Dual Nature of Matter and Radiation

ELECTRON EMISSION

We know that metals have **free electrons** (negatively charged particles) that are responsible for their conductivity. However, the free electrons **cannot normally escape out** of the metal surface.

If an electron attempts to come out of the metal, the metal surface **acquires a positive charge** and pulls the electron back to the metal

. The free electron is thus **held inside** the metal surface by the attractive forces of the ions.

Consequently, the electron can come out of the metal surface only if it has **got sufficient energy to overcome** the attractive pull.

A certain **minimum amount of energy** is required to be given to an electron to pull it out from the surface of the metal

This minimum energy required by an electron to escape from the metal surface is called the **work function** of the metal. It is generally denoted by $\boldsymbol{\varphi_0}$ and measured in **eV** (electron volt).

One electron volt is the **energy gained** by an electron when it has been **accelerated** by a potential difference of 1 volt, so that **1 eV = 1.602 ×10 –19 J.**

This unit of energy is commonly used in atomic and nuclear physics. The **work function** (φ_0) depends on the **properties of the metal** and **the nature of its surface**.

Metal	Work Function eV*
Li	2.9
Na	2.4
K	2.3
Cs	1.9
Ba	2.5
Ca	2.9
Nb	2.3
Zr	4.05
Mg	3.66
Al	4.2
Cu	4.6
Ag	4.64
Zn	3.6
Sc	3.5

Electron Emission

(i) Thermionic emission : By suitably heating, sufficient thermal energy can be imparted to the free electrons to enable them to **come out** of the metal.

(ii) Field emission : By applying a very strong electric field (of the order of **10^8 Vm–1**) to a metal, electrons can be pulled out of the metal, as in a spark plug.

(iii) Photo-electric emission: When light of **suitable frequency** illuminates a metal surface, electrons are emitted from the metal surface. These photo(light)-generated electrons are called **photoelectrons**.

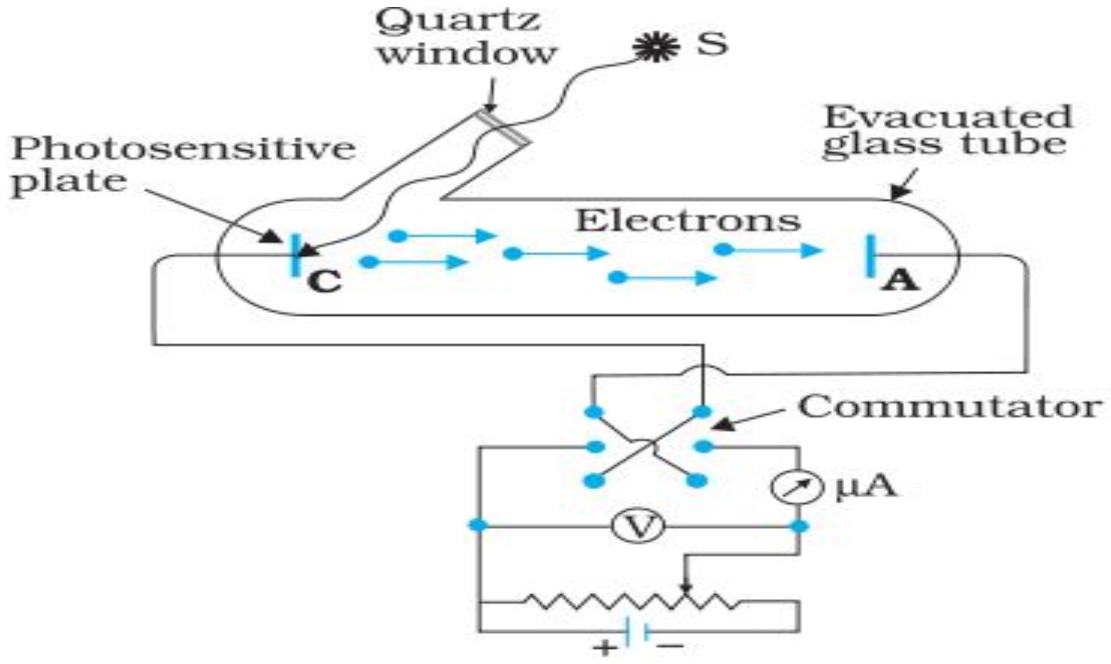
Photo Electric Effect

Hallwachs and Lenard also observed that when **ultraviolet** light fell on the emitter plate, no electrons were emitted at all when the frequency of the incident light was **smaller** than a certain **minimum** value, called the **threshold frequency**. This minimum frequency depends on the **nature** of the **material** of the **emitter** plate.

