DUAL NATURE OF MATTER AND RADIATION

Electron Emission : The phenomenon of emission of electrons from a metal surface is called electron emission. It is of following types :

(i) **Thermionic emission :** By heating, thermal energy is imparted to free electrons to enable them to emit from the metal surface.

(ii) **Field emission : Electrons are emitted from the metal surface by subjecting it to a very high electric field.**

(iii) **Photoelectric emission :** When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface.

Photons : According to quantum theory, an electromagnetic radiation travels in the form of discrete packets of energy called quanta. One quantum of light radiation is called a photon.

Properties of Photons :

1. They travel in straight line with speed of light in vacuum.

2. Frequency of photon does not change when photon travels through different media.

3. There is a change in space of photon of different media, which is due to change in its wavelength.

4. The energy of a photon is given by

$E = h\nu = h\frac{c}{\lambda}$ where h is Plank's constant = 6.62×10^{-34} Js & ν is the frequency of photon.

5. **Momentum of photon**

$p = mc = \frac{h\nu}{c^2}c$ $\left[E = mc^2 = h\nu \Rightarrow \frac{hc}{c^2}\right]$

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

6. We know 'm' mass of a particle moving with 'v' velocity comparable with velocity of light is given by

$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$ where m_0 is the rest mass.

Here photon moves with velocity of light, then $m_0 = m\sqrt{1 - \frac{v^2}{c^2}} = 0$

Hence, photon has zero rest mass. It shows that photon cannot exist at rest.

Energy of a photon is expressed in eV, where 1 eV is the KE gained by an electron when a is accelerated through a potential difference of 1 V, 1 eV = 1.6×10^{-19} J, 1 keV = 1.6×10^{-10} J, 1 MeV = 1.6×10^{-13} J

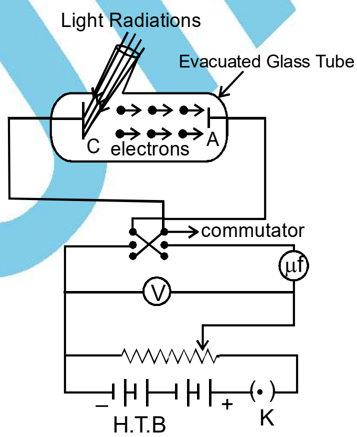
Photons are not deflected by electric & magnetic fields.

Dielectric Effect : The phenomenon of emission of electrons from a metallic surface when illuminated by of sufficiently high frequency is known as photoelectric effect. The electrons emitted in this process are of photoelectron & the current produced in the circuit is called as photoelectric current.

Herts observations : In 1887. Herts while demonstrating the existence of em. waves, the found that high voltage sparks across the detector loop were enhanced when the emitter plate was illuminated by UV light from an arc lamp. This observation led him to conclude that when lights falls on a metal surface, some electrons near the surface absorbs enough energy and can escape from the surface of the metal into the surrounding space.

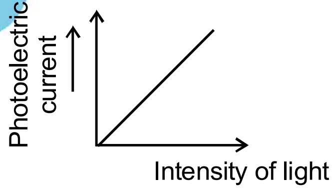
Hallwach's & Lenard's observation : Hallwachs, undertook the study further and found that negatively charged particles were emitted from the zine plate when it was exposed to ultraviolet light. Lenard used to apparatus as shown in the figure of experimental study of photoelectric effect. He observed that when ultra violet light was allowed to fall on a metallic electrode C, electrons were emitted by it. These electrons are attracted towards an electrode A maintained at positive potential. Thus, the electric current began to flow in the circuit. However, no electron is emitted when the electrode C was not exposed to ultra-villet light. He also concluded that the light of suitable frequency vacillated the emission of electrons from a metallic surface. Hallwachs and Lenard studied how this photo current varied with collector plate potential and with frequency of incident light.

Experimental study of photoelectric effect : The apparatus consists of an evacuated glass of quarts tube which encloses a photosensitive plate C (called emitter) & another metal plate A (called collector). A transparent window is sealed on to the glass tube which permits monochromatic radiations to pass through it and all on plate C. The plarities of the plate C and A can be reversed by a commutator. So, plate A can be given a desired +ve or –ve potential w.r.t P when the collector plate +ve w.r.t the emitter plate C, the photoelectrons emitted are accelerated towards the plate. A These electrons flow in the outer circuit resulting the photoelectric current which is measured by the micro-ammeter.



