"MBC-Mridul Bhaiya Classes."
- Physics Notes

DUAL NATURE OF LIGHT AND RADIATION

This is not a E-Book This is Notes

MADE BY MRIDUL YADU

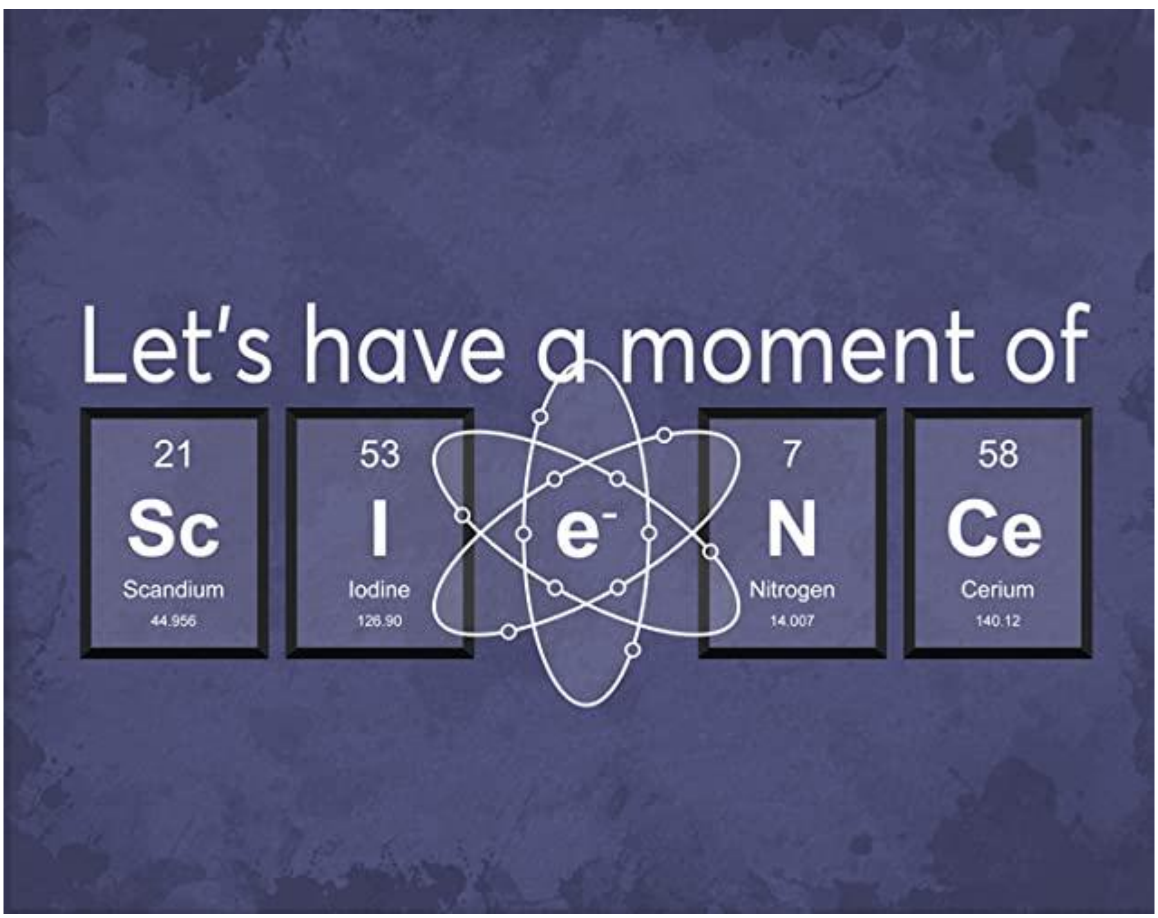
MBC – Mridul Bhaiya Classes

CLASS XII

PHYSICS NOTES

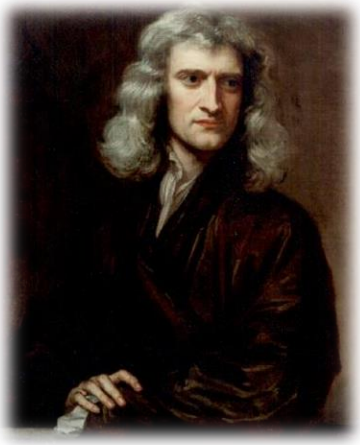
DUAL NATURE OF RADIATION AND MATTER

- ✓ Detailed notes
- ✓ PYQs with answers
- ✓ Graphics included



DUAL NATURE OF RADIATION AND MATTER

COMPLETE TIMELINE



ISAAC NEWTON

1675 : Newton's Corpuscular Theory

"Light is made up of tiny particles called CORPUSCLES"

Light travels with high speed in denser medium and with less speed in rarer medium

All luminous objects emits light in the form of small particles called CORPUSCLES

