystal. Hence, the high-energy neutron beam should first be thermalised, before using it for diffraction.

S60. (a) Momentum of electron,

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

$$p = \frac{6.63 \times 10^{-34}}{2 \times 10^{-9}} = 3.31 \times 10^{-25}\ \text{Kgms}^{-1}$$

Momentum of photon = Momentum of electron

(b) Energy of photon,

$$E_n = \frac{hc}{\lambda} = 9.945 \times 10^{-17}\text{J}$$

(c) Kinetic energy of electron

$$E_k = \frac{p^2}{2m} = \frac{(3.315 \times 10^{-25})^2}{2 \times 9.11 \times 10^{-31}} = 6.0314 \times 10^{-20}\ \text{J}$$

S61. Find the de-Broglie wavelength of electron at 27°C. It can be obtained that de Broglie wave-length of the electron,

$$\lambda = 62.3 \times 10^{-10} \text{ m} = \mathbf{62.3 \text{ Å}}$$

Mean separation between two electrons in the metal,

$$d = 2 \text{ Å}$$

$$\frac{\lambda}{d} = \frac{62.3}{2} \approx \mathbf{31}$$

i.e. de Broglie wavelength of the electron is much larger than the separation between two electrons in the metal.

S62. Let m and m' be the masses of electron and the particle. Let v and v' be their respective velocities. If λ and λ' are their respective de Broglie wave lengths, then

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

and $$\lambda' = \frac{h}{m'v'} \quad \text{... (ii)}$$

From Eq. (i) and (ii), we get

$\therefore$ $$\frac{\lambda'}{\lambda} = \frac{h}{m'v'} \times \frac{m\,v}{h} = \frac{mv}{m'v'}$$

or $$m' = \frac{v}{v'} \times \frac{\lambda}{\lambda'} \times m$$

Here, $$m = \frac{v}{3v} \times \frac{1}{1.813 \times 10^{-14}} \times 9.1 \times 10^{-31}$$

$$= \mathbf{1.673 \times 10^{-27} \text{ kg}}$$

From the order of the mass, it follows that particle may be a proton or a neutron.

S63. De Broglie wavelength associated with He atom = 0.7268×10^{-10} m

Room temperature, T = 27°C = 27 + 273 = 300 K

Atmospheric pressure, P = 1 atm = 1.01×10^5 Pa

Atomic weight of a He atom = 4

Avogadro's number, $N_A = 6.023 \times 10^{23}$

Boltzmann constant, $k = 1.38 \times 10^{-23}$ J mol^{-1} K^{-1}

Average energy of a gas at temperature T,is given as:

$$E = \frac{3}{2} kT$$

De Broglie wavelength is given by the relation:

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

Where, m = Mass of a He atom

$$= \frac{\text{Atomic weight}}{N_A}$$

$$= \frac{4}{6.023 \times 10^{23}}$$

$$= 6.64 \times 10^{-24}\,\text{g} = 6.64 \times 10^{-27}\,\text{kg}$$

$\therefore$

$$\lambda = \frac{h}{\sqrt{3mkT}}$$

$$= \frac{6.6 \times 10^{-34}}{\sqrt{3 \times 6.64 \times 10^{-27} \times 1.38 \times 10^{-23} \times 300}}$$

$$= 0.7268 \times 10^{-10}\,\text{m}$$

We have the ideal gas formula:

$$PV = RT$$

$$PV = kNT$$

$$\frac{V}{N} = \frac{kT}{P}$$

Where, V = Volume of the gas

N = Number of moles of the gas

Mean separation between two atoms of the gas is given by the relation:

$$r = \left(\frac{V}{N}\right)^{\frac{1}{3}} = \left(\frac{kT}{P}\right)^{\frac{1}{3}}$$

$$= \left[\frac{1.38 \times 10^{-23} \times 300}{1.01 \times 10^{5}}\right]^{\frac{1}{3}} = 3.35 \times 10^{-9}\,\text{m}$$

Hence, the mean separation between the atoms is much greater than the de Broglie wavelength.

