

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 appropriate 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.

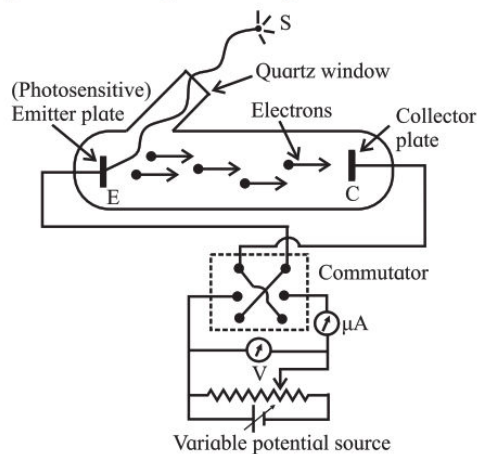
Definition: The minimum frequency of incident radiation for which photoelectrons are just emitted from photosensitive material is called threshold frequency.

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

Definition: The minimum negative potential V_0 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 Φ_0 of that material of the surface.

Experimental study of photoelectric effect



(Explanation please refer textbook 14.2.1)

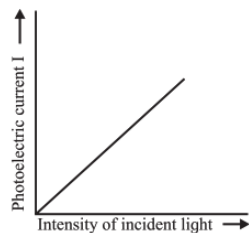
GRAPHS:

Collector at suitable +ve potential, Intensity constant, Frequency increased
No emission till certain frequency ν_0 , ν_0 called threshold frequency and is characteristic of the material of emitter plate

$\nu > \nu_0$, emission takes place (however small the Intensity is)

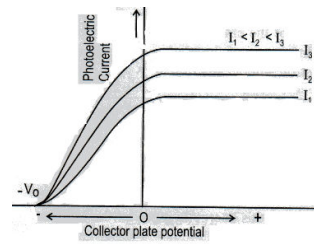
λ_0 called threshold wavelength

$\lambda < \lambda_0$, emission will take place.



Collector at suitable +ve potential
Frequency constant and above ν_0
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:

ν constant ($\nu > \nu_0$) & 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. (V_0)

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

$$\frac{1}{2} m v_{\max}^2 = e V_0$$

v_{\max} : maximum velocity of photoelectron

m : mass of electron

e : magnitude of charge on electron

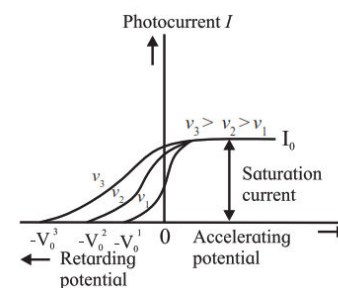
On repeating this with higher Intensity shows higher saturation current and no change in stopping potential

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

Intensity held constant

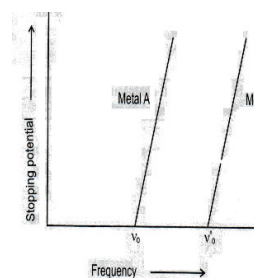
For a given curve, ν is held constant ($\nu > \nu_0$)

On changing the ν , there is no change in the saturation current (Since saturation current depends on Intensity and that is held constant in this case)



Changes in ν 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 ν

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 = $-h\nu_0/e$

Observations/Characteristics of photoelectric emission

1. For a given photosensitive material there exists a certain minimum frequency of the incident radiation, called threshold frequency ν_0 , below which no emission of photoelectrons takes place. The threshold frequency is different for different metals.
2. The emission of photoelectrons is an instantaneous process. There is no time lag between the irradiation of the metal surface and emission of photoelectrons (within 10^{-9} s). As soon as the incident radiation was stopped, the flow of current stopped.
3. For a given photosensitive material and given frequency of incident radiation (above threshold frequency), the photoelectric current is directly proportional to the intensity of incident light (keeping accelerating potential also constant)
4. Fixed intensity and frequency (above threshold frequency), current

increased with voltage but then became constant (called saturation current I_0).

5. Fixed accelerating potential and fixed frequency (above threshold frequency), If intensity is increased, saturation current I_0 also increases.

6. Above threshold frequency ν_0 , 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.

7. $-V_0$ the cut-off or stopping potential, is the voltage at which photocurrent becomes zero. It is independent of intensity

8. Intensity and accelerating potential constant and frequency is changed, then saturation current is constant, but stopping potential changes.