All the corpuscles have different size due which light shows different colours

CHRISTIAAN HUYGENS THEORY : 1676

"Light is made up of WAVE"

Explained YDSE & polarization effect with the help of wave nature of light

Newton could not explain YDSE & polarization with Particle theory of light

Speed of light in Denser Medium is less than the speed of light in Rarer medium

Light requires medium to travel which later proved wrong by other scientists

CHRISTIAAN HUYGENS

JAMES CLERK MAXWELL

1873: JAMES CLERK MAXWELL THEORY

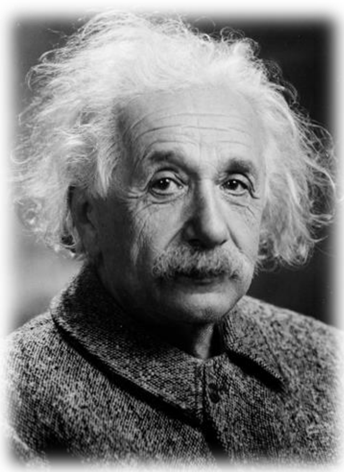
"Light is made up of ELECTROMAGNETIC WAVE which consists electric field and magnetic field both perpendicular to direction of wave propagation"

MAX PLANCK'S THEORY OF LIGHT : 1905

"Light is made up of small particles called QUANTA or PHOTON"

MAX PLANK

1905: EINSTEIN QUANTUM THEORY OF LIGHT



ALBERT EINSTEIN

LIGHT HAS DUAL

NATURE

Further Dual nature of light confirmed by DE BROGLIE

We will Study about this in detail later !

INTRODUCTION

Metals have free electrons that can move from one atom to the other withing the metal. This factor is responsible for their excellent conductivity. But if they try to escape the metal surface, they are unable to do so. This is because when these negatively charged particles (electrons) try to leave the metal, the surface of metal acquires a positive charge. Due to the attraction between negative and positive charges, the electrons are pulled back into the metal.

Therefore, the electrons are thus forced to stay inside the metal due to the attractive forces. This barrier provided by the metal surface to prevent escaping of free electrons is called the **Surface Barrier.**

ELECTRON EMMISION

We know that metals have free electrons but these free electrons cannot escapes the metal because when an electron escapes the metal, the metal surface becomes positively charged and it pulls back the electron. So, an electron can only escape a metal if it has a minimum amount of energy.

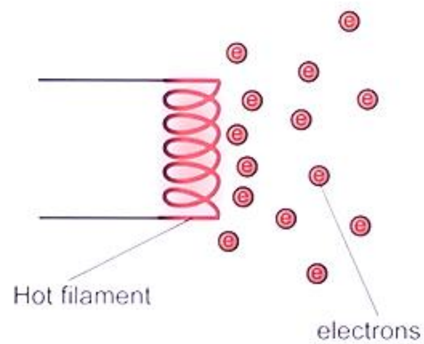
Work Funtion (ϕ_0) – The minimum energy required by an electron to escape from the metal surface is called the work function of the metal. It is generally measured in eV (electron volt).
The work function of the metal depends on its properties and the nature of its surface.

The work function of a metal depends on:
The properties of the metal
The purity of the metal
The nature of the metal surface

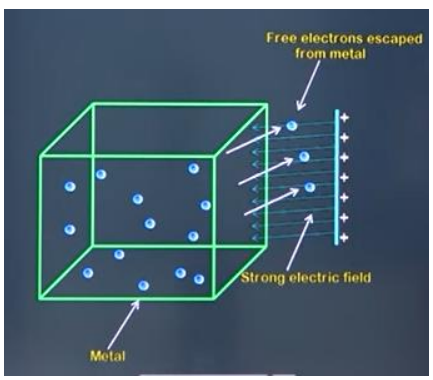
TYPES OF ELECTON EMISSION

The energy required by an electron emission can be supplied by-

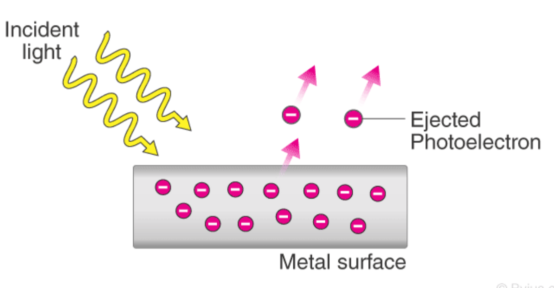
1. **Thermionic Emission** – By suitable heating, sufficient energy can be supplied to the electrons to enable them to come out of the metal.

