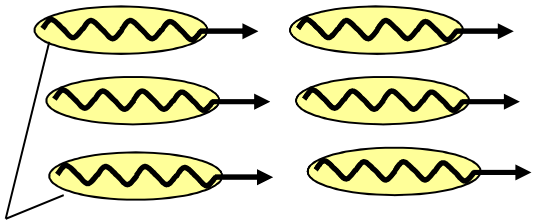
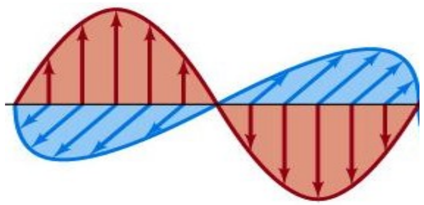
Comparison between Planck' quantum theory and classical theory of energy.

Planck's Quantum Theory	Classical theory
Energy of the e.m radiation is **quantised**. (**discrete**) 	Energy of the e.m radiation is **continously**. 
Energy of e.m radiation ***depends*** on its **frequency or wavelength** $$E = hf$$	Energy of e.m radiation ***does not*** depend on its **frequency or wavelength (depends on Intensity)** $I \propto A^2$ $\boxed{E_{classical} = k_B T}$ $k_B =$ Boltzmann's constant $T =$ temperature

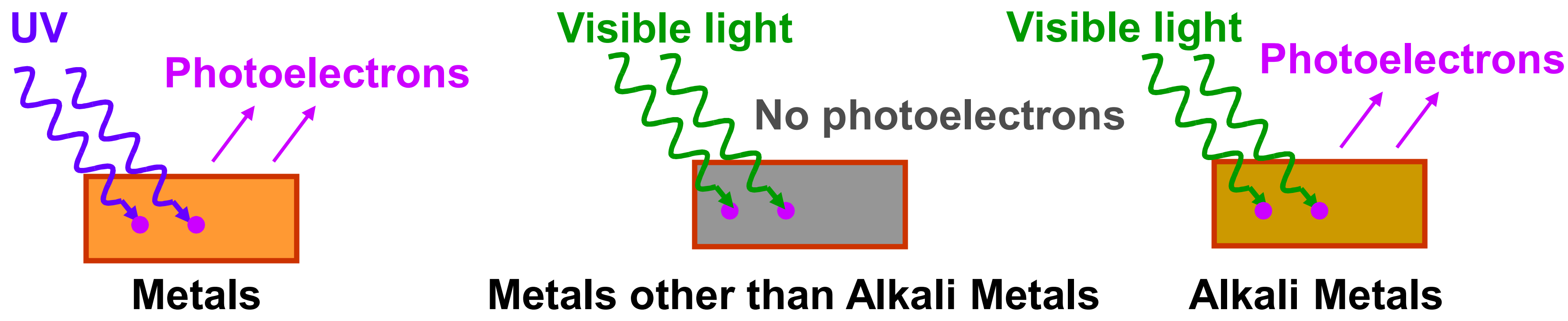
3

Photoelectric Effect:

