Chapter 11. Dual Nature of Radiation and Matter

Photoelectric Effect

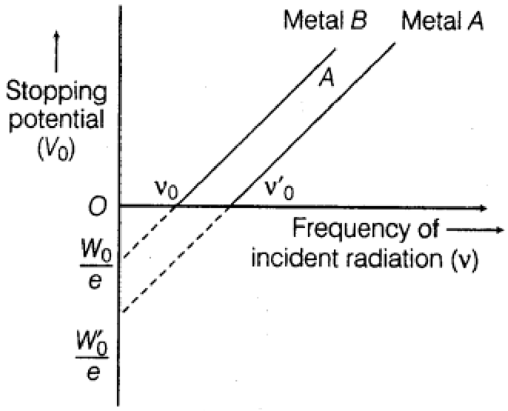
1 Mark Questions

1.Define intensity of radiation on the basis of photon picture of light. Write its SI unit. [All India 2014]

Ans. The intensity of radiation is defined as the rate of emitted energy from unit surface area through unit solid angle.

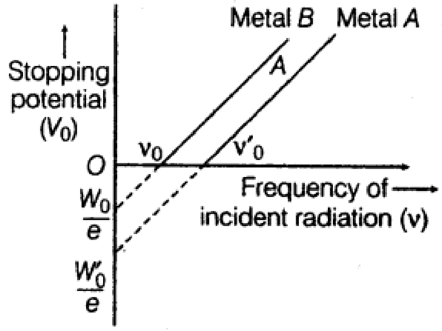
Its SI unit is $W/m^2\ sr^{-1}$.

2.The graph shows the variation of stopping potential with frequency of incident radiation for two photosensitive metals A and B. Which one of the two has higher value of work-function? Justify your answer. [All India 2014]

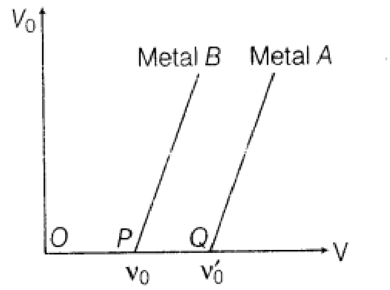


Ans. Metal A has higher value of work- function because and the intercept of the line of the given graph depends on work-function.

3.The graph shows variation of stopping potential V_0 versus frequency of incident radiation v for two photosensitive metals A and Which one of the two metals has higher threshold frequency and why? [All India 2014]



Ans.



As $\quad OQ > OP$

$\therefore \quad \nu'_0 > \nu_0 \quad$ **(1)**

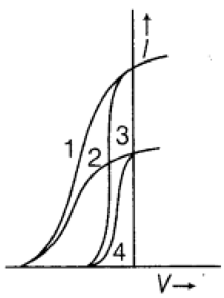
So, the threshold frequency of metal A is greater than metal B.

4.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]

Ans. 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 intensity of incident radiation number of photons).

Hence, the photo electrons ejected will be large, which in turn, will contribute to the increase in photoelectric current.

5.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 corresponds to different materials but same intensity of incident radiation. [Delhi 2013]

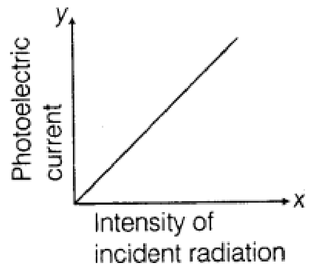


Ans.Curves 1 and 2 correspond to similar materials while curves 3 and 4 represent different materials, since the value of stopping potential for the pair of curves (1 and 2) and (3 and 4) are the same. For given frequency of the incident radiation, the stopping potential is independent of its intensity.

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

6.Show on a plot the nature of variation of photoelectric current with the intensity of radiation incident on a photosensitive surface. [Delhi 2013C]

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



7.Define intensity of radiation in photon picture of light. [All India 2012]

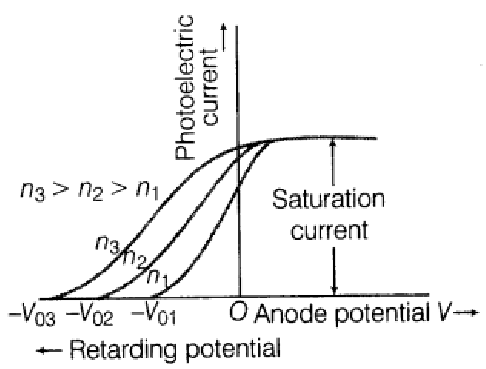
Ans. The intensity of radiation is defined as the rate of emitted energy from unit surface area through unit solid angle. Its SI unit is W/m^2 sr^{-1}.

8.Define the term stopping potential in relation to photoelectric effect. [All India 2011]

Ans. 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.

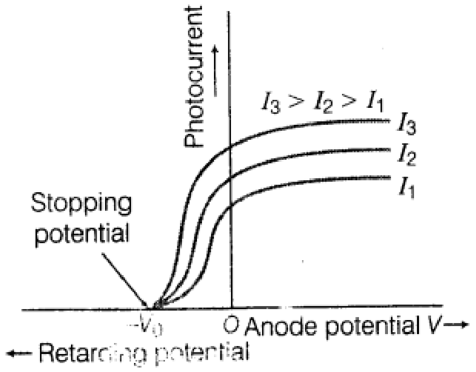
9.Show the variation of photocurrent with collector plate potential for different frequencies but same intensity of incident radiation. [Foreign 2011, All India 2010]

Ans. The variation of photocurrent with collector plate potential for different plate frequencies is shown as below:



10.Show the variation of photocurrent with collector plate potential for different intensities but same frequency of incident radiation. [Foreign 2011, All India 2010; 2011]

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



11.The stopping potential in an experiment on photoelectric effect is 1.5 V. What is the maximum kinetic energy of the photoelectrons emitted? [All India 2009, HOTS]

Ans.

