# DUAL NATURE OF RADIATION AND MATTER

**PHYSICS - VOL 2** **UNIT - 8**

**NAME :**

**STANDARD : 12 SECTION :**

**SCHOOL :**

**EXAM NO :**

ஒருமைக்கண் தான் கற்ற கல்வி ஒருவற்கு
எழுமையும் ஏமாப் புடைத்து

ஒருவன் ஒரு தலைமுறையில் பெறும் கல்வி அறிவானது,
ஏழேழு தலைமுறைக்கும் பாதுகாப்பாக அமையும்.

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## 2 & 3 Marks Questions and Answers

**1. Why do metals have a large number of free electrons?**

- In metals, the electrons in the outer most shells are loosely bound to the nucleus.
- Even at room temperature, due to thermal agitation the loosely bounded electrons are detached from their orbit and free to move inside the metal in a random manner. This is the reason for large number of free electrons in the metal.

**2. Define surface barrier.**

- The potential barrier which prevents free electrons from leaving the metallic surface is called surface barrier.
- It is created by the positive nuclei of the metal

**3. Define electron emission.**

- The liberation of electrons from any surface of a substance is called electron emission.
- The material with small work function is more effective in electron emission.

**4. Define work function of a metal. Give its unit.**

- The minimum energy needed for an electron to escape from the metal surface is called work function of that metal. It is denoted by $\phi_o$
- Its unit is ***electron volt*** (eV).

**5. Define electron volt (eV)**

- One electron volt is defined as the kinetic energy gained by a electron when accelerated by a potential difference of 1 volt.

$$\mathbf{1\ eV = 1.602\ X\ 10^{-19}\ J}$$

**6. What is photo electric effect?**

- The ejection of electrons from a metal plate when illuminated by light or any other electromagnetic radiation of suitable wavelength or frequency is called photo electric effect.
- The ejected electrons are called as photo electrons and the corresponding current is called photo electric current

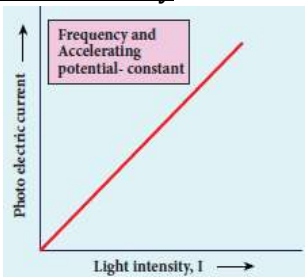
**7. What are called photo sensitive materials?**

- The materials which eject photoelectrons upon irradiation of electromagnetic wave of suitable wavelength are called photosensitive materials.
  (e.g.) Metals like cadmium, zinc, magnesium etc and Alkali metals like lithium, sodium, caesium

**8. How does photo electric current vary with the intensity of the incident light?**

**Variation of photo current with intensity** :

- Keeping the frequency ($\nu$) and acceleration potential (V) as constant, the intensity of incident light is varied and the corresponding photo eletric current is measured




- A graph is drawn between intensity along X-axis and the photo current along Y-axis.
- From the graph, *the photo current (i.e) the number of electrons emitted per second is directly proportional to the intensity of incident light.*

**9. Define stopping potential.**

- The negative or retarding potential given to collecting electrode which is just sufficient to stop the most energetic photoelectrons emitted and make the photo current zero is called stopping potential or cut - off potential.

**10. Define threshold frequency.**

- For a giver surface, the emission of photo electrons takes place only if the frequency of incident light is greater than a certain minimum frequency called threshold frequency.

**11. State the laws of photo electric effect.**

**Laws of photo electric effect** :

- For a given frequency of incident light, the number of photoelectrons emitted is directly proportional to the intensity of the incident light. The saturation current is also directly proportional to the intensity of incident light.
- Maximum kinetic energy of the photo electrons is independent of intensity of the incident light.
- Maximum kinetic energy of the photo electrons from a given metal is directly proportional to the frequency of incident light.
- For a given surface, the emission of photoelectrons takes place only if the frequency of incident light is greater than a certain minimum frequency called the threshold frequency.
- There is no time lag between incidence of light and ejection of photoelectrons.

**12. Explain why photoelectric effect cannot be explained on the basis of wave nature of light**

**Failures of classical wave theory** :

- According to wave theory, light of greater intensity should impart greater kinetic energy to the liberated electrons.
  But the experiments show that maximum kinetic energy of the photoelectrons does not depend on the intensity of the incident light.
- According to wave theory, if a sufficiently intense beam of light is incident on the surface, electrons will be liberated from the surface of the target, however low the frequency of the radiation is.
  But photoelectric emission is not possible below a certain minimum frequency called threshold frequency.
- Since the energy of light is spread across the wavefront, each electron needs considerable amount of time (a few hours) to get energy sufficient to overcome the work function and to get liberated from the surface.
  But experiments show that photoelectric emission is almost instantaneous process

**13. Explain the concept of quantization of energy.**

**Quantization of energy** :

- Max Planck proposed quantum concept in 1900 in order to explain the block body radiations.
- According to Planck, matter is composed of a large number of oscillating particles (atoms) which vibrate with different frequencies.
- Each atomic oscillator which vibrates with its characteristic frequency emits or absorbs electromagnetic radiation of the same frequency.
  (i) If an oscillator vibrates with frequency $\nu$, its energy can have only certain discrete values,
  $$\boldsymbol{E_n = n\,h\,\nu} \qquad [n = 1,2,3, \ldots.]$$
  where $h \rightarrow$ Planck's constant.
  (ii) The oscillators emit or absorb energy in small packets or quanta and the energy of each quantum is $\boldsymbol{E = h\,\nu}$
- This implies that the energy of the oscillator is quantized and not continuous This is called **quantization of energy**.