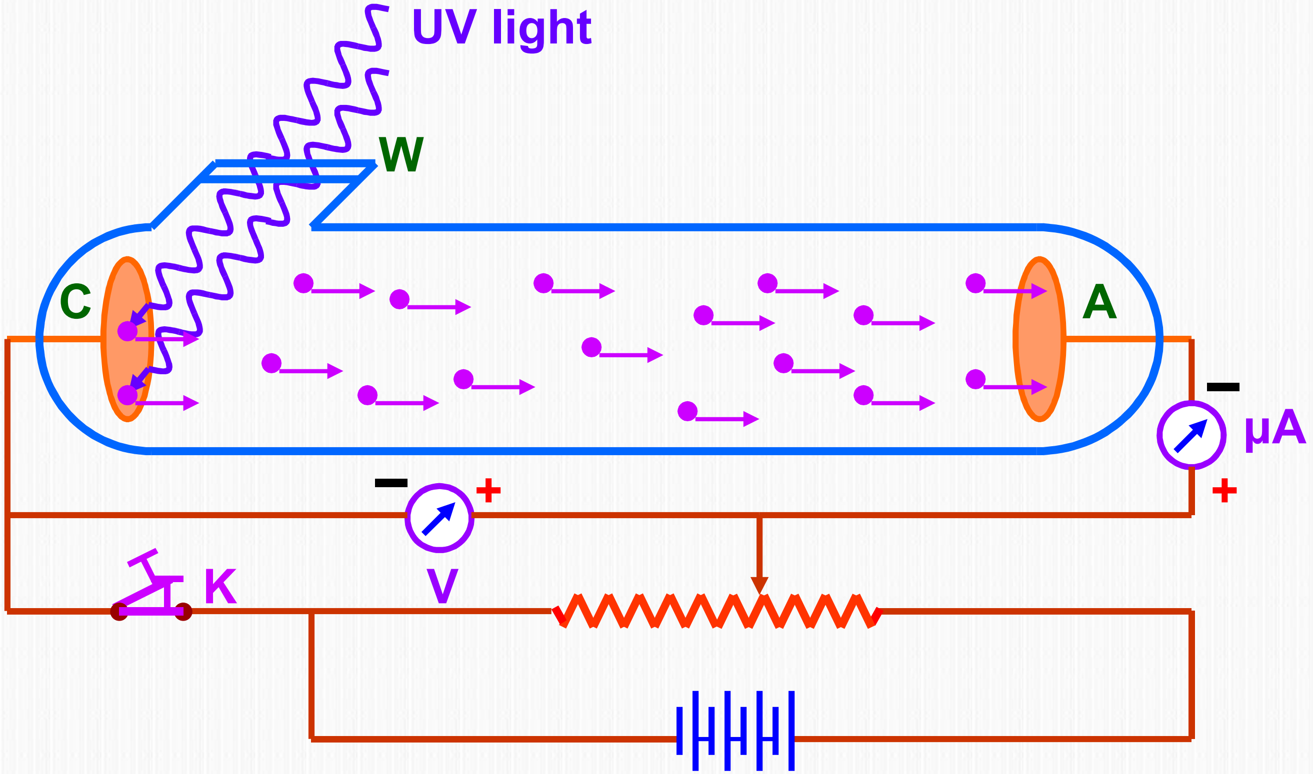
The phenomenon of emission of electrons from mainly metal surfaces exposed to light energy (X – rays, γ – rays, UV rays, Visible light and even Infra Red rays) of suitable frequency is known as photoelectric effect.

The electrons emitted by this effect are called photoelectrons.
The current constituted by photoelectrons is known as photoelectric current.

Note: Non metals also show photoelectric effect. Liquids and gases also show this effect but to limited extent.



Experimental Set-up to study Photoelectric Effect:



C – Metallic cathode

A – Metallic Anode

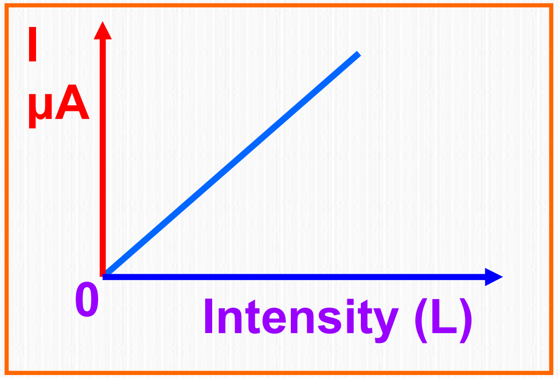
W – Quartz Window

● - Photoelectron

When light of suitable frequency falls on the metallic cathode, photoelectrons are emitted. These photoelectrons are attracted towards the +ve anode and hence photoelectric current is constituted.