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

$$KE_{max} = eV_0$$

where, $V_0 =$ cut-off potential

$$KE_{max} = 1.5 \text{ eV}.$$ **(1)**

12.The maximum kinetic energy of a photoelectron is 3eV. What is its stopping potential? [All India 2009]

Ans

Given, maximum kinetic energy of photoelectron = 3 eV

$\therefore$ Maximum KE = eV_0

where, V_0 = stopping potential

$$3eV = eV_0$$

$\therefore$ Stopping potential $V_0 = 3$ V **(1)**

13.The stopping potential in an experiment on photoelectric effect is 2 V. What is the maximum kinetic energy of the photoelectrons emitted? [All India 2009]

Ans

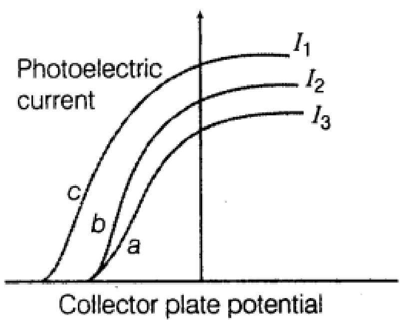
Given, stopping potential in an experiment on photoelectric effect = 2 V

Maximum kinetic energy, $KE_{max} = eV_0$

$$= e(2V) = 2 \text{ eV}.$$ **(1)**

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

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



[HOTS; Delhi 2009]

Ans. The photoelectric current is directly proportional to the intensity of incident radiation.

Energy of photoelectrons or cut-off potential depends on frequency of incident radiation.Curves, a and b have got same cut-off potential, so for these two curves frequencies will be same.

2 Marks Questions

15.(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]

Ans.

(i) Given, frequency, $f = 6.0 \times 10^{14}$ Hz

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

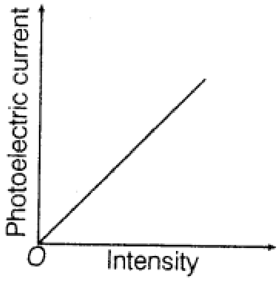
Number of photons emitted per second, $n = ?$

Energy of emitted photons, $E = hf$

$= 6.63 \times 10^{-34} \times 6 \times 10^{14} = 4 \times 10^{-19}$ J **(1)**

$\therefore n = \dfrac{P}{E} = \dfrac{2 \times 10^{-3}}{4 \times 10^{-19}} = 5 \times 10^{15}$ photons

(ii) Graph of photoelectric current and intensity is given as below



16.(i) Monochromatic light of frequency 5.0×10^{14} Hz is produced by laser. The power emitted is 3.0×10^{-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]

Ans. (i) 7.5×10^{15} Refer to ans. 15 (i)

(ii) Refer to ans. 15 (ii).

17.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 frequency of incident radiation. [All India 2014]

Ans. Three basic properties of photons are given as below :

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

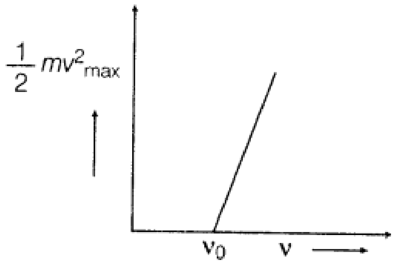
(ii) Energy of a photon is proportional to the frequency of light.

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

Einstein's photoelectric equation

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

The plot is shown as below.



(2)

18. (i) Define the term stopping potential.

(ii) Plot a graph showing the variation of photoelectric current as a function of anode potential for two light beams of same intensity but of different frequencies ν_1 and ν_2(ν_2 > ν_1). [All India 2014 C]

Ans. 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.

19.(i)Define the term threshold frequency as used in photoelectric effect.

(ii) Plot a graph showing the variation of photoelectric current as a function of anode potential for two light beams having the same frequency but different intensities and $I_2 > I_2$)• [All India 2014 C]

Ans. For a given material, there exists a certain minimum frequency of the incident radiation below which no emission of photoelectrons take place. This frequency is called the threshold frequency.

20.Two monochromatic radiations of frequencies ν_2 and ν_2(v1 >ν_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]

(*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 freqency ν_1.

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21.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 2010]

Ans

The intensities for both the monochromatic radiation are same but their frequencies are different. It represents **(1)**

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

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

[Einstein's photoelectric current]

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

22.Write Einstein's photoelectric equation. State clearly the three salient features observed in photoelectric effect which can be explained on the basis of above equation. [All India 2010]

Ans.

Einstein's photoelectric equation,

$$KE_{max} = h\nu - W_0 \quad \text{...(i)}$$

where, ν = frequency of incident light beam

W_0 = work-function of metal

KE_{max} = maximum kinetic energy

$\because \quad W_0 = h\nu_0$

where, ν_0 is threshold frequency.

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

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

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

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

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

$$\Rightarrow \quad \nu \geq \nu_0 \quad \text{[From Eq. (ii)]}$$

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

(*ii*) **KE_{max} of photoelectron** When incident frequency is greater than threshold frequency, then KE_{max} of photoelectron is directly proportional to $(\nu - \nu_0)$ as

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

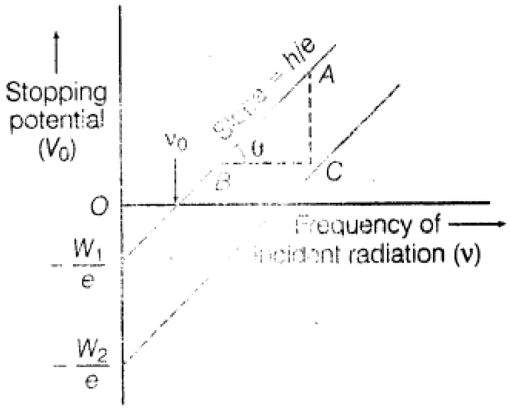
$$\Rightarrow \quad KE_{max} \propto (\nu - \nu_0)$$

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

23.Plot a graph showing the variation of stopping potential with the frequency of incident radiation for two different photosensitive materials having work-functions and W_2 (W_1> W_2). On what factors does the

- slope and
- intercept of the lines depend? [Delhi 2010]

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



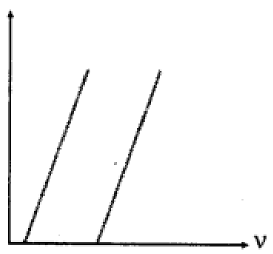
(1)

(*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 v_0.

Intercept on the potential axis = $-\frac{hv_0}{e}$

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



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

(ii) For which material will the emitted electrons have greater kinetic energy for the incident radiation of the same frequency? Justify your answer. [Foreign 2009]

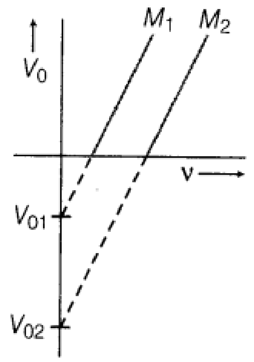
Ans.