S64. Here, λ = 2271 Å, V_s = 1.3 V

Energy of the incident photon

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

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{2271 \times 10^{-10} \times 1.6 \times 10^{-19}}\,eV = \frac{6.63 \times 3}{2271 \times 1.6} \times 10^{3}\,eV$$

$$= \frac{6.63 \times 3 \times 1000}{2271 \times 1.6} = 5.47\ eV$$

Now, $\frac{hc}{\lambda} = W_0 + eV$

$5.47\text{ eV} = 1.3\text{ eV} + W_0$

$W_0 = 5.47\text{ eV} – 1.3\text{ eV} = 4.17\text{ eV}$

(b) Energy of a photon of $\lambda = 6328 \times 10^{-10}$ m

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{6328 \times 10^{-10} \times 1.6 \times 10^{-19}} eV$$

$$= \frac{6.63 \times 3}{6328 \times 1.6} \times 10^3 = 1.96\ eV$$

Since, the energy of the incident (1.96 eV) photon is much less than the work function, photoelectric emission will not take place.

S65. As a charge q is accelerated by a potential V,

We have $W = qV = \frac{1}{2}mv^2 = \frac{p^2}{2m}$ as the work done on the charge becomes K. E.

$\therefore \quad P = \sqrt{2mqV}$

(a) Since, $\lambda = \frac{h}{p}$

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{2 \times 4m_p \times 2e \times V}{2 \times m_p \times e \times V}} = 2\sqrt{2} > 1$$

Proton will have greater de Broglie wavelength.

(b) Energy $E = qV$. So, the proton having lesser charge in coulomb will have the least K. E.

S66. (a) Rest mass of the electron = mc^2

$= 9.1 \times 10^{-31} \times (3 \times 10^8)^2 = 9.1 \times 9 \times 10^{-15}$ J

Now, mass of the proton = $1836 \times 9.1 \times 10^{-31}$ kg

Now, we know that de Broglie wavelength is given by

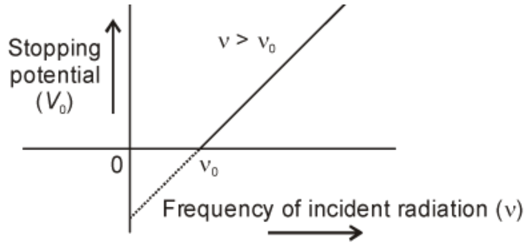
$$\lambda = \frac{h}{\sqrt{2m_pE}}$$

$$= \frac{6.63 \times 10^{23}}{181 \times 9.1} \times 10^{-13}\ m$$

$$= 0.4 \times 10^{-13} = 4 \times 10^{-14}\ \text{m}$$

(b) This wavelength lies in the γ-ray region.

S67. According to photoelectric equation



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

or $$V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi_0}{e}$$

This equation is of the form $y = mx + c$ which is the equation of straight line. Here slope is h/e and intercept is $-\frac{\phi_0}{e}$. From the intercept $\left(-\frac{\phi_0}{e}\right)$ and the known value of e, value of work function (ϕ_0) can be calculated.

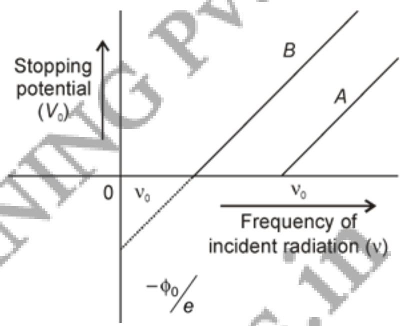
S68. (a) As work function = $h\nu_0$

Metal A is having higher value of work function

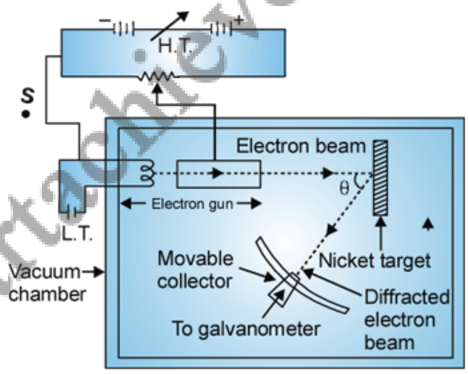
(b) Slope of the graph = $\frac{h}{e}$ Where 'h' is planck's constant.

(c) Intercept on the potential axis = $\frac{\phi_0}{e}$

where ϕ_0 is the value of work function.