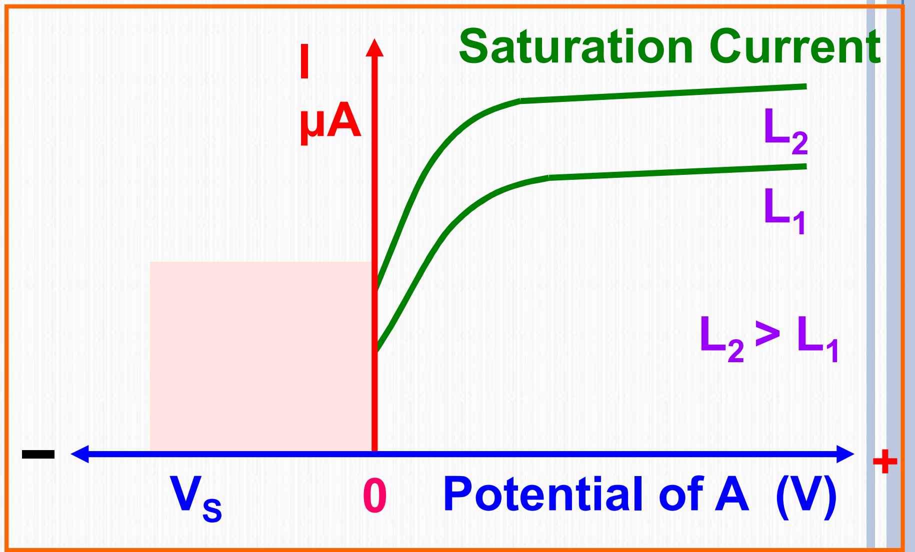
1) Effect of Intensity of Incident Light on Photoelectric Current:

For a fixed frequency, the photoelectric current increases linearly with increase in intensity of incident light.



2) Effect of Potential on Photoelectric Current:

For a fixed frequency and intensity of incident light, the photoelectric current increases with increase in +ve potential applied to the anode. When all the photoelectrons reach the plate A, current becomes maximum and is known as saturation current.



When the potential is decreased, the current decreases but does not become zero at zero potential.
This shows that even in the absence of accelerating potential, a few photoelectrons manage to reach the plate on their own due to their K.E.

When –ve potential is applied to the plate A w.r.t. C, photoelectric current becomes zero at a particular value of –ve potential called stopping potential or cut-off potential.

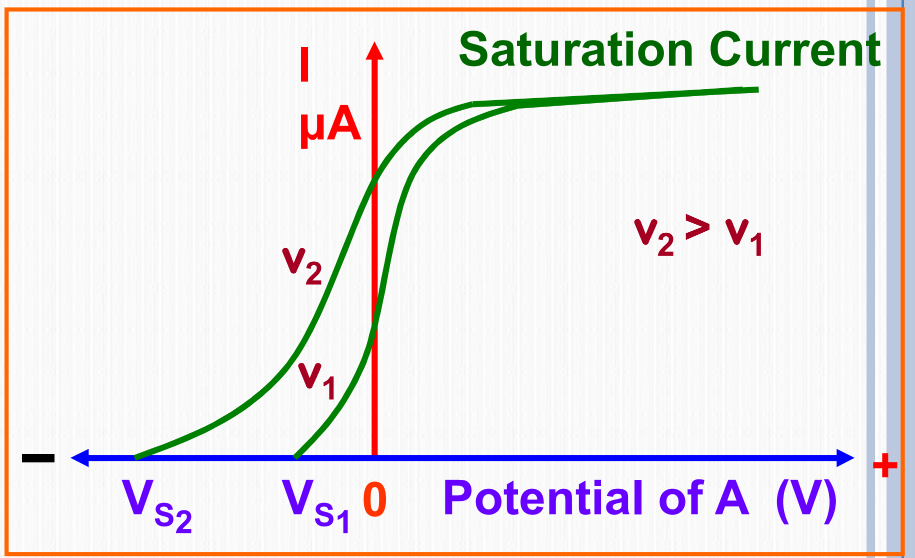
Intensity of incident light does not affect the stopping potential.

3) Effect of Frequency of Incident Light on Stopping Potential:

For a fixed intensity of incident light, the photoelectric current increases and is saturated with increase in +ve potential applied to the anode.

However, the saturation current is same for different frequencies of the incident lights.