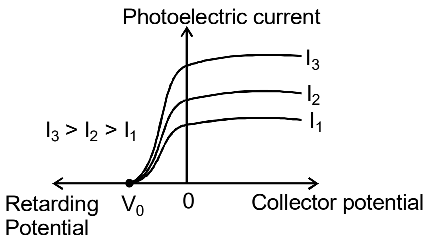
(1) Effect of intensity of light on photoelectric current :

Keeping the frequency of the incident radiation and the accelerating potential fixed, the intensity of light is varied and photoelectric current in measured. It is found that number of photoelectrons emitted per second from photosensitive plate i.e. photoelectric current is directly proportional to the intensity of incident radiation.



(2) Effect of potential of photoelectric current :

If frequency & intensity of incident radiation are kept fixed, it is found that photoelectric current increases gradually with the increase in +ve potential (accelerating potential) on plate A & then the photoelectric current becomes maximum. It attains saturation value & does not increase further for any increase in +ve potential of



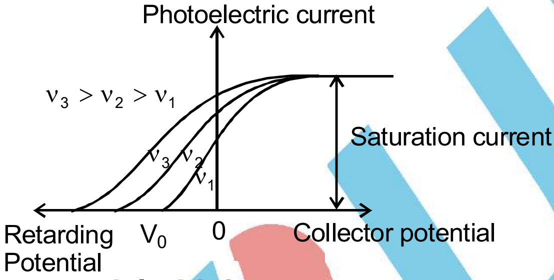
For a given frequency of incident radiation, the stopping potential is independent of intensity. For a given frequency of incident radiation, stopping potential V_0 is released to the maximum KE of the Auto electron that is just stopped from reaching the plate A.

Maximum KE of electron = $\frac{1}{2}mv^2_{max} = ev_0$

the above relation shows that maximum KE of photoelectron is independent of intensity of incident light

(3) Effect of frequency of the incident radiation on stopping potential :

Is found that saturation current is same for the radiations of different frequencies but the value of stopping potential is different for incident radiations of different frequencies. Greater is the frequency of the incident adiation, more is the value of stopping potential. The K.E. of the photoelectron emitted is independent of the density of incident light but depends upon fraudulence of incident light.

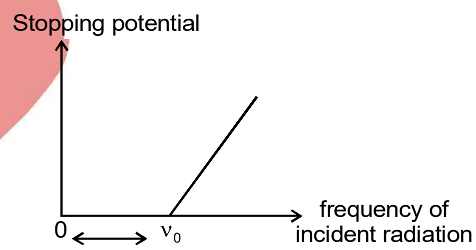


(4) Variation of stopping potential with frequency :

Graph between stopping potential and frequency of incident light is a straight line which shows that :

(a) stopping potential varies linearly with the frequency of incident radiation i.e. $\nu_0 \propto \nu$

(b) There is a certain minimum frequency ν_0 called threshold frequency for which the stopping potential is zero. It means that if the frequency of incident radiation is less than threshold frequency, no emission of photoelectron is possible.



Lows of photoelectric emission :

(1) The number of photoelectrons ejected per second is directly proportional to the intensity of incident light provided the frequency of the incident light is greater than threshold frequency.

(2) For a given photosensitive material, there exists a certain minimum frequency of incident radiation called threshold frequency below which no emission of photoelectrons takes place. For every substance the value fo threshold frequency is different.

(3) Above the threshold frequency, the stopping potential or maximum KE of emitted photoelectron is independent of intensity of incident light but is directly proportional to frequency of incident light.

(4) The photoelectric emission is an instantaneous process i.e., times lag between the incident of radiation & emission of photoelectron is very small i.e., less than 10^{-9} sec.

Note : Photoelectric effect cannot be explained on the basis of wave natural of light.

Einstein's theory of photoelectric Effect : Einstein explained photoelectric effect on the basic of quantum theory, according to which a light radiation travels in the form of discrete photons. Energy of each photon is hv, where h is the Plank's constant & v is frequency of light. Photoelectric emission is the result of interaction of two particles, one a photon of incident radiation & the other an electron of photosensitive metal. Each photon interacts with an electron. The energy hv of the incident photon is used up in two parts :

(a) A part of energy is used in liberating the electron from the metal surface, which is equal to work function W_0 of the metal.

(b) The remaining energy is used in imparting KE to the ejected electron.

