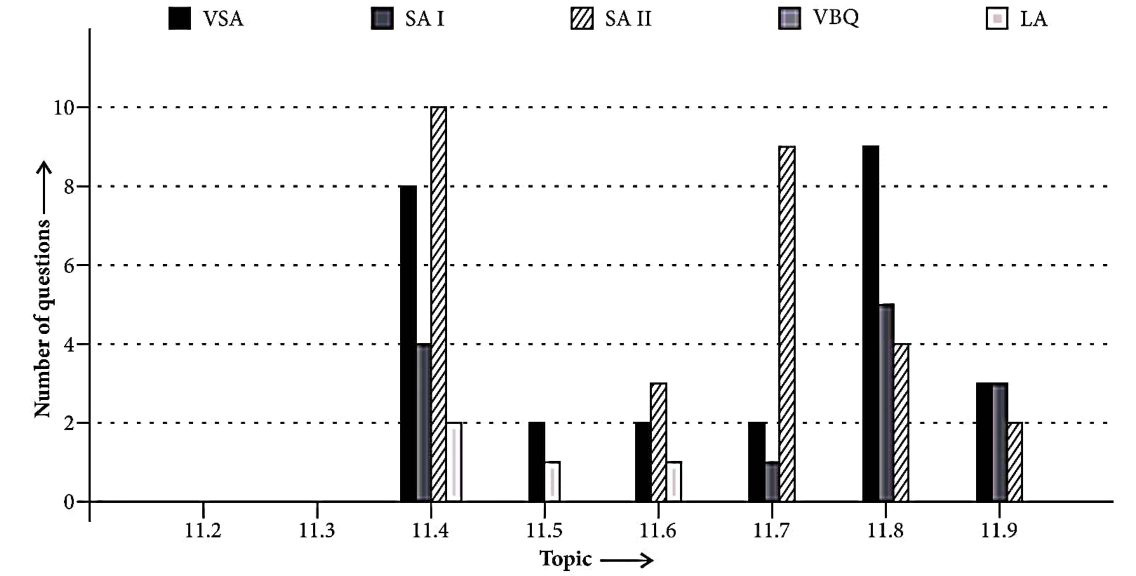
11 Dual Nature of Radiation and Matter

Topicwise Analysis of Last 10 Years' CBSE Board Questions



- Maximum weightage is of *Experimental study of Photoelectric Effect*
- Maximum VSA type questions were asked from *Wave Nature of Matter*
- Maximum SA II type questions were asked from *Experimental study of Photoelectric Effect*
- No VBQ type questions were asked till now

QUICK RECAP

- **Electron emission :** The phenomenon of emission of electrons from the surface of a metal. The minimum energy needed by an electron to come out from a metal surface is known as "work function" of the metal. It is denoted by ϕ_0 or W_0 and measured in electron volt (eV).

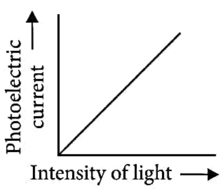
  Work function $W = h\upsilon_0 = \frac{hc}{\lambda_0}$

The electron emission can be obtained from the following physical processes :

- **Thermionic emission :** It is the phenomenon of emission of electrons from the metal surface when heated suitably.
- **Photoelectric emission :** It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.
- **Field emission or cold cathode emission :** It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.

Photoelectric effect : It is the phenomenon of emission of electrons from the surface of metals, when light radiations of suitable frequency fall on them.

- **Laws of photoelectric emission :** The laws of photoelectric effect are as follows :
  - For a given metal and frequency of incident radiation, the number of photoelectrons ejected per second is directly proportional to the intensity of the incident light.
  - For a given metal, there exists a certain minimum frequency of the incident radiation below which no emission of photoelectrons takes place. This frequency is known as threshold frequency.
  - Above the threshold frequency, the maximum kinetic energy of the emitted photoelectron is independent of the intensity of incident light but depends only upon the frequency (or wavelength) of the incident light.
  - The photoelectric emission is an instantaneous process. The time lag between the incidence of radiation and emission of photoelectrons is very small, less than 10^{-9} second.
- **Photoelectric current :** Photoelectric current depends on the intensity of incident light and the potential difference applied between the two electrodes.

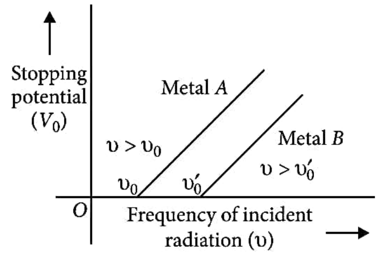


- **Stopping potential :** The minimum negative potential given to anode plate w.r.t. to cathode plate at which the photoelectric current becomes zero is known as stopping potential or cut off potential. It is denoted by V_0. If e is the charge on the photoelectron, then

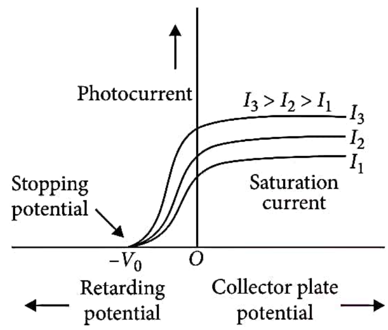
$$K_{max} = eV_0 = \frac{1}{2}mv_{max}^2$$

where m is the mass of photoelectron and v_{max} is the maximum velocity of emitted photoelectrons.

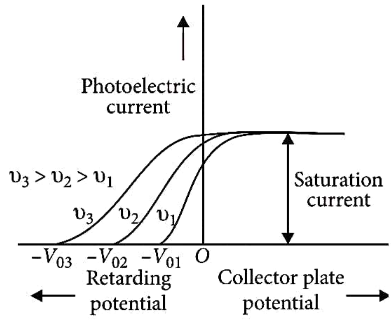
- Variation of stopping potential V_0 with frequency υ of incident radiation :



- Variation of photocurrent with collector plate potential for different intensity of incident radiation :



- Variation of photocurrent with collector plate potential for different frequencies of incident radiation :



Einstein's photoelectric equation : If a light of frequency υ is incident on a photosensitive material having work function (ϕ_0), then maximum kinetic energy of the emitted electron is given as

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

For $\upsilon > \upsilon_0$

or $eV_0 = h\upsilon - \phi_0 = h\upsilon - h\upsilon_0$

or $eV_0 = K_{max} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_0}\right)$.

where υ_0 = threshold frequency

λ_0 = threshold wavelength

λ = incident wavelength

Einstein's photoelectric equation is in accordance with the law of conservation of energy.

Dual nature of radiation : Wave theory of electromagnetic radiation explains the phenomenon of interference, diffraction and polarisation. On the other hand, photoelectric effect is supported by particle nature of light. Hence, we assume dual nature of light.

The photons : These are the packets of energy (or energy particles) which are emitted by a source of radiation. The photons emitted from a source, travel through space with the same speed c (equal to the speed of light).

- Energy of a photon $E = h\upsilon = \frac{hc}{\lambda}$

  where, υ = frequency, λ = wavelength

  h = Planck's constant, c = speed of the light
- Momentum of photon is

  $$p = \frac{E}{c} = \frac{h\upsilon}{c}$$
- The rest mass of photon is zero.
- The moving mass m of photon is $m = \frac{E}{c^2} = \frac{h\upsilon}{c^2}$.
- All photons of light of a particular frequency ν or wavelength λ have the same energy $E\left(= h\upsilon = \frac{hc}{\lambda}\right)$ and momentum $p\left(= \frac{h\upsilon}{c} = \frac{h}{\lambda}\right)$, whatever be the intensity of radiation.
- Photon energy is independent of intensity of radiation.
- Photons are not deflected by electric and magnetic fields.
- In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved.
- Number of photons emitted per second of frequency υ from a lamp of power P is

  $$n = \frac{P}{h\upsilon} = \frac{P\lambda}{hc}$$

de Broglie waves (Matter waves) : Radiation has dual nature, wave and particle. The nature of experiment determines whether a wave or a particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave like character to matter (material particles). The waves associated with the moving material particles are known as matter waves or de Broglie waves.

