UNIT - VII

DUAL NATURE OF MATTER AND RADIATION:

Q.1 Are matter waves are electromagnetic? Write de-Broglie wave equation. (1)

Ans: No, matter wave not electromagnetic. The de-Broglie wave equation is $\lambda = \frac{h}{mv}$. Where the symbols have their usual meaning.

2. If we go on increasing the wavelength of light incident on a metal surface, what change in the no. of electrons emitted take place? (1)

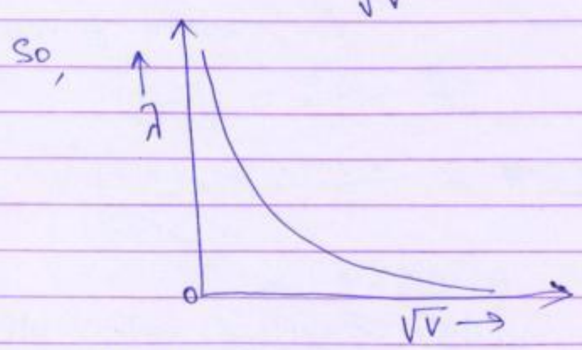
Ans: On increasing wavelength of incident light is increased, then the energy of incident photon $E = \frac{hc}{\lambda}$ will ~~decrease~~ decrease. As a result, the energy of emitted photoelectrons decreases but no change in emitted no. of electrons.

Q.3. Show on a graph the variation of the deBroglie wavelength (λ) associated with an electron with the square root of accelerating potential (V). (1)

Ans. Well we know that

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

So,



Variation of λ with accelerating potential V.

Q.4 An electron, an α-particle and a proton have same KE. Which one of these particles has the shortest de-Broglie wavelength? (1)

Ans: We know that the relation between wavelength λ and KE (K) of mass of a particle 'm' is

$$\lambda = \frac{h}{\sqrt{2mK}} \Rightarrow \lambda \propto \frac{1}{\sqrt{m}}. \text{ but } m_\alpha > m_p > m_e$$

as the mass of α-particle is more then the wavelength of α-particle is shortest.

5. The frequency (ν) of incident radiation is greater than threshold frequency (ν_0) in a photo-emitter. How will the stopping potential vary if the frequency (ν) is increased, keeping other factors constant? **(1)**

Ans: $E_{max} = h\nu - h\nu_0$ & $E_{max} = eV_0$

so, $eV_0 = h(\nu - \nu_0)$ $\quad$ $\nu \rightarrow$ frequency of incident radiation.

clearly as 'ν' increases, V_0 increases linearly.

2- Marks Questions:

Q.6 An electron and a photon have the same de-Broglie wavelength. Which one possesses more KE?

Ans: The KE of an electron is —

$$(KE)_e = \frac{1}{2}mv^2 = \frac{p^2}{2m} \quad \text{but, } p = \frac{h}{\lambda}$$

$$(KE)_e = \frac{h^2}{2m\lambda^2} \quad \text{———— (1)}$$

KE of photon. —

$$(KE)_p = h\nu = \frac{hc}{\lambda} \quad \text{but}$$

$$\frac{(KE)_p}{(KE)_e} = \frac{2mc\lambda}{h} = \frac{2 \times 9.1 \times 10^{-31} \times 3.0 \times 10^{8}\,\lambda}{6.63 \times 10^{-34}}$$

$$\simeq 8.0 \times 10^{11}\lambda$$

Thus the $(KE)_p \gg (KE)_e$

Q.7 Draw a graph showing the variation of stopping potential with the frequency of incident radiation in relation to photoelectric effect.

i) What does the slope of this graph represent?

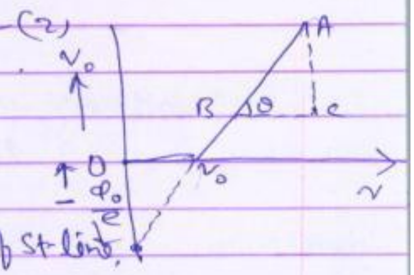
ii) How can the value of Planck's constant be determined from this graph?

Ans. Using Einstein's photo-electron equation, the maximum KE of the electron

$$K_{max} = h\nu - W_0 \quad \text{—— (1)}$$

If stopping potential for electron is V_0 then

$$eV_0 = K_{max} \quad \text{—— (2)}$$



From ① & ②

$$eV_0 = h\nu - W_0$$

$$V_0 = \left(\frac{h}{e}\right)\nu - \frac{W_0}{e}$$

This a eqn. of St line.

