ELECTRON PHOTON

It was found that certain metals like zinc, cadmium, magnesium, etc respond only to UV light, having short wavelength. Some alkali metals such as lithium, sodium, potassium, caesium and rubidium are sensitive even to visible light.

Definition: The phenomenon of emission of electrons by certain substances (metals), when it is exposed to radiations of suitable frequencies is called as photoelectric effect and the emitted electrons are called photoelectrons.

NOTE: Photoelectric effect is one photon – one electron phenomenon. One photon cannot eject more than one photoelectron.

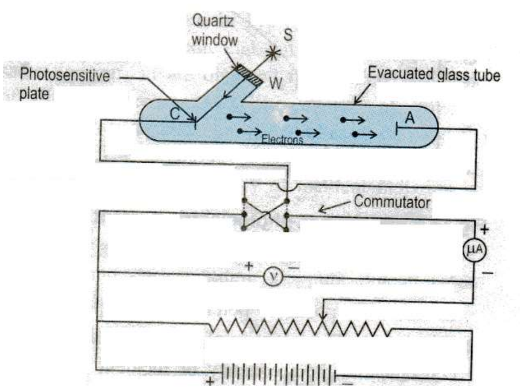
Definition: The minimum frequency of incident radiation for which photoelectrons are just emitted from photosensitive material is called threshold frequency.

Definition: The maximum value of photoelectric current is called saturation current.

Definition: The minimum negative potential Vo given to the collector plate for which photoelectric current stops or becomes zero is called cut off or stopping potential.

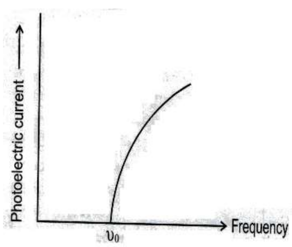
Definition: The minimum energy required to free electron from a given surface is called photoelectric work function Φo of that material of the surface.

Experimental study of photoelectric effect

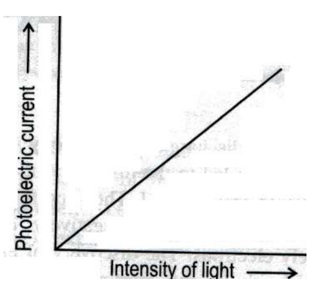


(Explanation please refer textbook)

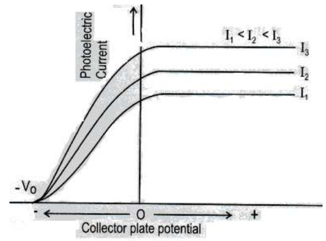
GRAPHS:



Collector at suitable +ve potential
Intensity constant
Frequency increased
No emission till certain frequency vo
vo is characteristic of the material of emitter plate
vo called threshold frequency
v>=vo, emission takes place
λo called threshold wavelength
λ<λo, emission will take place.



Collector at suitable +ve potential
Frequency constant and above vo
Intensity of light varied
Current increases linearly with increase in Intensity
Number of photoelectrons emitted per second is directly proportional to the intensity of incident radiation



For a given curve:
v constant(v>vo) & intensity constant
+ve potential at collector increased, current increases
At a certain stage further increase causes no increase in current.
Thus saturation current is reached.

On reversal of polarity and gradually increasing the –ve potential causes current to reduce. At one stage it becomes zero. That collector potential is called cut off or stopping potential. (Vo)

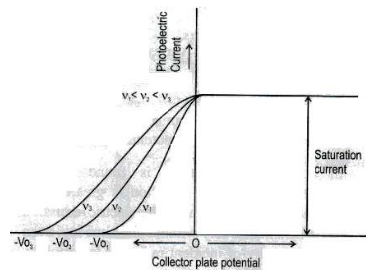
This stopping potential is sufficient to block the most energetic photoelectron (one with maximum KE) and hence current is zero.

$$\frac{1}{2} mV^2_{max} = eVo$$

Vmax : maximum velocity of photoelectron
m : mass of electron
e : magnitude of charge on electron

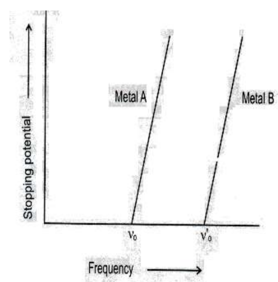
On repeating this with higher Intensity shows higher saturation current and no change in stopping potential

Stopping potential and maximum KE do not depend on the Intensity of radiation



Intensity held constant
For a given curve, v is held constant (v>vo)
On changing the v, there is no change in the saturation current (Since saturation current depends on Intensity and that is held constant in this case)
Changes in v causes changes in the maximum energy of the emitted photoelectrons and hence a change in the stopping potential.