By conservation of energy : Energy of incident photon = max KE of photoelectron + Work function.

$$h\nu = \frac{1}{2}mv^2_{max} + W_0$$

$$KE_{max} = \frac{1}{2}mv^2_{max} = h\nu - W_0 \qquad ...(1)$$

Here W_0 = $h\nu_0$, where ν_0 is there threshold frequency.

$$KE_{max} = \frac{1}{2}mv^2_{max} = h\nu - h\nu_0$$

$$\frac{1}{2}mv^2_{max} = h(\nu - \nu_0) \qquad ...(2)$$

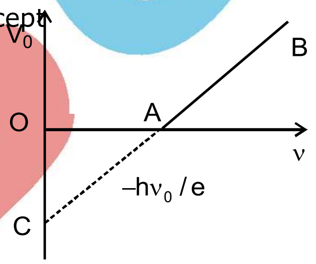
Eq. (1) & (2) are Einstein's photoelectric equation.

Determination of h and W_a of metal : According to Einstein's photoelectric eq., we have,

$\frac{1}{2}mv^2_{max} = h\nu - w_0$ Since $\frac{1}{2}mv^2_{max} = eV_0$ where V_0 is the stopping potential

$$eV_0 = h\nu - h\nu_0 \quad \Rightarrow \quad V_0 = \left(\frac{h}{e}\right)\nu - \frac{h\nu_0}{e}$$

Comparing with straight line sq. y = mx + c,
where m is the slope of the line and c is the intercept on y -axis.



$$m = \frac{h}{e} = \tan\theta = \frac{V_0}{\nu}$$

planck's constant h = e × tan θ

Intercept is $OC = -\frac{h\nu_0}{e} = -\frac{W_0}{e}$

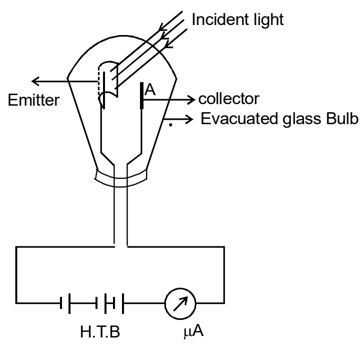
Photo Cell : A photocell is an arrangement which converts light energy into electrical energy. It works on the principle of photoelectric emission. Photo-cells are of three types :

1. Photo-emission cells **2.** Photo-Conductive Cell 3. Photo-Voltaic cell

Photo emissive cell : It is based on the principle of photo-electric emission.

Construction : It consists of an evacuated glass or quarts tube which encloses two electrodes. Cathode or mitter is a parabolic metal plate coated with a layer of photosensitive material like oxides of Na, Cs etc. The code is a thin rod of Pt or Ni which faces the cathode. It is also known as collector. The two electrodes are connected externally to a high tension battery & a micro ammeter (μA).

Working : When light of frequency greater than the threshold frequency falls on the cathode, photoelectrons are emitted which are attracted by the collector. The circuit gets completed & a current starts flowing the circuit. As the number of photoelectrons emitted is proportional to the intensity of incident light, the photoelectric current gives a measure of intensity of light.



Application of Phto Cells :

(1) In cinematographer, photocells are used for the reproduction of sound.
(2) In Counting device (3) In Burglar Alarm
(4) In Photographic cameras (5) In automatic control & checking of traffic signals
(6) In automic control of street light system
(7) In the preparation of solar batteries.

Dual nature of radiation : The phenomena like interfernce, diffraction and polarisation can be explained only on the basic of wave nature of light. On the other hand, the phenomena like photoelectric effect, Compton effect can be explained only on the basic of quantum theory of light i.e., by assuming particle nature of light. This shows that light radiation has dual natural, sometimes, behave like a wave and sometimes as a particle.

Dual nature of matter : de-Broglie wave : Since radiation has dual natura & universe is composed of radiation & matter. Therefore, de-Broglie concluded that matter i.e. moving material particles like electrons, protons, neutrons must also posses dual nature, sometimes like particle and sometimes like wave because nature loves symmetry. The wave associated with moving particle is called matter wave or de-Broglie wave whose wavelength is called as de-Broglie wavelength, given by $\lambda = \frac{h}{mv}$ where h is Plank's constant, m & v are mass & velocity of the particle respectively.

Derivation of de-Broglie wavelength : The energy of a photon is given by :

$E = hn$ ...(i) where h is Plank's constant.