- **de Broglie wavelength :** The de Broglie wavelength associated with a moving particle is related to its momentum as

  de Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$

  where m is the mass of the particle, v is the velocity of the particle, p is the momentum of the particle.

  – de Broglie wavelength is independent of the charge and nature of the material particle.

  – In terms of kinetic energy K, de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mK}}$.

  – If a particle of charge q is accelerated through a potential difference V, its de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{2mqV}}$.

  For an electron, $\lambda = \left(\frac{150}{V}\right)^{1/2}$ Å.

  – For a gas molecule of mass m at temperature T kelvin, its de Broglie wavelength is given by $\lambda = \frac{h}{\sqrt{3mkT}}$, where k is the Boltzmann constant.

Davisson and Germer experiment : Davisson and Germer performed an experiment to study the wave nature of electrons as suggested by de Broglie.

According this experiment the de-Broglie wave length $\lambda = \frac{1.227}{\sqrt{V}}$ nm

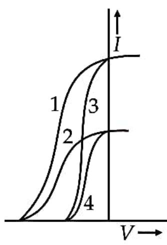
Previous Years' CBSE Board Questions

11.4 Experimental Study of Photoelectric Effect

VSA (1 mark)

1. In photoelectric effect, why should the photoelectric current increase as the intensity of monochromatic radiation incident on a photosensitive surface is increased? Explain. *(Foreign 2014)*

2. The given graph shows the variation of photoelectric current (I) versus applied voltage (V) for two different 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.? *(Delhi 2013)*

3. Show on a plot the nature of variation of photoelectric current with the intensity of radiation incident on a photosensitive surface. *(Delhi 2013C)*

4. Why is photoelectric emission not possible at all frequencies? *(AI 2012C)*

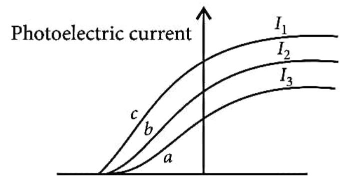
5. Define the term 'stopping potential' in relation to photoelectric effect. *(AI 2011)*

6. Define the term 'threshold frequency' in relation to photoelectric effect. *(Foreign 2011)*

7. 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? *(AI 2011C)*

8. 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 υ_1, υ_2 and υ_3 respectively incident on a photosensitive surface.

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



SA I (2 marks)

9. (i) Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W. Estimate the number of photons emitted per second on an average by the source.

(ii) Draw a plot showing the variation of photoelectric current versus the intensity of incident radiation on a given photosensitive surface. *(Delhi 2014)*

10. Two monochromatic radiations of frequencies υ_1 and $\upsilon_2 (\upsilon_1 > \upsilon_2)$ and having the same intensity are in turn, incident on a photosensitive surface to cause photoelectric emission. Explain, giving reason, in which case (i) more number of electrons will be emitted and (ii) maximum kinetic energy of the emitted photoelectrons will be more. *(Delhi 2014C)*

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

12. Two monochromatic radiations, blue and violet, of the same intensity, are incident on a photosensitive surface and cause photoelectric emission. Would (i) the number of electrons emitted per second and (ii) the maximum kinetic energy of the electrons, be equal in the two cases? Justify your answer. *(Delhi 2010C)*

SA II (3 marks)

13. Sketch the graphs showing variation of stopping potential with frequency of incident radiations for two photosensitive materials *A* and *B* having threshold frequencies $\upsilon_A > \upsilon_B$.

(i) In which case is the stopping potential more and why?

(ii) Does the slope of the graph depend on the nature of the material used ? Explain. *(AI 2016)*

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

Na : 2.75 eV and Mo : 4.175 eV.

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

15. Define the term "cut off frequency" in photoelectric emission. The threshold frequency of a metal is *f*. When the light of frequency 2*f* is incident on the metal plate, the maximum velocity of photo-electron is v_1. When the frequency of the incident radiation is increased to 5*f*, the maximum velocity of photoelectrons is v_2. Find the ratio $v_1 : v_2$. *(Foreign 2016)*

16. Describe briefly three experimentally observed features in the phenomenon of photoelectric effect. *(2/3, AI 2015)*

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

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

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

(c) On what factors does the number of emitted photoelectrons depend? *(Foreign 2015)*

18. Define the terms (i) 'cut-off voltage and (ii) threshold frequency' in relation to the phenomenon of photoelectric effect. *(2/3, AI 2012)*

19. Draw a graph between the frequency of incident radiation (υ) and the maximum kinetic energy of the electrons emitted from the surface of a photosensitive material. State clearly how this graph can be used to determine (i) Planck's constant and (ii) work function of the material. *(Foreign 2012)*

20. Draw a graph showing the variation of stopping potential with frequency of incident radiation for two photosensitive materials having work functions W_1 and $W_2 (W_1 > W_2)$. Write two important conclusions that can be drawn from the study of these plots. *(AI 2012C)*

21. Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $\upsilon_1 > \upsilon_2$, of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer. *(AI 2011)*

22. In a plot of photoelectric current versus anode potential, how does

(i) the saturation current vary with anode potential for incident radiations of different frequencies but same intensity?

(ii) the stopping potential vary for incident radiations of different intensities but same frequency.

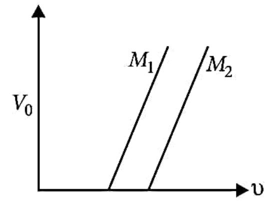
(iii) photoelectric current vary for different intensities but same frequency of incident radiations? Justify your answer in each case. *(Delhi 2007)*

LA (5 marks)

23. Figure shows a plot of stopping potential (V_0) with frequency (υ) of incident radiation for two photosensitive material M_1 and M_2. Explain.

(i) why the slope of both the lines is same?

(ii) for which material emitted electrons have greater kinetic energy for the same frequency of incident radiation?



(3/5, AI 2015C)

24. Define the terms 'threshold frequency' and 'stopping potential' in the study of photoelectric emission. *(2/5, Foreign 2010)*

11.5 Photoelectric Effect and Wave Theory of Light

SA II (3 marks)

25. Discuss briefly how wave theory of light cannot explain photoelectric effect. *(2/3, AI 2015)*

26. Why photoelectric effect cannot be explained on the basis of wave nature of light. *(2/3, Delhi 2013)*

LA (5 marks)

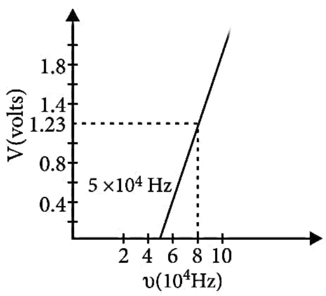
27. Write three observed features of photoelectric effect which cannot be explained by wave theory of light. *(2/5, AI 2015C)*

28. Explain briefly the reasons why wave theory of light is not able to explain the observed features in photoelectric effect. *(2/5, Foreign 2010)*

11.6 Einstein's Photoelectric Equation : Energy Quantum of Radiation

SA I (2 marks)

29. Using the graph shown in the figure for stopping potential *vs* the incident frequency of photons, calculate Planck's constant.