S69. We know that when an electron is accelerated under the effect of potential drop 'V' energy acquired by it, is



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

or $$mv = \sqrt{2meV}$$

We know that de Broglie wavelength is

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

thus $$\lambda = \frac{h}{\sqrt{2meV}}$$

On substituting numerical values

$$\lambda = \frac{1.227}{\sqrt{V}} nm$$

We have relation

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

i.e., $$\frac{\lambda_e}{\lambda_p} = \sqrt{\frac{m_p}{m_e}}$$

As $$m_p > m_e$$

$$\frac{\lambda_e}{\lambda_p} > 1$$

$$\lambda_e > \lambda_p$$

S70. ***Threshold frequency:*** The minimum frequency below which there is no occurence of photoelectric effect is called the cut-off frequency or threshold frequency and denoted by ν_0.

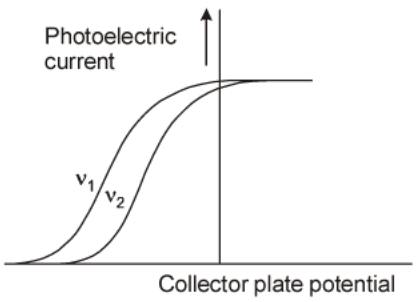
Stopping potential: The minimum negative potential given to plate w.r.t. cathode, at which no photoelectron reaches the plate is called stopping potential. It is represented by V_0.

The wave theory of light is not able to explain the observed features of photoelectric current because of following reasons

(a) The greater energy incident per unit time per unit area increases with the increase of intensity which should facilitate liberation of photoelectron of greater kinetic energy which is in contradiction of observed feature of photoelectric effect.

(b) Wave theory states that energy carried by wave is independent of frequency of light wave and hence wave of high intensity and low frequency (less than threshold frequency) should stimulate photoelectric emission but practically, it does not happen.

S71. Stopping potential will be higher corresponding to frequency, ν_2.



By Einstein's photoelectric equation

$$V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi_0}{e} \quad \ldots \text{(i)}$$

where, V_0 = cut-off potential

h = Planck's constant

e = electronic charge

ϕ_0 = work function of material

It is clear that for higher frequency ν, cut-off potential is higher.

S72. $$h\nu = h\nu_0 + eV_0 \qquad \text{... (i)}$$

For wavelength λ

$$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + eV_0$$

For wavelength 3λ

$$\frac{hc}{3\lambda} = \frac{hc}{\lambda_0} + e\frac{V_0}{6} \qquad \text{... (ii)}$$

On solving eqn. (i) and (ii) we get

$$\lambda_0 = \frac{4hc}{eV_0}$$

S73. Einstein's photoelectric equation is given as:

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

$$V_0 = \frac{h}{c}\nu - \frac{\phi_0}{e} \qquad \text{... (i)}$$

Where, V_0 = Stopping potential

h = Planck's constant

e = Charge on an electron

ν = Frequency of radiation

ϕ_0 = Work function of a metal

It can be concluded from Eq. (i) that potential V_0 is directly proportional to frequency ν.

Frequency is also given by the relation:

$$\nu = \frac{\text{Speed of light } (c)}{\text{Wavelength } (\lambda)}$$

This relation can be used to obtain the frequencies of the various lines of the given wavelengths.

$$\nu_1 = \frac{c}{\lambda_1} = \frac{3\times10^8}{3650\times10^{-10}} = 8.219\times10^{14}\text{ Hz}$$

$$\nu_2 = \frac{c}{\lambda_2} = \frac{3\times10^8}{4047\times10^{-10}} = 7.412\times10^{14}\text{ Hz}$$

$$\nu_3 = \frac{c}{\lambda_3} = \frac{3\times10^8}{4358\times10^{-10}} = 6.884\times10^{14}\text{ Hz}$$

$$\nu_4 = \frac{c}{\lambda_4} = \frac{3\times10^8}{5461\times10^{-10}} = 5.493\times10^{14}\text{ Hz}$$

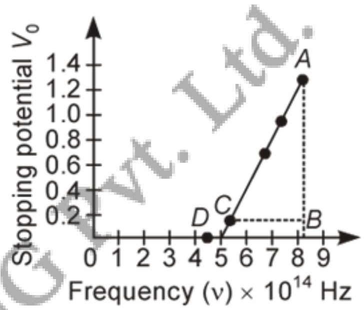
$$\nu_5 = \frac{c}{\lambda_5} = \frac{3 \times 10^8}{6907 \times 10^{-10}} = 4.343 \times 10^{14}\text{ Hz}$$

The given quantities can be listed in tabular form as:

Frequency $\times 10^{14}$ Hz	8.219	7.412	6.884	5.493	4.343
Stopping potential V_0	1.28	0.95	0.74	0.16	0

The following figure shows a graph between ν and V_0.

