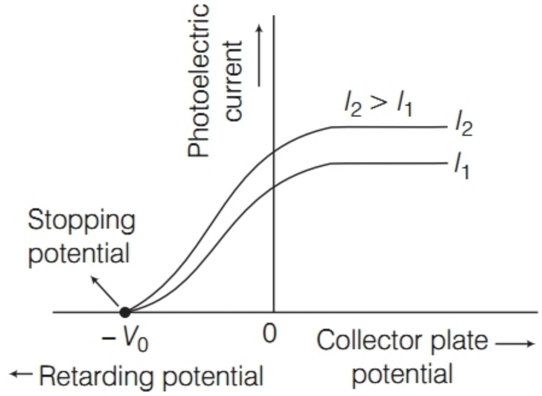
Explanations

1. Refer to text on page 335 (Laws of Photoelectric Emission). **(1)**
2. The intensity of radiation is defined as the rate of emitted energy from unit surface area in a given interval of time.
   Its SI unit is watt/metre^2. **(1)**

3. Variation of photoelectric current *versus* potential for different intensities and same frequencies.

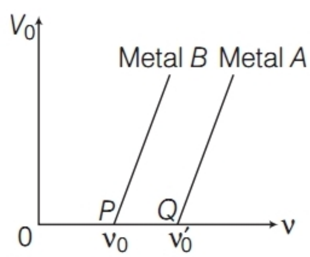


(1)

4. Refer to Sol. 2 on page 343. **(1)**

5. Metal A has higher value of work function because the intercept of the line of the given graph depends on work function. Thus, higher the intercept of the graph higher will be the work function. **(1)**

6.



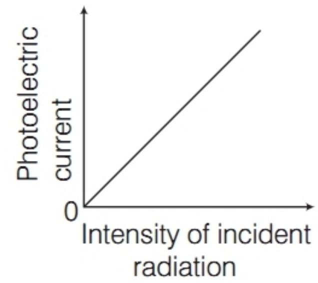
As $\quad OQ > OP \quad \therefore \nu_0' > \nu_0$

So, the threshold frequency of metal A is greater than metal B. **(1)**

7. Photoelectric effect is a one-photon-one electron phenomenon. Therefore, when the intensity of radiation incident on the surface increases, the number of photons per unit area unit time increases (since the intensity of incident radiation $\propto$ number of photons). Hence, the photoelectrons ejected will be large, which in turn, will contribute to the increase in photoelectric current. **(1)**

8. Curves 1 and 2 correspond to similar materials while curves 3 and 4 represent different 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. **(1)**

9. Graph of variation of photoelectric current with the intensity of incident radiation on a photosensitive surface is given below.



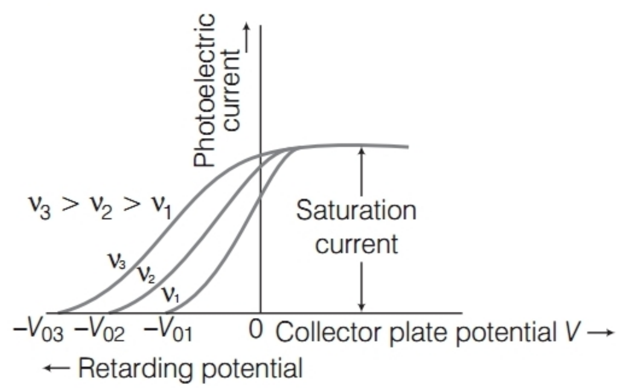
(1)

10. Photoelectric emission is not possible at all frequencies because below the threshold frequency for photosensitive surface of different atoms emission is not possible. **(1)**

11. 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. **(1)**

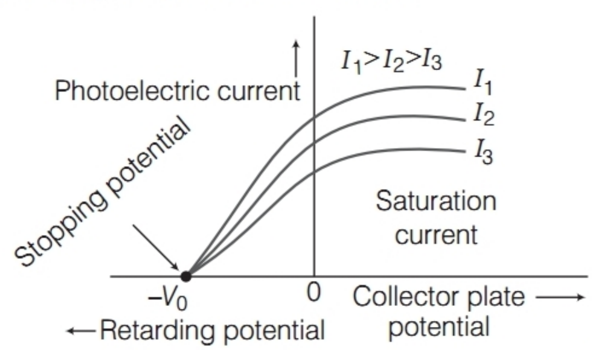
12. In experimental set up of photoelectric effect, the value of negative potential of anode at which photoelectric current in the circuit reduces to zero is called stopping potential or cut-off potential for the given frequency of the incident radiation. **(1)**

13. The variation of photoelectric current with collector plate potential for different plate frequencies is shown as below



(1)

14. The variation of photoelectric current with collector plate potential for different intensities at same frequency is shown as below



(1)

15. According to Einstein photoelectric equation,

$$h\nu = \phi_0 + K_{max}$$

where, $\phi_0 = h\nu_0$

and ν_0 = Threshold frequency.

In case (i), $h\nu_1 = h\nu_0 + K$

or $h(\nu_1 - \nu_0) = K$ ... (i)

In case (ii), $h\nu_2 = h\nu_0 + 2K$

or $h(\nu_2 - \nu_0) = 2K$ ... (ii)

Dividing Eq. (i) by Eq. (ii), we get

$$\frac{\nu_1 - \nu_0}{\nu_2 - \nu_0} = \frac{1}{2}$$

$\Rightarrow$ $\nu_0 = 2\nu_1 - \nu_2$ **(2)**

16. (i) The photoelectric emission depends on

(a) intensity of light

(b) potential applied

(c) frequency of incident radiation **(1)**

(ii) Refer to text on page 335 [Laws of Photoelectric Emission (iii)]. **(1)**

17. (i) The energy of photoelectrons in a photocell is given by,

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

So, if the frequency of light incident on the cathode is increased, the energy of photoelectrons increases linearly. **(1)**

(ii) As, photoelectric current/photocurrent of the photocell is independent of frequency of the incident light, till intensity remains constant.

So, when the frequency of light incident on the cathode of photocell is increased keeping other factors same, the photoelectric current remains the same. **(1)**

18. From Einstein's photoelectric equation,

$$K_{max} = \frac{1}{2}mv_{max}^2 = h(\nu - \nu_0)$$

where, h = Planck's constant,

ν = frequency of incident light

and ν_0 = threshold frequency of the photosensitive surface.