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

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

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

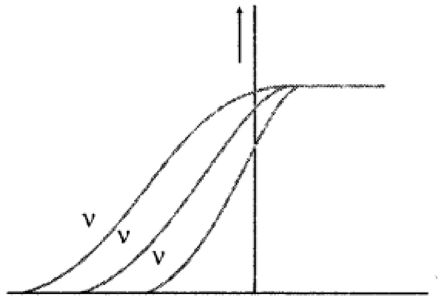
So, for the photoelectrons to be emitted from material M_2, kinetic energy will also be higher.



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

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

(ii) Which frequency (v_1 ,v_2 or v_3) is the highest? [Foreign 2009]



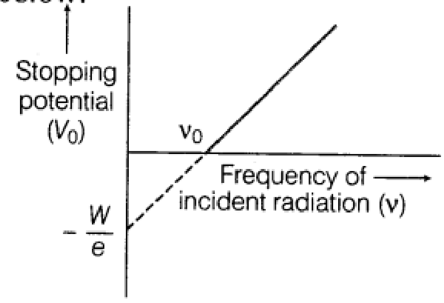
Ans. (i) According to laws of photoelectric emission, the photoelectric current depends on the intensity of incident light. The constant saturation value of photoelectric current reveals that intensity of incident light is constant.

(ii) Frequency Vt is the highest among v_1 ,v_2 and v_3 because higher the cut-off potential, higher will be the frequency of incident light.

26.Plot a graph showing variation of stopping potential (V_0) with the frequency (v) of the incident radiation for a given photosensitive material. Hence, state the significance of the threshold frequency in photoelectric emission. Using the principle of energy conservation, write the equation relating the energy of incident photon, threshold frequency and the maximum kinetic energy of the emitted photoelectrons [Delhi 2009c]

Ans.

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



(1/2)

where,

W = work-function of photosensitive material

e = electronic charge.

From Einstein's photoelectric equation,

$$(KE)_{max} = h\nu - h\nu_0 = h(\nu - \nu_0)$$

where, ν = frequency of incident radiation,

ν_0 = threshold frequency. **(1/2)**

From the equation, if $v < v_0$ then $(KE)_{max}$ is negative, which is not possible. For a given material, there exists a certain minimum frequency of the incident radiation below which no emission of photoelectrons take place, this is called threshold frequency, i.e. photoelectric effect will take place only when $v>v_0$.

27.Write Einstein's photoelectric equation relating the maximum kinetic energy of the emitted electron to the frequency of the radiation incident on a photosensitive surface. State clearly the basic elementary process involved in photoelectric effect. [All India 2009C]

Ans.

Einstein's photoelectric equation,

$$KE_{max} = h\nu - W_0 \quad \text{...(i)}$$

where, ν = frequency of incident light beam

W_0 = work-function of metal

KE_{max} = maximum kinetic energy

$\because \quad W_0 = h\nu_0$

where, ν_0 is threshold frequency.

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

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

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

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

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

$\Rightarrow \quad \nu \geq \nu_0 \quad$ [From Eq. (ii)]

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

(*ii*) **KE_{max} of photoelectron** When incident frequency is greater than threshold frequency, then KE_{max} of photoelectron is directly proportional to $(\nu - \nu_0)$ as

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

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

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

28.Write Einstein's photoelectric equation. Explain the terms:

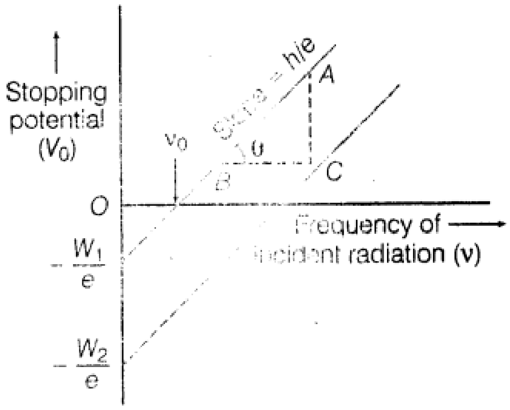
- **threshold frequency and**
- **stopping potential. [Delhi 2008C]**

Ans. (i) For Einstein's photoelectric equation and definition of threshold frequency Refer to ans. 22.

(ii) Stopping potential The minimum negative potential given to plate w.r.t. cathode, at which no photoelectron reaches the plate is called stopping potential. It is represented by V_0.

29.Write Einstein's photoelectric equation in terms of the stopping potential and the threshold frequency for a given photosensitive material. Draw a plot showing the variation of stopping potential versus the frequency of incident radiation. [All India 2008]

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

3 Marks Questions

30.(i) Why photoelectric effect cannot be explained on the basis of wave nature of light? Give reasons.

(ii) Write the basic features of photon picture of electromagnetic radiation on which Einstein's photoelectric equation is based. [Delhi 2013]

Ans.(i) The photoelectric effect cannot be

explained on the basis of wave nature of light because wave nature of radiation cannot explain the following:

- The instantaneous ejection of photoelectrons.
- The existence of threshold frequency for a metal surface.
- The fact that kinetic energy of the emitted electrons is independent of the intensity of light and depends upon its frequency

(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:

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.

Each photon has energy $E\left(=h\nu=\frac{hc}{\lambda}\right)$ 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.

- In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.
- By increasing the intensity of light of given wavelength, there is only an increase in the number of photons per second crossing a given area with each photon having the same energy. Thus, photon energy is independent of intensity of radiation.
- Photons are electrically neutral and are not deflected by electric end magnetic fields.
- In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved. However, number of photons may not be conserved.
- The velocity of photon in different media is different which is due to the change in its wavelength.

31.Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which this equation is based. Briefly explain three observed features which can be explained by this equation. [All India 2013]

Ans. For Einstein equation Refer to ans. 22.

The two characteristic properties of photons on which this equation is based are as follows

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

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

32.(i) State three important properties of photons which describe the particle picture of electromagnetic radiation.

(ii) Use Einstein's photoelectric equation to define the terms :

- **Stopping potential and**
- **Threshold frequency. [Delhi 2013C]**

Ans. The three important properties of photon are given as below:

(a) photon is massless, has no electric charge and is stable.

(b) Photons are emitted in many natural processes.

(c) The photon also carries spin angular momentum that does not depend on its frequency.

