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DUAL NATURE OF MATTER AND RADIATION

- **Work function**

  Work function indicates the minimum energy required to eject electrons from a metal surface. It depends on the properties of metal and nature of its surface.
  It is represented by ϕ_0 .It is measured in electron volt(eV).

- **Thermionic emission**

  When a metal is heated to extremely high temperatures, the electrons escape from metal surface. This process is called thermionic emission.

- Valves or vacuum tubes work with the phenomenon of thermionic emission.
- **Field emission**

  When a strong electric field (about 10^8 V/m) is applied to a metal, electrons are emitted from its surface. This process is called field emission. Field emission is used in a spark plug. Field emission is otherwise known as cold cathode emission.

- **Secondary emission**

  When high speed electrons strike a metal surface, they transfer some of their energy to the free electrons of the metal. The energy of the free electrons become more than the work function of the metal and they get ejected from metal surface. These electrons are called secondary electrons and the method is called secondary emission.

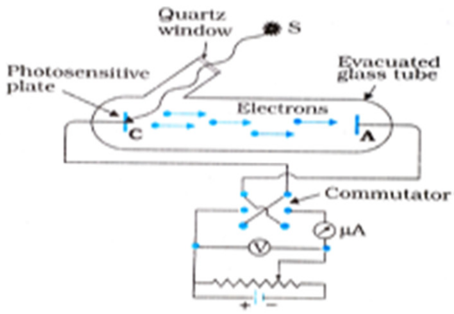
- **Photo electric emission**

  When light of a particular frequency falls on a metal surface, electrons are emitted from the metal surface. This process is called photoelectric emission. The emitted electrons are called photo electrons.

- The minimum frequency required for the incident light to eject out an electron from metal surface is called threshold frequency.

- Note: Zinc, cadmium, magnesium,aluminium etc. show photo electric emission when UV light falls. Lithium, sodium, potassium, caesium, rubidium etc. are sensitive to visible light.
- Photo electric effect was discovered by Hertz.
- X rays can eject electrons even from heavy metals.

- **Experimental set up used for the study of photo electric effect**



The experimental set up consists of an evacuated glass/quartz tube having a photo sensitive plate C (emitter) and another metal plate A (collector). There is a window for the entry of light. When light falls on plate C, electrons are emitted. These electrons are attracted towards the plate A as it is positive. This positive potential of A is called accelerating potential.

There is a provision for changing the polarity of electrodes. When A is given no voltage, only the powerful electrons emitted from C reaches A.

When A is positive, electrons are attracted towards it. Thus there is a photo electric current in the circuit.

When A is negative, the number of electrons reaching it decreases.

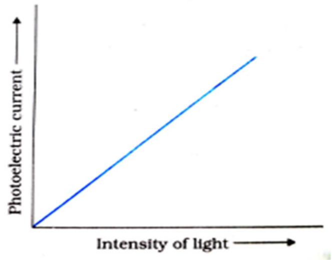
When A is strong –ve, no electrons reach it. Photo electric current stops. This negative potential of A is called stopping potential (cut off potential).

- **Effect of intensity of light on photoelectric current**

Collector plate A is kept +ve and emitter plate C is kept –ve.

Frequency of incident radiation and accelerating potential are kept constant. Radiation of different intensities are allowed to fall on emitter.

It is found that photo electric current is directly proportional to intensity of light. The variation of photo electric current with intensity is shown below.



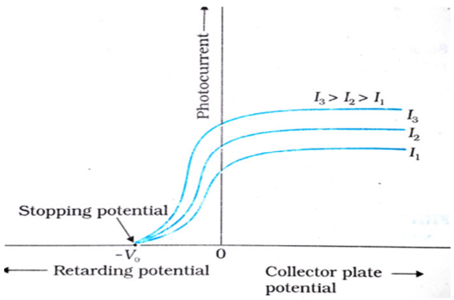
- **Effect of potential on photo electric current**

The +ve potential of collector plate A is increased in steps. Light of a particular frequency is allowed to fall on emitter plate C. When the +ve potential of A is increased, the photo electric current increases. It reaches a maximum value called saturation current and then remains constant.

Now potential of A is reduced to zero. Photo electric current does not become zero.

When A is given –ve potential, photo electric current decreases. At a particular –ve potential of 'A', photo electric current becomes zero. This potential is called stopping potential or cut off potential.