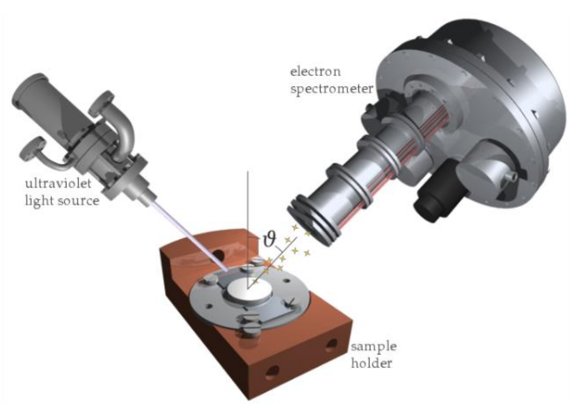


2. **Field emission** – By applying very strong electric field to a metal, electrons can be pulled out of the metal, as in a spark plug.

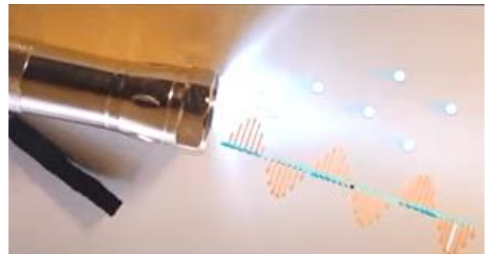


3. **Photo-electric emission** – When light of suitable frequency illuminates a metal surface, electrons are emitted from the metal surface. The photo (light) generated electrons are called photo electrons.





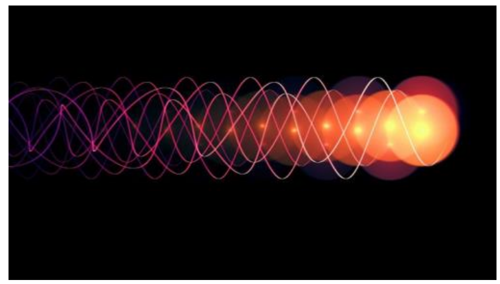
PHOTON



The particles of light are called **Photons.**

PROPERTIES OF PHOTONS

1. A photon always travel at a speed C = 299,792,458 $ms^{-1} \approx 3.0 \times 10^8$ ms^{-1} in vaccum. This is true for any frame of reference used to observe the photon.
2. The mass of a photon is not defined or we can say rest mass of photon is zero.

   Relativistic Mass:

   $$m = \frac{m_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

   Where
   m = mass of object in motion
   m_o = rest mass of object
3. Each photon has a definite energy and a definite linear momentum.
4. Let E and ρ be the energy and linear momentum of a photon of light, and ν and λ be the frequency and wavelength of the same light when it behaves as a wave. Then,

   $E = h\nu = hc/\lambda$ where h is plack's contant

   $\rho = h/\lambda = E/c$ $h = 6.626 \times 10^{-34}$
5. A photon may collide with a material particle. The total energy and the total momentum remain conserved in such a collision. The photon may get absorbed or a new photon may be emitted. Thus, the number of photons may not be conserved.

6. If the intensity of light of a given wavelength is increased, there is an increase in the number of photon crossing a gien area in given time. The energy of each photon remains the same.

Intensity = $\frac{Energy}{Area.Time} = \frac{nhc/\lambda}{A.t}$

If λ is fixed, to increase I we have to increase n

HERTZ OBSERVATION

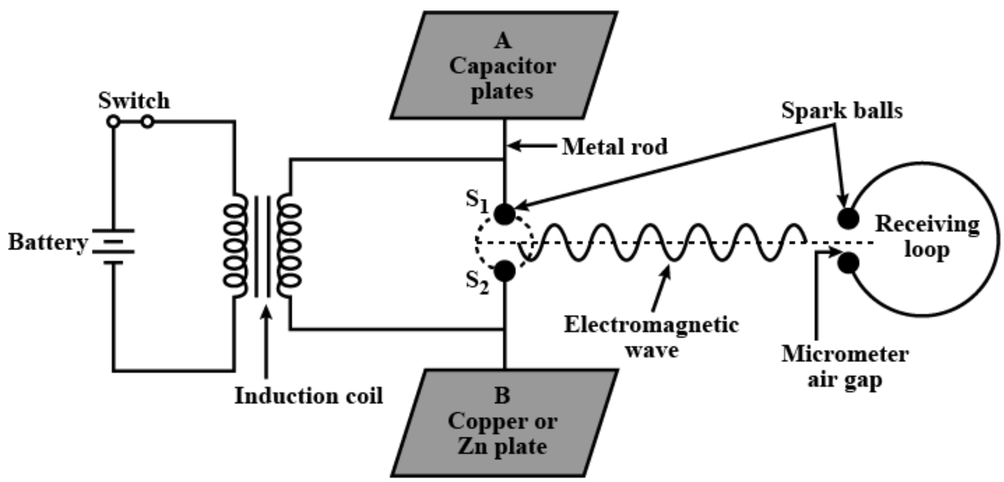
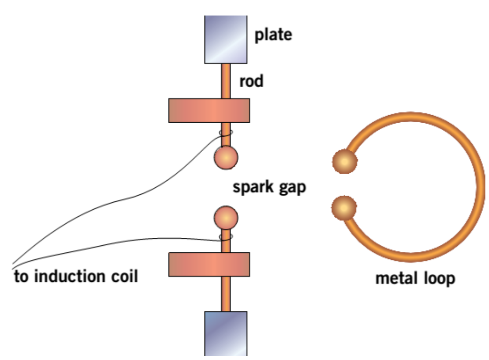