So, for photoemission to takes place, $\nu > \nu_0$. **(1)**

Therefore,

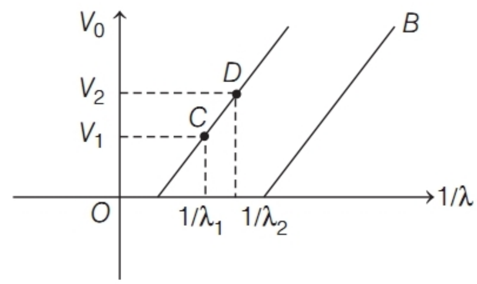
(i) threshold frequency of surface A is higher than the frequency of incident light, as no emission takes place.

(ii) threshold frequency of surface B is equal to the frequency of incident light, as photoelectrons are just emitted.

(iii) threshold frequency of surface C is lower than the frequency of incident light, as the emitted photoelectrons have some kinetic energy.

$\therefore$ $(\nu_0)_A > (\nu_0)_B > (\nu_0)_C$ **(1)**

19. (i) The variation of stopping potential (V_0) for the photoelectron *versus* $\left(\frac{1}{\lambda}\right)$ graph is as shown below



Take any two points C and D on the graph as shown above.

According to Einstein's photoelectric equation, we can write, $eV_1 = \frac{hc}{\lambda_1} - \phi_0$ ...(i)

where, ϕ_0 is the work function of metal A.

and $eV_2 = \frac{hc}{\lambda_2} - \phi_0$ ...(ii)

Subtracting Eq. (i) from Eq. (ii), we get

$$\Rightarrow e(V_2 - V_1) = hc\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)$$

or $$h = \frac{e(V_2 - V_1)}{c\left(\frac{1}{\lambda_2} - \frac{1}{\lambda_1}\right)} = \frac{e(V_2 - V_1)\lambda_1\lambda_2}{c(\lambda_1 - \lambda_2)}$$

Thus, Planck's constant can be determined from graph.

NOTE Since, h is a constant, so it will be same for both metals A and B. **(1)**

(ii) Stopping potential (V_0) for the electrons emitted will not be affected by the increase in distance between light source and the metal surface A. This is because V_0 is independent of the intensity of the incident light but depends only upon the frequency (or wavelength) of incident light. So, increase in the given distance affects only the intensity of the light but not the frequency. Thus, V_0 remains same. **(1)**

20. The wave theory of light is not able to explain the observed features of photoelectric current because of following reasons

(i) 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.

(ii) 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. **(1)**

Considering the following few properties of photon, the above problem was resolved.

(i) In interaction of radiation with radiation behaves as if it is made up of particle called photon.

(ii) Energy of a photon is directly proportional to the frequency of the incident light. **(1)**

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

(i) **Threshold frequency** For $KE_{max} \geq 0$.

$$\Rightarrow \qquad \nu \geq \nu_0$$

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. **(1)**

(ii) **Effect of intensity of incident light** The number of photons incident per unit time per unit area increases with the increase of intensity of incident light. More number of photons facilitates ejection of more number of photoelectrons from metal surface leads to further increase of photocurrent till its saturation value is reached. **(1)**

22. (i) Refer to text on page 335 and Sol. 12 on page 344. **(1)**

(ii) Refer to Sol. 3 on page 344. **(1)**

23. Given, $\lambda = 412.5\,\text{nm} = 412.5 \times 10^{-9}$ m

$$\therefore \qquad E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{412.5 \times 10^{-9} \times 1.6 \times 10^{-19}} \text{ eV}$$

$$= 3.01 \text{ eV}$$ **(1)**

From the given question, work function (ϕ) of the following metals are given as

$$\text{Na} \rightarrow 1.92, \text{ K} \rightarrow 2.15$$

$$\text{Ca} \rightarrow 3.20, \text{ Mo} \rightarrow 4.17$$

As the given energy is greater than the work function of Na and K only, hence these metals shows photoelectric emission. **(1)**

24. Given, $V = 3.3$ V and

frequency of photons (ν) $= 8 \times 10^{14}$ Hz

As we know, $eV_0 = h\nu - \phi$

So, $\qquad \phi = h\nu - eV_0$

$$\Rightarrow \quad \phi(\text{eV}) = \frac{6.63 \times 10^{-34} \times 8 \times 10^{14}}{1.6 \times 10^{-19}} \text{ eV} - 3.3\text{eV}$$

$$= (3.31 - 3.3) \text{ eV}$$

$$\Rightarrow \qquad \phi = 0.01 \text{ eV}$$ **(2)**

25. Given, frequency, $f = 6.0 \times 10^{14}$ Hz

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

(i) Energy of emitted photons, $E = h\nu$

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

$$= 4 \times 10^{-19} \text{ J}$$ **(1)**

(ii) Number of photons emitted per second,

$$n = \frac{P}{E} = \frac{2 \times 10^{-3}}{4 \times 10^{-19}} = 5 \times 10^{15} \text{ photons}$$ **(1)**

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

$$I = \frac{\text{Energy of photons}}{\text{Area} \times \text{Time}} = \frac{n \times h\nu}{A \times t}$$

where, n is the number of photons incident normally on crossing area A in time t. **(2)**

27. Using Einstein's photoelectric equation,

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

On differentiation, we get $e\Delta V = h\Delta\nu$

$$\text{or} \qquad h = \frac{e\Delta V}{\Delta\nu} = \frac{1.6 \times 10^{-19} \times (1.23 - 0)}{(8 - 5) \times 10^{14}}$$

$$= 6.56 \times 10^{-34} \text{ J-s}$$ **(2)**

28. (i) Refer to Sol. 25 on page 346. **(1)**

(ii) Refer to Sol. 9 on page 344. **(1)**

Or

(i) 10^{15} photons; Refer to Sol. 25 on page 346. **(1)**

(ii) Refer to Sol. 9 on page 344. **(1)**

29. *Three basic properties of photons are given as below*

(i) Photons are quanta or discrete carriers of energy.