9. The photocurrent and hence number of electrons depends on the intensity and not on frequency.

Einstein's Photoelectric Equation:

>> A radiation of frequency ν consists of a stream of discrete quanta or photons, each of energy $h\nu$, 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 $h\nu$ is used partly by the electron to overcome the work function of the emitter surface ($\Phi_0 = h\nu_0$) and the remaining ($h\nu - \Phi_0$) 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

$$\frac{1}{2} mV_{\max}^2 = h\nu - \Phi_0 = eV_0$$

Explanation of characteristics based on Einstein's equation

1. If frequency is reduced, the KE of the photoelectron also decreases $\frac{1}{2} mV_{\max}^2 = h\nu - \Phi_0$; and finally becomes zero for say frequency ν_0 .

Thus, $\nu = \nu_0$, $KE_{\max} = 0$

Thus, $0 = h\nu_0 - \Phi_0$. therefore, $\Phi_0 = h\nu_0$

Therefore, the Einstein's equation can be written as

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

If $\nu > \nu_0$, photoelectrons are emitted with some velocity

If $\nu = \nu_0$, the photoelectrons are just ejected with zero velocity

If $\nu < \nu_0$, no photoelectrons are emitted.

This explains why there exists a minimum cut-off frequency for photoelectrons to be emitted (however small the intensity)

2. 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 since there are no photons to transfer energy to the electrons. **Thus, the photoelectric effect is instantaneous.**

3. According to quantum theory, more intense beams contain 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 (assuming $\nu > \nu_0$)**

4. Collector potential increases, accelerates the electrons towards the collector. Hence higher potential, higher the current. Intensity fixed, the current can increase with potential only till all the knocked off electrons have reached the collector. Then its not going to increase current even if the accelerating potential is increased. This explains the constant level of current called saturation current (for a given intensity).

5. Intensity increased, number of photons increases and hence the saturation current increases.

6. The photoelectric work function Φ_0 is constant for a given emitter. Hence, KE_{\max} of the photoelectrons, for a given type of emitter, increases linearly with frequency ν , of the incident radiation and does not depend on the intensity of the incident radiation.

7. Electrons are emitted from the metal surface with different KE's since all electrons do not possess the same energy and do not come out from the same depth and may suffer collision while coming to the surface and escaping the surface. The maximum energy with which it comes out, KE_{\max} , if that is less than eV_0 then photocurrent becomes zero. V_0 is called the stopping potential and depends on the material of the emitter and the incident frequency and not on the intensity of incident radiation.

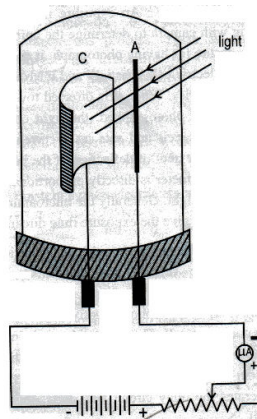
$$KE_{\max} = h\nu - \Phi_0 = eV_0$$

$$\text{thus } V_0 = \frac{h}{e}\nu - \frac{\Phi_0}{e}$$

so V_0 varies linearly with frequency ν and slope is h/e which is a constant (independent of the material of the emitter). But, the y-intercept (Φ_0/e) is different for each metal

9. Magnitude of photoelectric current depends on intensity and not on the incident frequency (assuming $\nu > \nu_0$)

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 14.4)

Failures of Wave Theory of Light

>> If light was only a wave then there would be continuous absorption of energy by the surface. It would take a reasonable time (few minutes to hours) before the electron would gain sufficient energy to leave the surface. Greater the intensity lesser the time it would take to knock off the electron.

>> But larger intensity in wave theory means larger energy and the electron would be released with larger KE. But we know max KE does not depend on intensity but depends on frequency. So wave theory of light fails in this regard.

>> But in wave theory frequency has no role in deciding max KE. Wave theory assumes that photoelectrons should be emitted at any frequency if the intensity was just right. But we observed and know that frequency has to be more than the threshold frequency to emit the photoelectrons and below threshold frequency there will be no emission for any intensity. So this is another failure of wave theory of Light