According to Einstein's mass energy relation

$E = mc^2$ ..(2)

From (1) & (2) $h\nu = mc^2$ or $m = \frac{mv}{c^2}$

Momentum of photon $p = m \times \text{velocity} = \frac{h\nu}{c^2} \times c = \frac{h\nu}{c} = \frac{h}{c/\nu}$

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

is the de-Broglie wave equation for material particle. de-Broglie wavelength in terms of kinetic energy K of electron is given by : $\frac{1}{2}mv^2 = K$ or $v = \sqrt{\frac{2K}{m}}$

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

De-Broglie wavelength of an electron moving through a potential difference :

Let us consider a electron traveding through a potential difference of V volt. The K.E. of electron is

$$\frac{1}{2}mv^2 = eV \quad \text{or} \quad m^2v^2 = 2meV$$

$$mv = \sqrt{2meV} \qquad ...(1)$$

But De-Broglie wavelength is given by $\lambda = \frac{h}{mv}$ ...(2)

Substituting the value of mv from eq. (1) in eq. (2), we get.

$$\boxed{\lambda = \frac{h}{\sqrt{2meV}}} \qquad ...(3)$$

Putting $h = 6.62 \times 10^{-34}$ Js, $m = 9.1 \times 10^{-31}$ kg, $e = 1.6 \times 10^{-19}$ C in eq. (3), we get.

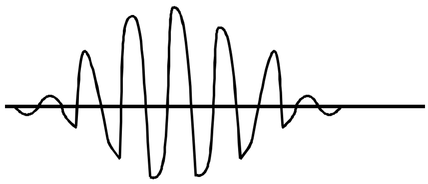
$$\boxed{\lambda = \frac{12.27}{\sqrt{V}}\text{Å} = \frac{1.227}{\sqrt{V}}\text{nm}}$$

Heisenberg's Uncertainty Principle : The matter wave incorporate the Heisenberg's uncertainty principle. According to this principle, it is impossible to measure simultaneously both the position and the momentum of particle accurately

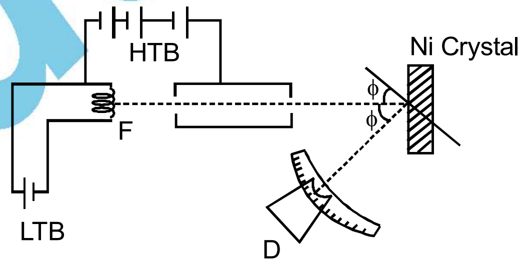
$$\Delta\xi \, \Delta p = h \qquad \text{where } \hbar = \frac{h}{2\pi}$$

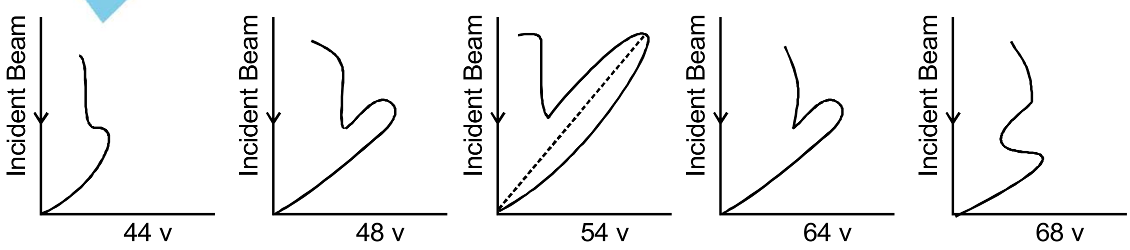
If $\Delta x = 0$ i.e., the position of a particle is measured accurately. Then $\Delta p = \infty$. That is the uncertainty in the measurement of the momentum of the particle is infinite. In other words, the momentum of the particle cannot be measured. (ii) If $\Delta p = 0$ i.e., the momentum of the particle is measured accurately, then $\Delta x = \infty$. That is the position of the particle cannot be measured.

A matter wave associated with a moving particle is represented by a wave packet as shown in the given figure.