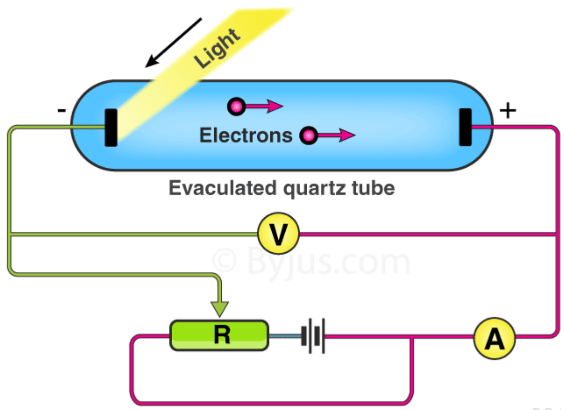
Fig : Sketch of the apparatus used by Hertz for producingand detecting radiowaves

→ Hertz observed that high voltage sparks across the detector loop were enhanced when the emitted plate was illuminated by ultravoilet light from an arc lamp.



→ When light falls on a metal surface, some electrons near the surface absorb enough energy from the incident radiation to overcome the attraction of ions in the material of surface.

HALLWACH'S AND LENARD OBSERVATION



- Lenard (1862-1947) observed that when ultravoilet radiations were allowed to fall on the emitter plate of an evacuated glass tube enclosing two electrodes (metal plates), current flows in the circuit. As soon as the ultravoilet radiations were stopped, the current flow also stopped.

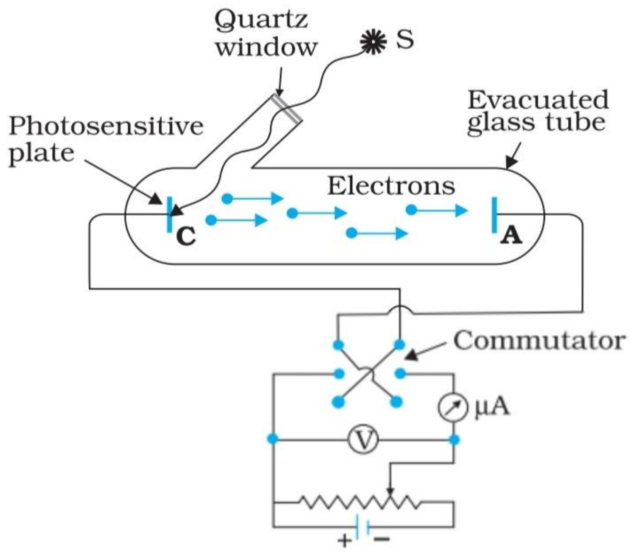
- Hallwach's in 1888, undertook the study further and connected a negatively charged zinc plate to an electroscope.

- After discovery of the electron in 1987, it became evident that the incident light causes electrons to be emitted from the emitter plate.

PHOTOELECTRIC EFFECT

When a light of certain wavelength incident on the emitter plate electrons are ejected from the plate and this phenomena is called **PHOTOELECTRIC EFFECT** and the ejected electrons are called **PHOTOELECTRONS.**

❖ To eject an electron a minimum energy is required and this minimum energy is called **WORK FUNCTION. (φ)**



❖ Energy of a single photon is given by

$$\boxed{E = \frac{hc}{\lambda}}$$

(where h = planck constant = 6.626×10^{-34} Js and λ is wavelength)

❖ The minimum frequency required to eject an electron is called threshold frequency.

❖ The maximum wavelength of light by which an electron can be ejected is called Threshold wavelength.

❖ The extra energy other then work function will go into the energy losses during collision or into the kinetic energy of the photoelectron.

$hc/\lambda = (K.E)_{max} + \varphi$

❖ Maximum Kinetic energy of the photoelectron is given by

$$K.E_{max} = \frac{hc}{\lambda} - \varphi$$

Note : It is not necessary that if we givee energy equal to or more than the work function then the electron must come out.