**14. Explain Eienstein's explanation for the particle nature (quanta ) of light**

**Particle nature of light - Eienstein's explanation :**

- ♥ According to Einstein, the energy in light is not spread out over wavefronts but is concentrated in small packets or energy quanta. Therefore, light of frequency $\nu$ from any source can be considered as a stream of quanta
- ♥ The energy of each light quantum ; $\boldsymbol{E = h\nu}$
- ♥ The linear momentum of quanta is ; $\boldsymbol{p = \frac{h\nu}{c}}$
- ♥ The individual light quantum of definite energy and momentum can be associated with a particle. The light quantum can behave as a particle and this is called ***photon.***

15. **Define intensity of light according to the quantum concept**.

- ♥ According to quantum concept, the intensity of light of given wavelength is defined as the number of energy quanta or photons incident per unit area per unit time with photon having same energy.
- ♥ The unit is $\boldsymbol{W\,m^{-2}}$

**16. What is the nature of light?**

- ♥ The light possesses dual nature that of both ***wave*** and ***particle.***
- ♥ Light behaves as a wave during its propagation and behaves as a particle during its interaction with matter.

**17. What is photo electric cell? Give its type.**

- ♥ The device which converts light energy into electrical energy is called photo electric cell or simply photo cell.
- ♥ It works on the principle of photo electric cell
- ♥ Photo cells are classified in to three types.
  - (1) Photo emissive cell
  - (2) Photo voltaic cell
  - (3) Photo conductive cell

**18. What is De Broglie hypothesis?**

- ♥ Due to the symmetry in nature, de Broglie suggested that if radiation like light can act as particles at times, then matter particles like electrons should also act as waves at times.
- ♥ According to de Broglie hypothesis, all matter particles like electrons, protons, neutrons in motion are associated with waves. These waves are called de Broglie waves or matter waves.

**19. What is called matter waves or de Broglie waves?**

- ♥ The waves assoiated with matter particles like electrons in motion is called matter waves or de Broglei waves.

**20. Derive the expression of de Broglie wavelength.**

**De Broglei wavelength** :

- ♥ The momentum of photon of frequency $'\nu'$ is,

$$p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda} \qquad [c = \lambda\nu]$$

- ♥ The wavelength of a photon is, $\lambda = \frac{h}{p}$
- ♥ According to de Broglie, this equation is applicable to matter particle also.
- ♥ Let '**m**' be the mass and '$\boldsymbol{v}$' be the velocity of the particle, then the wavelength

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

- ♥ This wavelength of the matter waves is known as ***de Broglie wavelength***.

**21. Write the expression for the de Broglie wavelength associated with a charged particle of charge 'q' and mass 'm', when it is accelerated through a potential *V*.**

- ♥ De Broglie wavelength in terms of potential 'V' ,

$$\boldsymbol{\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2\,m\,q\,V}}}$$

**22. Why we do not see the wave properties of a baseball?**

- ♥ The de Broglie wavelength of matter is ; $\boldsymbol{\lambda = \frac{h}{mv}}$
- ♥ Thus the de Broglie wavelength is inversely proportional to the mass
- ♥ Since the mass of base ball is too large as compared with the electron, the de Broglie wavelength of base ball is negligibly small
- ♥ So we do not see the wave property of the baseball

23. **A proton and an electron have same kinetic energy. Which one has greater de Broglie wavelength. Justify**.

- ♥ De Broglei wavelength of proton ; $\boldsymbol{\lambda_p = \frac{h}{\sqrt{2\,m_p\,K}}}$
- ♥ De Broglei wavelength of electron ; $\boldsymbol{\lambda_e = \frac{h}{\sqrt{2\,m_e\,K}}}$
- ♥ Here the mass of the proton is greater than the mass of the electron ($\boldsymbol{m_P > m_e}$)
- ♥ Hence the de Broglei wavelength of electron is greater than that of proton ($\boldsymbol{\lambda_e > \lambda_P}$)

**24. Write the relationship of de Broglie wavelength $\lambda$ associated with a particle of mass *m* in terms of its kinetic energy *K*.**

- ♥ De Broglie wavelength in terms of potential 'V' ,

$$\boldsymbol{\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2\,m\,q\,V}}}$$

- ♥ Since, q V = K (kinetic energy), we have

$$\boldsymbol{\lambda = \frac{h}{\sqrt{2\,m\,K}}}$$

**25. Name an experiment which shows wave nature of the electron. Which phenomenon was observed in this experiment using an electron beam?**

- ♥ The wave nature of electron (i.e) de Broglie hypothesis of matter waves was experimentally confirmed by ***Davisson and Germer*** experiment.
- ♥ Diffraction is the important property of waves. So in this experiment, ***diffraction of electron beam*** was observed when they fall on crystalline solids.

**26. An electron and an alpha particle have same kinetic energy. How are the deBroglie wavelengths associated with them related?**

- ♥ De Broglei wavelength of electron beam,

$$\lambda_e = \frac{h}{\sqrt{2\,m_e\,K}}$$

- ♥ De Broglei wavelength of alpha particle,

$$\lambda_\alpha = \frac{h}{\sqrt{2\,m_\alpha\,K}}$$

$$\therefore \qquad \frac{\lambda_e}{\lambda_\alpha} = \sqrt{\frac{m_\alpha}{m_e}}$$

**27. What are called X - rays? Why are they so called?**

- ♥ X - rays are invisible, electromagnetic waves of very short wavelength ranging from **0.1 A°** to **100 A°**
- ♥ When a fast moving electrons strike a metal target of high atomic weight, X - rays are produced.
- ♥ At the time of discovery, the orgin of this highly penetrating rays were not known. So they were called as X - rays.