Experimental Demonstration of wave - nature of electron : Wave nature of electron wave established by Davisson & Garmer. The apparatus consists of a filament F of tungsten, coated with Barium oxide which on heating with current from low tension battery emits large number of electrons. Electrons emitted by the filament are accelerated by applying suitable potential difference between cathode and anode. The electrons are made to pass through a cylinder with fine holes along its axis producing a fine collimated beam. 'D' is an electron detector which can be rotated on a circular scale. A fine beam of accelerated electrons obtained from electron gun is made to fall normally on the nickel crystal. The incident electron sare scattered in different directions by atoms of the crystal. By rotating the electron detector on circular scale at different position, the intensity of scattered beam is measured fro different values of angle of scattering ϕ, (angle between incident & scattered electron beam). Polar graphs are plotted showing the variation of intensity of scattered beam & scattering angle ϕ for different accelerating voltage from 44 V to 68 V. The graphs show that there is a sharp bump when accelerating voltage is 54 V scattering angle ϕ = 50°. The appearance of bump in a particular direction is due to constructive interference of electrons scattered from different layer of regularly spaced atoms of the crystal. This establishes wave nature of electron. There is a close agreement of de-Broglie wavelength (0.167nm) & the experimental value (0.165 nm) determined by Devaission & Germer. This proves the wave nature of moving particles.





SOLVED PROBLEMS

1. An electron and photon have same energy 100 eV. Which has greater associated wave-length ?

Sol. de Broglie wavelength associated with electron

$$\lambda_e = \frac{h}{\sqrt{2mE_0}} \Rightarrow E_e = \frac{h^2}{2m\lambda_e^2} \qquad ...(1)$$

Also wavelength of photon of energy E_{ph} is

$$E_{ph} = \frac{hc}{\lambda_{ph}} \Rightarrow E_{ph}^2 = \frac{h^2c^2}{\lambda_{ph}^2} \qquad ...(2)$$

Given $E_e = E_{ph} = E(\text{say}) = 100$ eV

$\therefore$ Dividing (2) by (1) and using (3), we get

$$E = \frac{h^2e^2/\lambda_{ph}^2}{h^2/2m\lambda_e} \quad \text{or} \quad E = \frac{2mc^2\lambda_e}{\lambda_{ph}^2} \qquad \therefore \quad \frac{\lambda_e}{\lambda_{ph}} = \sqrt{\frac{E}{2mc^2}}$$

As E = 100 eV 2 mc^2 $\simeq$ 1 MeV

$\therefore$ $E << 2\,mc^2 \Rightarrow \lambda_e < \lambda_{ph}$

2. How did de Brogie hypothesis lead to Bohr's quantum condition of atomic orbits :

Sol. According to Bohr's quantum condition "Only those atomic orbits are allowed as stationary orbits in whcih angular momentum of an electron is the integral multiple of $\frac{h}{2\pi}$.

If m is the mass, v velocity and r radius of orbit, then angular momentum of electron L = mvr.

According to Bohr's quantum condition

$$mvr = n\frac{h}{2\pi} \qquad ...(1)$$

According to de Brolie quantum condition only those atomic orbits are allowed as stationary orbits in which circumference of electron- orbit is the integral multiple of de Broglie wave-length associated with electron i.e.,

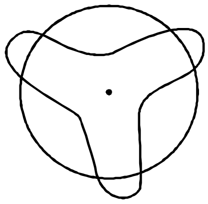
$$2\pi r = n\,\lambda \qquad ...(2)$$

According to de Broglie hypothesis

$$\lambda = \frac{h}{mv} \qquad ..(3)$$

Substituting this value in (2), we get

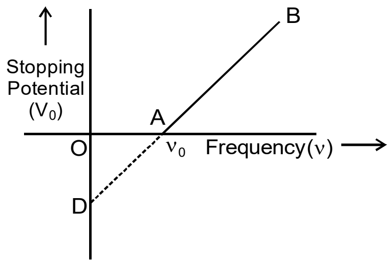
$$2\pi r = n\left(\frac{h}{mv}\right) \Rightarrow mvr = n\frac{h}{2\pi}$$



Orbit with n = 3 houses 3 complete wavelengths

3. Sketch a graph between frequency of incident radiations and stopping potential for a given photosensitive material. What information can be ontained from the value of the intercept on the potential axis ?

A source of light of frequency greater than the threshold frequency is at a distance of 1 m from the cathode of a photocell. The stopping potential is foudn to be V. If the distance of the light source from the cathode is reduced, explain giving reasons, what change will you observe in the (i) photoelectric current, (ii) stopping potential.



Sol. From Einstein's photoelectric equation

$$E_k = h\nu - W$$

$$eV_0 = h\nu - W$$

$$V_0 = \frac{h}{e}\nu - \frac{W}{e}$$

Comparing with y = mc + c,

The intercept $-\frac{W}{e}$ will help to obtain the work function of the substance.

(i) **Photoelectric Current :** As the distance of the light source from the cathode is reduced, the intensity of light is increased. Thus, photoelectric current is increased because more photo electrons will get emitted.