(Delhi 2015C)

30. Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect, which can be explained on the basis of the above equation. *(AI 2010)*

SA II (3 marks)

31. Write three characteristic features in photoelectric effect which cannot be explained on the basis of wave theory of light, but can be explained only using Einstein's equation. *(Delhi 2016)*

32. Write Einstein's photoelectric equation and mention which important features in photoelectric effect can be explained with the help of this equation.

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

33. Light of wavelength 2000 Å falls on a metal surface of work function 4.2 eV. What is the kinetic energy (in eV) of the fastest electrons emitted from the surface?

(i) What will be the change in the energy of the emitted electrons if the intensity of light with same wavelength is doubled?

(ii) If the same light falls on another surface of work function 6.5 eV, what will be the energy of emitted electrons? *(Foreign 2011)*

LA (5 marks)

34. Explain how Einstein's photoelectric equation is used to describe photoelectric effect satisfactorily. *(3/5, AI 2015C)*

11.7 Particle Nature of Light : The Photon

VSA (1 mark)

35. Define intensity of radiation on the basis of photon picture of light. Write its S.I. unit. *(AI 2014)*

36. Define 'intensity' of radiation in photon picture of light. *(Delhi 2012)*

SA I (2 marks)

37. Write three basic properties of photons which are used to obtain Einstein's photoelectric equation. Use this equation to draw a plot of maximum kinetic energy of the electrons emitted versus the frequency of incident radiation. *(AI 2014C)*

SA II (3 marks)

38. In the wave picture of light, intensity of light is determined by the square of the amplitude of the wave. What determines the intensity in the photon picture of light? *(2/3, AI 2016)*

39. (a) Write the important properties of photons which are used to establish Einstein's photoelectric equation.

(b) Use this equation to explain the concept of (i) threshold frequency and (ii) stopping potential. *(AI 2015)*

40. Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based. *(2/3, Delhi 2013)*

41. Write Einstein's photoelectric 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. *(AI 2013)*

42. State three important properties of photons which describe the particle picture of electromagnetic radiation. *(Delhi 2013C)*

43. Write Einstein's photoelectric equation. Mention the underlying properties of photons on the basis of which this equation is obtained. Write two important observations of photoelectric effect which can be explained by Einstein's equation. *(AI 2013C)*

44. Write Einstein's photoelectric equation. 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. *(Delhi 2012)*

45. Write two characteristic features observed in photoelectric effect which support the photon picture of electromagnetic radiation. *(2/3, Foreign 2012)*

46. Write Einstein's photoelectric equation, giving the main points of the photon-picture of electromagnetic radiation on which this equation is based. State three observed features of photoelectric effect which can be explained by Einstein's equation. *(AI 2012C)*

47. (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 W/m^2) red light of wavelength 6328 Å produced by a He - Ne laser? *(Delhi 2011C)*

11.8 Wave Nature of Matter

VSA (1 mark)

48. Draw a plot showing the variation of de Broglie wavelength of electron as a function of its K.E. *(Delhi 2015C)*

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

50. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why? *(AI 2012)*

51. Show on a graph the variation of the de Broglie wavelength (λ) associated with an electron, with the square root of accelerating potential (V). *(1/3, Foreign 2012)*

52. Show graphically, the variation of the de-Broglie wavelength (λ) with the potential (V) through which an electron is accelerated from rest. *(Delhi 2011)*

53. Write the relationship of de-Broglie wavelength λ associated with a particle of mass m in terms of its kinetic energy E. *(Delhi 2011C)*

54. 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. *(AI 2011C)*

55. An electron and an alpha particle have the same de-Broglie wavelength associated with them. How are their kinetic energies related to each other? *(Delhi 2008)*

56. An electron, an alpha-particle and a proton have the same kinetic energy. Which one of these particles has the largest de-Broglie wavelength? *(Delhi 2007)*

SA I (2 marks)

57. The wavelength λ of a photon and the de-Broglie wavelength of an electron have the same value. Show that energy of a photon is $(2\lambda\, mc/h)$times the kinetic energy of electron, where m, c and h have their usual meaning. *(Foreign 2016)*

58. A proton and an α-particle have the same de-Broglie wavelength. Determine the ratio of
(i) their accelerating potentials
(ii) their speeds. *(Delhi 2015)*

59. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has
(a) greater value of de-Broglie wavelength associated with it, and
(b) less momentum?
Give reasons to justify your answer. *(Delhi 2014)*

60. X-rays fall on a photosensitive surface to cause photoelectric emission. Assuming that the work function of the surface can be neglected, find the relation between the de-Broglie wavelength (λ) of the electrons emitted and the energy (E_v) of the incident photons. Draw the nature of the graph for λ as a function of E_v. *(Delhi 2014C)*

61. An α-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de Broglie wavelengths. *(AI 2010)*

SA II (3 marks)

62. An electron microscope uses electrons accelerated by a voltage of 50 kV. Determine the de-Broglie wavelength associated with the electrons. Taking other factors, such as numerical aperture etc. to be same, how does the resolving power of an electron microscope compare with that of an optical microscope which uses yellow light? *(AI 2014)*

63. An electron and a photon each have a wavelength 1.00 nm. Find
(i) their momenta,
(ii) the energy of the photon and
(iii) the kinetic energy of electron. *(Delhi 2011)*

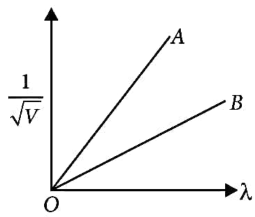
64. A proton and an alpha particle are accelerated through the same potential. Which one of the two has (i) greater value of de-Broglie wavelength associated with it, and (ii) less kinetic energy? Justify your answers. *(Delhi 2009)*

65. An electromagnetic wave of wavelength λ is incident on a photosensitive surface of negligible work function. If the photoelectrons emitted from this surface have the de-Broglie wavelength λ_1, prove that $\lambda = \left(\frac{2mc}{h}\right)\lambda_1^2$. *(Delhi 2008)*

11.9 Davisson and Germer Experiment

VSA (1 mark)

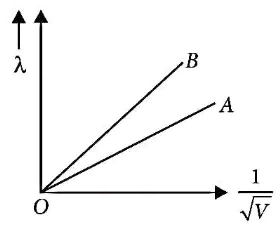
66. Figure shows a plot of $\frac{1}{\sqrt{V}}$, where V is the accelerating potential, *vs.* the de Broglie wavelength 'λ' in the case of two particles having same charge 'q' but different masses m_1 and m_2. Which line (A or B) represents a particle of large mass?



(AI 2013C)

67. Name an experiment which shows wave nature of electrons. Which phenomenon was observed in this experiment using an electron beam? *(Foreign 2010)*

68. Two lines, A and B, in the plot given in the figure show the variation of de-Broglie wavelength, λ versus $1/\sqrt{V}$, when V is the accelerating potential difference, for two particles carrying the same charge. Which one of the two represents a particle of smaller mass?



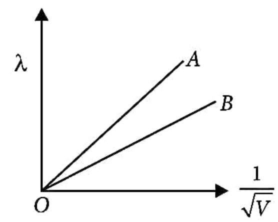
(AI 2008)

SA I (2 marks)

69. An electron is accelerated through a potential difference of 100 volts. What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond? *(Delhi 2010)*

70. Find the ratio of the de Broglie wavelengths, associated with
(i) protons, accelerated through a potential of 128 V, and
(ii) α-particles, accelerated through a potential of 64 V. *(Delhi 2010C)*

71. The two lines marked '*A*' and '*B*' in the given figure, show a plot of de Broglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where *V* is the accelerating potential, for two nuclei $_1^2H$ and $_1^3H$.
(i) What does the slope of the lines represent?
(ii) Identify which lines correspond to these nuclei.