(ii) Einsten's photoelectric equation is given by

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

- Refer to ans. 28.
- Refer to ans. 19 (i). (1/2)

33.Write two characteristic features observed in photoelectric effect which supports the photon pictures of electromagnetic radiation. Draw a graph between the frequency of incident radiation (v) and the maximum kinetic energy of the electrons emitted from the surface of a photosensitive material. State clearly how this graph can be used to determine the

(i) Planck constant and (ii) work-function of the material? [Foreign 2012]

Ans.

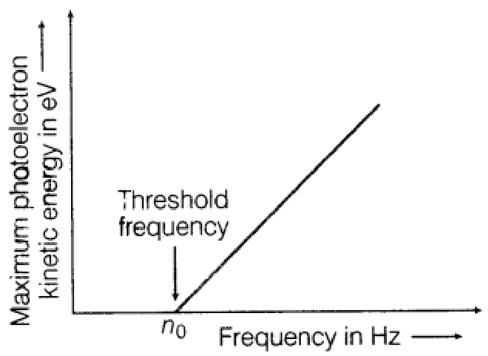
The two characteristic features observed in photoelectric effect which support the photon pictures of electromagnetic radiation are given as below:

(a) All photons of light of a particular frequency ν or wavelength λ have the same energy.

$$E\left(=h\nu=\frac{hc}{\lambda}\right) \text{ and momentum, } p\left(=\frac{h}{\lambda}\right)$$

whatever the intensity of radiation may be. The increase in intensity of the radiation implies an increase in the number of photons crossing a given area per second. **(1)**

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



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

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

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

$$\phi = h\nu_0 \qquad \textbf{(2)}$$

Here, ν_0 is the threshold frequency.

34.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]

Ans.

Einstein's photoelectric equation,

$$KE_{max} = h\nu - W_0 \quad \text{...(i)}$$

where, ν = frequency of incident light beam

W_0 = work-function of metal

KE_{max} = maximum kinetic energy

$\because \quad W_0 = h\nu_0$

where, ν_0 is threshold frequency.

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

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

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

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

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

$\Rightarrow \quad \nu \geq \nu_0$ [From Eq. (ii)]

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

(*ii*) **KE_{max} of photoelectron** When incident frequency is greater than threshold frequency, then KE_{max} of photoelectron is directly proportional to $(\nu - \nu_0)$ as

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

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

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

35.Define the terms cut-off voltage and threshold frequency in relation to the phenomenon of photoelectric effect. Using Einstein's photoelectric equation show how the cut-off voltage and threshold frequency for a given photosensitive material can be determined with the help of a suitable plot/graph. [All India 2012]

Ans.

Cut-off voltage The minimum negative voltage (V_0) applied on anode plate the cathode w.r.t. for which photocurrent in the circuit reduces to zero. **(1)**

Refer to ans. 19 (*i*).

Einstein's equation, $h\nu = KE_{max} + W_0$

$\because$ $$W_0 = h\nu$$

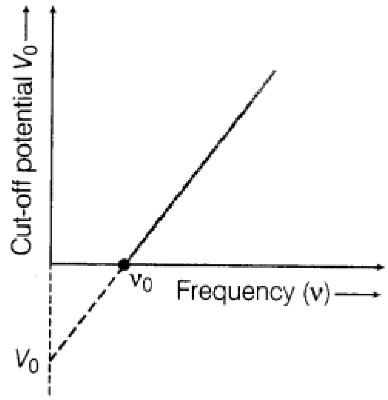
$$h\nu = KE_{max} + h\nu_0$$

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

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

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

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



(1/2)

From this graph, we can calculate the value of threshold frequency (point of intersection of frequency axis) and stopping potential (point of intersection on potential axis).

36.Draw a plot showing the variation of photoelectric current with collector plate potential for two different frequencies, $\nu_2 > \nu_1$ of incident radiation having the same intensity. In which case will the stopping potential be higher? Justify your answer. [All India 2011]

Ans.

For plot Refer to ans 9. **(1)**

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

By Einstein's photoelectric equation

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

where, V_0 = cut-off potential

h = Planck constant

e = electronic charge

ϕ = work-function of material

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

37.(i) Ultraviolet light of wavelength 2271 A from a 100 W mercury source is incident on a photocell made of molybdenum metal. If the stopping potential is 13 V, estimate the work-function of the metal.

(ii) How would the photocell respond to high intensity? ($10^5 W/m^2$) red light of wavelength 6328 A produced by a He-Ne laser? [Delhi 2011C]

Ans.

(*i*) Einstein's photoelectric equation is

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

But, $KE_{max} = eV_0$

where, V_0 = cut-off potential =1.3 V

$$eV_0 = h\nu - \phi \quad \Rightarrow \quad \phi = h\nu - eV_0 \quad \textbf{(1)}$$

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

$$\lambda = 2271 \text{ Å} = 227 \times 10^{-10} \text{ m}$$

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

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

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

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

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

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

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

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

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

As, $KE_{max} = h\nu - \phi$ ...(i)

Here, $h\nu = \dfrac{hc}{\lambda} = 3.14 \times 10^{-19} \text{J} = 1.96$ 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)**

38.Define the terms threshold frequency and stopping potential in the study of photoelectric emission. Explain briefly the reasons why wave theory of light is not able to explain the observed features in photoelectric effect?
[Foreign 2010]

Ans. Threshold frequency The minimum frequency below which there is no occurrence of photoelectric effect is called the cut-off frequency or threshold frequency and denoted by ν_0.

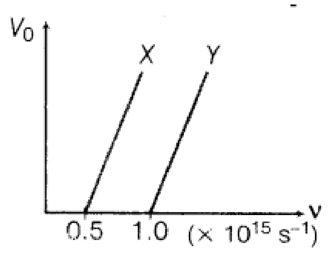
Stopping potential Refer to ans. 18 (ii). The wave theory of light is not able to explain the observed features of photoelectric current because of following reasons

(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

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

- Which of the metals has larger threshold wavelength? Give reason.
- Explain giving reason, which metal gives out electrons having larger kinetic energy. For the same wavelength of the incident radiation.
- If the distance between light source and metal X is halved, how will the kinetic energy of electrons emitted from it change? Give reason. [All India 2008]



Ans.

