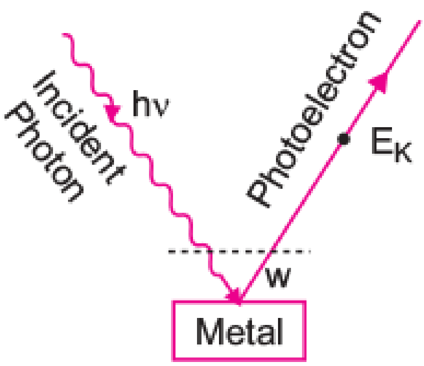
Long Answer Questions

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

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

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



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

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

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

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

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

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

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

where c is the speed of light in vacuum

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

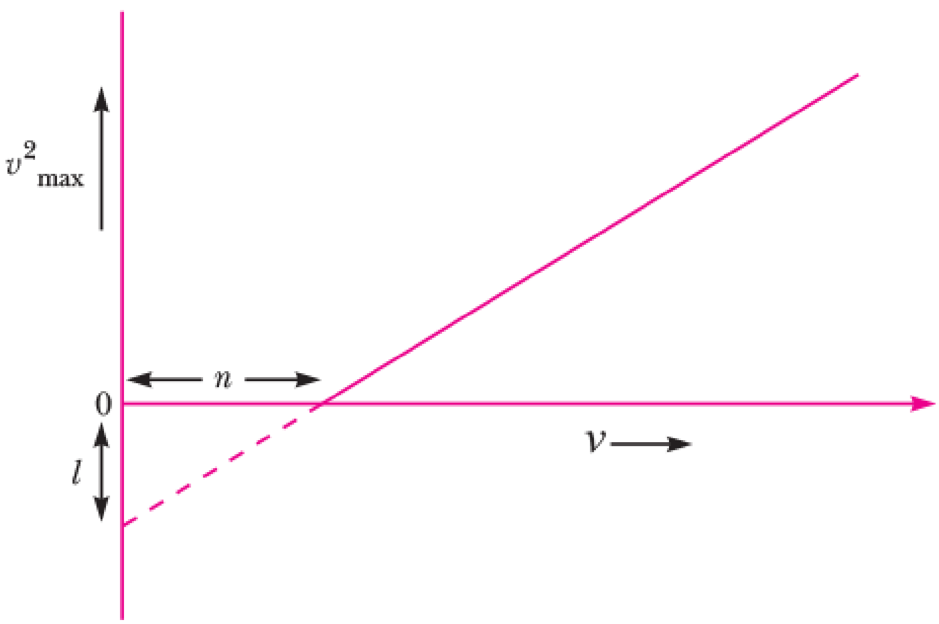
Substituting this value in equation (i), we get

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

This is another form of Einstein's photoelectric equation.

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

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



Use Einstein's photoelectric equation to find the expressions for

(i) Planck's constant and

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

Ans.

a. Refer to Q. 1 above.

b. i. v_1^2 and v_2^2 are the velocities of the emitted electrons for radiations of frequencies $\nu_1 > \nu$ and $\nu_2 > \nu$ respectively. So,

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

and

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

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

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

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

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

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

$$\therefore \quad h = \frac{1}{2}m \,.\, \tan\theta$$

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

So,

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

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

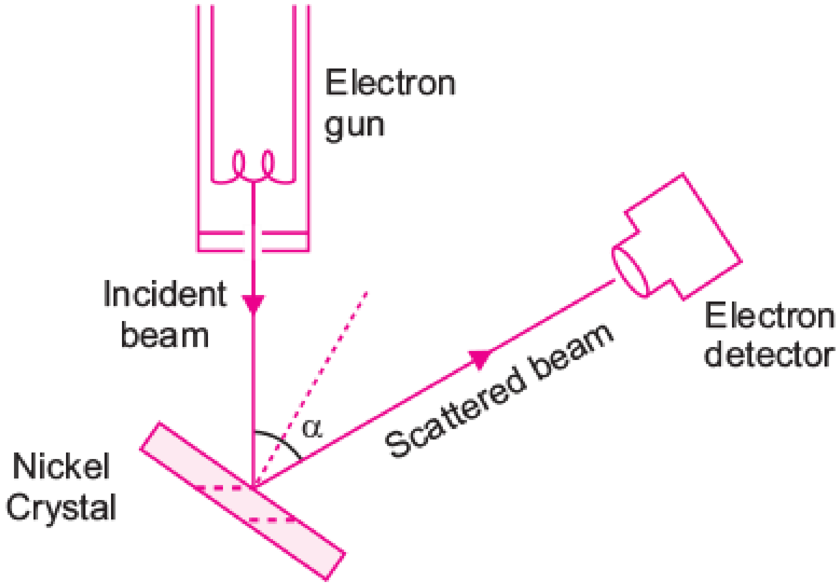
$$w = hn \quad \ldots(iv)$$

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

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

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

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



Apparatus: It consists of three parts:

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

$$\lambda = \frac{h}{\sqrt{2\,\mathrm{mE}_K}}$$

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

E_K = Kinetic energy of electron = 54 eV

$= 54\times1.6\times10^{-19}$ joule $= 86.4\times10^{-19}$ joule

$$\therefore \quad \lambda = \frac{6.6\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times86.4\times10^{-19}}}$$

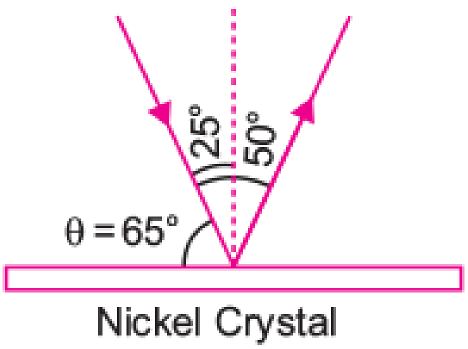
$= 1.66\times10^{-10}$ m = **1.66 Å**

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

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

Method: The crystal is rotated in small steps to change the angle (α say) between incidence and scattered directions and the corresponding intensity (I) of scattered beam is measured. The variation of the intensity (I) of the scattered electrons with the angle of scattering α is obtained for different accelerating voltages.

The experiment was performed by varying the accelerating voltage from 44 V to 68 V. It was noticed that a strong peak appeared in the intensity (I) of the scattered electron for an accelerating voltage of 54 V at a scattering angle α = 50°



∴ From Bragg's law

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

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

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

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

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

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

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