(ii) **Stopping Potential :** The stoping potential remains unaffected by reducing the distance of the light source from the cathode, as frequcny is not change on reducing the distance between source of light and cathode.

4. **Derive Einstein's photoelectric equation $\frac{1}{2}mv^2 = h\nu - h\nu_0$**

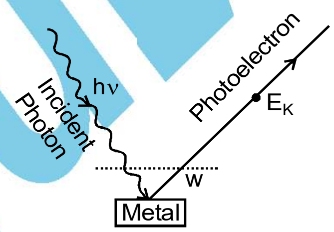
Einstein's Explanation of Photoelectric Effect : Einstein's Phtoelectric Equation

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

1. Light is propaged in the form of bundles of energy. Each bundle of energy is called a **quantum** or **proton** and has energy $h\nu$, where h = Planck's constant ν = frequency of light.

2. The photoelectric effect is due to collision of a photon of incident light and a bound electronof 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 surface (i.e., in overcoming work function) and the remaining part appears in the form of kinetic energy of the same electron.



If ν be the frequency of incident light, the energy of photon = $h\nu$. If W be the work function of metal and K_K the maximum kinetic energy of photoelectron, then according to Einstein's explanation

$$h\nu = W + E_K \qquad ....(1)$$

or $$K_K = h\nu - W$$

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 (1)

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

If λ_0 be the threshold wavelengh, then $\nu_0 = \frac{c}{\lambda_0}$, where c is the speed of light in vacuum

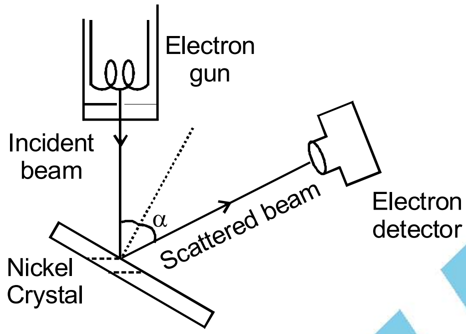
$\therefore$ Work funciton W = $h\nu_0 = \frac{hc}{\lambda_0}$

Substituting this value in equation (1), we get

$$E_K = h\nu - h\nu_0$$

This is another form of Einstein's photoelectric equation.

5. **Describe Davisson and Germer's experiment to demostrate the wave nature of electrons. Draw a labelled diagram of appratus used.**



Sol. **Davisson and Germer Experiment :** In 1927 Davisson and Germer performed a diffraction experiment with electron beam in analoogy 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

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

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

E_K = Kinetic energy of electron = 54 eV

= $54 \times 1.6 \times 10^{-19}$ Joule

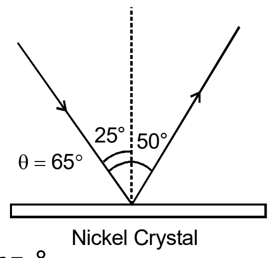
$$\therefore \quad \lambda = \frac{6.6 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 86.4 \times 10^{-19}}} = 1.66 \times 10^{-10} \text{ m} = 1.66 \text{ Å}$$

(ii) 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.

(iii) 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 postion of detector can all be varied.

Method : The crystal is rotated in small steps to change the anlge (α say) between incidence and scattered directins 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 storng peak appeared in the intensity (I) of the scatered electron for an accelerating voltage of 54 V at a scattering angle α = 50°.



$\therefore$ From Bragg's law $2d \sin\theta = n\lambda$

Here n = 1, d = 0.914 Å, θ = 65°

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

$$= \frac{2\times(0.914\,\text{Å})\sin 65^\circ}{1} = 2 \times 0.914 \times 0.9063\ \text{Å} = 1.65\ \text{Å}$$

The measured wavelength is in close agreement with the estimated de Broglie wavelength. Thus the wave nature of electron is varified. Later on G.P. Thomson demostrated 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.

5. 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 photon is $\frac{2\lambda mc}{h}$ times the kinetic energy of electron, where m, c, h have their usual meanings.