**28. List the properties of X - rays.**

**Properties of X - rays** :

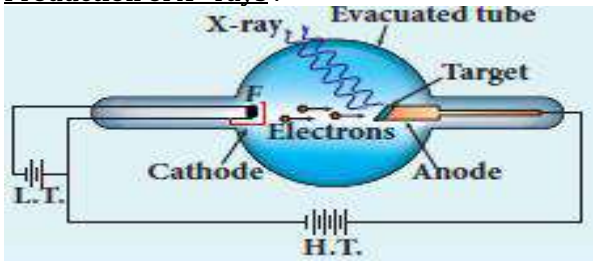
- ♥ They travel in straight line with the velocity of light
- ♥ They are not deflected both by electric and magnetic field
- ♥ X - ray photons are highly energetic
- ♥ They pass through materials which are opaque to visible light.

**29. What factor does the quality and intensity of X - rays were depends?**

- The quality of X - rays is measured in terms of its penetrating power which depends on the velocity of the striking electron and the atomic number of target material.
- The intensity of X - rays is depends on the number of electrons striking the target

**30. Write a note on the production of X - rays.**

**Production of X - rays** :




- X - rays are produced in a Coolidge tube which is a discharge tube.
- Here a tungsten filament 'F' is heated by L.T, so that electrons are emitted from it by thermionic emission.
- These electrons are accelerated to very high speeds by H.T
- The target material like tungsten is embedded in the face of solid copper anode.
- When high speed electrons strike the target, they are decelarated suddenly and lose their kinetic energy.
- As a result, X -ray photons are produced.
- The face of target is inclined at particular angle, so that the X - rays can leave the tube through its side.
- Since most of the kinetic energy of electrons get converted in to heat, the target made of high melting point and a cooling system are usally employed.

**31. What is X -ray spectra? Give its types.**

- The intensity of the X-rays when plotted against its wavelength gives a curve called X - ray spectrum.
- X - ray spectrum consists of two parts, namely
  (1) Continuous X -ray spectrum
  (2) Characteristic X - ray spectrum

**32. Write a note on continuous X - ray spectrum.**

**Continuous X - ray spectrum** :

- When a fast moving electron penetrates and approaches a target nucleus, it get accelerates or decelerates
- It may results in a change of path of the electron.
- The radiation produced from such decelerating electron is called ***Bremsstrhlung*** or ***braking radiation***.
- The energy of the emitted photon (radiation) is equal to the loss of kinetic energy of the electron.
- So the photons are emitted with all possible energies or frequencies.
- The continuous X -ray spectrum is due to such radiations.
- When an electron gives up all its energy, then the photon is emitted with highest frequency ($\nu_0$) or lowest wavelength ($\lambda_0$)
- The intial kinetic energy of an electron = eV where, V → accelerating voltage
- Thus,

$$e\,V = h\,\nu_0 = h\,\frac{c}{\lambda_0}$$

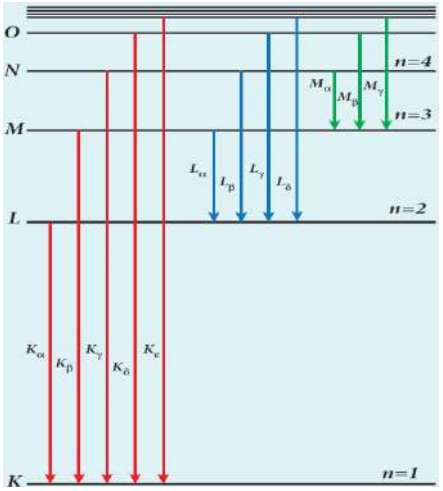
$$(or) \qquad \boldsymbol{\lambda_0 = \frac{h\,c}{e\,V} = \frac{12400}{V}\,A^\circ}$$

- This relation is known as ***Duane - Hunt*** formula.

**33. Write a note on characteristic X - ray spectra.**

**Characteristic X - ray spectra** :

- When the target is hit by fast electrons, the obtained X - ray spectra shows some narrow peaks at some well-defined wavelength.
- The line spectrum showing these peaks is called characteristic X - ray spectrum.
- This X -ray spectrum is due to the ***electronic transitions*** within the atoms.
- For example, when an energetic electron penetrates in to the target atom and removes the electrons in K - shell and create a vacancy in it.
- So the electrons from outer orbits jump to fill up the vacancy in K - shell.
- During the downward transition, the energy difference between the levels is given out in the form of X - ray photon of definite wavelength.
- Such wavelengths, characteristic of the target, consitute the line spectrum.
- It is evident that **K - series** of lines in the X - ray spectrum arise due to the electronic transistions from L, M. N, O, ..... shells to K - shell.




- Similarly **L - series** originates due to electronic transition from M, N, O, ..... shells to L - shell.