So, from graph.

(I) $\text{Slope} = \left(\frac{h}{e}\right)$

(II) $\boxed{\tan\theta = \frac{AC}{BC} = \frac{h}{e}} \Rightarrow \boxed{h = e \times \frac{AC}{BC}}$ hence 'h' can be determined.

Q.8. A radiotransmitter operates at a frequency of 880kHz and a power of 10kW. Find the no. of photons emitted per second.

Ans: No. of photons (n) emitted per second is —

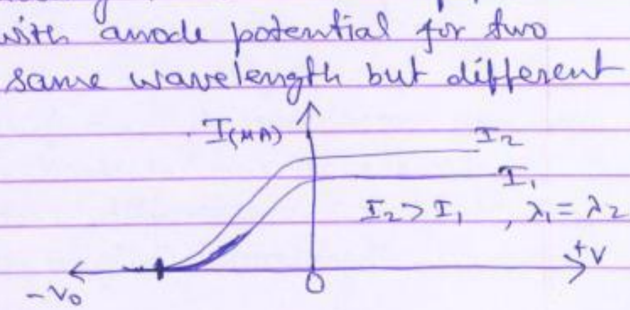
Power $= P = 10kW = 10 \times 10^3$ W

$$n = \frac{P}{h\nu} = \frac{10 \times 1000}{6.63 \times 10^{-34} \times 880 \times 10^3}$$

$$n = \frac{10 \times 10^{33}}{634 \times 88} \simeq 1.72 \times 10^{31}$$

Q.9. Plot a graph showing the variation of photo-electric current with anode potential for two light beams of same wavelength but different intensity.

Ans:



Q.10 Two metals A and B have work functions 4eV and 10eV respectively. Which metal has higher threshold wavelength?

Ans: We know that the work function

$$\phi_0 = h\nu_0$$
$$= \frac{hc}{\lambda_0}$$

or, $\boxed{\lambda_0 \propto \frac{1}{\phi_0}}$

As metal 'A' has lower work function $(\phi_0)_A$ so threshold wavelength for metal A is higher as compared to metal 'B'.

Q.11. 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.

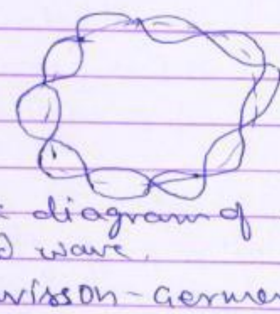
Ans: We know that when an electron accelerated with a potential 'V', the work done eV will be converted into its KE i.e,

$$eV = \frac{p^2}{2m} \Rightarrow p = \sqrt{2meV}$$

where 'p' is momentum of an electron.

de-Broglie wavelength

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



Schematic diagram of localized wave.

Q.12 Mention the significance of Davisson-Germer Experiment. An α particle are accelerated through the same potential difference V, calculate the ratio of their de-Broglie wavelength.

Ans: Davisson - Germer experiment is the first experiment which prove the wave nature of material particles.

Now, $\frac{1}{2}mv^2 = qV$

$mv^2 = 2qV$

or, $m^2v^2 = 2qmV$

$mv = \sqrt{2qmV}$

$p = mv = \sqrt{2qmV}$

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

So, $\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p q_p}{m_\alpha q_\alpha}} = \boxed{\frac{1}{2\sqrt{2}}}$

03 Marks Quest-Ans.

Q.13. Write the laws of photoelectric effect. Why photo electric effect can not explained on the basis of wave nature of light. Give reasons.

Ans. **Laws of Photo-Electric Effect:**

1. For a given photosensitive material the photo electric current is directly proportional to the intensity of light provided frequency is enough.
2. For a given photo-sensitive material, there exists a certain minimum cutoff frequency called threshold frequency below which no emission of photoelectrons.
3. Above threshold frequency the KE energy of emitted photoelectrons is directly proportional to the frequency incident radiation but independent on intensity of its.
4. The photo-electric effect is an instantaneous process.