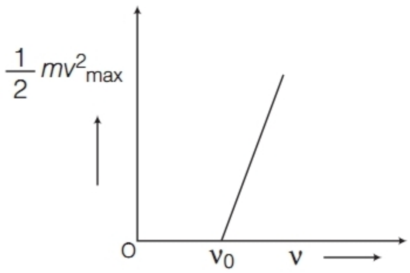
(ii) Energy of a photon is proportional to the frequency of light.

(iii) The photon gives all its energy to the electron with which it interacts. **(1)**

Einstein's photoelectric equation,

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

The plot is shown as below



(1)

30. (i) Refer to Sol. 12 on page 344. **(1)**

(ii) Refer to Sol. 13 on page 344. **(1)**

31. (i) Refer to text on page 335 (Laws of Photoelectric Emission). **(1)**

(ii) Refer to Sol. 14 on page 344. **(1)**

32. (i) Intensity of incident radiation, $I = nh\nu$, where n is number of photons incident per unit time per unit area, h is Planck's constant and ν is frequency of photon.

For same intensity of two monochromatic radiations of frequencies ν_1 and ν_2

$$n_1 h\nu_1 = n_2 h\nu_2$$

As, $\nu_1 > \nu_2$

and $n_2 > n_1$ **(1)**

Therefore, the number of electrons emitted for monochromatic radiation of frequency ν_2, will be more than that for radiation of frequency ν_1.

(ii) As, $h\nu = \phi_0 + KE_{max}$

$\therefore$ For given ϕ_0 (work function of metal)

K_{max} increases with ν

$\therefore$ Maximum kinetic energy of emitted photoelectron will be more for monochromatic light of frequency ν_1 (as $\nu_1 > \nu_2$). **(1)**

33. The intensities for both the monochromatic radiation are same but their frequencies are different. Thus,

(i) The number of electrons ejected in two cases are same because it depends on the number of incident photons. **(1)**

(ii) As, $KE_{max} = h\nu - \phi_0$

[Einstein's photoelectric current]

$\Rightarrow KE_{max} \propto \nu$

Since, $\nu_{violet} > \nu_{blue}$

$\therefore$ The KE_{max} of violet radiation will be more. **(1)**

34. 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

and KE_{max} = maximum kinetic energy.

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

where, ν_0 is threshold frequency.

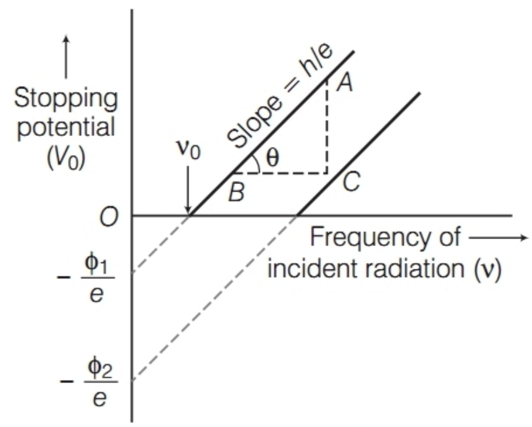
$\Rightarrow \quad KE_{max} = h\nu - h\nu_0$

$\Rightarrow \quad KE_{max} = h(\nu - \nu_0)$ ...(ii) **(1)**

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

For salient features Refer to Sol. 21 on page 346. **(1)**

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



(1)

(i) The slope of stopping potential *versus* frequency of incident radiation gives the ratio of Planck's constant (h) and electronic charge (e). **(1/2)**

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

Intercept on the potential axis $= -\dfrac{h\nu_0}{e}$ **(1/2)**

36. Einstein's photoelectric equation Refer to text on pages 335 and 336. **(1)**

From Einstein photoelectric equation,

$$KE_{max} = h\nu - \phi \Rightarrow \frac{m}{2}v^2_{max} = h\nu - \phi$$

$$\Rightarrow \quad v^2_{max} = \frac{2h}{m}\nu - \frac{2\phi}{m} \quad \text{...(i)}$$

As we know that, the equation of straight line

$$y = mx + c \quad \text{...(ii)}$$

where, m is the slope of the line.

By comparing Eq. (i) with Eq. (ii), we get

$$m = \frac{2h}{m} \text{ and } c = \frac{-2\phi}{m}$$

$$\Rightarrow \quad \tan\theta = \frac{2h}{m} \Rightarrow h = \frac{m\tan\theta}{2}$$

and l (from graph) $l = c = \dfrac{-2\phi}{m}$

$$n = \left.\frac{\phi}{h}\right|_{v_{max}=0} \quad \text{[from Eq. (i)]}$$

(2)

37. (i) From Einstien's photoelectric equation, we have,

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

where, K_{max} is maximum kinetic energy of the photoelectrons, ϕ_0 is work function and $h\nu$ is energy of the incident photon.

As $\quad K_{max} \geq 0$

So, $\quad h\nu - \phi_0 \geq 0$ or $\nu \geq \frac{\phi_0}{h}$

Thus, photoemission occurs, when frequency is greater than threshold frequency, $\nu \geq \frac{\phi_0}{h}$. **(1½)**

(ii) Energy of the incident radiation of wavelength λ

$$E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}) \times (3 \times 10^8)}{3300 \times 10^{-10} \times 1.6 \times 10^{-19}} = 3.76 \text{ eV}$$

This energy of the incident radiation is greater than the work function of Na and K but less than those of Mo and Ni, so photoelectric emission will occur only in Na and K metals and not in Mo and Ni.

If the laser is brought closer, the intensity of incident radiation increases. This does not affect the result regarding Mo and Ni metals, while photoelectric current from Na and K will increase in proportion to intensity. **(1½)**

38. (i) Einstein's photoelectric equation is

$$eV_0 = K_{max} = h\nu - \phi_0$$

Important features of this equation are given below :

(a) Photoemission occurs when frequency of incident radiation is more than the threshold frequency, $\nu \geq \frac{\phi_0}{h}$.

(b) Energy of emitted photoelectron is proportional to energy of incident photon. **(1½)**

(ii) Energy of incident photon is less than work function of P but just equal to that of Q.

For Q,

Work function, $\phi_0 = \frac{h\nu}{e}(\text{eV})$

$$= \frac{6.6 \times 10^{-34} \times 10^{15}}{1.6 \times 10^{-19}} = 4.1 \text{ eV}$$ **(1½)**

39. (i) Einstein's photoelectric equation,

$$h\nu = \phi + eV$$

$$V = \frac{h\nu}{e} - \frac{\phi}{e} \quad \text{...(i)}$$

where, h is Planck's constant.