Sol. Due to large mass of a football the de-Broglie wavelength associated with a moving football is much smaller than its dimensions, so its wave nature is not visible.

de Broglie wavelength of electron $\lambda = \frac{h}{mv} \Rightarrow v = \frac{h}{m\lambda}$ ...(1)

energy of photon $E = \frac{hc}{\lambda}$ (because λ is same) ...(2)

Ratio of energy of photon and kinetic energy of electrons

$$\frac{E}{E_K} = \frac{hc/\lambda}{\frac{1}{2}mv^2} = \frac{2hc}{\lambda mv^2}$$

Substituting value of V from (1), we get

$$\frac{E}{E_K} = \frac{2hc}{\lambda m(h/m\lambda)} = \frac{2\lambda mc}{h}$$

$\therefore$ Energy of photon = $\frac{2\lambda mc}{h}$ × kinetic energy of electron.

EXERCISE - I UNSOLVED PROBLEMS

1. Calculate the frequency associated with a photon of energy 3.3×10^{-10} J.

2. The max. K.E. of electron emitted by a photocell is 3 eV, what is the stopping potential.

3. Calculate the energy of a photon of frequency 6×10^{14} Hz in electron volt. Given h = 6.62 $\times 10^{-34}$ Js.

4. The work function for a certain metal is 4.2 eV. Will this metal give photoelectric emission for wavelength 330 nm ?

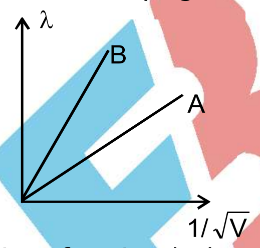
5. **An α - particle & a proton are accelerated from rest through same pot. difference V. Find the ratio of** de-Broglie wavelength associated with them.

6. Calcualte de-Broglie wavelengths for an electron moving with speed of 6×10^5 ms^{-1}

7. Which photon is more energetic violet one or red one ?

8. Which photon is more energetic violet one or red one ?

9. The graph represents de-Broglie wavelength versus $1/\sqrt{V}$, where V is the accelerating potential difference, for two particles carrying the same charge, which one has smaller mass ?



10. What is the effect on velocity of emitted photoelectrons if wavelength of incident light is decreased ?

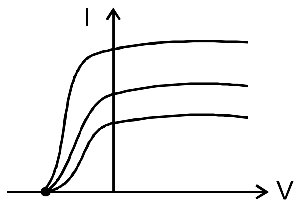
11. If intensity of incident radiation on a metal is doubled, what happens to the K.E. Of electrons emitted ?

12. The frequency (v) of incident radiation is greater than threshold frequency (v_0) in a photocell. How will the stopping potential vary if frequency v is increased, keeping other factors constant.

13. If intensity of incident radiation in a photocell is increased, how does stopping potential vary ?

14. Plot a graph showing variation of photoelectric current with anode potential for two light beam of same wavelength but different intensity.

15. Name the quantity kept constant.



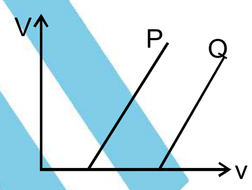
16. The wavelength λ of a photon & de Broglie wavelength of an electron have the same value. Show that the energy of the photon is 2λ mc/h times the K.E. of the electron.

17. The threshold frequency of a metal fo f_0. When light of frequency $2f_0$ is incident. The maximum velocity of electrons is v_1. When frequency is increased to $5f_0$, max velocity of v_2. Find ratio of v_1 & v_2

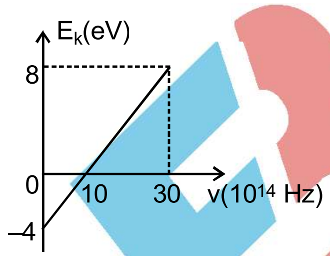
18. Ultraviolet light is incident on two phtosensitive materials having work function W_1 & W_2 ($W_1 > W_2$)
(i) In which case KE of electron will be greater ? (ii) If KE is same, which has higher frequency ?

19. Name the phenomenon which illustrates the particle nature of light.

20. In a photoelectric effect experiment. the graph is shown. :
(i) Which of the two metals P & Q have greater value of work function ?
(ii) What does slope of line depict ?
(iii) Which has smaller threshold wavelength ? Which has smaller KE, for the same wavelength ?



21. Find the value (1) threshold frequency (ii) Work function from the graph .

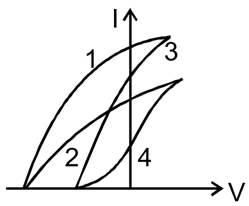


22. What is the de-Broglie wavelength associated with an electron accelerated through a p.d of 100 V ?

23. 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.

24. The de-Broglie wavelength of a particle of kinetic energy K is λ. What would be the wave-length of the particle, if its KE is K/4 ?