(i) From graph, threshold frequency for metal X, $\nu_X = 0.5 \times 10^{15}\ s^{-1}$

Threshold frequency for metal Y, $\nu_Y = 1 \times 10^{15}\ s^{-1}$

It is clear that $\nu_y > \nu_x$

Threshold wavelength, $\lambda = \frac{c}{\nu}$

i.e. $\lambda \propto \frac{1}{\nu}$

$\therefore$ $\lambda_X > \lambda_Y$.

(ii) $\because$ $KE_{max} = h\nu - h\nu_0$

ν_0 is higher for metal Y for given wavelength and hence frequency ν.

$\therefore$ KE_{max} for metal X is greater than that of the metal Y.

(iii) No effect, as kinetic energy depends only on frequency of incident electron beam.

Matter Wave

1 Mark Questions

1.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 [All India 2014]

Ans.

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. $K = qV$

$\Rightarrow \quad \frac{1}{2}mv^2 = qV$

$\Rightarrow \quad \frac{p^2}{2m} = qV$

$\Rightarrow \quad p = \sqrt{2mqV}$ **(1)**

.

2.State de-Broglie hypothesis. [Delhi 2012]

Ans.

de-Broglie hypothesis A Moving object sometimes acts as a wave and sometimes as a particle or a wave is associated with the moving particle which control this particle in every respect. This wave associated with the moving particle is called **matter wave** or de-Broglie wave. Its wavelength is given by

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

where, $h =$ Planck constant, $m =$ mass of object, $v =$ velocity of the object. **(1)**

3.A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why? [All India 2012]

Ans.

de-Broglie wavelength,

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

where, $K =$ KE

For given KE,

$\Rightarrow \quad \lambda \propto \frac{1}{\sqrt{m}}$

Electron have smaller mass, $\lambda_e > \lambda_p$

$[\because m_e < m_p]$

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

4.Write the relationship of de-Broglie wavelength X associated with a particle of mass m in terms of its kinetic energy E . [Delhi 2011c]

Ans.

Kinetic energy, $K = \dfrac{p^2}{2m}$

p = momentum

m = mass

and K = kinetic energy

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

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

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

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

5.Show graphically, the variation of de-Broglie wavelength (A,) with the potential (V) through which an electron is accelerated from rest. [Delhi 2011]

Ans.

> To plot the graph between the two quantities, first of all we have to find the relation between the two through the connecting formula.

Kinetic energy, $K = eV$

where, V = potential difference

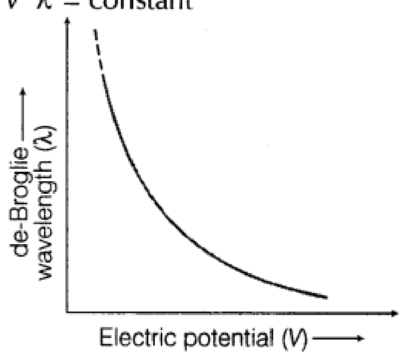
$\Rightarrow \quad p = \sqrt{2mK} = \sqrt{2meV}$

$\therefore$ de-Broglie wavelength

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

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

$\Rightarrow \quad V^2\lambda$ = constant



(1)

6.Name an experiment which shows wave nature of the electron. Which phenomenon was observed in this experiment using an electron beam? [Foreign 2010]

Ans.

Davisson-Germer experiment shows wave nature of electron.

The phenomenon of constructive interference was observed in Davisson-Germer experiment. **(1)**

7.An electron and a-particle have the same kinetic energy. How are the de-Broglie wavelengths associated with them related? [Delhi 2008]

Ans.

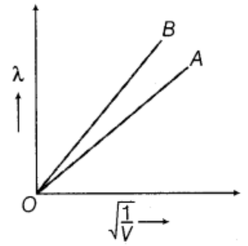
de-Broglie wavelength,

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

$$\Rightarrow \qquad \lambda \propto \frac{1}{\sqrt{m}}$$

$$\frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_e}}$$ **(1)**

8. Two lines A and B in the given shows the variation of de-Broglie wavelength λ *versus* $\frac{1}{\sqrt{V}}$, where V is the accelerating potential difference for two particles carrying the same charge. Which one of the two represents a particle of smaller mass?



[All India 2008]

Ans.

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

The slope of λ *versus* $\frac{1}{\sqrt{V}}$ graph will be inversely proportional to the square root of the mass of the particles.

Now, slope of B is greater it represents that mass is smaller. **(1)**

2 Marks Questions

9. A proton and a deuteron are accelerated through the same accelerating potential. Which one of the two has

- **greater value of de-Broglie wavelength associated with it and**
- **less momentum? Give reasons to justify your answer. [Delhi 2014]**

Ans.

(*i*) de-Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mV_0q}}$$

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

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

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

(*ii*) de-Broglie wavelength is given by

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

As, $\lambda_d > \lambda_p$

So, $p_d < p_p$ **(1)**

10.A deuteron and an a-particle are accelerated with the same accelerating potential. Which one of the two has

- **greater value of de-Broglie wavelength, associated with it and**
- **less kinetic energy? Explain. [Delhi 2014]**

Ans.

(*i*) de-Broglie wavelength is given by

$$\lambda = \frac{h}{\sqrt{2mV_0q}} \Rightarrow \lambda \propto \frac{1}{\sqrt{mq}}$$

$$\frac{\lambda_d}{\lambda_a} = \frac{\frac{1}{\sqrt{2me}}}{\frac{1}{\sqrt{4m2e}}} = \frac{2}{1}$$ **(1)**

wavelength of deuteron is two times the wavelength of α-particle.

(*ii*) $\frac{KE_d}{KE_a} = \frac{V_0e}{V_02e} = \frac{1}{2}$

KE of deuteron is half of KE of α-particle.

11.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 (A,) of the electrons emitted to the energy (E_v) of the incident photons. Draw of the graph for A, as function of E_v. [Delhi 2014 C]

Ans.

From Einstein and photoelectric equation

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

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

According to the question, $\phi_0 = 0$

So, $E = K_{max}$

$$E = \frac{P^2}{2m}, \quad \left[\because K_{max} = \frac{p^2}{2m}\right]$$

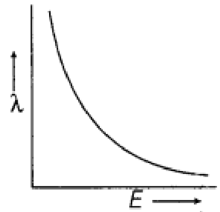
$$p = \sqrt{2mE} \quad \text{... (i)}$$

de-Broglie wavelength is given by

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

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

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



(2)

12.An electron is revolving around the nucleus with a constant speed of 2.2 xl0^8 m/s. Find the de-Broglie wavelength associated with it. [All India 2014 C]

Ans.