(AI 2010C)

SA II (3 marks)

72. (a) Describe briefly how the Davisson-Germer experiment demonstrated the wave nature of electrons.
(b) An electron is accelerated from rest through a potential *V*. Obtain the expression for the de-Broglie wavelength associated with it. *(Foreign 2014)*

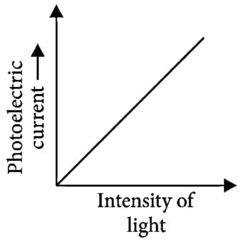
73. Draw a schematic diagram of the experimental arrangement used by Davisson and Germer to establish the wave nature of electrons. Explain briefly how the de-Broglie relation was experimentally verified in case of electrons. *(AI 2007)*

Detailed Solutions

1. Since photoelectric current is directly proportional to the number of photoelectrons emitted per second. On increasing intensity, more photoelectrons will emit.

2. Since the value of stopping potential for the pair of curves (1 and 2) and (3 and 4) are the same hence curves 1 and 2 correspond to one material while curves 3 and 4 represent another material. The pairs of curves (1 and 3) and (2 and 4) correspond to different materials but same intensity of incident radiation as the saturation current depends upon intensity and not on material.

3. Variation of photoelectric current with intensity of light for a given frequency of incident radiation



4. Photoelectric emission is not possible at all frequencies because below the threshold frequency for photosensitive surface of different atoms emission is not possible.

5. For a given frequency of incident radiation stopping potential is that minimum negative potential given to anode for which the photoelectric current becomes zero. It is denoted by V_s. For a given frequency of the incident radiation, the value of stopping potential is different for different metals but it is independent of the intensity of the incident light.

6. Threshold frequency is defined as the minimum frequency of incident radiation below which the photoelectric emission stops altogether.

7. Threshold frequency does not depend upon the intensity of light. The intensity of light mainly depends on the number of photons for given frequency of incident radiation. Therefore, the photoelectric current increases with the intensity of incident light.

8. For the curves a and b, the stopping potential is same. Hence, for curves a and b, the frequency of incident radiation is same ($\upsilon_1 = \upsilon_2$) but intensities I_1 and I_2 are different.

9. (i) Given, $\upsilon = 6.0 \times 10^{14}$ Hz

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

Let n is the number of photons emitted by the source per second.

$$n = \frac{P}{E} = \frac{P}{h\upsilon}$$

$$= \frac{2 \times 10^{-3}}{6.63 \times 10^{-34} \times 6.0 \times 10^{14}} = 0.0502 \times 10^{17}$$

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

(ii) *Refer to answer 3.*

10. (i) Intensity = Number of photons per unit area per unit time

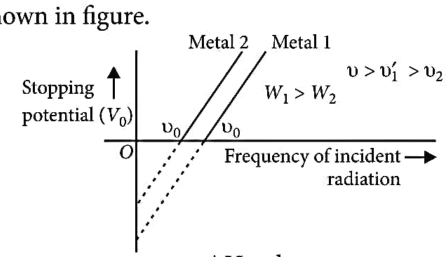
For unit area and unit time, $I_1 = I_2 \Rightarrow n_1\upsilon_1 = n_2\upsilon_2$

$$\frac{n_2}{n_1} = \frac{\upsilon_1}{\upsilon_2} > 1 \Rightarrow n_2 > n_1$$

For same intensity number of photons per unit area per unit time is large for υ_2 *i.e.* n_2. Hence, more electrons will be emitted corresponds to υ_2.

(ii) The maximum kinetic energy of emitted electrons is more for the light of greater frequency. Since $\upsilon_1 > \upsilon_2$, maximum kinetic energy of emitted photoelectrons will be correspond to υ_1.

11. The graph showing the variation of stopping potential (V_0) with the frequency of incident radiation (υ_0) for two different photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) is shown in figure.



(i) Slope of the line $= \frac{\Delta V}{\Delta\upsilon} = \frac{h}{e}$ $[\because e\Delta V = h\Delta\upsilon]$

$\therefore$ Slope of the line $= \frac{h}{e}$ *i.e.*, it is a constant quantity and does not depend on nature of metal surface.

(ii) Intercept of graph 1 on the stopping potential axis

$$= \frac{\text{work function}(W)}{e} = -\frac{h\upsilon_0}{e}$$

$\therefore$ Intercept of the line depends upon the stopping function of the metal surface.

12. (i) Frequency of violate light (υ_v) > frequency of blue light (υ_b) *i.e.*, $\left(\frac{\upsilon_v}{\upsilon_b}\right) > 1$

As both light have same intensity, so

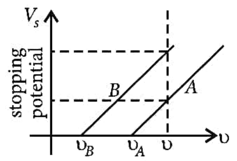
$$n_v\upsilon_v = n_b\upsilon_b \Rightarrow \frac{n_v}{n_b} = \frac{\upsilon_b}{\upsilon_v} < 1$$

$\therefore \quad n_b > n_v$

(i) Since $n_b > n_v$, hence number of electrons emitted per second corresponding to blue light will be more than that for violet light.

(ii) Since $\upsilon_v > \upsilon_b$, hence maximum kinetic energy of the electrons ($K_{max} = h\upsilon - \phi_0$) for violet light will more than that for blue light.

13. We know,



$K_{max} = eV_s = h(\upsilon - \upsilon_0)$

or, $V_s = \frac{h}{e}\upsilon - \frac{h}{e}\upsilon_0$

(i) From the graph for the same value of υ, stopping potential is more for material *B*.

as $V_s = \frac{h}{e}(\upsilon - \upsilon_0)$

$\therefore \quad V_s$ is higher for lower value of υ_0. Here $\upsilon_B < \upsilon_A$

so $V_{SB} > V_{SA}$.

(ii) Slope of the graph is given by $\frac{h}{e}$ which is constant for all the materials. Hence slope of the graph does not depend on the nature of the material used.

14. *Refer to answer 3.*

Given that λ = 3300 × 10^{-10} m, ϕ_{Na} = 2.75 eV, ϕ_{Mo} = 4.175 eV

Then energy of the laser beam is

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^{8}}{3300\times10^{-10}\times1.6\times10^{-19}} = 3.75 \text{ eV}$$

Since $E < \phi_{Mo}$ therefore there will be no emission of photoelectrons for molybdenum (Mo).

Bringing the source nearer will cause to emit more photoelectrons as intensity on the plate will increase.

15. The minimum value of the frequency of light below which the photoelectric emission stops completely, howsoever large may be the intensity of light, is called the cut-off frequency.

Given that threshold frequency of metal is f and frequency of light is $2f$. Using Einstein's equation for photoelectric effect, we can write

$$h(2f - f) = \frac{1}{2}mv_1^2 \quad \text{...(i)}$$

Similarly, for light having frequency $5f$, we have

$$h(5f - f) = \frac{1}{2}mv_2^2 \quad \text{...(ii)}$$

Using (i) and (ii), we find

$$\frac{f}{4f} = \frac{v_1^2}{v_2^2} \Rightarrow \frac{v_1}{v_2} = \sqrt{\frac{1}{4}} \Rightarrow \frac{v_1}{v_2} = \frac{1}{2}.$$

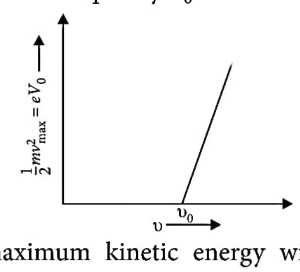
16. On the basis of experiments on photoelectric effect, three observed features are :

(i) Emission of photoelectrons start as soon as light falls on metal surface *i.e.*, there is no time lag between incidence of light and emission of photoelectrons.