It was found that certain metals like zinc, cadmium, magnesium, etc., responded only to **ultraviolet** light, having short wavelength, to cause electron emission from the surface.

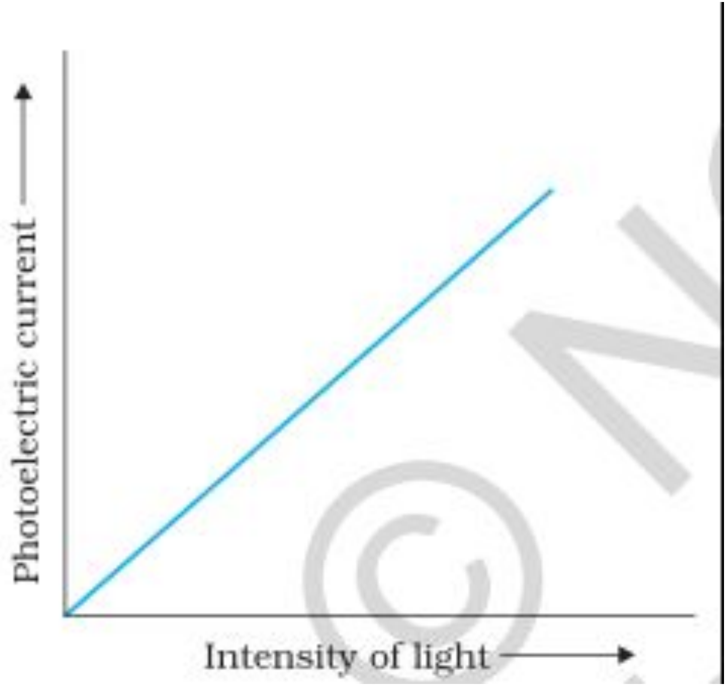
However, some alkali metals such as lithium, sodium, potassium, caesium and rubidium were sensitive even to **visible** light. All these photosensitive substances emit electrons when they are illuminated by light. After the discovery of electrons, these electrons were termed as **photoelectrons**. The phenomenon is called **photoelectric effect**.

Experimental Study of Photo Electric Effect



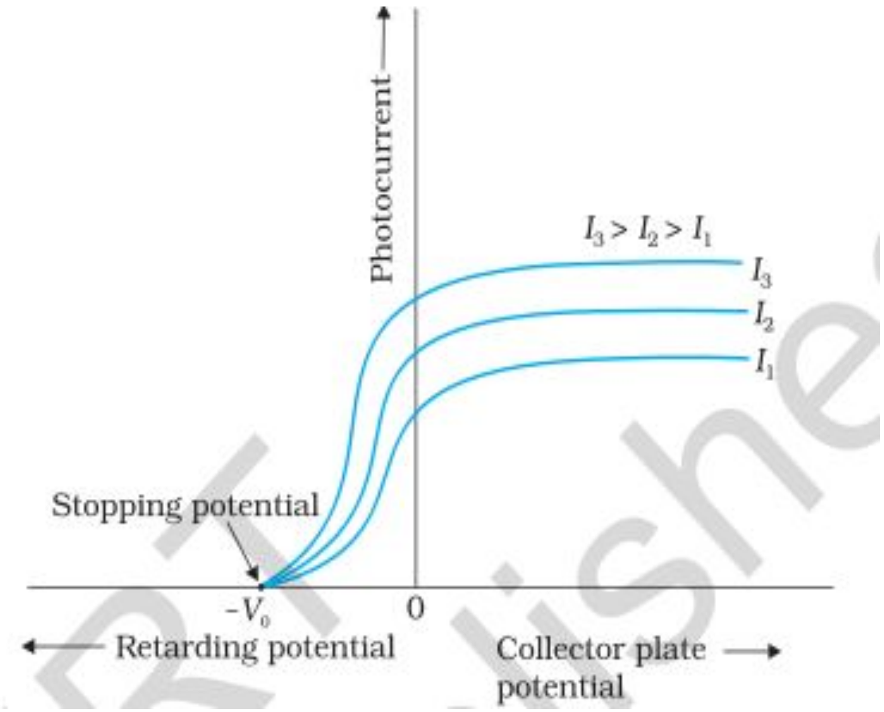
Effect of intensity of light on photocurrent