Failure of wave Theory to explain photo-electric effect:

Wave theory fails to explain photoelectric effect due to the following reasons:

1. A higher intensity of incident radiation should liberate photoelectrons of higher KE. But K_{max} is found to be independent of intensity.
2. No matter what the frequency of incident radiation is, a light wave of sufficiently high intensity should eject the electrons from the metal. Thus the wave theory fails to explain the existence of threshold frequency.
3. Acc. to wave theory the energy of photons should distribute energy uniformly among the electrons then emission started but emission is almost instantaneous.

Q.14. Show that the de-Broglie wavelength λ of electrons accelerated through a potential difference V volts can be expressed as $\lambda = \frac{12.27}{\sqrt{V}}$ A°.

Sol. Consider an electron of mass 'm' and charge 'e' acquired a velocity 'v' when accelerated through a potential difference V. Then.

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

$$v = \sqrt{\frac{2eV}{m}}$$

de-Broglie wavelength

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

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

$$= \frac{12.27}{\sqrt{V}}\times10^{-10}\,m.$$

or, $\boxed{\lambda = \frac{12.27}{\sqrt{V}}}$ A°.

Q.15. Why are de-Broglie waves associated with a moving football not visible? The wavelength λ of a photon and the de-Broglie wavelength of an electron have the same value. Show that the energy of the photon $\frac{2\lambda mc}{h}$ times the KE of the electron.

Ans: We know that the de-Broglie waves are given by $\lambda = \frac{h}{mv}$

In case of football, mass is very high so λ is very small hence not visible.

For the electron $\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda}$

$$KE = \frac{p^2}{2m}$$

$$(KE)_e = \frac{h^2}{2m\lambda^2} \quad \text{—(1)}$$

$$(KE)_p = h\nu = \frac{hc}{\lambda} \quad \text{—(2)}$$

(1) ÷ (2)

$$\frac{(KE)_e}{(KE)_p} = \frac{h^2}{2m\lambda^2} \times \frac{\lambda}{hc} = \boxed{\frac{h}{2m\lambda c}}$$

i.e., $\boxed{\text{energy of photon} = \frac{2m\lambda c}{h} \times \text{electron energy}}$

Q.16. Briefly describe the observations of Hertz, Hallwachs and Lenard on regard of photo-electric effect?

Ans:
- The phenomenon of photoelectric effect was discovered by Heinrich Hertz in 1887. During demo of the experiment for the production of em waves, Hertz found that the enhancement enhancement of the spark between the metal electrodes when it is illuminated with UV radiation.
- During 1886-1902 Hallwachs and P. Lenard

investigated the phenomenon of photoelectric emission in detail.

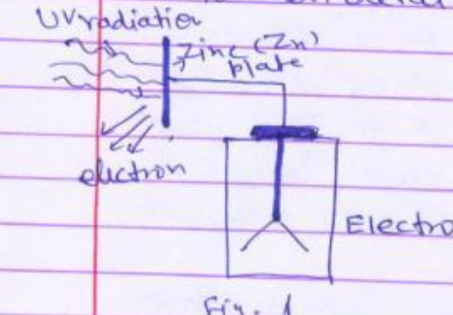


Fig. 1

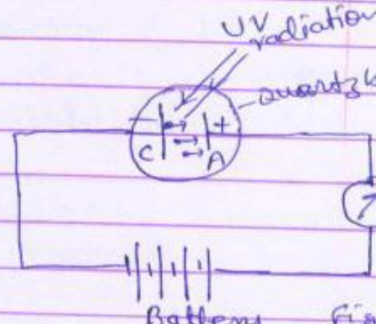


Fig. 2

According to Hallwachs, A zinc plate, connected to electroscope, is illuminated with UV radiation then he observed that i) Zn plate becomes neutral if it is negatively charged and ii) Zn plate becomes positively charged when initially it was neutral. So he concluded that a negative charge particles emitted by Zn plate when it was exposed with UV radiation (Fig 1)

Few years latter Lenard observed that when UV radiation falls on emitter plate of an evacuated quartz tube (see fig. 2) ~~causes~~ current started to flow in circuit ie due to the emission of electrons from C. This current was named as photoelectric current.

Hallwachs and Lenard have also given the concept of threshold frequency.

Q.17. Which two main observations in photoelectricity led Einstein to suggest the photon theory for interaction of light with the free electrons in the metal? Obtain an expression for threshold frequency for photoelectric emission in terms of the work function of the metal.