IMPORTANT DEFINITIONS

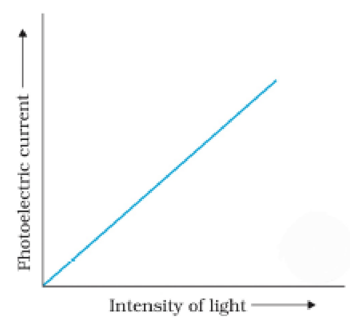
- **Threshold Frequency (ν_0) :** The minimum frequency required to eject an electron is called threshold frequency.
  It is denoted by ν_0
  $\nu_0 = \varphi/h$
  Unit – hertz (Hz)

- **Threshold Wavelength (λ_0) :** The maximum wavelength of light by which an electron can be ejected is called Threshold wavelength.
  It Is denoted by λ_0

$\lambda_0 = hc/E_{min} = hc/\varphi$ $\quad \lambda_0 = \frac{c}{\nu_0}$

EFFECT OF INTENSITY OF LIGHT ON PHOTOCURRENT

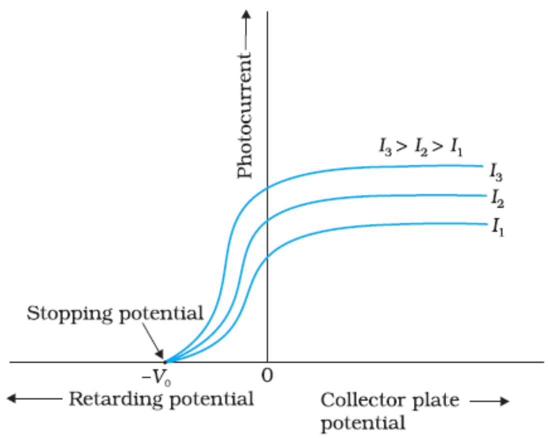
The photocurrent is directly proportional to the number of photoelectrons emitted per second. This implies that the number of photoelectrons emitted per second is directly proportional to the intensity of the incident radiation.



If we increase the intensity of light keeping the wavelength constant that means number of photons incident is increasing.

EFFECT OF POTENTIAL ON PHOTOELECTRIC CURRENT

If we keep the plate A at some positive accelerating potential with respect to plate C and illuminate the plate C with light of fixed Frequency and fixed intensity. And if we gradually increases and after sometime it becomes constant and will not change on further increasing the potencial and this maximum value of photoelectric current is called **SATURATION CURRENT.**



Now if we apply in negative potential to a plate A with respect to plate C and make it increasingly negative gradually then the electrons are repelled and only the most energetic electron are able to reach the collector A.

For a particular frequency the minimum negativ potencial V_0 given to the plate A for which the photocurrent stops or becomes zero is called **CUT-OFF** or **STOPPING POTENTIAL**

All the photoelectrons emitted from the metal do not have the same energy. Photoelectric current is zero when the stopping potential is sufficient to repel even the most energetic photoelectron.

To find out the stopping potential

$\boxed{K_{max} = eV_0}$

$\boxed{V_0 = K_{max}/e}$

For a given frequency of the incident radiation the stopping potential is independent of its intensity.

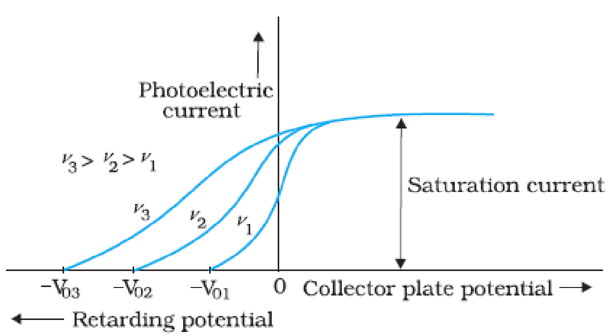
The maximum kinetic energy of the photoelectron depends on the light source and the emitter plate material but it is independent of the intensity of incident radiation.

We can see that for different higher intensity stopping potential is same but the saturation current values are higher for higher intensities.

EFFECT OF FREQUENCY OF INCIDENT RADIATION ON STOPPING POTENTIAL

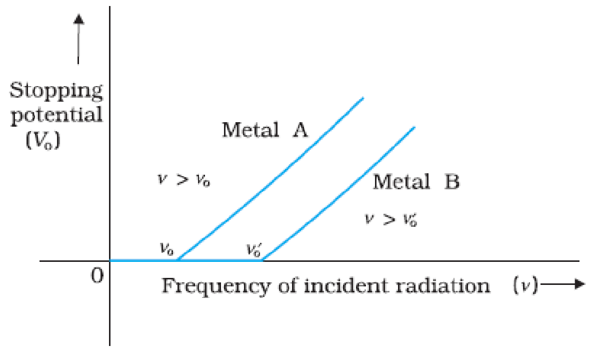
For the same intensity of radiation at various frequency we can see different values of stopping potential but the same value of saturation current.

The energy of emitted electron depends on the frequency of incident radiations the stopping potential is more negative for higher frequency of incident radiation.



The stopping potential V_0 varies linearly with the frequency of incident radiation for a given photosensitive material.