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 intensity of light.



Effect of potential on photo-electric current

It is found that the photoelectric current increases with increase in **accelerating** (positive) potential. At some stage, for a certain positive potential of plate A, all the emitted electrons are **collected** by the plate A and the photoelectric current becomes **maximum** or **saturates**. If we increase the accelerating potential of plate A further, the photocurrent **does not increase**. This maximum value of the photoelectric current is called **saturation current**.



The minimum negative (retarding) potential **V_0** given to the plate A for which the photocurrent **stops** or becomes **zero** is called the **cut-off** or **stopping potential**.

The maximum kinetic energy (K_{max}),

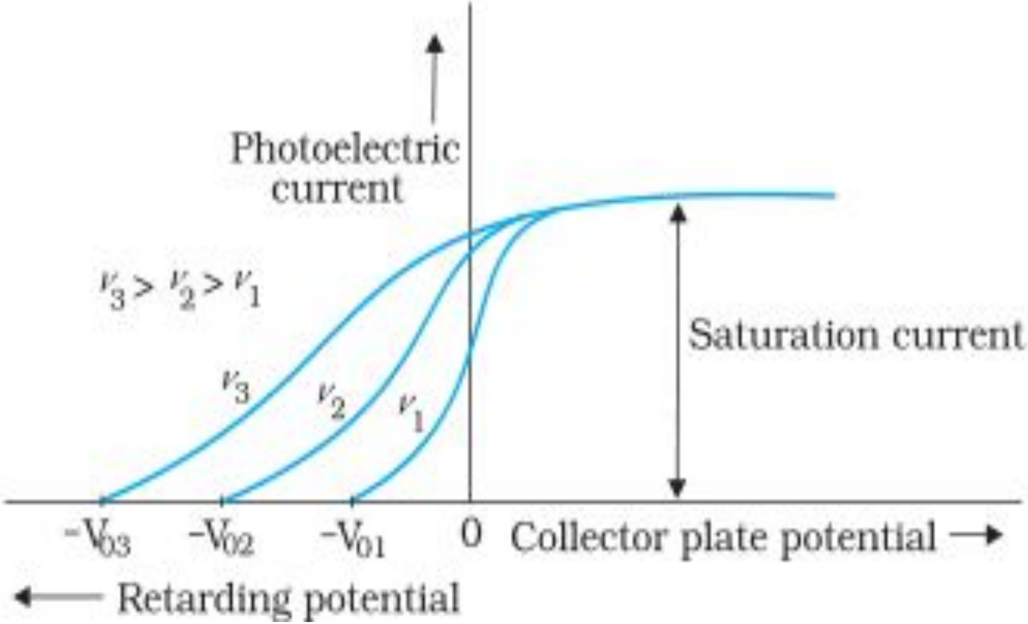
so that **$K_{max} = eV_0$**

for a given frequency of the incident radiation,

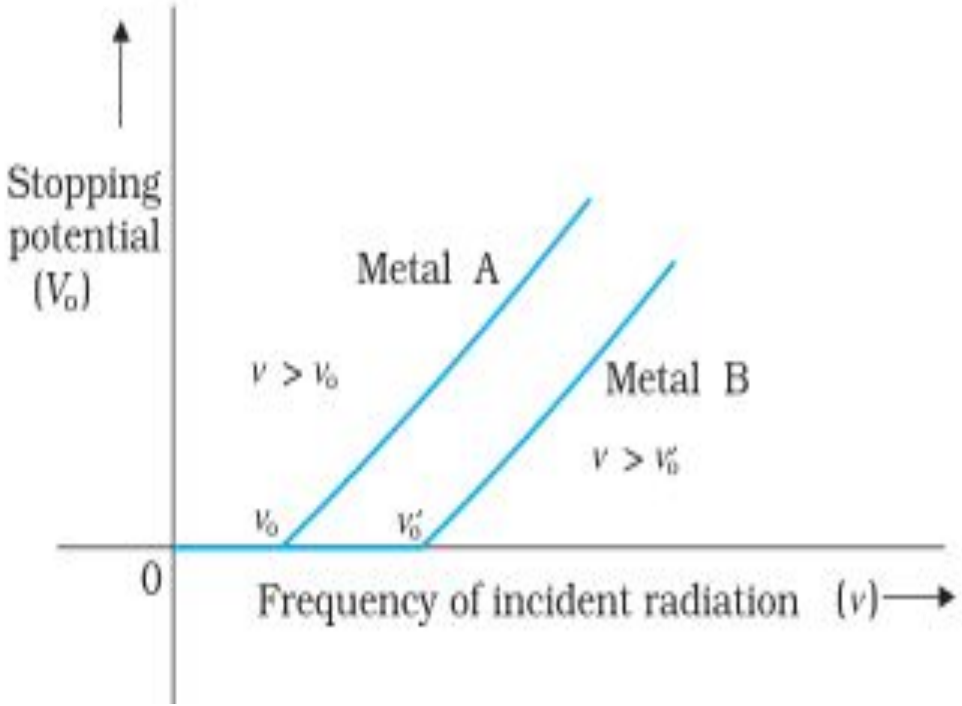
the stopping potential is **independent** of its **intensity**. In other words, the maximum kinetic energy of photoelectrons depends on the light source and the emitter plate material, but is **independent** of intensity of incident radiation.

Effect of frequency of incident radiation on stopping potential

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



If we plot a graph between the **frequency** of incident radiation and the corresponding **stopping potential** for different metals we get a straight line,



(i) the **stopping potential** V_0 varies **linearly** with the **frequency** of incident radiation for a given photosensitive material.

(II) there exists a certain minimum **cut-off** frequency for which stopping potential is zero. These observations have two implications:

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

(ii) For a frequency v of incident radiation, **lower** than the cut-off frequency v_0 , **no** photoelectric emission is possible even if the intensity is large.

Summary

(i) For a given photosensitive material and **frequency** of incident radiation (above the threshold frequency), the **photoelectric current** is directly proportional to the **intensity** of incident light

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

(iii) For a given photosensitive material, there exists a certain minimum **cut-off** frequency of the incident radiation, called the **threshold** frequency, below which **no emission** of photoelectrons takes place, no matter how intense the incident light is.

Above the **threshold** frequency, the **stopping potential** or equivalently the **maximum kinetic energy** of the emitted photoelectrons **increases linearly** with the **frequency** of the incident radiation, but is **independent** of its **intensity**

(iv) The photoelectric emission is an **instantaneous** process without any apparent time lag (**~10^{-9}s or less**), even when the incident radiation is made exceedingly dim.

EINSTEIN 'S PHOTOELECTRIC EQUATION: ENERGY QUANTUM OF RADIATION

If the quantum of energy (hv) absorbed exceeds the minimum energy needed for the electron to escape from the metal surface (work function φ_0), the electron is emitted with maximum kinetic energy

$$K_{max} = hv - \varphi_0$$

$$h\nu > \phi_0$$

or $\nu > \nu_0$, where

$$\nu_0 = \frac{\phi_0}{h}$$

$$eV_0 = h\nu - \phi_0; \text{ for } \nu \geq \nu_0$$

$$\text{or } V_0 = \frac{h}{e}\nu - \frac{\phi_0}{e}$$