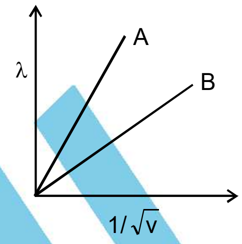
25. From the given graph identify the pair of curves that corresponds to different materials but same intensity of incident radiation.



EXERCISE - II BOARD PROBLEMS

1. Draw suitable graphs to show the variation of Photo electric current with collector plate potential for
(1) a fixed frequency but different intensitier $I_1 > I_2 > I_3$ of radiation
(2) a fixed intensity but different frequencier $\nu_1 > \nu_2 > \nu_3$ of radiation

2. Two lines marked A & B as given, shows a plot of debroglie wavelength λ versus $\frac{1}{\sqrt{V}}$, where V is the acceleration potential, for protons and α-particles



1. What does the slope of lines represent ?
2. Identify which lines corresponds to these particles.

3. The stopping potential in an experiment on photo electric effect is 1.5 V. What is the maximum kinetic energy of the photoelectron emitted.

4. Draw a schematic arrangement of the Geiger Marsden experiment. How did the scattering of α-particle by a thin foil of gold provide animportant way to determine an upperlimit on the size of the nuclear ? Explain

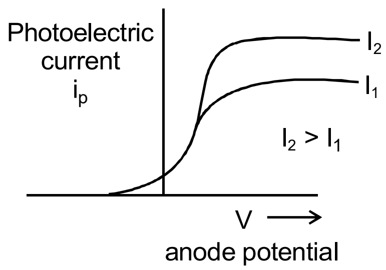
5. What is the stopping potential applied to a photocell if the maximum kinetic energy of a phtoelectron is 5 eV ?

6. How does the stopping potential applied to a photocell change, if the distance between the light source and the cathode of the cell is doubled ?

7. An electron, an alpha particle and a proton have the same kinetic energy. Which one of these particles has (i) the shortest and (ii) the largest, de Broglie wavelength ?

8. With what purpose was framous Devisson - Germer experiment with electrons performed ?

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



10. de Brolgie wavelength associated with an electron accelerated through a potential difference V is λ. What will be the Broglie wavelength when the acceleating potential is increased to 4 V

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

12. Two beams, one of red light and the othe r of blue light, of the same intensity are incident on a metallic surface to emit phtoelectrons. Which one of the two beams emits electrons of greater kinetic energy ?

13. An electron and an alpha particle have the same de Broglie wavelength associated with them. How are their kinetic energies related to each other ? 3

14. The frequency ν of incident radiation of greater than threshold frequency (ν_0) in a photocell. How will the stopping potential vary if frequency (ν) is increased, keeping other factors constant ?

15. Green light ejects photoelectrons from a given photosensitive surface whereas yellow light does not. What will happen in case of violet and red light ? Give reason for your answer.

16. A proton and an electron have same kinetic energy. Which one has greater de-Broglie wavelength and why ?

Ans. e^-

17. Define the terms (i) 'cut-off' voltage' and (ii) '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 of a suitable plot/ graph.

18. Wriete the expression for the de Broglie wavelength associated with a charged particle having charge 'q' and mass 'm', when it is accelerated by a potential V.

19. Write Einstein's photoelectric equation and point out any two characteristic properties of photons on which equation is based. Briefly explain the three observed features which can be explained by this equation.

ANSWER KEY

EXERCISE - I — UNSOLVED PROBLEMS

1. 5×10^{23} Hz **2.** 3 V **3.** 2.48 eV **4.** No.

5. $1 : 2\sqrt{2}$ **6.** 1.21×10^{-9} m **7.** Violet **8.** (a) $\frac{h\nu}{c}$ (b) $\frac{h}{\lambda}$

9. B **10.** increase **11.** uncharged **12.** increases

13. unchanged **15.** frequency **17.** 1 : 2

18. (i) One having W_2 (ii) One having W_1 **19.** Photoelectric effect

20. (i) Q (ii) h/e **21.** (i) 10^{15} Hz (ii) At v = 0, $E_k = h\nu_0 = W_0 = 4eV$

22. 0.123 nm **23.** 1.675×10^{-27} kg, neutron **24.** 2λ

25. 1 & 3, 2 & 4

EXERCISE - II — BOARD PROBLEMS

3. $-\ KE_{max} = 2.4 \times 10^{-19}$ J **5.** 5 volt (negative)

7. $\frac{\lambda}{2}$