(ii) The emission of photoelectrons takes place only when the frequency of the incident radiations is above a certain critical value called threshold frequency υ_0, which is characteristic of that metal emitting electrons.

Above threshold frequency υ_0, maximum kinetic energy with which photoelectrons are emitted is directly proportional to frequency υ of incident radiation.

So the graph plotted between $(1/2)mv^2_{max}$ or eV_0 with frequency υ is a straight line for frequencies above threshold frequency υ_0.



(iii) The maximum kinetic energy with which a photoelectron is emitted from a metallic surface is independent of the intensity of light and depends only upon its frequency.

17. (a) Yes, all emitted photoelectrons have same kinetic energy as the kinetic energy of emitted photoelectrons depends upon frequency of the incident radiation for a given photosensitive surface.

(b) No, the kinetic energy of emitted electrons does not depend on the intensity of incident radiation. If the intensity is increased, number of photons will also increase but energy of each photon remains same as the frequency is also same. The maximum kinetic energy depends on frequency not on intensity.

(c) The number of emitted photoelectrons depends only on intensity of incident light. For a given frequency of incident radiation, its intensity depends on the number of photons.

18. Cut-off voltage : For a particular frequency ($\upsilon > \upsilon_0$) of incident radiation, the minimum negative potential V_0 applied to the plate or anode, (A) for which the photoelectric current just becomes zero is called cut-off voltage.

Refer to answer 6.

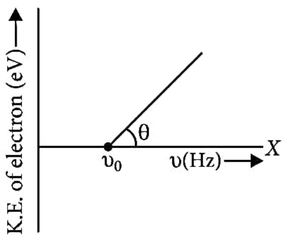
19. Kinetic energy of photoelectrons emitted from the surface of a photosensitive material,

$KE = h\upsilon - \phi = h\upsilon - h\upsilon_0$

This is a equation of straight line of the form,

$y = mx + c$

(i) From this graph, the Planck constant can be calculated by the slope of the line.



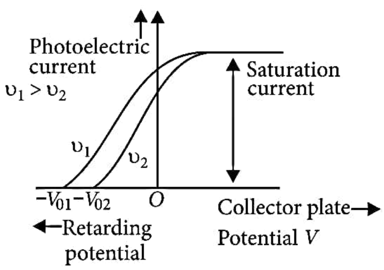
(ii) Work function is the minimum energy required to eject the photo-electron from the metal surface.

$\phi = h\upsilon_0$, where υ_0 = threshold frequency

From the graph, work function is given by intercept of line on the kinetic energy axis.

20. *Refer to answer 11.*

21. The stopping potential is more negative for higher frequencies of incident radiation. Therefore, stopping potential is higher for υ_1.

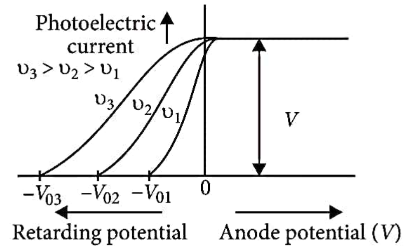


$(KE)_{max} = eV_0 = h\upsilon - \phi$

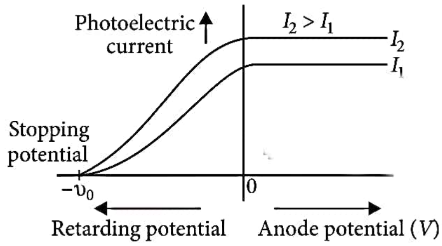
$\Rightarrow \quad V_0 = \frac{h}{e}\upsilon - \frac{\phi}{e}$

From this equation we can conclude that V_0 will increase if υ increases.

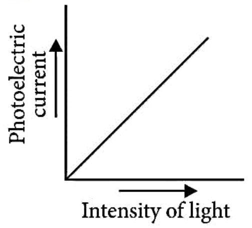
22. (i) The saturation current remains same because the saturation current depends upon intensity of incident radiation.



(ii) Stopping potential remains same. It depends upon the frequency of incident radiation.



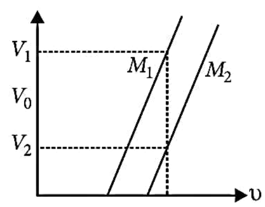
(iii) At constant frequency and accelerating potential, photoelectric current is directly proportional to the intensity of light.



It is so because photoelectric current is directly proportional to the number of photoelectrons emitted per second.

23. (i) Slope of line = $\frac{\Delta V}{\Delta \upsilon}$ $\quad [\because e\Delta V = h\Delta\upsilon]$

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



⇒ It is a constant quantity and does not depend on nature of metal surface.
(ii) Maximum kinetic energy of emitted photoelectron,
$KE = eV_0 = h\upsilon - h\upsilon_0$, ...(i)
For a given frequency $V_1 > V_2$ (from the graph)
So from equation (i),
$(KE)_1 > (KE)_2$
Since the metal M_1 has smaller threshold frequency *i.e.*, smaller work function. It emits electrons having a larger kinetic energy.

24. Threshold Frequency : The minimum frequency of incident light which is just capable of ejecting electrons from a metal is called the threshold frequency. It is denoted by υ_0.
Stopping Potential : The minimum retarding potential applied to anode of a photoelectric tube which is just capable of stopping photoelectric current is called the stopping potential. It is denoted by V_0 (or V_S).

25. Failure of wave theory of light to explain photoelectric effect
(i) According to wave theory, greater the intensity of radiation, greater the amplitudes of electric and magnetic fields and hence greater the energy density of the wave. So, the maximum kinetic energy of the photoelectron emitted must depend on intensity of incident light, however practically it does not happens. So independence of maximum kinetic energy of photoelectron emitted on intensity of incident light cannot be explained using wave theory of light.
(ii) Also, whatever the frequency of incident radiation may be, incident light of large intensity over a sufficient time must be able to impart enough energy to the electrons, so that they can get off the metal surface. So, a threshold frequency must not exist.
(iii) Further, number of electrons absorb energy continuously over the entire wavefront of the radiation. So, energy absorbed per unit time by an electron becomes very small. So, in that case electrons may take quite long time to come out of metallic surface on continuous exposure of light on the surface. However, practically we found that there is no time lag between incident of light and emission of photoelectron. So, we conclude that wave nature of light cannot be used to explain photoelectric effect.

26. *Refer to answer 25.*

27. The observed characteristics of photoelectric effect could not be explained on the basis of wave theory of light.
(i) According to wave theory, the light propagates in the form of wavefronts and the energy is distributed uniformly over the wavefronts. With increase of intensity of light, the amplitude of waves and the energy stored by waves will increase. These waves will then, provide more energy to electrons of metal; consequently the energy of electrons will increase.
Thus, according to wave theory, the kinetic energy of photoelectrons must depend on the intensity of incident light; but according to experimental observations, the kinetic energy of photoelectrons does not depend on the intensity of incident light.
(ii) According to wave theory, the light of any frequency can emit electrons from metallic surface provided the intensity of light be sufficient to provide necessary energy for emission of electrons, but according to experimental observations, the light of frequency less than threshold frequency can not emit electrons; whatever be the intensity of incident light
(iii) According to wave theory, the energy transferred by light waves will not go to a particular electrons, but it will be distributed uniformly to all electrons present in the illuminated surface. Therefore, electrons will take some time to collect the necessary energy for their emission. The time for emission will be more for light of less intensity and vice versa. But experimental observations show that the emission of electrons take place instantaneously after the light is incident on the metal; whatever be the intensity of light

28. *Refer to answer 25.*

29. Using Einstein's photoelectric equation,
$eV = h\upsilon - \phi$
on differention we get $e\Delta V = h\Delta\upsilon$

$$\text{or } h = \frac{e\Delta V}{\Delta\upsilon} = \frac{1.6\times10^{-19}\times(1.23-0)}{(8-5)\times10^{14}} = 6.56\times10^{-34}\ \text{JS}$$

30. Einstein's photoelectric equation is given below.

$$h\upsilon = \frac{1}{2}mv_{max}^2 + W_0$$

where υ = frequency of incident radiation
$\frac{1}{2}mv_{max}^2$ = maximum kinetic energy of an emitted electron

W_0 = work function of the target metal

Three salient features observed are

(i) Below threshold frequency υ_0 corresponding to W_0, no emission of photoelectrons takes place.