**34. Explain the applications of X -rays.**

(1) **Medical diagnosis** :
- X - rays can pass through flesh more easily than through bones. Thus X -ray radiograph containing a deep shadow of the bones and a light shadow of flesh. So X -rays radiographs ae used to detect fractures, foreign bodies, diseased organs etc.,

(2) **Medical therapy** :
- X - ray can kill diseased tissues. So they are employed to cure skin diseases, malignant tumours etc.,

(3) **Industry** :
- They are used to check for flaws in welded joints, motor tyres, tennis balls and wood,
- At the custom post, they are used for detection of contraband goods.

(4) **Scientific Research** :
- X - ray diffraction is important tool to study the structure of the crystalline materials (i.e) the arrangement of atoms and molecules in crystals.

**35. Mention the two features of x-ray spectra, not explained by classical electromagnetic theory.**

- Though classical electromagnetic theory suggests the emission of radiations from accelerating electrons, it could not explain two features exhibited by x-ray spectra. These features are given below.
  - (1) For a given accelerating voltage, the lower limit for the wavelength of continuous x-ray spectra is same for all targets. This minimum wavelength is called cut-off wavelength.
  - (2) The intensity of x-rays is significantly increased at certain well-defined wavelengths

**36. What is Bremsstralung?**

- When a fast moving electron penetrates and approaches a target nucleus, it get accelerates or decelerates. It may results in a change of path of the electron.
- The radiation produced from such decelerating electron is called ***Bremsstrhlung*** or ***braking radiation***.

## 5 Marks Questions and Answers

**1. What do you mean by electron emission? Explain briefly various methods of electron emission.**

**Electron emission :**

- The liberation of electrons from any surface of a substance is called electron emission.
- The minimum energy needed to liberate the electorns from the metal surface is called work function of that metal.
- Depending upon the energy source, the electron emission is classified as four types which are explained below.

(1) **Thermionic emission** :

- When a metal is heated to a high temperature, the free electrons on the surface get sufficient energy in the form of heat, so that they are emitted from the metallic surface. This type of emission is known as thermionic emission.
- The intensity of the thermionic emission depends on the metal used and its temperature.
  (e.g.) electron microscopes, X-ray tubes

(2) **Field emission** :

- When a very strong electric field is applied across the metal, this strong field pulls the free electrons and helps to overcome the surface barrier of the metal. This type of emission of electron is called field emission.
  (e.g.) Field emission display

(3) **Photo electric emission** :

- When an electromagnetic radiation of suitable frequency is incident on the surface of the metal, the energy is transferred from the radiation to free electrons.
- Hence the free electrons gets sufficient energy to cross the surface barrier and this type is called photo electric emission.
  (e.g.) photo electric cells, phot diodes

(4) **Secondary emission** :

- When a beam of fast moving electrons strikes the surface of the metal, the kinetic energy is transferred to the free electrons on the metal surface.
- Thus free eletrons get sufficient kinetic energy and emitted from the surface. This type is called seconday emission.
  (e.g.) photo multiplier tube

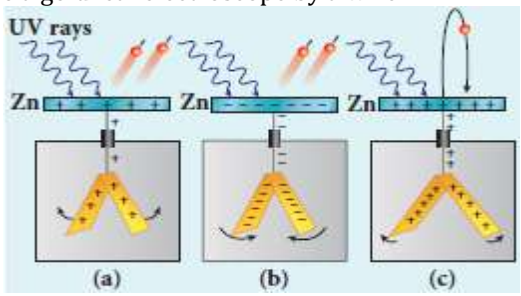
**2. Briefly discuss the observations of Hertz, Hallwachs and Lenard.**

**Hertz experiment** :

- Heinrich Hertz successfully generating and detecting the existence of electromagnetic waves.
- He used high voltage induction coil to cause a spark discharge between two metallic spheres.
- When spark is formed, the charges will oscillate back and forth rapidly and the electromagnetic waves are produced.
- To detect this electromagnetic waves, a copper wire bent in the shape of a circle is used as detector.

**Hallwachs's experiment** :

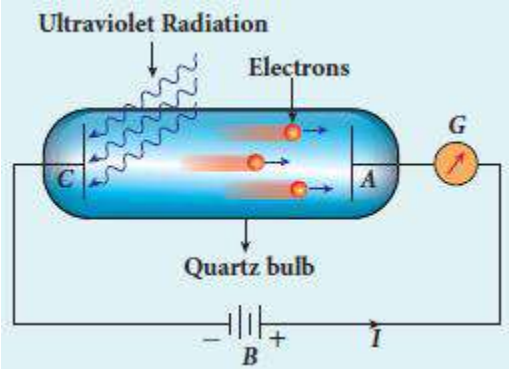
- In Hertz experiment, in order to improve the visibility of the spark, it is exposed to ultra violet rays which makes the spark as more vigorous.
- ***Wilhelm Hallwachs*** confirmed that the strange behaviour of the spark is due to the photo electric emission under the action of ultra violet light.
- In Hallwachs experiment, a clean circular plate of zinc is mounted in insulating stand and is attached to a gold leaf electroscope by a wire.




- When uncharged zinc plate is irradiated by ultraviolet light, it becomes positively charged and the leaves are open as shown in figure (a)
- If negatively charged zinc plate is exposed to ultraviolet light, the leaves will close as the charges leaked away quickly as shown in figure (b)
- If positively charged plate is exposed to uv-light, it becomes more positive and the leaves are open further as shown in figure (c)

- From these observations, it was concluded that negatively charged electrons were emitted from the zinc plate under the action of uv - light.