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

de-Broglie wavelength is given by

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

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

$$\lambda = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-3.1} \times 2.2 \times 10^8}$$

$$\lambda = 3.31 \times 10^{-12} \text{ m}$$

(2)

13.An a-particle and a proton are accelerated from rest by the same potential. Find the ratio of their de-Broglie wavelengths. [All India 2010; Foreign 2008]

Ans.

$\because$ de-Broglie wavelength,

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

Here, potential is kept constant. **(1)**

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

$$= \sqrt{\left(\frac{m_p}{m_\alpha}\right)\left(\frac{q_p}{q_\alpha}\right)} = \sqrt{\left(\frac{1}{4}\right)\left(\frac{1}{2}\right)}$$

$$\frac{\lambda_\alpha}{\lambda_p} = \frac{1}{2\sqrt{2}} \Rightarrow \lambda_\alpha : \lambda_p = 1:2\sqrt{2}$$ **(1)**

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

Ans.

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

$\lambda = 1.227$ Å **(1)**

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

15.An electron is accelerated through a potential difference of 144 V. What is the de-Broglie wavelength associated with it? To which part of electromagnetic spectrum does this wavelength correspond? [Delhi 2010]

Ans.

Refer to ans. 14.

$\lambda = 1$ Å **(2)**

This wavelength belongs to X-ray part of electromagnetic spectrum.

16.An electron is accelerated through a potential difference of 64 V What is the de-Broglie wavelength associated with it? To which part of the electromagnetic spectrum does this value of wavelength correspond? [Delhi 2010]

Ans. Refer to ans 14

17.Find the ratio of de-Broglie wavelengths associated with

- **protons, accelerated through a potential of 128 V and**
- **a-particles, accelerated through a potential of 64 V. [HOTS; Delhi 2010C]**

Ans.

To calculate the ratio of de-Broglie wavelengths of two particles, find the ratio in terms of symbols and then put the given numerical values.

de-Broglie wavelength is given by

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

$$\Rightarrow \quad \lambda \propto \frac{1}{\sqrt{mqV}}$$

where, m = mass of charged particle,

q = charge, V = potential difference

∴ Ratio of de-Broglie wavelengths of proton and α-particle.

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

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

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

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

$$\Rightarrow \quad \frac{\lambda_p}{\lambda_\alpha} = \sqrt{4 \times 2 \times \frac{1}{2}} = 2$$

$$\lambda_p : \lambda_\alpha = 2 : 1 \quad \textbf{(1)}$$

18.The ratio between the de-Broglie wavelengths associated with protons, accelerated through a potential of 512 V and a-particles, accelerated through a potential of X volt is found to be one. Find the value of X. [Delhi 2010c]

Ans.

de-Broglie wavelength of accelerated charged particle is given by

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

$$\Rightarrow \quad \lambda \propto \frac{1}{\sqrt{mqV}}$$

Ratio of wavelengths of proton and α-particle.

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

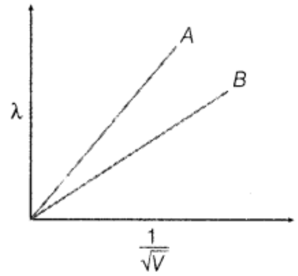
Here, $\frac{m_\alpha}{m_p} = 4, \quad \frac{q_\alpha}{q_p} = 2$

$$\frac{V_\alpha}{V_p} = \frac{X}{512}, \quad \frac{\lambda_p}{\lambda_\alpha} = 1$$

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

$$\Rightarrow \quad X = 64\text{ V} \quad \textbf{(1)}$$

19. 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 ${}_1^2\text{H}$ and ${}_1^3\text{H}$.



(*i*) What does the slope of the lines represent?

(*ii*) Identify which of the lines corresponded to these nuclei.

[All India 2010]

Ans.

$\because$ de-Broglie wavelength of accelerated charged particle is given by

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

$$\Rightarrow \quad \lambda\sqrt{V} = \frac{h}{\sqrt{2mq}} = \text{constant} \qquad \textbf{(1)}$$

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

(*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)**

20.Derive an expression for the de-Broglie wavelength associated with an electron accelerated through a potential V. Draw a schematic diagram of a localised wave describing the wave nature of the moving electron. [Foreign 2009]

Ans.

Let an electron beam is accelerated by potential difference V from the position of rest.

$\therefore$ Kinetic energy of the electron, $K = eV$

Momentum of electron, $p = \sqrt{2mK}$

$$p = \sqrt{2meV}$$

where, m = mass of an electron

∴ By de-Broglied equation

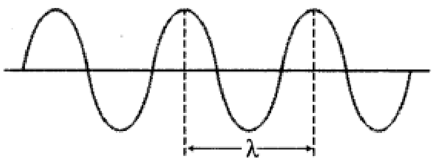
$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$

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

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

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

$$\Rightarrow \quad \lambda = \frac{12.27}{\sqrt{V}} \text{ Å} \quad \textbf{(1)}$$



A matter wave associated with an electron of definite momentum has single wavelength and extends all over space. **(1)**

21.Calculate the ratio of the accelerating potential required to accelerate a proton and an cx- article to have the same de-Broglie wavelength associated with them. [Delhi 2009C]

Ans.

∵ de-Broglie matter wave equation for accelerating charged particle is given by

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

where, h = Planck's constant

m = mass of charged particle

q = charge of charged particle

V = potential difference

Ratio of wavelengths of proton and α-particle,

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

$$\because \frac{\lambda_p}{\lambda_\alpha} = 1, \frac{m_\alpha}{m_p} = 4,$$

$$\frac{q_\alpha}{q_p} = 2, \frac{V_\alpha}{V_p} = ?$$

$$1 = \sqrt{4 \times 2 \times \left(\frac{V_\alpha}{V_p}\right)}$$

$$\Rightarrow 1 = 8 \times \frac{V_\alpha}{V_p} \quad \Rightarrow \quad \frac{V_p}{V_\lambda} = 8$$

$$\Rightarrow V_p : V_\alpha = 8 : 1$$

(1)

22.Calculate the ratio of the accelerating potential required to accelerate a deuteron and an a-particle to have the same de-Broglie wavelength associated with them. (Given, mass of deuteron = 3.2 x 1CT^{27} kg) [Delhi 2009C]

Ans.