There exists a certain minimum cut-off frequency ν_0 for which the stopping potential is zero.



The maximum kinetic energy of the photoelectrons varies linearly with the frequency of incident radiation, but is independent of its intensity.

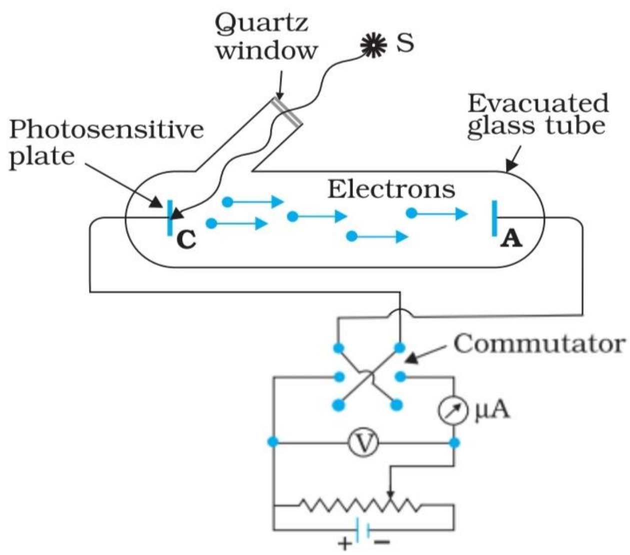
For a frequency ν of incident radiation, lower than cut-off frequency ν_0, no photoelectric emission is possible even if the intensity is large.

SUMMARY OF PHOTOELECTRIC EFFECT

For a given photo sensitive material and frequency of incident radiation the photoelectric current is directly proportional to the intensity of incident light.

For a given photosensitive material and frequency of incident radiation saturation current is found to be proportional to intensity of incident radiation whereas the stopping potential is independent of its intensity.

For a given photosensitive material there exists a certain minimum frequency called cut-off frequency below which no emission of photoelectrons takes place.



The photoelectric emission is an instantaneous process without any apparent time lag.

Some basic to solve questions

E = hc/λ = 1240/λ (in nm) = 12400/λ (in Å)

Where h = 6.626×10^{-34} ; c = 3×10^{8} ; E comes in Joule

1ev = 1.6×10^{-19} J

1nm = 10^{-9} m

1 Å = 10^{-10} m

Example : Monochromatic light of frequency 6.0×10^{14} Hz is produced by a laser. The power emitted is 2.0×10^{-3} W.

a) What is the energy of a photon in the light beam?
b) How many photons per second, on an average, are emitted by the source?

Solution : a.) Energy of photon = hc/λ = hf = $6.626 \times 10^{-34} \times 6.0 \times 10^{14}$ J b.) Power = energy/time = nhf/time

$2.0 \times 10^{-3} = n/t\ [6.626 \times 10^{-34} \times 6.0 \times 10^{14}] = n/t$

Example : The work function of caesium is 2.14 eV. Find

a) The threshold frequency for caesium
b) The wavelength of the incident light if the photocurrent is brough to zero by a stopping potential of 0.60 V.

Solution : $\phi = 2.14$ eV

a.) Energy incident = hf

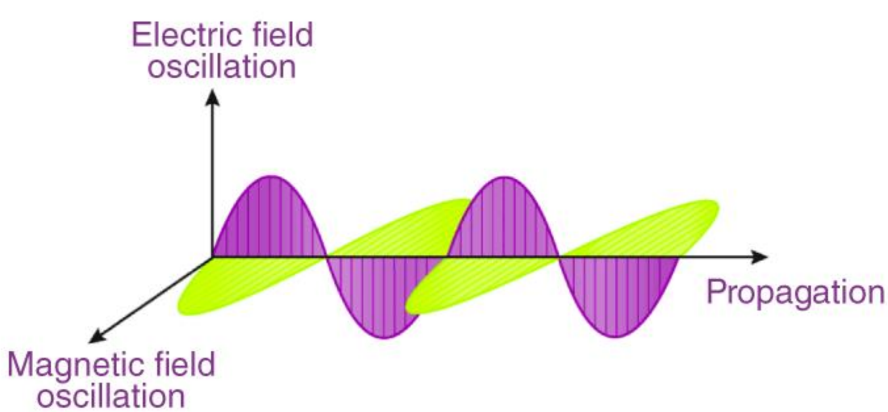
Minimum energy required = $hf_0 = 2.14$ eV

$$F_0 = \frac{2.14 \times 1.6 \times 10^{-19}\ J}{6.626 \times 10^{-34}\ Js}$$

b.) $V_0 = 0.60 = hc/\lambda e - \phi/e$

PHOTOELECTRIC EFFECT AND WAVE THEORY OF LIGHT

If we consider light as a wave then energy should be distributed in the space where the wave is present.