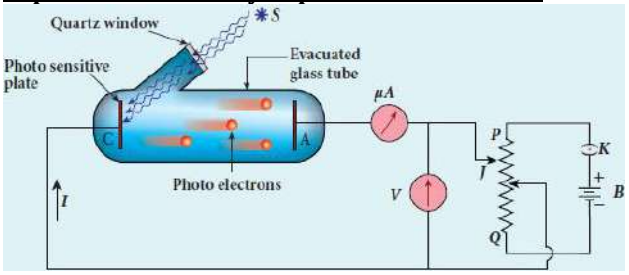
**Lenard experiment** :




- A and C are two metallic plates placed in an evacuated quartz bulb.
- Galvanometer G and battery B are connected in the circuit.
- When uv - light is incident on plate C, and electric current flows in a circuit which is indicated by the deflection in the galvanometer.
- But if the plate A is irradiated by uv - light, no current is observed in the circuit.
- From these observations, it is concluded that when uv- light falls on the negative plate C, electrons are ejected from it, which are attracted by the positive plate A.
- Hence the circuit is completed and the current flows in it.
- Thus the uv - light falling on the negative plate causes the electron emission from the surface of the plate.

**3. Explain the experimental set up for study of photo electric effect**

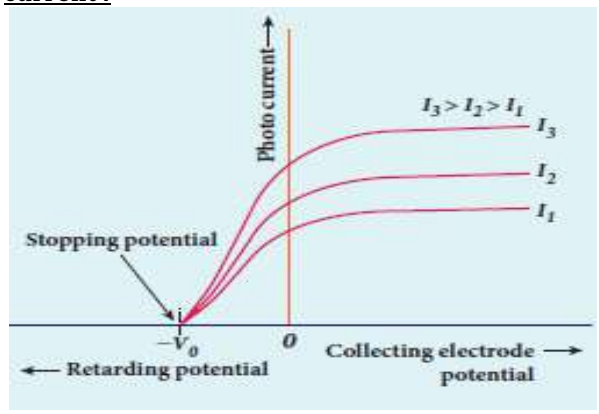
**Experiment for study of photo electric effect** :




- S is the source of electromagnetic wave of frequency '$\nu$' and intensity 'I'
- C is the cathode made up of photo sensitive material and is used to emit electrons.
- A is the anode which collects the emitted electrons
- A and C are placed in an evacuated glass envelope with a quartz window that permits uv -light and visible light.
- PQ is a potential divider arrangement which is connected through a key K and battery B
- The voltmeter 'V' and micro ammeter 'μA' also included in this circuit.
- If there is no light incident on the cathode C, no photoelectrons are emitted and the micro ammeter reads zero.
- When uv - light or visible light is allowed to fall on C, the photo electrons are emitted and are attracted towards anode.
- As a result, the photo electric current is set up in the circuit which is measured using micro ammeter.
- The photo electric current depends following quantities,
  (1) the intensity of incident light
  (2) the potential difference between the electrodes
  (3) the nature of the material
  (4) frequency of incident light

**4. Explain the effect of potential difference on photo electric current.**

**Effect of potential difference on photoelectric current :**




- Let the frequency and intensity of the incident light are kept constant.
- Now, the potential of $A$ is increased and the corresponding photocurrent is noted.
- Simillarly, a negative (retarding) potential is applied to $A$ and again the photocurrent is noted.
- Plot a graph by taking anode potential along X -axis and photo current along Y - axis
- From the graph,
  (1) When the potential of A increases, the photo current also increases and reaches a saturation value called ***saturation current***.
  (2) When a negative potential is applied to A, the photo current does not immediately drop to zero, because the photo electrons are emitted wity some definite and different kinetic energies.
  (3) If the negative or retarding potential of A gradually increased, the photo current starts decreasing and becomes zero at one particular negative potential $V_O$
  (4) The value of negative or retarding potential give to anode A which is just sufficient to stop the most energetic photo electrons emitted and make the photo current zero is called ***stopping potential or cut - off potential*** ($V_O$)
  (5) Here the initial kinetic energy of the fastest electron (0 is equal to the work done by the stopping potential to stop it. (i.e.)

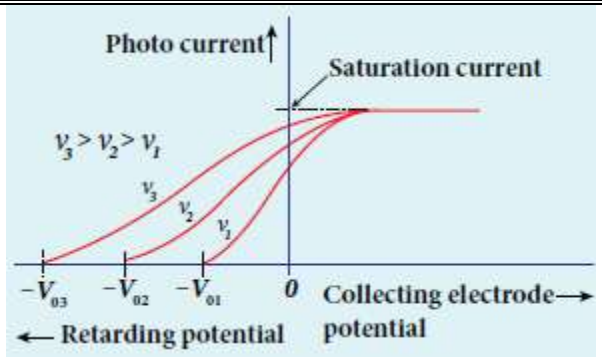
$$e\,V_O = \frac{1}{2} m\, v_{max}^2$$

$$(or) \qquad \boldsymbol{v_{max} = \sqrt{\frac{2\,e\,V_O}{m}} = 5.93\,X\,10^5\sqrt{V_O}}$$