$\because$ de-Broglie matter wave equation for accelerating charged particle is given by

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

where, h = Planck's constant

m = mass of charged particle

q = charge of charged particle

V = potential difference

Ratio of wavelengths of proton and α-particle,

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

$$\because \quad \frac{\lambda_p}{\lambda_\alpha} = 1, \frac{m_\alpha}{m_p} = 4,$$

$$\frac{q_\alpha}{q_p} = 2, \frac{V_\alpha}{V_p} = ?$$

$$1 = \sqrt{4 \times 2 \times \left(\frac{V_\alpha}{V_p}\right)}$$

$$\Rightarrow 1 = 8 \times \frac{V_\alpha}{V_p} \quad \Rightarrow \quad \frac{v_p}{v_\lambda} = 8$$

$$\Rightarrow V_p : V_\alpha = 8 : 1 \qquad \textbf{(1)}$$

23.Crystal diffraction experiments can be performed either by using electrons accelerated through appropriate voltage or by using X-rays. If the wavelength of these probes (electrons or X-rays) is 1 A, estimate which of the two has greater energy. [All India 2009]

Ans.

For an accelerated electron beam, the de-Broglie matter wave equation states that $\lambda = \frac{h}{\sqrt{2emV}} = \frac{h}{\sqrt{2mK}}$

$$\Rightarrow \qquad K = \frac{h^2}{2m\lambda^2} \qquad \text{...(i)}$$

For X-ray of same wavelength, $\lambda = 1\,\mathring{A}$.

$$E' = h\nu = \frac{hc}{\lambda} \qquad \text{...(ii)}$$

$$\frac{K}{E'} = \frac{h^2}{2m\lambda^2} \bigg/ \frac{hc}{\lambda}$$

$$\frac{K}{E'} = \frac{h^2}{2m\lambda^2} \times \frac{\lambda}{hc} = \frac{h}{2mc\lambda} \qquad \textbf{(1)}$$

where, $h = 6.6 \times 10^{-34}$ J-s, $c = 3 \times 10^8$ m/s

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

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

$$\frac{K}{E'} = \frac{6.6 \times 10^{-34}}{2 \times 9.1 \times 10^{-31} \times 3 \times 10^8 \times 1 \times 10^{-10}}$$

$$\frac{K}{E'} = 0.012 \quad \Rightarrow \quad \frac{K}{E'} = \frac{11}{911} < 1$$

$\Rightarrow \quad K < E'$

$\Rightarrow$ Energy possess by X-ray is more than electron. **(1)**

24.In Davisson-Germer experiment, state the observations which led to

- **show the wave nature of electrons and**
- **confirm the de-Broglie relation. [Delhi 2008]**

Ans.

(*i*) The existence of peak corresponding to sharp diffraction maximum in the electron distribution at a voltage 54 V and scattering angle 50° led to show wave nature of electron. **(1)**

The existence of peak depicts the wave properties like interference.

(*ii*) As per Bragg's law for first order diffraction (maximum),

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

Here, $d = 0.914$ Å, $\theta = 65°$

$\Rightarrow \quad \lambda = 1.65$ Å ...(i)

By de-Broglie equation

$$\lambda = \frac{h}{p} = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{54}} \cong 1.65\text{ Å} \quad \text{...(ii)}$$

$\Rightarrow$ Bragg's law confirms the de-Broglie equation. **(1)**

25.For what kinetic energy of a neutron will the associated de-Broglie wavelength be 1.32 x 10^{-10} m? [All India 2008]

Ans.

From de-Broglie matter wave equation

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

$$\Rightarrow \qquad K = \frac{h^2}{2m\lambda^2} \qquad \ldots(i)$$

(1)

where, $m = 1.66 \times 10^{-27}$ kg

$\lambda = 1.32 \times 10^{-10}$ m

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

$\therefore$

$$K = \frac{(6.63 \times 10^{-34})^2}{2 \times 1.66 \times 10^{-27} \times (1.32 \times 10^{-10})^2}$$

$$K = 7.5 \times 10^{-21}\ \text{J}$$

(1)

26.An electron and a-particle have the same de-Broglie wavelength with them. How are their kinetic energies related to each other? [Delhi 2008]

Ans.

From de-Broglie matter wave equation,

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

constant

(for given wavelength)

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

(1)

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

where, m_e and m_α are masses of electron and α-particles, respectively **(1)**

27.For what kinetic energy of a neutron, will the associated de-Broglie wavelength be 1.32 x 10-1° m? Given that the mass of a neutron = 1.675 xlO-27 kg. [All India 2008C]

Ans.

It is given that $\lambda = 1.32 \times 10^{-10}$ m

and $m_n = 1.675 \times 10^{-27}$ kg

As, $\lambda = \dfrac{h}{\sqrt{2m_n K}} \Rightarrow K = \dfrac{h^2}{2m_n\lambda^2}$

$\therefore$ Kinetic energy of neutron

$$K = \frac{(6.63\times10^{-34})^2}{2 \times (1.675 \times 10^{-27}) \times (1.32 \times 10^{-10})^2}$$

$$= 7.53 \times 10^{-21}\ \text{J}$$

(2)

3 Marks Questions

28.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? [All india 2014]

Ans.

Given, $V = 50 \text{ kV} = 50 \times 10^3 \text{ V}$

$\therefore$ de-Broglie wavelength,

$$\lambda = \frac{12.27}{\sqrt{V}} \text{ Å} = \frac{12.27}{\sqrt{50 \times 10^3}} \text{ Å} = 0.0526 \text{ Å}$$

Resolving power of a microscope

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

From the formula, it is clear that if other factors remains same, then resolving power is inversely proportional to wavelength of the radiation used. The wavelength of moving electron is very small as compared to that of yellow light; so it has greater resolving power than optical microscope.

29.(i) Describe briefly how the Davission-Germer experiment demonstrated the wave nature of electrons.

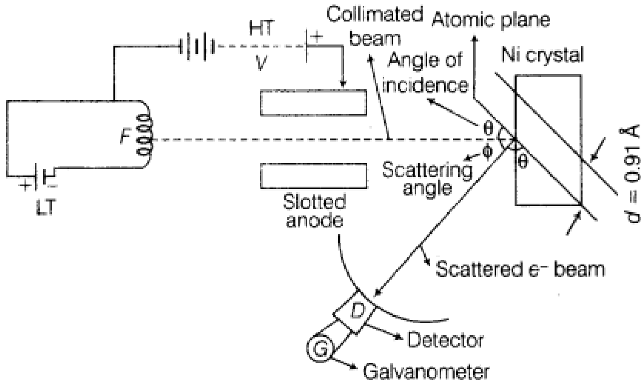
(ii) An electron is accelerated from rest through a potential V, obtain the expression for the de-Broglie wavelength associated with it.