According to the wave picture of light the free electrons of metal absorb the radiant energy continously the greater should be the kinetic energy of electron but in reality this is not happened.

Because of the wave nature of light electron is getting energy continuously so according to this all the electrons should come out of the metal after getting required energy but in reality this not happened.

Based upon the above point photoelctric effect could not be explained with the help of wave nature of light.

WAVE NATURE OF MATTER

In 1924 **De Broglie** stated that *" Nature is symmetrical and that the two basic entities – matter and energy must have symmetrical character, if radiation shows dual aspects so matter should also* have *dual character ".*

De Broglie proposed that the wavelength associated with a particle of momentum p is given as

$$\boxed{\lambda = h/p = h/mv}$$

For heavier particle λ is very small and becomes unobservable this is the reason why macroscopic object in our daily life do not show wave like properties.

Calculation of wavelength for electron accelerated by potential V

$$\boxed{K = eV}$$

Now,

$$\boxed{K = \frac{1}{2} mv^2 = p^2/2m^2}$$

$$\boxed{P = \sqrt{2mKE} = \sqrt{2meV}}$$

The De Broglie wavelength λ of the electron is then

$$\boxed{\lambda = h/p = h/\sqrt{2mKE} = h/\sqrt{2meV}}$$

Substituting the numerical values of h,m,e

$$\boxed{\lambda = 1.227/\sqrt{V}\,\text{nm}}$$

Example : An electron, an α - particle, and a proton have the same kinetic energy. Which of these particles has the shortest de Broglie Wavelength ?

Solution : $\lambda = h/\sqrt{2mKE}$

$m_e < m_p < m_\alpha$ α - particle – He nucleus

If KE is constant $\lambda \propto 1/\sqrt{m}$

Therefore

$\lambda_\alpha < \lambda_p < \lambda_e$

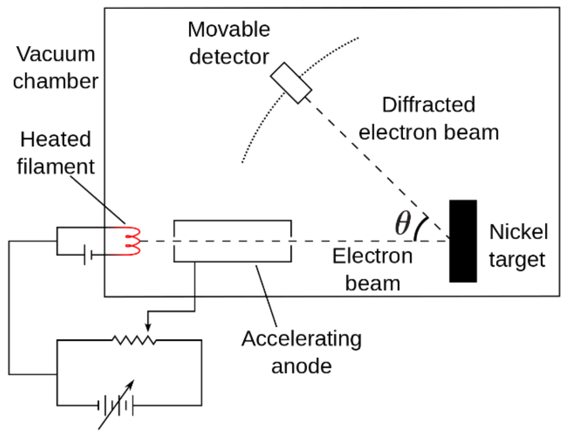
Example : What is the de Broglie wavelength associated with an electron, accelerated through a potential difference of 100 volts?

Solution : $\lambda = 1.227/\sqrt{V}$nm

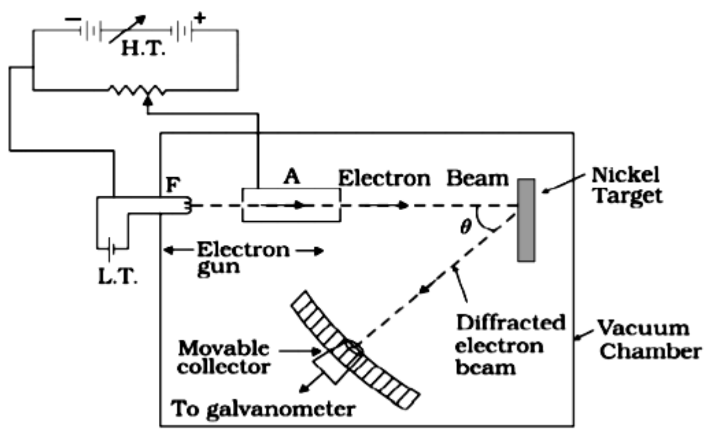
= .1227 nm

DAVISSON AND GERMER EXPERIMENT

In the experiment a electron gun which consist of tungsten filament F, coated with barium oxide heated by a low voltage power supply



Electrons from electron gun are accelerated to a desired velocity by applying high voltage power supply.



Now the electrons strikes to nickel plate and scattered in different direction

These electrons are detected by electron detector

OBSERVATION

Electron detector moved along the circular path and it is observed that intensity of electrons are very high at certain angle and very low at certain angle.