Eq. (i) represents a straight line given by line P and Q. $\frac{\phi}{e}$ represents negative intercept on the Y-axis. Since, Q has greater negative intercept, it will have greater ϕ (work function) and hence, higher threshold frequency. **(1)**

(ii) To know work function of Q, we put $V = 0$ in the Eq. (i),

$$0 = \frac{h\nu}{e} - \frac{\phi}{e}$$

$$\Rightarrow \quad \phi = h\nu$$

$$\therefore \quad \phi = 6.6 \times 10^{-34} \times 6 \times 10^{14} \text{ J}$$

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

$$= \frac{6.6 \times 6 \times 10^{-20}}{1.6 \times 10^{-19}} \text{ eV}$$

$$= 2.5 \text{ eV}$$ **(1)**

(iii) From the equation, $\nu\lambda = c$

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{8 \times 10^{14}} = \frac{30}{8} \times 10^{-7} \text{m}$$

$$= \frac{30}{8} \times 10^3 \times 10^{-10} \text{m}$$

$$= \frac{30}{8} \times 10^3 \text{ Å} = 3750 \text{ Å}$$

$$\text{Energy} = \frac{12375}{\lambda} = \frac{12375}{3750} \text{eV}$$

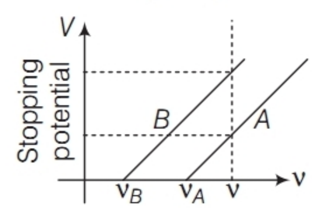
$$= 3.3 \text{ eV}$$

Maximum KE of emitted electron $= 3.3 - 2.5$ eV

$= 0.8$ eV **(1)**

40. We know, $\quad K_{max} = eV = h(\nu - \nu_0)$

or $\quad V = \frac{h}{e}\nu - \frac{h}{e}\nu_0$



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

As, $V = \frac{h}{e}(\nu - \nu_0)$

$\therefore$ V is higher for lower value of ν_0. Here $\nu_B < \nu_A$, so $V_B > V_A$. **(2)**

(ii) Slope of the graph is given by h/e which is constant for all the materials. Hence, slope of the graph does not depend on the nature of the material used. **(1)**

41. For graph Refer to Sol. 9 on page 344. **(1)**

Given that, $\lambda = 3300 \times 10^{-10}$ m,

$$\phi_{Na} = 2.75 \text{ eV}, \phi_{Mo} = 4.175 \text{ eV}.$$

Then energy of the laser beam is

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{3300 \times 10^{-10} \times 1.6 \times 10^{-19}} = 3.75 \text{ eV}$$

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. **(2)**

42. Refer to text on page 335 (Laws of Photoelectrtic Emission). **(1)**

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

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

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

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

Using Eqs. (i) and (ii), we get

$$f/4f = v_1^2/v_2^2$$

$$\Rightarrow \quad v_1/v_2 = \sqrt{1/4} \Rightarrow v_1/v_2 = 1/2$$ **(2)**

43. Einstein's photoelectric equation is given below :

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

where, ν = frequency of incident radiation,

$\frac{1}{2}mv_{max}^2$ = maximum kinetic energy of an emitted electron

and ϕ_0 = work function of the target metal. **(1)**

Three salient features observed are

(i) Below threshold frequency ν_0 corresponding to ϕ_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. **(2)**

44. (i) Important properties of photons which are used to establish Einstein's photoelectric equations.

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

(b) Each photon has energy $E (= h\nu = hc/\lambda)$ and momentum $p (= h\nu/c = h/\lambda)$, where c is the speed of light, h is Planck's constant, ν and λ are frequency and wavelength of radiation respectively.

(c) All photons of light of a particular frequency ν or wavelength λ have the same energy $E (= h\nu = hc/\lambda)$ and momentum $p (= h\nu/c = h/\lambda)$ whatever the intensity of radiation may be. **(1½)**

(ii) Since, Einstein's photoelectric equation is given by

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

(a) For a given material, there exist a certain minimum frequency of the incident radiation below, which no emission of photoelectron takes place. This frequency is called threshold frequency. Above threshold frequency, the maximum kinetic energy of the emitted photoelectron or equivalent stopping potential is independent of the intensity of the incident light but depends only upon the frequency of the incident light.

(b) If the collecting plate in the photoelectric apparatus is made at high negative potential, then most of the high energetic electrons get repelled back along the same path and the photoelectric current in the circuit becomes zero. So, for a particular frequency of incident radiation, the minimum negative potential for which the electric current becomes zero is called cut-off or stopping potential. **(1½)**

45. (i) *Three experimentally observed features in the phenomenon of photoelectric effect is*

(a) **Intensity** When intensity of incident light increases as one photon ejects one electron, the increase in intensity will increase the number of ejected electrons. Frequency has no effect on photoelectron.

(b) **Frequency** When the frequency of incident photon increases, the kinetic energy of the emitted electrons increases. Intensity has no effect on kinetic energy of photoelectron.

(c) **No time lag** When energy of incident photon is greater than the work function, the photoelectron is immediately ejected. Thus, there is no time lag between the incidence of light and emission of photoelectron. **(½ × 3)**

(ii) Also, according to the wave theory, the absorption of energy by electron takes place continuously over the entire wavefront of the radiation.

Hence, it will take hours or more for a single electron to come out of the metal which contradicts the experimental fact that photoelectron emission of instantaneous.

(½ × 3)

46. Einstein's photoelectric equation

$$K_{max} = \frac{1}{2}mv^2 = h\nu - \phi_0 = h\nu - h\nu_0 \quad \dots \text{(i)}$$

For important features,

Refer to Sol. 44(i) on page 349. **(1)**

From Eq. (i),

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

According to question,

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

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

From Eqs. (ii) and (iii), **(1)**

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

$$\phi_0 = \frac{2hc}{\lambda_1} - \frac{hc}{\lambda_2}$$

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

Also, $\phi_0 = \frac{hc}{\lambda_0}$

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

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

$$\lambda_0 = \frac{\lambda_1\lambda_2}{2\lambda_2 - \lambda_1}$$ **(1)**

47. (i) Yes, all emitted photoelectrons have same kinetic energy as the kinetic energy of emitted photoelectrons depending upon frequency of the incident radiation for a given photosensitive surface. **(1)**

(ii) 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. **(1)**

(iii) The number of emitted photoelectrons depends only on intensity of incident light. **(1)**

48. **For Einstein's equation** Refer to text on pages 335 and 336.