**5. Explain how frequency of incident light varies with stopping potential.**

**Effect of frequency on photoelectric current** :

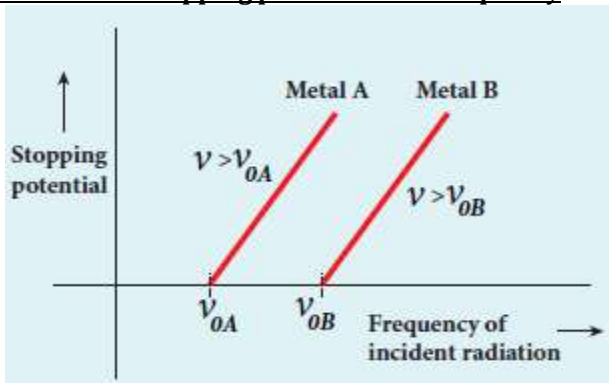
- Let the intensity of incident light is kept constant.
- The variation of photo current with the Anode potential is studied for different incident frequencies.
- A graph is plotted by taking anode potential along x - axis and photo current along y - axis
- From the graph,




(1) Stopping potential vary over different frequencies of incident light. (i.e) Greater the frequency, larger the stopping potential

(2) Thus as the frequency is increased, *the photoelectrons are emitted with greater kinetic energies so that the retarding potential needed to stop thephotoelectrons is also greater*.

**Variation of stopping potential with frequency** :




♥ From the graph,

(1) The stopping potential varies linealy with frequency.

(2) Below a particular frequency called ***threshold frequency*** ($\nu_0$), no electrons are emitted.

(3) Hence at threshold frequency stopping potential is zero for that reason.

**6. List out the laws of photoelectric effect.**

**Laws of photoelectric effect** :

♥ For a given frequency of incident light, the number of photoelectrons emitted is directly proportional to the intensity of the incident light. The saturation current is also directly proportional to the intensity of incident light.

♥ Maximum kinetic energy of the photo electrons is independent of intensity of the incident light.

♥ Maximum kinetic energy of the photo electrons from a given metal is directly proportional to the frequency of incident light.

♥ For a given surface, the emission of photo electrons takes place only if the frequency of incident light is greater than a certain minimum frequency called the ***threshold frequency***.

♥ There is no time lag between incidence of light and ejection of photoelectrons. (i.e.) phote electric effect is an instantaneous process

**7. Explain the particle nature of light. List the characteristics of photons.**

**Particle nature of light** :

♥ According to Eienstein, the energy in light is not spread out over wavefronts, but is concentrated in small packets or energy quanta.

♥ The energy of each light quantum is ; $\boldsymbol{E = h\nu}$

♥ The individual light quantum of definite energy and momentum can be associated with a particle and this is called ***photon***.

**Characteristics of photons** :

♥ Each photon will have energy given by

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

♥ The energy of a photon is determined by the frequency of the radiation and not by its intensity.

♥ The photons travel with the velocity of light and its momentum is given by,

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

♥ Photons are electrically neutral, and hency they are not deflected ny electric and magnetic fields.

♥ When photon interacts with matter, the total energy, total linear momentum and angular momentum are conserved.

**8. Obtain Einstein's photoelectric equation with necessary explanation.**

**Einstein's explanation of photoelectric equation** :

♥ When a photon of energy 'hv' is incident on a metal surface, it is completely absorbed by a single electron and the electron is ejected.

♥ In this process, the energy of incident photom is utilized in two ways.

(1) Part of the photon energy is used for the ejection of the electrons from the metal surface and it is called ***work function*** ($\phi_0$)

(2) Remaining energy as the kinetic energy (K) of the ejected electron.

♥ From the law of conservation of energy,

$$h\nu = \phi_0 + K$$

$$(or) \qquad h\nu = \phi_0 + \frac{1}{2} m v^2 \qquad ---- (1)$$

where m → mass of the electron and

υ → velocity

♥ At threshold frequency, the kinetic energy of ejeced electrons will be zero. (i.e.)

when. $\nu = \nu_0$ then $K = 0$ Thus eqn (1) becomes

$$h\nu_0 = \phi_0 \qquad ---- (2)$$

♥ Put eqn (2) in (1)

$$h\nu = h\nu_0 + \frac{1}{2} m v^2 \qquad ---- (3)$$

♥ The equation (3) is known as Einstein's photoelectric equation.

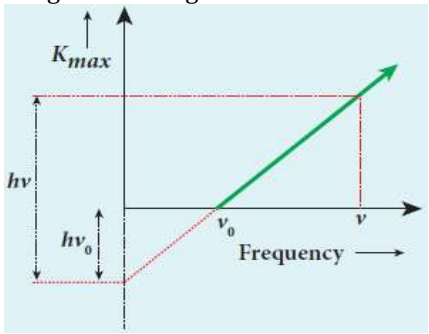
♥ If the electron does not lose energy by internal collisions, then it is emitted with maximum kinetic energy $K_{max}$. Then

$$h\nu = h\nu_0 + \left[\frac{1}{2} m v^2\right]_{max}$$

$$(or) \qquad \frac{1}{2} m v_{max}^2 = h\nu - h\nu_0$$

$$(or) \qquad \boldsymbol{K_{max} = h\nu - \phi_0} \qquad ---- (4)$$

♥ A graph between maximum kinetic energy Kmax of the photoelectron and frequency ν of the incident light is a straight line



**9. Explain experimentally observed facts of photoelectric effect with the help of Einstein's explanation.**

**Explanation for photo electric effect** :

- ♥ As each photon liberates one electron, then the increase of intensity of the light increases the number of electrons emitted there by increasing the photo current.
- ♥ From, $K_{max} = h\nu - \phi_0$, it is evident that $K_{max}$ is proportional to the frequency of the light and is independent of intensity of the light.
- ♥ From, $h\nu = h\nu_0 + \frac{1}{2} m v^2$ , there must be minimum energy (equal to the work function of the metal) for incident photons to liberate electrons from the metal surface. Below which, emission of electrons is not possible. Correspondingly, there exists minimum frequency called ***threshold frequency*** below which there is no photoelectric emission.
- ♥ According to quantum concept, the transfer of photon energy to the electrons is ***instantaneous*** so that there is no time lag between incidence of photons and ejection of electrons.