By the above observation it is only possible when the interference takes place

And interference can only takes place when we consider electron as a wave

By finding out the angle where the intensity electron is too high it is found that λ where the intensity is maximum is equal to the λ given by de Broglie

It is found that maximum intensity is when the electron gets accelerated by a potential V = 54 volt and θ is 50°

FORMULAS

$\Rightarrow$ Energy of a single photon is given by

$E = hc/\lambda$

(where h is plack's contant = 6.626×10^{-34} Js and λ is wavelength)

$\Rightarrow$ Maximum kinetic energy of the photoelectron Is given by

$K.E_{max} = hc/\lambda - \phi$

$\Rightarrow$ To find out the stopping potential

$K_{max} = eV_0$

$V_0 = K_{max}/e$

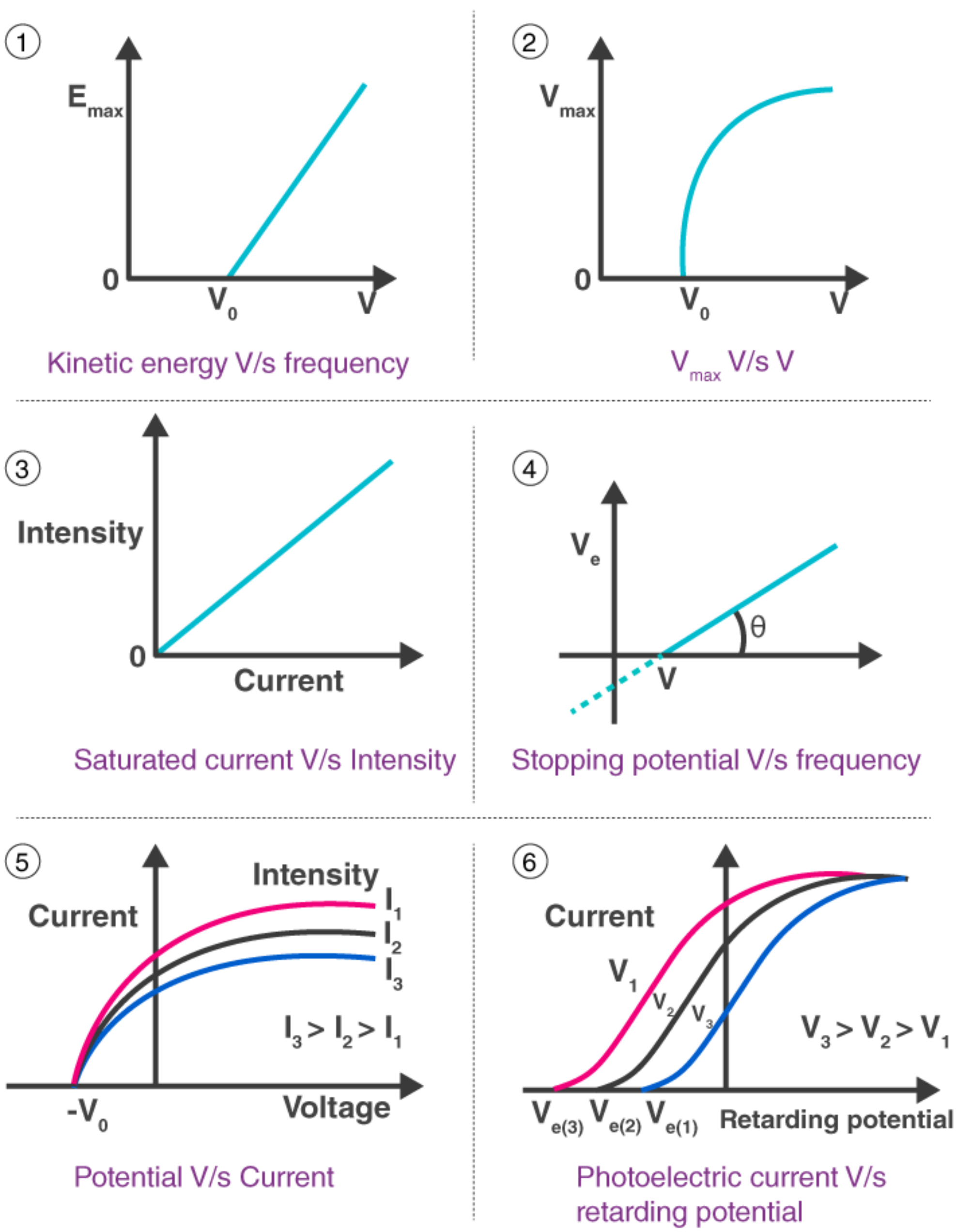
⇒ De Broglie proposed that the wavelength associated with a particle of momentum p is given as

$\lambda = h/p = h/mv$

⇒ Wavelength associated with the electron accelerated with potential difference V

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

Graphs of photoelectric equation



Kinetic energy V/s frequency

V_{max} V/s V

Saturated current V/s Intensity

Stopping potential V/s frequency

Potential V/s Current

Photoelectric current V/s retarding potential

This Chapter Ends here !! But not your work

Go to Practice Questions, Solve Dpps attend MCQs and revise the notes after some 2nd 4th and 7th day

To get 95+ you have to keep on revising what you studied.

[Remember Consistency and HardWork Gives Great Result]

NOTES MADE BY

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