Properties of photons Refer to Sol. 44(i) on page 349. **(1½)**

For these observed features Refer to Sol. 43 on page 349. **(1½)**

49. (i) **For three important properties of photon** Refer to Sol. 44 (i) on page 349. **(1½)**

(ii) Refer to Sol. 44 (ii) on page 349. **(1½)**

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

(a) The instantaneous ejection of photoelectrons.

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

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

(1½)

(ii) Photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based on particle nature of light. Its basic features are given as below

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

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

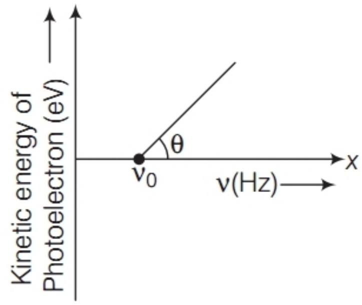
(c) All photons of light of a particular frequency ν or wavelength λ have the same energy $E\left(= h\nu = \frac{hc}{\lambda}\right)$ and momentum $p\left(= \frac{h\nu}{c} = \frac{h}{\lambda}\right)$ whatever the intensity of radiation may be. **(1½)**

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

$$KE = h\nu - \phi = h\nu - h\nu_0$$

This is an equation of straight line of the form,

$$y = mx + c \qquad \textbf{(1)}$$



(i) From this graph, the Planck's constant can be calculated by the slope of the line. **(1)**

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

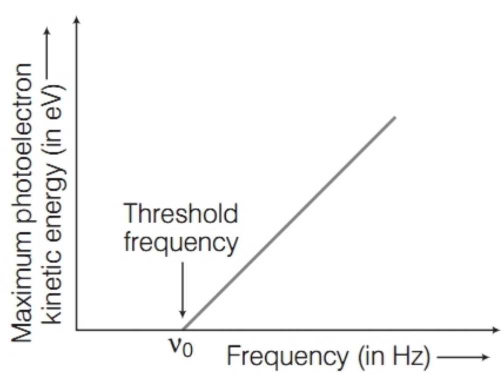
$\phi = h\nu_0$, where ν_0 = threshold frequency.

From the graph, work function is given by intercept of line on the kinetic energy axis. **(1)**

52. The two characteristic features observed in photoelectric effect which support the photon pictures of electromagnetic radiation are given as below:

(a) 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, $p\left(= \dfrac{h}{\lambda}\right)$ whatever the intensity of radiation may be.

(b) Photons are electrically neutral and not deflected by electric and magnetic fields. **(1)**



(1)

(i) Planck constant is given by the slope of the curve,

i.e. Slope of graph $= \dfrac{h}{e}$

(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.

$\therefore$ From the given graph, work is given by intercept of the line on the kinetic energy axis. **(1)**

53. Refer to Sol. 48 on page 350. **(3)**

54. **Cut-off voltage** The minimum negative voltage (V_0) applied on anode plate w.r.t. the cathode for which photocurrent in the circuit reduces to zero.

For threshold frequency Refer to text on page 335 (Laws of Photoelectric Emission). **(1)**

Einstein's equation, $h\nu = KE_{max} + \phi_0$

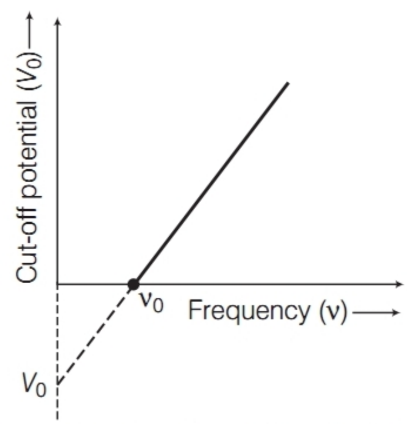
$$\Rightarrow \quad h\nu = KE_{max} + h\nu_0 \qquad [\because \phi_0 = h\nu_0]$$

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

$$eV_0 = h\nu - h\nu_0 \qquad [\because KE_{max} = eV_0]$$

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

The variation of cut-off potential with frequency of incident radiation is shown as below.



From this graph, the value of threshold frequency is given by the point of intersection of the straight on the frequency axis and stopping potential is given by the point of intersection of the straight line on potential axis, i.e. the intercept of the line on cut-off potential axis. **(2)**

55. $\lambda = 2000\ \text{Å} = 2000 \times 10^{-10}\ \text{m}$, $\phi_0 = 4.2\ \text{eV}$

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

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

$$\Rightarrow \quad KE = \frac{hc}{\lambda} - \phi_0$$

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

$= (6.2 - 4.2)$ eV $= 2.0$ eV **(1)**

(i) The energy of the emitted electrons does not depend upon intensity of incident light, hence the energy remains unchanged. **(1)**

(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. **(1)**

56. **For plot** Refer to Sol. 13 on page 344. **(1)**

By Einstein's photoelectric equation,

$$V_0 = \left(\frac{h}{e}\right)\nu - \frac{\phi_0}{e} \qquad \ldots(i)$$

where, V_0 = cut-off potential,

h = Planck's constant,

e = electronic charge

and ϕ_0 = work function of material.