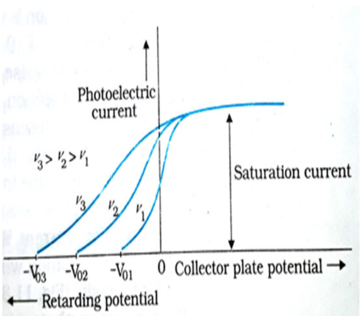
If we increase the intensity of radiation, the stopping potential remains same. But saturation current increases.



- **Effect of frequency of incident radiation on stopping potential**

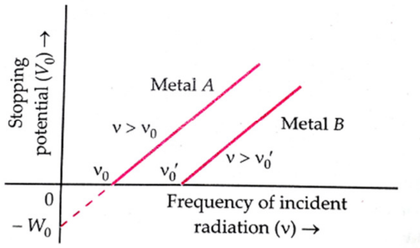
We use light of different frequencies but of same intensity, saturation current remains the same.

But when frequency of incident radiation is increased, stopping potential also increases (in –ve direction). The variation of stopping potential with frequency is shown below.



- **Variation of stopping potential with frequency of incident radiation**

Stopping potential varies linearly with frequency of incident radiation.
There is a minimum cut off frequency for which stopping potential is zero. The variation of stopping potential with frequency of incident radiation is shown below.



- Threshold frequency is different for different metals.

- **Einstein's photo electric equation**

When a radiation of energy $h\vartheta$ falls on a metal, it is used for work function and for providing kinetic energy to electrons (where h is Planck's constant).

Energy of photon= (KE)+(work function)

$h\vartheta = K_{max} + \phi_0$ This is known as Einstein's photo electric equation.

OR $h\vartheta = ½ mv^2 + h\vartheta_0$

OR $h(\vartheta - \vartheta_0) = ½ mv^2$

- **Einstein's explanation of photo electric effect**

Photo electric effect is an instantaneous process. There is no time lag between fall of radiation and emission of electrons.

One photon can knock out, one electron. When intensity of light increases, number of photons striking the metal increases. Therefore number of electrons emitted also increases.

$h(\vartheta - \vartheta_0) = KE$

KE is +ve only $\therefore\ \vartheta > \vartheta o$

ie, if frequency of incident radiation is less than threshold frequency, no photoelectric emission takes place.

When frequency of incident radiation increases, KE of photoelectron increases .

- **Photoelectric effect is an instantaneous process. Explain.**

Photo electric emission is due to the elastic collision between a photon and an electron. Electron of the metal receives energy from the photon in a single event. There is a transfer of energy in one lump instead of continuous absorption. Hence there is no time lag between the fall of the photon and emission of photo electron.

- **Explain why photoelectric effect cannot be explained using wave nature of light.**

According to the theory, when a wave front strikes a metal surface the free electrons of the metal surface absorb the radiant energy continuously. If the intensity of radiation is more, the amplitude of electric and magnetic fields and hence energy density is more. Hence the photoelectrons must have greater kinetic energy. But it is contradictory to the experimental result that kinetic energy of photoelectrons does not depend on intensity of incident radiation.

According to this theory, a light wave having sufficient intensity can eject electrons from a metal surface. This theory fails to explain the existence of threshold frequency.

According to classical electromagnetic theory, the energy of light wave is smoothly and evenly distributed in the advancing wave front. Each electron intercepts a very small amount of energy and hence it takes a finite time to escape from metal surface. But photoelectric emission is actually instantaneous.

- **Photon picture of electromagnetic radiation**
  - In the interaction between electro magnetic radiation and matter, electro magnetic radiation behaves as if it is made of particles called photons.
  - Each photon has energy $h\vartheta$ and momentum $h\vartheta/c$.
  - Energy of a photon is independent of intensity of radiation.
  - Photons are electrically neutral.
  - In a photon – particle collision, total energy and total momentum are conserved (elastic collision).

- **de Broglie equation**

The wave length associated with a moving particle, $\lambda = h/mv$ where h is Planck's constant m is the mass and v is the velocity of the particle.

- **For an electron**

We know that kinetic energy ,$K=P^2/2m$ where P is the momentum and m is the mass of electron.