It can be observed that the obtained curve is a straight line. It intersects the ν-axis at 5×10^{14} Hz, which is the threshold frequency (ν_0) of the material. Point D corresponds to a frequency less than the threshold frequency. Hence, there is no photoelectric emission for the λ_5 line, and therefore, no stopping voltage is required to stop the current.



$$\text{Slope of the straight line} = \frac{AB}{CB} = \frac{1.28 - 0.16}{(8.214 - 5.493) \times 10^{14}}$$

From Eq. (i), the slope $\frac{h}{e}$ can be written as:

$$\frac{h}{e} = \frac{1.28 - 0.16}{(8.214 - 5.493) \times 10^{14}}$$

$\therefore$
$$h = \frac{1.12 \times 1.6 \times 10^{-19}}{2.726 \times 10^{14}}$$
$$= 6.573 \times 10^{-34}\text{ Js}$$

The work function of the metal is given as:

$$\phi_0 = h\nu_0 \qquad [\nu_0 = \text{Threshold frequency}]$$
$$= 6.573 \times 10^{-34} \times 5 \times 10^{14}$$
$$= 3.286 \times 10^{-19}\text{ J}$$
$$= \frac{3.286 \times 10^{-19}}{1.6 \times 10^{-18}} = 2.054\text{ eV.}$$

S74. When electron is accelerated though a potential difference of V volt.

Gain in kinetic energy of electron = $\frac{1}{2}mv^2$

Work done on the electron = eV

$\therefore$
$$\frac{1}{2}mv^2 = eV$$

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

If λ is de Broglie wavelength associated with the electron, then

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{h}{\sqrt{2meV}}$$

Thus, $$\lambda = \frac{h}{\sqrt{2meV}}$$

$$\frac{\lambda}{\frac{1}{\sqrt{V}}} = \frac{h}{\sqrt{2me}}$$

$$M_A > M_B$$

S75. (a) Einstein's photoelectric equation is

$$K.E._{max} = h\nu - \phi_0$$

But, $K.E._{max} = eV_0$

where, V_0 = cut-off potential = 1.3 V

$$eV_0 = h\nu - \phi$$

$\Rightarrow$ $\phi = h\nu - eV_0$

Here, $h = 6.63 \times 10^{-34}$ J-s

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{2271 \times 10^{-10}}$$

$$= 1.32 \times 10^{15} \text{ Hz}$$

$$eV_0 = 1.6 \times 10^{-19} \times 1.3 = 2 \times 10^{-19} \text{ J}$$

$\therefore$ Work function = $h\nu - eV_0$

$$= (6.63 \times 10^{-34}) \times (3.2 \times 10^{15}) - 2 \times 10^{-19}$$

$$= 8.76 \times 10^{-19} - 2 \times 10^{-19}$$

$$= 6.76 \times 10^{-19} \text{ J}$$

$$= \frac{6.76 \times 10^{-19}}{1.6 \times 10^{-19}} \text{eV}$$

Work function $\phi = 4.22$ eV

(b) $\lambda = 6328 \times 10^{-10}$ m

As $K.E._{max} = h\nu - \phi$ ... (i)

Here, $h\nu = \frac{hc}{\lambda} = 3.14 \times 10^{-19}$ J = 1.96 eV

But $\phi = 4.22$ eV

i.e., $h\nu < \phi$

$\therefore$ $KE_{max} < 0$ [From Eq. (i)]

Which is not possible.

Photoelectric effect does not take place.

S76. Let v be the velocity acquired by an electron when accelerated through a potential difference of V volt.

$$eV = \frac{1}{2}mv^2 \quad \text{... (i)}$$

Where, eV = Work done on the electron

From eqn. (i), we get

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

Suppose λ is the de Broglie wavelength associated with the electron.

$$\lambda = \frac{h}{mv} = \frac{h}{m\sqrt{\frac{2eV}{m}}} = \frac{h}{\sqrt{2emV}} \quad \text{... (ii)}$$

On substituting standard values is eqn. (ii), we get.

$$\lambda = \frac{12.27}{\sqrt{V}} Å$$

Davisson and Germer's experiment provides first experimental proof towards the concept of wave nature of material particles. In crystal lattice interatomic distances between layers and de Broglie wavelengths are approximately of same order of an electron.