It is clear that for higher frequency ν, cut-off potential is higher. **(1)**

$\therefore$ Stopping potential will be higher corresponding to frequency ν_2. **(1)**

57. (i) Einstein's photoelectric equation is

$$KE_{max} = h\nu - \phi_0$$

But, $KE_{max} = eV_0$

where,

V_0 = cut-off potential = 1.3 V

$$eV_0 = h\nu - \phi_0 \Rightarrow \phi_0 = h\nu - eV_0 \qquad \textbf{(1)}$$

Here, $h = 6.63 \times 10^{-34}$ J-s

$\lambda = 2271$ Å $= 2271 \times 10^{-10}$ m

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^8}{2271 \times 10^{-10}}$$

$$= 1.32 \times 10^{15} \text{Hz}$$

$$eV_0 = 1.6 \times 10^{-19} \times 1.3 = 2 \times 10^{-19} \text{ J}$$

$\therefore$ Work function, $= h\nu - eV_0$

$= (6.63 \times 10^{-34}) \times (1.32 \times 10^{15}) - 2 \times 10^{-19}$

$= 8.76 \times 10^{-19} - 2 \times 10^{-19} = 6.76 \times 10^{-19}$ J

$= \dfrac{6.76 \times 10^{-19}}{1.6 \times 10^{-19}}$ eV

Work function, $\phi_0 = 4.22$ eV **(1)**

(ii) $\lambda = 6328 \times 10^{-10}$ m

As, $KE_{max} = h\nu - \phi_0 \qquad \ldots(i)$

Here, $h\nu = \dfrac{hc}{\lambda}$

$= 3.14 \times 10^{-19}$ 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. **(1)**

58. Refer to text on page 335 (Laws of Photoelectric Emission).

Stopping potential Refer to Sol. 12 on page 344. **(1)**

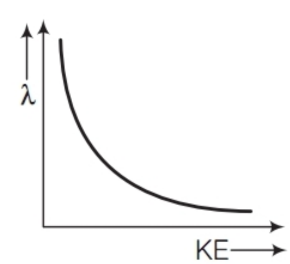
For wave theory of light Refer to Sol. 45 (ii) on page 350. **(1)**

Explanations

1. de-Broglie wavelength

$$\lambda = h/p = h/\sqrt{2m\text{KE}}$$

$$\Rightarrow \quad \lambda^2 \text{ KE} = \text{constant}$$



(1)

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

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

3. A charged particle having charge q and mass m then kinetic energy of the particle is equal to the work done on it by the electric field.

i.e. $K = qV \Rightarrow \frac{1}{2}mv^2 = qV$

$\Rightarrow p^2/2m = qV \Rightarrow p = \sqrt{2mqV}$

$\therefore$ de-Broglie wavelength,

$$\lambda = h/p = h/\sqrt{2mqV}$$ **(1)**

4. Refer to the text on page 352 (de-Broglie hypothesis). **(1)**

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

where, K = KE

For given KE, $\lambda \propto \frac{1}{\sqrt{m}}$

$\because$ Electron have smaller mass,

$\therefore \quad \lambda_e > \lambda_p \quad [\because m_e < m_p]$

For given kinetic energy, electrons have greater wavelength as it has smaller mass. **(1)**

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

$$\frac{\lambda_1}{\lambda_2} = \frac{M_e v_e}{M_1 v_1} = 8.3 \times 10^{-4}$$

$$\therefore \quad M_1 = \frac{M_e v_e}{8.3 \times 10^{-4}(3v_e)} \quad (\because v_1 = 3v_e)$$

$$= \frac{9.1 \times 10^{-31}}{8.3 \times 10^{-4} \times 3} = 0.36 \times 10^{-27} \text{kg}$$

Thus, the particle may be either proton or neutron. **(1)**

7. Kinetic energy, $K = \frac{p^2}{2m}$

where, p = momentum,

m = mass and K = kinetic energy.

$\Rightarrow \quad p = \sqrt{2mK}$

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

where, $p = \sqrt{2mK}$

$$\Rightarrow \quad \lambda = \frac{h}{\sqrt{2mK}} = \frac{h}{\sqrt{2mE}} \quad [\because K = E]$$ **(1)**

8. Kinetic energy, $K = eV$

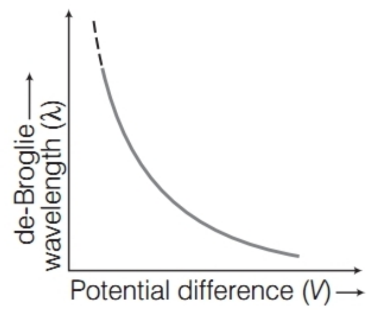
where, V = potential difference.

$\Rightarrow \quad p = \sqrt{2mK} = \sqrt{2meV}$

$\therefore$ de-Broglie wavelength

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{V}}$$

$\Rightarrow \quad V \cdot \lambda^2 = \text{constant}$



(1)

9. Energy of proton, $E_p = \frac{hc}{\lambda}$

Energy of electron (moving particle), $E_e = \frac{1}{2}\frac{p^2}{m}$

de-Broglie wavelength associated with the moving particle is

$$\lambda = h/p \text{ or } p = h/\lambda$$

$$E_e = \frac{1}{2}\frac{(h/\lambda)^2}{m} = \frac{1}{2}\frac{h^2}{\lambda^2 m}$$

$$\therefore \quad \frac{E_p}{E_e} = \frac{hc/\lambda}{\frac{1}{2}\frac{h^2}{\lambda^2 m}} = \frac{2m\lambda c}{h}$$ **(2)**

10. Given, $\lambda = 590 \text{ nm} = 590 \times 10^{-9}$ m

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

Planck's constant, $h = 6.63 \times 10^{-34}$ J-s

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

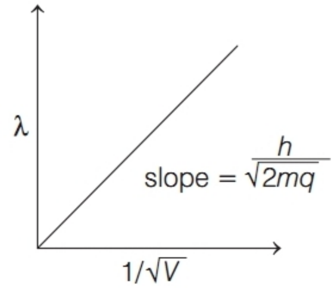
Kinetic energy of electron,

$$K = \frac{h^2}{2\lambda^2 m_e} = \frac{(6.63 \times 10^{-34})^2}{2 \times (590 \times 10^{-9})^2 \times 9.1 \times 10^{-31}}$$

$$= 6.94 \times 10^{-25} \text{J}$$ **(2)**

11. The de-Broglie wavelength is given by

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



(1)

Thus, it gives a straight line graph.

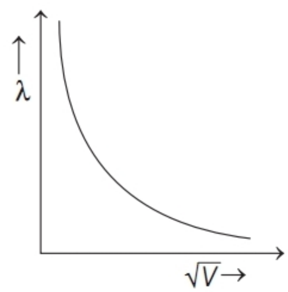
$$\lambda\sqrt{V} = \frac{h}{\sqrt{2mqV}} = \text{slope of graph}$$

Knowing the mass of particle (m) and slope of graph, we can calculate charge (q) on a particle. **(1)**

12. (i) We know that, de-Broglie wavelength,

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

Hence, graph is as shown below



(1)

(ii) The de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mK}}$

where, m = mass of particle
and K = kinetic energy of particle.
As kinetic energy is same, for electron, proton and α-particle, so $\lambda \propto \frac{1}{\sqrt{m}}$.
Therefore, α-particle has shortest wavelength as its mass is more than electron and proton. **(1)**

13. We have, de-Broglie wavelength, $\lambda = \frac{h}{\sqrt{2mqV}}$

where, V is potential difference, q is charge of the particle and m is mass of the particle.