(ii) As energy of a photon depends on the frequency of light, so the maximum kinetic energy with which photoelectron is emitted depends only on the energy of photon or on the frequency of incident radiation.

(iii) For a given frequency of incident radiation, intensity of light depends on the number of photons per unit area per unit time and one photon liberates one photoelectron, so number of photoelectrons emitted depend only on its intensity.

31. *Refer to answer 30.*

32. Einstein's photoelectric equation

$$K_{max} = \frac{1}{2}mv^2 = h\upsilon - \phi_0 = h\upsilon - h\upsilon_0 \quad \text{...(i)}$$

Refer to answer 30.

(ii) From eqn. (i)

$$K_{max} = \frac{hc}{\lambda} - \phi_0$$

According to question,

$$K_{max} = \frac{hc}{\lambda_1} - \phi_0 \quad \text{...(ii)}$$

$$2K_{max} = \frac{hc}{\lambda_2} - \phi_0 \quad \text{...(iii)}$$

From eqn. (ii) and (iii),

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

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

$$\text{Also, } \phi_0 = \frac{hc}{\lambda_0} \quad \therefore \quad \frac{hc}{\lambda_0} = hc\left(\frac{2}{\lambda_1} - \frac{1}{\lambda_2}\right)$$

$$\text{or} \quad \frac{1}{\lambda_0} = \frac{2\lambda_2 - \lambda_1}{\lambda_1\lambda_2}; \lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$

33. $\lambda = 2000 \text{ Å} = 2000 \times 10^{-10}$ m

$W_0 = 4.2$ eV

$h = 6.63 \times 10^{-34}$ J-S

$$\frac{hc}{\lambda} = W_0 + K.E.$$

$$\text{or} \quad K.E. = \frac{hc}{\lambda} - W_0$$

$$= \frac{(6.63\times10^{-34})\times(3\times10^8)}{(2000\times10^{-10})} \times \frac{1}{1.6\times10^{-19}}\text{eV} - 4.2 \text{ eV}$$

$= (6.2 - 4.2)$ eV $= 2.0$ eV

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

(ii) For this surface, electrons will not be emitted as the energy of incident light (6.2 eV) is less than the work function (6.5 eV) of the surface.

34. *Refer to answer 30.*

35. The amount of light energy or photon energy, incident per unit area per unit time is called intensity of radiation.

S.I. Unit : W m^{-2} or J $m^{-2}s^{-1}$.

36. *Refer to answer 35.*

37. Photons : According to Planck's quantum theory of radiation, an electromagnetic wave travels in the form of discrete packets of energy called quanta.

The main features of photons are as follows:

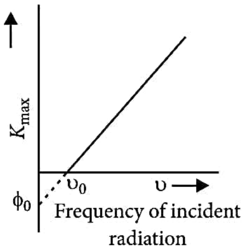
(i) In the interaction of photons with free electrons, the entire energy of photon is absorbed.

(ii) Energy of photon is directly proportional to frequency. Intensity of incident radiation depends on the number of photons falling per unit area per unit time for a given frequency.

(iii) In photon electron collision, the total energy and momentum remain constant.

Einstein's photoelectric equation is

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



38. For a given frequency, intensity of light in the photon picture is determined by

$$I = \frac{\text{Energy of photons}}{\text{area} \times \text{time}} = \frac{n \times h\upsilon}{A \times t}$$

Where n is the number of photons incident normally on crossing area A in time t.

39. (a) *Refer to answer 37.*

(b) Einstein's photoelectric equation : According to Einstein, when light is incident on metal surface, incident photons are absorbed completely by valence electrons of atoms of metal on its surface. Energy $h\upsilon$ of each photon is partially utilized by an electron to become free or to overcome its "work function" W_0 and rest of the absorbed energy provides the maximum kinetic energy to the photoelectron during the emission. *i.e.*

$$h\upsilon = \frac{1}{2}mv_{\max}^2 + W_0$$

The minimum value of the frequency of incident radiation below which the photoelectric emission stops *i.e.* kinetic energy of photoelectron is zero is called threshold frequency (υ_0).

Threshold frequency, $\upsilon_0 = \frac{W}{h}$

$$\frac{1}{2}mv_{\max}^2 = K.E._{\max} = h\upsilon - W_0$$

or, $K.E._{\max} = eV_0$

When work done by collecting electrode potential on a photoelectron is equal to its maximum kinetic energy then the electrode potential is known as stopping potential.

Stopping potential, $V_0 = \frac{K.E._{\max}}{e}$

40. *Refer to answer 37.*

41. Einstein's photoelectric equation

$$K_{\max} = \frac{1}{2}mv_{\max}^2 = h\upsilon - h\upsilon_0$$

(a) *Refer to answer 37.*
(b) *Refer to answer 30.*

42. *Refer to answer 37.*

43. *Refer to answers 30 and 37.*

44. *Refer to answers 30 and 37.*

45. *Refer to answer 30.*

46. *Refer to answers 30 and 37.*

47. From Einstein's equation $h\upsilon = \phi_0 + K = \phi_0 + eV_s$

or $\phi_0 = h\upsilon - eV_s = \frac{hc}{\lambda} - eV_s$

(Equation is independent of the power of the source)

$$\phi_0 = \frac{6.6\times10^{-34}\times3\times10^8}{2271\times10^{-10}} - 1.3\text{eV}$$

$$= \left(\frac{6.6\times10^{-34}\times3\times10^8}{2271\times10^{-10}\times1.6\times10^{-19}} - 1.3\right)\text{eV}$$

= 5.5 eV – 1.3 eV = 4.2 eV

Threshold frequency $\upsilon_0 = \frac{\phi_0}{h}$

$$= \frac{4.2\times1.6\times10^{-19}}{6.6\times10^{-34}} = 1.0\times10^{15}\,\text{Hz}$$

and the frequency of red light from the source is 10^5 W/m^2.

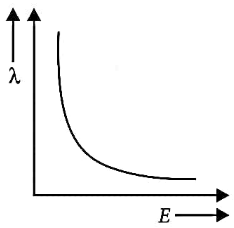
$$\upsilon = \frac{c}{\lambda} = \frac{3\times10^8}{6328\times10^{-10}} = 4.7\times10^{14}\,\text{Hz}$$

Since frequency of red light is less than threshold frequency so photocell will not respond to red light, however high (10^5 W/m^2) be the intensity of light.

48. de Broglie wavelength

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

$\Rightarrow$ $\lambda^2 KE$ = constant.



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

50. We know the relation

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

kinetic energy, $K = \frac{p^2}{2m}$

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

$K_p = K_e \Rightarrow \lambda \propto \frac{1}{\sqrt{m}}$

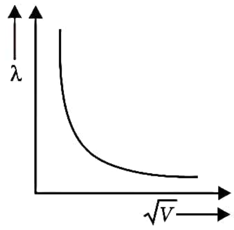
$\because$ $m_p >> m_e$ $\therefore$ $\lambda_p << \lambda_e$

Hence for same kinetic energy wavelength associated with electron will be greater.