Ans.

(*i*) The wave nature of electron was verified by Davisson-Germer experiment in 1927. The experimental arrangement is shown in the figure. It consists of an electron gun which comprises of a tungsten filament *F* coated with barium oxide and heated by a low voltage power supply. Electrons emitted by the filament are accelerated to a desired velocity by applying suitable potential from a high voltage power supply.

They are made to pass through a cylinder with free holes along its axis producing a fine collimated beam. The beam is made to fall on the surface of a nickel crystal. The electrons are scattered in all directions by the atoms of the crystal.

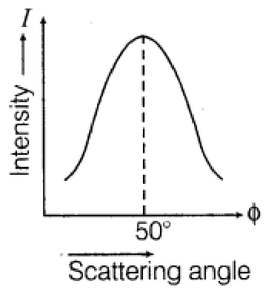
A beam of electrons emitted by the electron gun is made to fall on nickel crystal cut along cubical axis at a particular angle.



The scattered beam of electrons is received by detector which can be rotated at any angle.

The energy of the incident beam of electrons varied by changing the applied voltage to the electron.

Intensity of scattered beam of electrons is found to maximum when angle of scattering is 50° and accelerating potential is 54 V.



Here, $\theta + 50° + \theta = 180°$, i.e. $\theta = 65°$

For Ni crystal, lattice spacing $(d) = 0.91$ Å

For first principle maximum, $n = 1$

Electron's diffraction is similar to X-ray diffraction.

According to Bragg's equation,

$$2d \sin\theta = n\lambda \quad \text{gives} \quad \lambda = 1.65 \text{ Å}$$

According to de-Broglie hypothesis,

$$\lambda = \frac{12.27}{\sqrt{V}} \text{ Å} = \frac{12.27}{\sqrt{54}}$$ **(2)**

$\therefore$ de-Broglie wavelength of moving electron at $V = 54$ is $1.67 Å$ which is in close agreement with 1.675 Å

This proves the existence of de-Broglie waves for slow moving electrons.

(*ii*) Energy of electron, $E = eV$

Momentum is given by

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

de-Broglie wavelength

$$\lambda = \frac{h}{p} \quad \text{...(ii)}$$

From Eq. (i) substituting the value of p in Eq. (ii)

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

30.Determine the de-Broglie wavelength of a proton whose kinetic energy is equal to the rest mass energy of an electron. Mass of a proton 1836 times that of electron, (ii) In which region of electromagnetic spectrum does this wavelength lie? [All India 2011C]

Ans.

In these types of questions, we have to mind that in full-wave rectifier, full cycle of the input will be used.

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

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

where, m = mass of proton

K = kinetic energy of proton.

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

(Einstein's mass-energy relation)

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

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

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

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

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

(*ii*) This region of electromagnetic spectrum is X-ray. **(1)**

31.The mass of a particle moving with velocity 5 x 10^6 m/s has de-Broglie wavelength associated with it to be 0.135 nm. Calculate its mass.

(ii) In which region of the electromagnetic spectrum does this wavelength lie? [All India 2011C]

Ans.

(*i*) From de-Broglie matter wave equation,

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

Here, $\lambda = 0.135 \times 10^{-9}$ m

$v = 5 \times 10^6$ m/s

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

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

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

32. (*i*) 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.

(*ii*) An electron and a proton have the same kinetic energy. Which of the two will have larger de-Broglie wavelength? Give reason. **[All India 2011C]**

Ans.

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

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

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

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

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

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

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

Particle is either a proton or a neutron.

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

Therefore, it is clear that KE of electron is more than that of proton or neutron. **(1)**

33.An electron and a photon each have a wavelength lnm. Find [Ail India 2011C]

- **their momenta**
- **the energy of the photon and**
- **the kinetic energy of electron.**

Ans.

(i) For electron or photon, momentum

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

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

$$= 1243 \text{ eV}$$

(iii) As, $E = \frac{p^2}{2m} = 2.9 \times 10^{-31} \times (1.6 \times 10^{-19})$

$$= 1.52 \text{ eV}$$

34.A proton and an a-particle are accelerated through the same potential. Which of the two has ‘

- **greater value of de-Broglie wavelength associated with it and**
- **less kinetic energy? Justify your answer. [Delhi 2009]**

Ans.

From de-Broglie matter wave equation,

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

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

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

where, m = mass of charged particle

q = charge

V = potential difference

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

(for same accelerating voltage) **(1/2)**

(i) Ratio of wavelengths of proton and α-particle.

$$\frac{\lambda_p}{\lambda_\alpha} = \sqrt{\frac{m_\alpha q_\alpha}{m_p q_p}} = \sqrt{\left(\frac{m_\alpha}{m_p}\right)\left(\frac{q_\alpha}{q_p}\right)}$$ **(1/2)**

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

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

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

Proton have greater de-Broglie wavelength associated with it. **(1)**

(*ii*) $\because$ Kinetic energy, $K = qV$

$$\Rightarrow \quad \frac{K_p}{K_\alpha} = \left(\frac{q_p}{q_\alpha}\right)$$

(for same accelerating voltage)

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

Proton have less KE. **(1)**

35.An electron and a proton are accelerated through the same potential. Which one of the two has

- **greater value of de-Broglie wavelength associated with it and**
- **less momentum? Justify your answer. [Delhi 2009]**

Ans.

(*i*) From de-Broglie equation

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

As, $\quad p = \sqrt{2mK}$

and $\quad K = qV$

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

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

Ratio of wavelengths of electron and proton

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

$\because$ Ratio of mass of proton and electron

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

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

(Both electron and proton have same charge)

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

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

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

$\left(1\frac{1}{2}\right)$

(ii) $\because \quad \lambda = \frac{h}{p}$ (de-Broglie equation)

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

$$\Rightarrow \quad p \propto \frac{1}{\lambda} \quad \Rightarrow \quad \frac{p_e}{p_p} = \frac{\lambda_p}{\lambda_e}$$

But from Eq. (i), we get

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

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

Momentum of proton is nearly 42.8 times to that of momentum of electron. (1)