**10. Explain photo electric cells and its types.**

**Phot electric cell** :

- ♥ Photo electric cell or photo cell is a device which converts light energy into electrical energy.
- ♥ It works on the principle of photo electric effect.
- ♥ When light is incident on the photosensitive materials, their electric properties will get affected, based on which photo cells are classified into three types. They are ***Phote emissive cell, Phot voltaic cell and Photo conductive cell***

(1) **Photo emissive cell** :

- ♥ Its working depends on the electron emission from a metal cathode due to irradiation of light or other radiations.

(2) **Photo voltaic cell** :

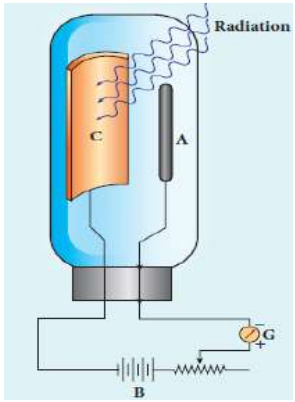
- ♥ Here sensitive element made of semiconductor is used which generates voltage proportional tothe intensity of light or other radiations.

(3) **Photo conductive cell** :

- ♥ In this, the resistance of the semiconductor changes in accordance with the radiant energy incident on it.

**11. Give the construction and working of photo emissive cell.**

**Photo emissive cell** :




- ♥ It consists of an evacuated glass or quartz bulb in which two metallic electrodes a cathode and an anode are fixed.
- ♥ The cathode C is semi-cylindrical in shape and is coated with a photo sensitive material.
- ♥ The anode A is a thin rod or wire kept along the axis of the semi-cylindrical cathode.
- ♥ A potential difference is applied between the anode and the cathode through a galvanometer G.

**Working** :

- ♥ When cathode is illuminated, electrons are emitted from it.
- ♥ These electrons are attracted by anode and hence a current is produced which is measured by the galvanometer.
- ♥ For a given cathode, the magnitude of the current depends on
  - (1) the intensity to incident radiation and
  - (2) the potential difference between anode and cathode.

**12. Give the application of photo cells .**

**Applications of photo cells** :

- ♥ Photo cells have many applications especially as switches and sensors.
- ♥ Automatic lights that turn on when it gets dark use photocells, as well as street lights that switch on and off according to whether it is night or day.
- ♥ Photo cells are used for reproduction of sound in motion pictures
- ♥ They are used as timers to measure the speeds of athletes during a race.
- ♥ Photo cells of exposure meters in photography are used to measure the intensity of the given light and to calculate the exact time of exposure.

**13. Derive an expression for de Broglie wavelength of electrons.**

**De Boglie wavelength of electrons** :

- ♥ An electron of mass m is accelerated through a potential difference of V volt.
- ♥ The kinetic energy acquired by the electron is given by

$$\frac{1}{2} m v^2 = e V$$

- ♥ Hence the speed of the electron is.

$$v^2 = \frac{2 e V}{m}$$

$$v = \sqrt{\frac{2 e V}{m}} \quad ---- \quad (1)$$

- ♥ The de Broglie wavelength of electron is

$$\lambda = \frac{h}{m v} = \frac{h}{m\sqrt{\frac{2 e V}{m}}}$$

$$\boldsymbol{\lambda = \frac{h}{\sqrt{2 m e V}}} \quad --- \quad (2)$$

where, $h = 6.626\ X\ 10^{-34}\ J\ s$

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

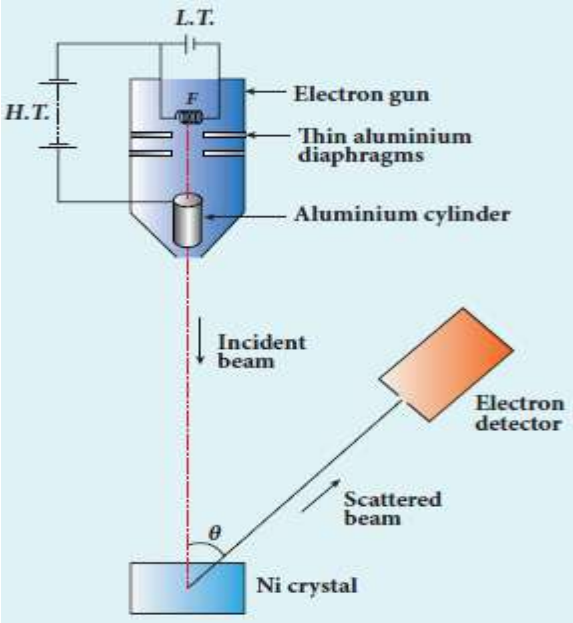
$m = 9.11\ X\ 10^{-31}\ kg$

$$\therefore \quad \boldsymbol{\lambda = \frac{12.27\ X\ 10^{-10}}{\sqrt{V}} = \frac{12.27}{\sqrt{V}}\ A^o}$$