51. We know $\lambda = \frac{12.27}{\sqrt{V}}$ Å

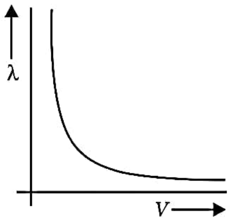
$\therefore$ $\lambda\sqrt{V}$ = constant

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



52. $\lambda = \frac{12.27}{\sqrt{V}}$ Å

$\lambda^2 V$ = constant



53. $\lambda = \frac{h}{\sqrt{2mE}}$

54. de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

$\frac{\lambda_1}{\lambda_2} = \frac{M_2 v_2}{M_1 v_1} = 1.813 \times 10^{-4}$

$\therefore \quad M_1 = \frac{M_e v_e}{1.813 \times 10^{-4}(3v_e)} \qquad (\because v_1 = 3v_e)$

$= \frac{9.1 \times 10^{-31}}{1.813 \times 10^{-4} \times 3} = 1.675 \times 10^{-27}$ kg.

Thus, the particle may be a proton or a neutron.

$\because \quad m_p << m_n$

$\therefore$ Proton will have larger de-Broglie wavelength.

55. De-Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}}$

$\because$ An electron and an alpha particle have the same de-Broglie wavelength.

i.e., $\lambda_e = \lambda_\alpha$

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

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

56. As $\lambda \propto \frac{1}{\sqrt{m}}$ and $m_e << m_p < m_\alpha$, electron will have largest de-Broglie wavelength.

57. Given that λ is the wavelength of the photon. The de-Broglie wavelength of the electron is $\lambda = \frac{h}{mv}$.

Kinetic energy of electron,

$$E_e = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\frac{h}{m\lambda}\right)^2 = \frac{h^2}{2m\lambda^2} \qquad \text{...(i)}$$

We know that energy of photon is $E_p = \frac{hc}{\lambda}$ ...(ii)

Dividing (i) by (ii),

$$\frac{E_e}{E_p} = \frac{h^2}{2m\lambda^2} \times \frac{\lambda}{hc}$$

$$E_p = \frac{2\lambda mc}{h} E_e$$

58. de Broglie wavelength of a particle of mass m and charge q accelerating through a potential V is given by

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

(i) Here, $m_p = m$, $q_p = e$, $m_\alpha = 4m_p = 4m$, $q_\alpha = 2q_p = 2e$

From eqn. (i)

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

$$1 = \sqrt{\frac{4m \times 2e \times V_\alpha}{m \times e \times V_p}} \qquad (\because \lambda_p = \lambda_\alpha)$$

$\therefore \quad \frac{V_p}{V_\alpha} = \frac{8}{1}$; $V_p : V_\alpha = 8 : 1$

(ii) Again from eqn. (i)

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

$\therefore \quad \frac{\lambda_p}{\lambda_\alpha} = \frac{m_\alpha v_\alpha}{m_p v_p}$; $1 = \frac{4mv_\alpha}{mv_p}$ or $\frac{v_p}{v_\alpha} = \frac{4}{1}$

$v_p : v_\alpha = 4 : 1$

59. For same accelerating potential, a proton and a deutron have same kinetic energy.

(a) de-Broglie wavelength is given by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2\,mK}} = \frac{h}{\sqrt{2m(qV)}}$$

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

Mass of a deutron is more than that of a proton. So, proton will have greater value of de-Broglie wavelength.

(b) Momentum, $p=\sqrt{2\,mK}$

$p \propto \sqrt{m}$

Mass of a deutron is more than that of a proton. So, a proton has less momentum.

60. According to Einstein's photo electric effect

$$E = W + \frac{1}{2}mv^2$$

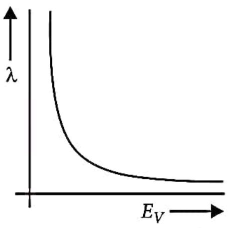
Since work function of the surface is negligible, the above equation becomes

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

$$mv = \sqrt{2mE}$$

If λ is de-Broglie wavelength of the emitted electrons, then

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$$



61. de Broglie wavelength $\lambda = \dfrac{h}{\sqrt{2mE}}$

$$= \frac{h}{\sqrt{2mqV}} \quad [\because \text{ kinetic energy } E = qV]$$

$$\therefore \quad \frac{\lambda_\alpha}{\lambda_p} = \frac{h}{\sqrt{2m_\alpha q_\alpha V}} \times \frac{\sqrt{2m_p q_p V}}{h}$$

$$\Rightarrow \quad \frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \sqrt{\frac{m_p q_p}{(4m_p)\cdot(2q_p)}} = \sqrt{\frac{1}{8}} = \frac{1}{2\sqrt{2}}$$

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

62. $\lambda = \dfrac{h}{p} = \dfrac{h}{\sqrt{2meV}}$ or $\lambda = \dfrac{12.27}{\sqrt{V}}$ Å

$$\therefore \quad \lambda = \frac{6.63\times10^{-34}}{\sqrt{(2\times9.1\times10^{-31}\times1.6\times10^{-19}\times50\times10^3)}}$$

$\lambda = 5.49 \times 10^{-12}$ m

The resolving power of an electron microscope is much better than that of optical microscope.

Resolving power of a microscope

$$R.P. = \frac{2\mu\sin\theta}{\lambda}$$

This formula suggests that to improve resolution, we have to use shorter wavelength and media with large indices of refraction. For an electron microscope, μ is equal to 1 (vacuum).

For an electron microscope, the electrons are accelerated through a 50,000 V potential difference. Thus the wavelength of electrons is found to be 10^{-12} m. As, λ is very small (approximately 10^{-5} times smaller) for electron microscope than an optical microscope which uses yellow light of wavelength (5700 Å to 5900 Å). Hence, the resolving power of an electron microscope is much greater than that of optical microscope.

63. (i) Momentum of photon

$$p = \frac{h}{\lambda} = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25} \text{ kg m s}^{-1}$$

Momentum of electron

$$p = \frac{6.6\times10^{-34}}{1\times10^{-9}} = 6.6\times10^{-25} \text{ kg m s}^{-1}$$

(ii) Energy of photon

$$E = \frac{hc}{\lambda} = \frac{6.6\times10^{-34}\times3\times10^8}{1\times10^{-9}} = 1.98\times10^{-16} \text{ J}$$

(iii) Kinetic energy of electron

$$E_e = \frac{p^2}{2m} = \frac{(6.6\times10^{-25})^2}{2\times9.1\times10^{-31}} = 2.39\times10^{-19} \text{ J}$$

64. As $m_\alpha = 4m_p$ and $q_\alpha = 2e$, $q_p = e$

As both are accelerated through same electric potential, so

$$\frac{\frac{1}{2}m_p v_p^2}{\frac{1}{2}m_\alpha v_\alpha^2} = \frac{q_p V}{q_\alpha V}$$

$$\text{or} \quad \frac{m_p}{4m_p}\times\left(\frac{V_p}{V_\alpha}\right) = \frac{e}{2e} \quad \text{or} \quad \left(\frac{V_p}{V_\alpha}\right) = \frac{4}{2} = 2$$

$$\text{or} \quad \frac{V_p}{V_\alpha} = \sqrt{2} \qquad \text{...(i)}$$

$$\text{(i)} \quad \frac{\lambda_p}{\lambda_\alpha} = \frac{h/m_p v_p}{h/m_\alpha v_\alpha} = \frac{m_\alpha v_\alpha}{m_p v_p} = \frac{4m_p}{m_p}\times\frac{1}{\sqrt{2}}$$

$$\text{or} \quad \frac{\lambda_p}{\lambda_\alpha} = 2\sqrt{2} > 1 \text{ or } \lambda_p > \lambda_\alpha$$

So, proton has greater value of de-Broglie wavelength associated with it.