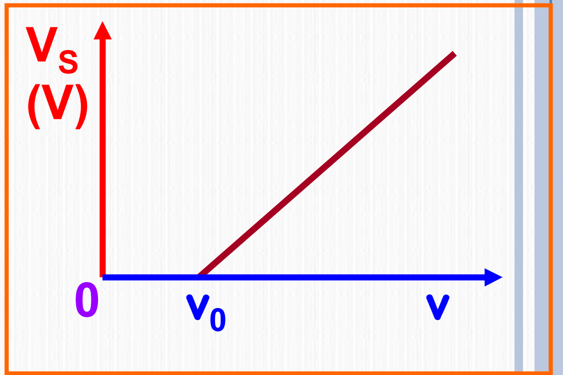
When potential is decreased and taken below zero, photoelectric current decreases to zero but at different stopping potentials for different frequencies.



Higher the frequency, higher the stopping potential. i.e. $V_S \propto \nu$

4) Threshold Frequency:

The graph between stopping potential and frequency does not pass through the origin. It shows that there is a minimum value of frequency called threshold frequency below which photoelectric emission is not possible however high the intensity of incident light may be. It depends on the nature of the metal emitting photoelectrons.



Laws of Photoelectric Emission:

i) For a given substance, there is a minimum value of frequency of incident light called threshold frequency below which no photoelectric emission is possible, howsoever, the intensity of incident light may be.

ii) The number of photoelectrons emitted per second (i.e. photoelectric current) is directly proportional to the intensity of incident light provided the frequency is above the threshold frequency.

iii) The maximum kinetic energy of the photoelectrons is directly proportional to the frequency provided the frequency is above the threshold frequency.

iv) The maximum kinetic energy of the photoelectrons is independent of the intensity of the incident light.

v) The process of photoelectric emission is instantaneous. i.e. as soon as the photon of suitable frequency falls on the substance, it emits photoelectrons.

vi) The photoelectric emission is one-to-one. i.e. for every photon of suitable frequency one electron is emitted.

Einstein's theory of Photoelectric Effect

- According to Einstein's theory, an electron is ejected/emitted from the target metal by a collision with a single photon.

- In this process, all the photon energy is transferred to the electron on the surface of metal target.

- Since electrons are held in the metal by attractive forces, some minimum energy, W_o (***work function***, which is on the order of a few electron volts for most metal) is required just enough to get an electron out through the surface.

Einstein's theory of Photoelectric Effect

- If the frequency f of the incoming light is so low that is $hf < W_o$, then the photon will not have enough energy to eject any electron at all.

- If $hf > W_o$, then electron will be ejected and energy will be conserved (the excess energy appears as kinetic energy of the ejected electron).

- This is summed up by **Einstein's photoelectric equation ,**

$$\boxed{E = W_o + K.E_{\max}}$$

$$\boxed{hf = W_0 + \frac{1}{2} m v_{\max}^{\ 2}}$$

but

$$\boxed{eV_s = \frac{1}{2} m v^2}$$

$$\boxed{hf = W_0 + eV_s}$$

Einstein's theory of Photoelectric Effect

$$\boxed{E = W_o + K.E_{\max}}$$

$$\boxed{hf = W_0 + \frac{1}{2}mv_{\max}^{2}}$$

Einstein's photoelectric equation

$E = hf = h\dfrac{c}{\lambda}$ = photon energy

f = frequency of em radiation /incoming light

$K.E_{\max} = \dfrac{1}{2}mv_{\max}^{2}$ = maximum kinetic energy of ejected electron.