Ans: Two main observations in photoelectricity which support photon theory of light are

i) the maximum KE of emitted photoelectrons is independent of the intensity of light.

ii) for each photoemitter, there exists a threshold frequency of incident light below which no emission takes place.

Energy of incident photon = Max. KE of photoelectron + work function of metal.

$$h\nu = \frac{1}{2} m v_{max}^2 + W_0$$

At $\nu = \nu_0$ (threshold frequency)

$$\frac{1}{2} m v_{max}^2 = 0$$

So, $h\nu_0 = W_0$

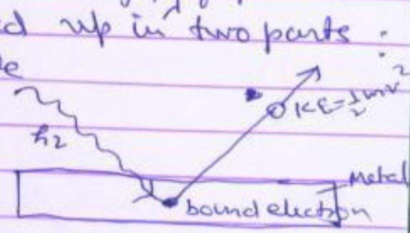
$$\boxed{\nu_0 = \frac{W_0}{h}}$$

Q.18: Establish ~~Eien~~ Einstein's photoelectric equation. Use this equation to explain the laws of photoelectric emission.

Ans: Einstein's photoelectric equation: Acc. to Planck's quantum theory, light radiation consist of tiny packets of energy called quanta. One quantum is called photon passes energy, $E = h\nu$ where h is Planck's constant and $\nu \rightarrow$ frequency of radiation.

According to Einstein, the energy $(h\nu)$ of photon incident on metal is used up in two parts:

i) one part used to liberate the electron from the metal surface i.e. equal to work function W_0 of the metal,



ii) the ~~rest part of energy~~ remaining energy of photon is used in imparting KE to the ejected electron.

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

$$h\nu - W_0 = \frac{1}{2}mv_{max}^2 = K_{max}$$

$$K_{max} = h\nu - W_0 \qquad W_0 = h\nu_0$$

$$\boxed{K_{max} = h(\nu - \nu_0)} \quad \text{—(1)} \quad \nu_0 \rightarrow \text{Threshold freq}$$

Explanation of Laws:

i) When $\nu < \nu_0$ K_{max} is negetive which is not possible, hence photoemission will not take place.

ii) From above equation it is clear that K_{max} is linearly depends on (ν) frequency of incident radiation.

iii) Increase in intensity of incident radiation will increase the number of incident photons and hence the emitted no. of photoelectrons increases in the same ratio.

iv) The collision of photon and electron is perfectly elastic hence there is no time lag between incident photon and emission of photo-electrons.

Q.19: What is the ~~de-B~~ de-Broglie wavelength associated with i) an electron moving with a speed of $5.4\times10^6\ ms^{-1}$. and ii) a ball of mass 1.50g travelling at $30.0\ ms^{-1}$?

Sol. i) $\lambda_e = \frac{h}{mv_e} = \frac{6.63\times10^{-34}}{9.1\times10^{-31}\times5.4\times10^6} = 0.135\times10^{-9}\ m$

$$\boxed{\lambda_e = 0.135\ nm}$$

ii) $\lambda_b = \frac{6.63\times10^{-34}}{0.150\times30.0}$

$$\boxed{\lambda_b = 1.47\times10^{-34}\ m}$$

Q.20. Describe Davisson and Germer Experiment to establish the wave nature of electron. Describe a labelled diagram of the apparatus used. 5

Ans: Davisson and Germer Experiment:
The experimental setup has shown in the following fig. It consists of a filament 'F' connected to a low tension battery. F emits large no. of electron when it is heated. A cathode 'C' connected to negative terminal of HT battery and an anodes A_1 & A_2 to the ⊕ terminal of battery (HT.).
A nickel (Ni) crystal is used to get diffraction of electron beam. The diffracted beam will be detected by a ~~detector D~~ movable detector D.