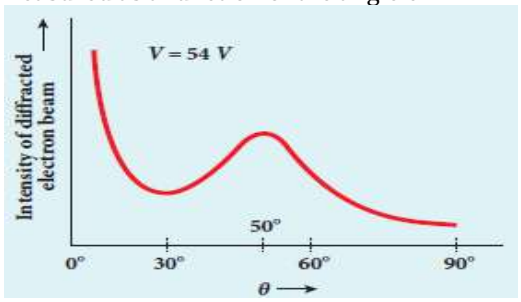
**14. Describe briefly Davisson – Germer experiment which demonstrated the wave nature of electrons.**

**Davisson - Gerner experiment :**

- ♥ De Broglie hypothesis of matter waves was experimentally confirmed by Clinton Davisson and Lester Germer in 1927.
- ♥ They demonstrated that electron beams are diffracted when they fall on crystalline solids.
- ♥ Since crystal can act as a three-dimensional diffraction grating for matter waves, the electron waves incident on crystals are diffracted off in certain specific directions.
- ♥ The filament F is heated by a low tension (L.T.) battery so that electrons are emitted from the hot filament by thermionic emission.




- They are then accelerated due to the potential difference between the filament and the anode aluminium cylinder by a high tension (H.T.) battery.
- Electron beam is collimated by using two thin aluminium diaphragms and is allowed to strike a single crystal of ***Nickel***.
- The electrons scattered by Ni atoms in different directions are received by the electron detector which measures the intensity of scattered electron beam.
- The detector is rotatable in the plane of the paper so that the angle $\theta$ between the incident beam and the scattered beam can be changed at our will.
- The intensity of the scattered electron beam is measured as a function of the angle θ.



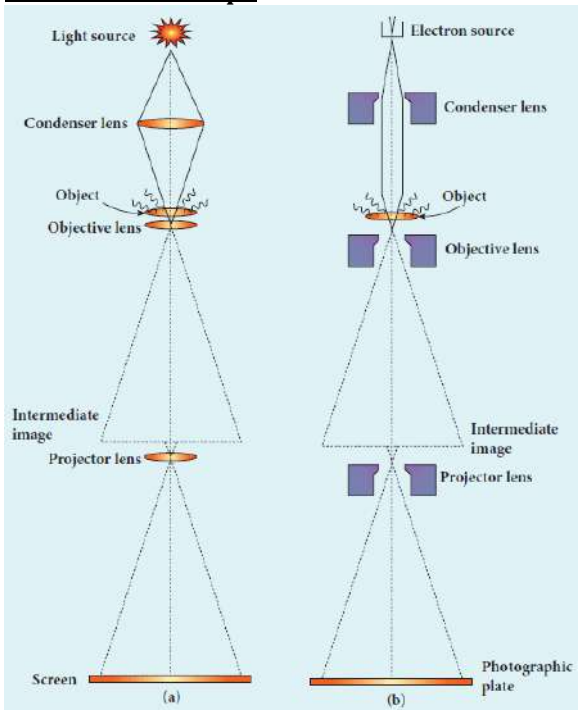

- The graph shows the variation of intensity of the scattered electrons with the angle θ for the accelerating voltage of 54V.
- For a given accelerating voltage V, the scattered wave shows a peak or maximum at an angle of 50° to the incident electron beam.
- This peak in intensity is attributed to the constructive interference of electrons diffracted from various atomic layers of the target material.
- From the known value of interplanar spacing of Nickel, the wavelength of the electron wave has been experimentally calculated as 1.65Å.
- The wavelength can also be calculated from de Broglie relation for V = 54 V as

$$\lambda = \frac{12.27}{\sqrt{V}}\,A^o = \frac{12.27}{\sqrt{54}}\,A^o = \mathbf{1.67\ A^\circ}$$

- This value agrees well with the experimentally observed wavelength of 1.65Å.
- Thus this experiment directly verifies de Broglie's hypothesis of the wave nature of moving particles.

**15. Briefly explain the principle and working of electron microscope.**

**Electron microscope** :




**Principle** :

- The wave nature of the electron is used in the construction of microscope called electron microscope.
- The resolving power of a microscope is inversely proportional to the wavelength of the radiation used.
- Thus higher resolving power can be obtained by employing the waves of shorter wavelengths.
- De Broglie wavelength of electron is very much less than (a few thousands less) that of the visible light.
- As a result, the microscopes employing de Broglie waves of electrons have very much higher resolving power than optical microscope.
- Electron microscopes giving magnification more than 2,00,000 times are common in research laboratories.

**Working** :

- The construction and working of an electron microscope is similar to that of an optical microscope except that in electron microscope focussing of electron beam is done by the electrostatic or magnetic lenses.
- The electron beam passing across a suitably arranged either electric or magnetic fields undergoes divergence or convergence thereby focussing of the beam is done
- The electrons emitted from the source are accelerated by high potentials.
- The beam is made parallel by magnetic condenser lens.
- When the beam passes through the sample whose magnified image is needed, the beam carries the image of the sample.
- With the help of magnetic objective lens and magnetic projector lens system, the magnified image is obtained on the screen.
- These electron microscopes are being used in almost all branches of science.