More the incident frequency, more negative the stopping potential



Intensity constant
For a given graph, above the threshold frequency of that metal, stopping potential varies linearly with increase in v
Change of material of the emitter implies change in the threshold frequency and the new characteristic graph is parallel to the previous
The slope = h/e
y-intercept = - hvo/e

Characteristics of photoelectric emission

>> For a given photosensitive material there exists a certain minimum frequency of the incident radiation, called threshold frequency vo, below which no emission of photoelectrons takes place. The threshold frequency is different for different metals.

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

>> Above threshold frequency vo, the maximum KE of the emitted photoelectrons increases linearly with the frequency of the incident radiation, and is independent of the intensity of incident light.

>> The emission of photoelectrons in an instantaneous process. There is no time lag between the irradiation of the metal surface and emission of photoelectrons.

Einstein's Photoelectric Equation:

>> A radiation of frequency ν consists of a stream of discrete quanta or photons, each of energy hν, where h is Planck's constant. Photons move with a speed of light

>> When radiation of frequency ν is incident on the photosensitive surface, there are collisions between photons and electrons in the emitter. The entire energy of the photon is transferred to the electron without any time lag. (Photon is not a material particle)

>>The absorbed energy hν is used partly by the electron to overcome the work function of the emitter surface ($\Phi o = h\nu o$) and the remaining ($h\nu - \Phi o$) appears as KE of the electron. If there is no energy loss by the electron in form of collision inside the surface, then the electron escapes with maximum KE , given as

$$\frac{1}{2} mV^2_{max} = h\nu - \Phi o = eVo$$

Explanation of characteristics based on Einstein's equation

>> If frequency is reduced, the KE of the –photoelectron also decreases

$\frac{1}{2} mV^2_{max} = h\nu - \Phi o$; and finally becomes zero for say frequency νo.

Thus, $\nu = \nu o$, KEmax= 0

Thus, $0 = h\nu o - \Phi o$. therefore, $\Phi o = h\nu o$

Therefore, the Einstein's equation can be written as

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

If $\nu > \nu o$, photoelectrons are emitted with some velocity

If $\nu = \nu o$, the photoelectrons are just ejected with zero velocity

If $\nu < \nu o$, no photoelectrons are emitted.

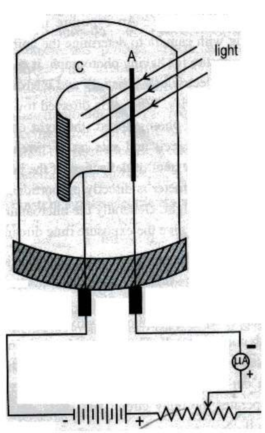
This explains why there exists a minimum cut-off frequency for photoelectrons to be emitted

>> According to quantum theory, more intense beams contains greater number of photons. Hence the number of collisions between these photons and electrons would increase and hence more photoelectrons are emitted. ***This explains why there is an increase in photoelectric current with increase in intensity of incident radiation.***

>> The photoelectric work function Φo is constant for a given emitter. Hence KEmax of the photoelectrons increases with frequency ν, of the incident radiation and does not depend on the intensity of the incident radiation.

>> Emission of photoelectrons is a result of collisions between photons and electrons. As soon as the incident radiation strikes the metal surface, collision occurs and the photoelectrons are emitted. The moment , the incident radiation is cut – off, there is no emission of photoelectrons. ***Thus the photoelectric effect is instantaneous.***

PHOTOCELL:



Converts light energy to electric energy

Works on the principle of photoelectric effect

Construction: It consists of a semicylindrical photosensitive metal plate C (emitter) and a wire loop A, (collector) supported in an evacuated glass bulb. It is connected to a high tension battery and a microammeter.

Working: When light of suitable wavelength falls on the emitter, photoelectrons are emitted. These are attracted by the collector. A small current flows through the circuit, which is recorded by the microammeter. If the intensity Is increased, the rate of emission will increase and hence the current will increase. Thus current is directly proportional to the intensity of incident radiation.

Application: Exposure meter, Burglar alarm, sound reproduction from motion pictures. ***(refer textbook for explanation)***

Particle nature of Light

>> In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.

>> Each photon has energy $E(=h\nu)$ and momentum $p\ (=h\nu/c)$ where c=speed of light

>> All photons of light of a particular frequency ν, or wavelength λ, have the same energy $E(=h\nu=hc/\lambda)$ and momentum $p(=h\nu/c = h/\lambda)$ whatever may be the intensity of radiation. By increasing the intensity of light , there is only an increase in the number of photons emitted per second, but each photon will have the same energy as before. Thus, ***photon energy is independent of intensity of radiation***

>> Photons are electrically neutral and are not deflected by electric or magnetic field.

>> In a photon – particle collision (eg photon – electron collision) , the total energy and total momentum is conserved. However, the number of photons may not be conserved.