(ii) $\dfrac{\frac{1}{2}m_p v_p^2}{\frac{1}{2}m_\alpha v_\alpha^2} = \dfrac{q_p V}{q_\alpha V} = \dfrac{q_p}{q_\alpha} = \dfrac{1}{2} < 1$

or $\frac{1}{2}m_p v_p^2 < \frac{1}{2}m_\alpha v_\alpha^2$

So, proton has less kinetic energy.

Since mass of alpha particle is larger than a proton

$\therefore\ \lambda_{proton} > \lambda_{alpha}$

(ii) Since $K.E. = h\nu = h\,\dfrac{c}{\lambda}$

$E \propto \dfrac{1}{\lambda}$

Since $\lambda_{proton} > \lambda_{alpha}$

$\therefore$ K_{proton} is less than K_{alpha}.

65. As the work function of the metal can be neglected, so, according to Einstein's photoelectric equation, K.E. of emitted electron = Energy of X-ray photon.

$\frac{1}{2}mv^2 = h\upsilon,\ \dfrac{p^2}{2m} = \dfrac{hc}{\lambda}$ or $p = \sqrt{\dfrac{2mhc}{\lambda}}$

de-Broglie wavelength of emitted electrons,

$$\lambda_1 = \frac{h}{p} = \frac{h}{\sqrt{\dfrac{2mhc}{\lambda}}}$$

or $\lambda_1 = \sqrt{\dfrac{h\lambda}{2mc}}$ or $\lambda_1^2 = \dfrac{h\lambda}{2mc} \Rightarrow \lambda = \left(\dfrac{2mc}{h}\right)\lambda_1^2$

66. de Broglie wavelength, $\lambda = \dfrac{h}{\sqrt{2mqV}}$ or

$\lambda = \dfrac{h}{\sqrt{2mq}} \cdot \dfrac{1}{\sqrt{V}}$. The graph of λ versus $\dfrac{1}{\sqrt{V}}$ is a straight line of slope $\dfrac{h}{\sqrt{2mq}}$. The slope of line B is small, so particle B has larger mass (charge is same).

67. Davisson-Germer experiment shows wave nature of electrons. The phenomenon of diffraction of electron beam was observed in this experiment

68. $\therefore\ \lambda = \dfrac{h}{\sqrt{2mqV}} \Rightarrow \lambda = \dfrac{h}{\sqrt{mq}} \cdot \dfrac{1}{\sqrt{V}}$

Slope of line = $\dfrac{h}{\sqrt{mq}}$

$\because$ Slope of B > Slope of A

$\dfrac{1}{\sqrt{m_B}} > \dfrac{1}{\sqrt{m_A}}$ (for same q)

$\therefore\ m_B < m_A$

Therefore, line B represents a particle of smaller mass.

69. Here $V = 100$ volts. The de Broglie wavelength

$\lambda = \dfrac{1.227}{\sqrt{V}}\text{nm} = \dfrac{1.227}{\sqrt{100}} = \dfrac{1.227}{10} = 0.1227 = 0.123$ nm

The value of de-Broglie wavelength is associated with the wavelength of X-rays.

70. The de Broglie wavelength λ is

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

$\therefore\ \lambda_p = \dfrac{h}{\sqrt{2mqV}}$ and $\lambda_\alpha = \dfrac{h}{\sqrt{2m'q'V'}}$

$$\lambda_p : \lambda_\alpha = \sqrt{\frac{m'q'V'}{mqV}}$$

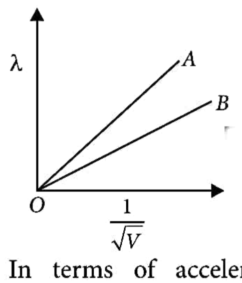
$\because\ m' = 4m,\ q = e,\ q' = 2e$

$V = 128$ V, $V' = 64$ V

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{4m \times 2e \times 64}{m \times e \times 128}}$$

$\therefore$ Required ratio = 2 : 1

71.



(i) In terms of accelerating potential V, the de Broglie wavelength of a charged particle is given by

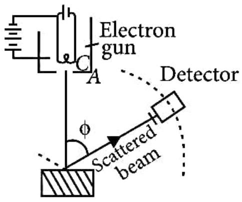
$$\lambda = \frac{h}{\sqrt{2mqV}} \quad \text{...(i)}$$

Where q is the charge and m is the mass of the particle. The equation (i) represents a straight line, whose slope is $\dfrac{h}{\sqrt{2mq}}$. The slope of the line is inversely proportional to $\sqrt{m}$ for given value of q.

(ii) Since the slope of line B is lesser, it represents the particle of heavier mass *i.e.*, ${}_1^3$H.

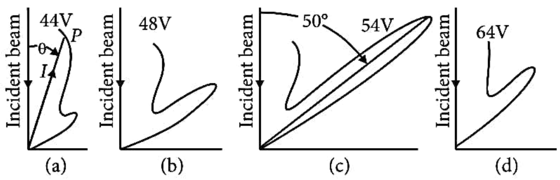
The line A represents the particle of lighter mass ${}_1^2$H.

72. (a) Experimental arrangement used by Davisson and Germer : Electrons from a hot tungsten cathode are accelerated by a potential difference V between the cathode (C) and anode (A). A narrow hole in the anode renders the electrons into a fine beam of electrons and allows them to strike a nickel crystal.



The electrons are scattered in all directions by the atoms in the crystal and its intensity in a given direction is found by the use of a detector. The graph is plotted between angle ϕ (angle between incident and the scattered direction of the electron beam) and intensity of the scattered beam.

The experimental curves obtained by Davisson and Germer are as shown in the figure below.



The appearance of the peak in a particular direction at 54 V is due to the constructive interference of electrons scattered from different layers of the regularly spaced atoms of the crystals.

(b) Consider an electron of mass m and charge e. Let v be the final velocity attained by the electron when it is accelerated from rest through a potential difference of V volts. Then kinetic energy gained by the electron equals the work done on the electron by the electric field.

K.E. gained by the electron,

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

Work done on the electron $= eV$

$$\therefore \quad K = \frac{p^2}{2m} = eV \text{ or } p = \sqrt{2mK} = \sqrt{2meV}$$

Hence the de Broglie wavelength of the electron is

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

Now $h = 6.63 \times 10^{-34}$ J s, $m = 9.1 \times 10^{-31}$ kg

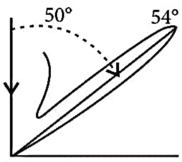
$e = 1.6 \times 10^{-19}$ C

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

$$= \frac{12.3\times10^{-10}}{\sqrt{V}}\text{m} = \frac{12.3}{\sqrt{V}}\text{Å}$$

73. *Refer to answer 72 (a).*

This is the experimental value of wavelength of electron.



According to de-Broglie hypothesis, the wavelength of electron accelerated through a potential V is

$$\lambda = \frac{h}{p} = \frac{12.27}{\sqrt{V}}\text{ Å}$$

For $V = 54$ volt, $\lambda = 0.167$ nm

As there is a close approximation between the estimated value of de-Broglie wavelength and experimental value determined by Davisson and Germer. This proves existence of de-Broglie waves for electron in motion.