v_{max} = maximum speed of the photoelectron

Einstein's theory of Photoelectric Effect

$$\boxed{E = W_o + K.E_{\max}}$$

$$\boxed{hf = W_0 + \frac{1}{2} m v_{\max}{}^2}$$

$$\boxed{W_o = hf_o = \frac{hc}{\lambda_o}}$$

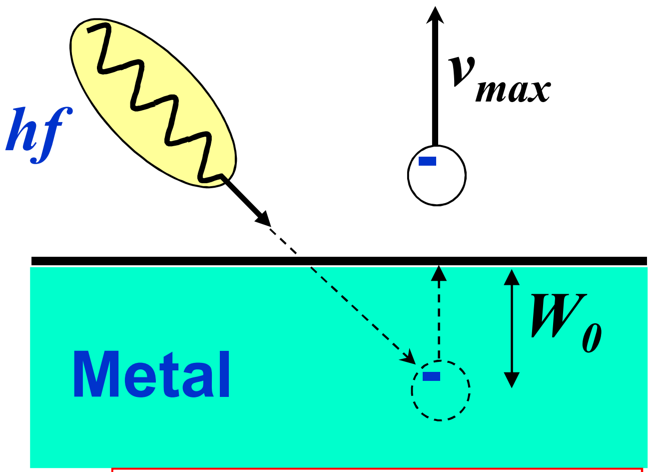
W_o = the **work function** of a metal.
= the minimum energy required (needed) to eject an electron from the surface of target metal.

f_o = **threshold frequency**.
= minimum frequency of e.m. radiation required to eject an electron from the surface of the metal.

$$\boxed{f_o = \frac{c}{\lambda_o}}$$

λ_o = **threshold wavelength**.
= maximum wavelength of e.m. radiation required to eject an electron from the surface of the target metal.

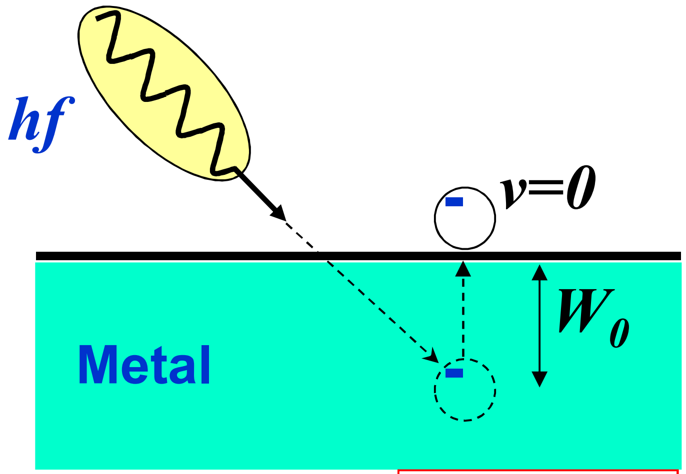
Einstein's theory of Photoelectric Effect



Electron is emitted

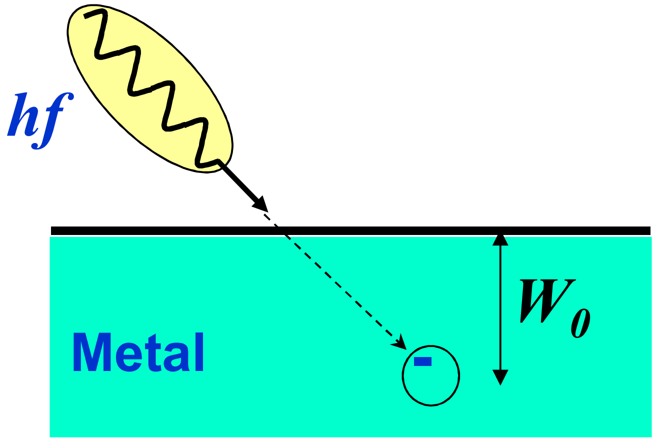
$$hf = W_0 + \frac{1}{2} m v_{\max}^{2}$$

$$hf > W_o$$



Electron is ejected.

$$hf = W_o$$



No electron is ejected. $hf < W_o$

Einstein's theory of Photoelectric Effect

Verification of Laws of Photoelectric Emission based on Einstein's Photoelectric Equation:

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

i) If $\nu < \nu_0$, then $\frac{1}{2} mv^2_{max}$ is negative, which is not possible. Therefore, for photoelectric emission to take place $\nu > \nu_0$.

ii) Since one photon emits one electron, so the number photoelectrons emitted per second is directly proportional to the intensity of incident light.

iii) It is clear that $\frac{1}{2} mv^2_{max} \propto \nu$ as h and ν_0 are constant. This shows that K.E. of the photoelectrons is directly proportional to the frequency of the incident light.

iv) Photoelectric emission is due to collision between a photon and an electron. As such there can not be any significant time lag between the incidence of photon and emission of photoelectron. i.e. the process is instantaneous. It is found that delay is only 10^{-8} seconds.