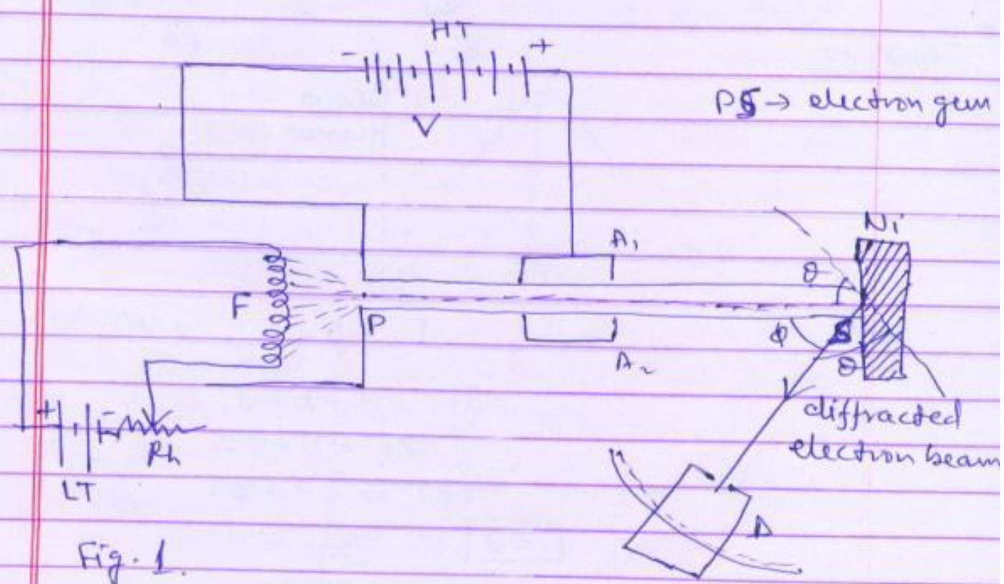
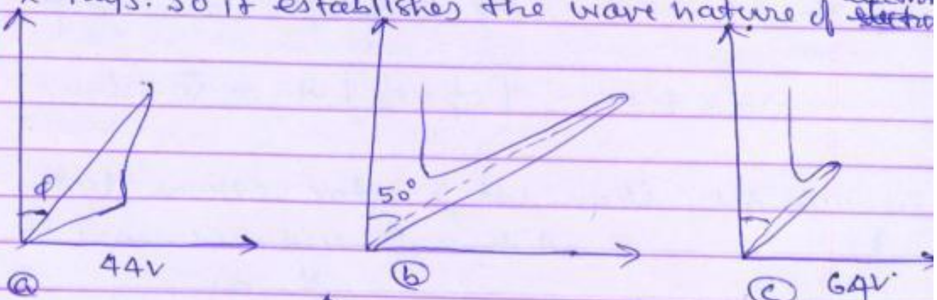


Fig. 1.

A fine beam of accelerated electron obtained from ~~an~~ the electron gun is made to fall on Ni crystal. These electrons are scattered in different directions by the atoms of Ni crystal, which is detected by detector D.
Davisson and Germer varied the accelerating potential (V) from 44V to 68V and and

measured the intensity of scattered beam at different scattered angle ϕ. They plot a polar graph as shown below, and found ~~that~~ a sharp hump at accelerating voltage 54V and scattering angle 50°. They concluded that this sharp peak due to diffraction electron beam. This observation is similar to diffraction of X-rays. So it establishes the wave nature of electron.



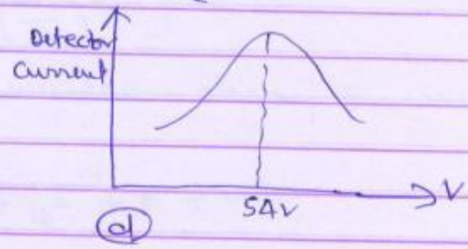


Fig. 2.

Also from fig. 1

$$\theta + \phi + \theta = 180^\circ$$
$$2\theta + \phi = 180^\circ$$
$$2\theta + 50^\circ = 180^\circ \quad \text{for } \phi = 50^\circ$$
$$\theta = \frac{130}{2} = \boxed{65^\circ}$$

$d = 0.91\ A^\circ$ for Ni so,

using Bragg's law for first order of diffraction

$$2d\sin\theta = n\lambda \qquad n=1$$
$$2 \times 0.91 \times \sin 65^\circ = \lambda$$
$$\boxed{\lambda = 1.65 A^\circ} \quad \text{——} (1)$$

Acc. to de-Broglie hypothesis $\lambda = \frac{12.27}{\sqrt{V}} = \frac{12.27}{\sqrt{54}}$

$$\boxed{\lambda = 1.66 A^\circ} \quad \text{——} (2)$$

Result (1) and (2) are in close agreement, hence proves the existence of de-Broglie waves for slow moving electron.