Given, $V_\alpha = V_p = V$ (say) and $m_\alpha = 4m_p$, $q_\alpha = 2q_p$

$$\therefore \quad \frac{\lambda_\alpha}{\lambda_p} = \frac{\sqrt{2m_p q_p V}}{\sqrt{2m_\alpha q_\alpha V}} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \sqrt{\frac{1}{4\times 2}} = \frac{1}{2\sqrt{2}} \quad \textbf{(2)}$$

14. Refer to Sol. 9 on page 356.

15. (i) The de-Broglie wavelength of a particle is given by

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

(here, V is the accelerating potential of the particle)

$$\because \quad \lambda_{\text{proton}} = \lambda_\alpha \quad \text{(given)}$$

$$\therefore \quad \frac{12.27}{\sqrt{V_{\text{proton}}}} = \frac{12.27}{\sqrt{V_\alpha}}$$

$$\Rightarrow \quad \frac{V_{\text{proton}}}{V_\alpha} = 1$$

(1)

(ii) The de-Broglie wavelength of α-particle is given by $\lambda = \frac{h}{mv}$

$$\therefore \quad \lambda_{\text{proton}} = \frac{h}{m_{\text{proton}} \cdot v_{\text{proton}}} \text{ and } \lambda_\alpha = \frac{h}{m_\alpha v_\alpha}$$

We know that, $m_\alpha = 4\,m_{\text{proton}}$

$$\lambda_{\text{proton}} = \lambda_\alpha \quad \text{(given)}$$

$$\therefore \quad \frac{h}{m_{\text{proton}} \cdot v_{\text{proton}}} = \frac{h}{4m_{\text{proton}} \cdot v_\alpha}$$

$$\Rightarrow \quad \frac{v_{\text{proton}}}{v_\alpha} = 4$$

(1)

16. (i) de-Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mV_0 q}} \Rightarrow \lambda \propto \frac{1}{\sqrt{m}}$$

[$\because V_0$ and q are same, because proton and deuteron have been accelerated by same potential and have same charge].

Since, mass of proton is less as compared to a deuteron. So, it will have higher value of de-Broglie wavelength associated with it. **(1)**

(ii) de-Broglie wavelength is given by

$$\lambda = h/p \Rightarrow p = h/\lambda$$

As, $\lambda_d < \lambda_p$

So, $p_d > p_p$

Hence, momentum of proton is less than that of deuteron. **(1)**

17. (i) de-Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mV_0 q}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mq}}$$

$$\frac{\lambda_d}{\lambda_\alpha} = \frac{1/\sqrt{2me}}{1/\sqrt{4m2e}} = \frac{2}{1}$$

Wavelength of deuteron is two times the wavelength of α-particle. **(1)**

(ii) $\frac{\text{KE}_d}{\text{KE}_\alpha} = \frac{V_0 e}{V_0 2e} = \frac{1}{2} \Rightarrow \text{KE}_d = \frac{\text{KE}_\alpha}{2}$

KE of deuteron is half of KE of α-particle. **(1)**

18. From Einstein and photoelectric equation

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

$$E = \phi_0 + K_{max} \quad [\because E = h\nu]$$

According to the question, $\phi_0 = 0$

So, $E = K_{max}$

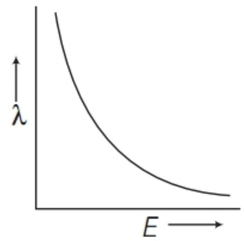
$$E = p^2/2m \quad [\because K_{max} = p^2/2m]$$

$$p = \sqrt{2mE} \quad \text{... (i)}$$

de-Broglie wavelength is given by, $\lambda = h/p$

Substituting the value of p from Eq. (i), we get

$$\lambda = h/\sqrt{2mE}$$ **(2)**



19. Given, $v = 2.2 \times 10^8$ m/s

de-Broglie wavelength is given by

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

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

$h = 6.63 \times 10^{-34}$ kg-m^2-s

Substituting all values in Eq. (i), we get

$$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 2.2 \times 10^8}$$

$$\lambda = 3.31 \times 10^{-12} \text{ m}$$ **(2)**

20. Given, $V = 100$ V.

Wavelength of accelerated electron beam from de-Broglie equation

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

For $V = 100$ V $\Rightarrow \lambda = 1.227$ Å **(1)**

This wavelength belongs to the X-ray part of electromagnetic radiation. **(1)**

Or

Similarly, for $V = 144$V

$$\lambda = 1.02 \text{ Å}$$

This wavelength belongs to X-ray part of electromagnetic spectrum. **(2)**

Or

Similarly, for $V = 64$V

$\lambda = 1.5$ Å and X-ray. **(2)**

21. de-Broglie wavelength is given by

$$\lambda = h/\sqrt{2mK} = h/\sqrt{2mqV} \quad (\because K = qV)$$

$$\Rightarrow \lambda \propto 1/\sqrt{mqV}$$

where, m = mass of charged particle,

q = charge and V = potential difference.

$\therefore$ Ratio of de-Broglie wavelengths of proton and α-particle.

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha V_\alpha}{m_p q_p V_p}} = \sqrt{\left(\frac{m_\alpha}{m_p}\right)\left(\frac{q_\alpha}{q_p}\right)\left(\frac{V_\alpha}{V_p}\right)}$$ **(1)**

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

[($\because$α - particle is 4 times heavier than proton and it has double the charge than that of proton)]

$$\frac{V_\alpha}{V_p} = \frac{64}{128} = \frac{1}{2}$$

$$\therefore \quad \frac{\lambda_p}{\lambda_\alpha} = \sqrt{4 \times 2 \times \frac{1}{2}} = 2 \text{ or } \lambda_p : \lambda_\alpha = 2:1$$ **(1)**

22. de-Broglie wavelength of accelerated charged particle is given by $\lambda = \frac{h}{\sqrt{2mqV}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mqV}}$

Ratio of wavelengths of proton and α-particle.