$P^2 = 2mK$ OR $P=\sqrt{2mK}$

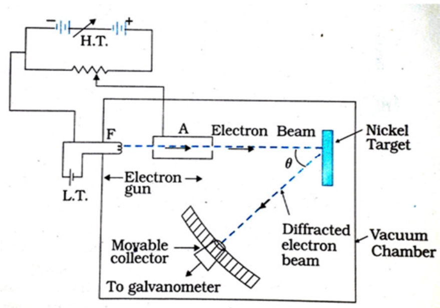
$\lambda = h/P$ OR $\lambda=h/\sqrt{2mK}$

But for electron, K=eV

$\lambda = h/\sqrt{2\,me\,V}$ where V is the potential , e is the charge of electron OR $\lambda=1.227/\sqrt{V}$ nm.

- **Davisson and Germer experiment**

It is an experimental verification of wave nature of electron. The experimental set up consists of an electron gun with tungsten filament. It is coated with barium oxide. It is heated by a low tension battery. Electrons are accelerated with the help of high positive potential from a high tension battery. These electrons pass through a cylinder with a narrow passage. This narrow beam strikes a nickel crystal. Electrons are scattered in all directions after diffraction from different layers of the crystal. The scattered electrons are detected using a detector which is movable over a circular scale.



It is found that at 54 V (accelerating potential) maximum intensity of scattered electrons is at $\theta = 50^0$

A sharp peak appears in the intensity of scattered electron.

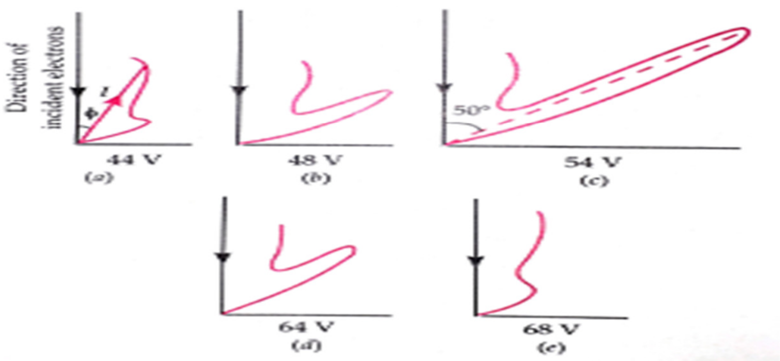
For electron diffraction experiments the wave length of matter wave is found as 0.165nm.

The de-Broglie wave length associated with electron when V=54 V is

$\lambda = 1.227/\sqrt{V} = 1.227/\sqrt{54} = 0.167$nm

The theoretical value and experimental value are in good agreement. It shows that electron exhibits wave nature.

Graphs showing the intensity of electrons as a function of scattering angle in Davisson and Germer experiment.



- **Heisenberg's uncertainty principle**

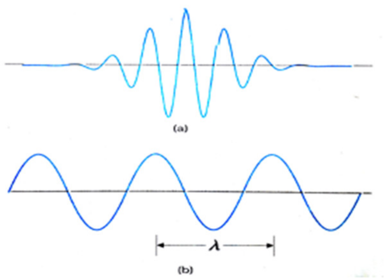
  It is impossible to determine the exact position and exact momentum of a moving particle simultaneously.
  If Δx is the uncertainty in position and Δp is the uncertainty in momentum,

  $\Delta x \Delta p \approx nh/2\pi$ where n is an integer.

- To locate the position of a particle associated with matter wave, Max Born suggested that the square of amplitude(or intensity)of matter wave at a point is related to probability density of particle at that point. If the intensity is of matter wave is more, the probability of finding the particle is more.

- **Wave packet description of electron**:

  The matter wave associated with a particle(like electron) does extend all over space. It is a wave packet that extends over some finite region of space .Such a wave packet does not have a single wavelength. It has a spread of wavelengths around some central wavelength, as shown in figure.



  By de Broglie relation, there is a spread in momentum. The uncertainty in position of electron is (Δx) and uncertainty in momentum is (Δp) . This wave packet picture of electron is incorporating both de Broglie relation and Born's probability density concept. It is in complete agreement with the Heisenberg's uncertainty principle.

- **Electron microscope. (Designed by Ernest Ruska)**

  It is an application of de Broglie wave to study minute objects like viruses, microbes etc.

  Principle:

  ❖ Electron beam behaves as waves having smaller wavelengths.

  ❖ Like the focusing of light by lenses, electron beams can be focused using electric and magnetic fields.

  Note: Magnifying power of electron microscope is inversely related with the wavelength of radiation used.

  Magnification of electron microscope is approximately 10000.