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\left(\frac{m_\alpha}{m_p}\right)\left(\frac{q_\alpha}{q_p}\right)\left(\frac{V_\alpha}{V_p}\right)}$$ **(1)**

Here, $\frac{m_\alpha}{m_p} = 4, \frac{q_\alpha}{q_p} = 2, \frac{V_\alpha}{V_p} = \frac{X}{512}, \frac{\lambda_p}{\lambda_\alpha} = 1$

$$\Rightarrow \quad 1 = \sqrt{4 \times 2 \times \left(\frac{X}{512}\right)} = \frac{X}{64} \Rightarrow X = 64 \text{ V}$$ **(1)**

23. de-Broglie wavelength of accelerated charged particle is given by

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

$$\Rightarrow \lambda\sqrt{V} = h/\sqrt{2mq} = \text{constant}$$

(i) The slope of the line represents $h/\sqrt{2mq}$ where, h = Planck's constant, q = charge and m = mass of the charged particle. **(1)**

(ii) $\because$ ${}_1H^2$ and ${}_1H^3$ carry same charge (as they have same atomic number)

$$\therefore \quad \lambda\sqrt{V} \propto \frac{1}{\sqrt{m}}$$

The lighter mass, i.e. ${}_1H^2$ is represented by line of greater slope, i.e. A and similarly ${}_1H^3$ by line B. **(1)**

24. The de-Broglie wavelength of a particle is given by

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

(i) When they have same speed i.e. $v_\alpha = v_p$, then

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{m_p}{m_\alpha} = \frac{m_p}{4m_p} = \frac{1}{4}$$ **(1)**

(ii) When they have same kinetic energy i.e. $K_1 = K_2$, then

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p}{m_\alpha}} = \sqrt{\frac{m_p}{4m_p}} = \frac{1}{2}$$ **(1)**

(iii) When they are accelerated by same potential, i.e. $V_1 = V_2$, then

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{q_p m_p}{q_\alpha m_\alpha}} = \sqrt{\frac{e \times m_p}{4e \times 2m_p}} = \frac{1}{\sqrt{8}} = \frac{1}{2\sqrt{2}}$$ **(1)**

25. Given, $V = 100\text{ V}$

(i) The wavelength associated with a moving electron is given by

$$\lambda = \frac{\lambda}{\sqrt{2eVm_e}} = \frac{12.27}{\sqrt{V}} = \frac{1227}{\sqrt{100}} = 1.227\text{ Å}$$ **(1)**

(ii) Momentum of electron is, $p = \sqrt{2eVm_e}$

$$= \sqrt{2 \times 1.6 \times 10^{-19} \times 100 \times 9.1 \times 10^{-31}}$$ **(1)**

$$= 53.96 \times 10^{-25}\text{ kg-ms}^{-1}$$

(iii) The velocity required, $v = \frac{p}{m_e} = \frac{53.96 \times 10^{-25}}{9.1 \times 10^{-31}}$

$$= 5.93 \times 10^6\text{ ms}^{-1}$$ **(1)**

26. (i) de-Broglie matter wave equation is given by

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} \qquad (\because p = \sqrt{2mK})$$

where, m = mass of proton

and K = kinetic energy of proton.

According to the question, kinetic energy of proton, $K = m_e c^2$

(Einstein's mass-energy relation)

$$\Rightarrow \lambda = \frac{h}{\sqrt{2m(m_e c^2)}}$$ **(1)**

$$\lambda = \frac{h}{\sqrt{2}\, c\sqrt{mm_e}} = \frac{h}{\sqrt{2}c \times (m_e)\sqrt{1836}}$$

$$(\because m = 1836\, m_e)$$

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

$$\lambda = 4 \times 10^{-14}\text{ m}$$ **(1)**

(ii) This wavelength belongs to X-ray of electromagnetic spectrum. **(1)**

27. (i) From de-Broglie matter wave equation,

$$\lambda = \frac{h}{mv} \Rightarrow m = \frac{h}{\lambda v}$$ **(1)**

Here, $\lambda = 0.135 \times 10^{-9}\text{ m} \Rightarrow v = 5 \times 10^6\text{ m/s}$

$$\therefore \quad m = \frac{6.63 \times 10^{-34}}{0.135 \times 10^{-9} \times 5 \times 10^6}$$

$$= 9.82 \times 10^{-31}\text{ kg}$$ **(1)**

(ii) This wavelength 0.135 nm falls in the region of X-ray of electromagnetic spectrum. **(1)**

28. Given, $v_{\text{particle}} = 3\, v_{\text{electron}}$ ...(i)

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

$$\frac{\lambda_{\text{electron}}}{\lambda_{\text{particle}}} = \frac{1}{1.813 \times 10^{-4}}$$ ...(ii)

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

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

$$= \frac{1}{1.813 \times 10^{-4}} \times \frac{1}{3} = 1838.57$$

$\therefore$ $m_{\text{particle}} = 1839\, m_{\text{electron}}$ [from Eqs. (i) and (ii)]

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

$$= 1.673 \times 10^{-27}\text{ kg}$$ **(2)**

Particle is either a proton or a neutron.

(ii) Now, $\lambda = h/\sqrt{2mK}$

As the kinetic energy is same for electron and proton, so $\lambda \propto \frac{1}{\sqrt{m}}$

As, $m_e < m_p \Rightarrow \lambda_p < \lambda_e$ **(1)**

29. (i) For electron and photon,

momentum, $p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{10^{-9}}$

$[\therefore \lambda = 1\text{ nm} = 10^{-9}\text{ m}]$

$$= 6.63 \times 10^{-25}\text{ m}$$ **(1)**

(ii) $E = \frac{hc}{\lambda} = \frac{(6.63 \times 10^{-34}) \times (3 \times 10^8)}{10^{-9} \times (1.6 \times 10^{-19})} = 1243\text{ eV}$ **(1)**

(iii) As, $E = \frac{p^2}{2m} = \frac{(6.63 \times 10^{-25})^2}{2 \times 9 \times 10^{-31} \times 1.6 \times 10^{-19}} = 1.52\text{ eV}$ **(1)**