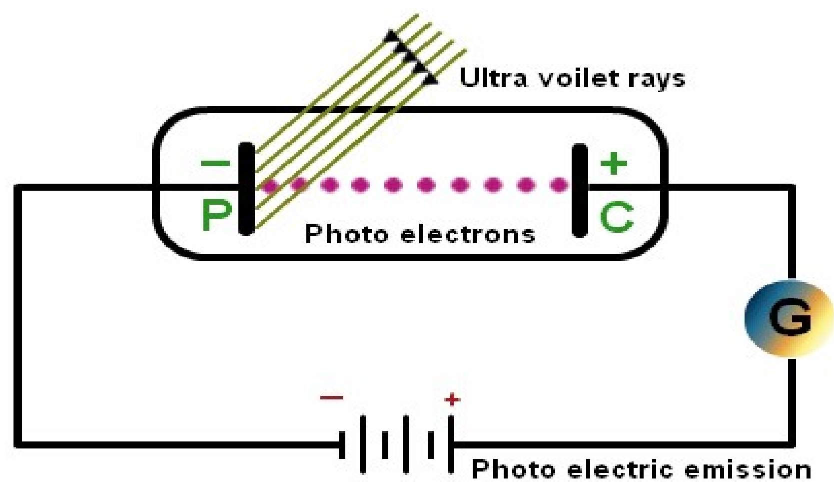
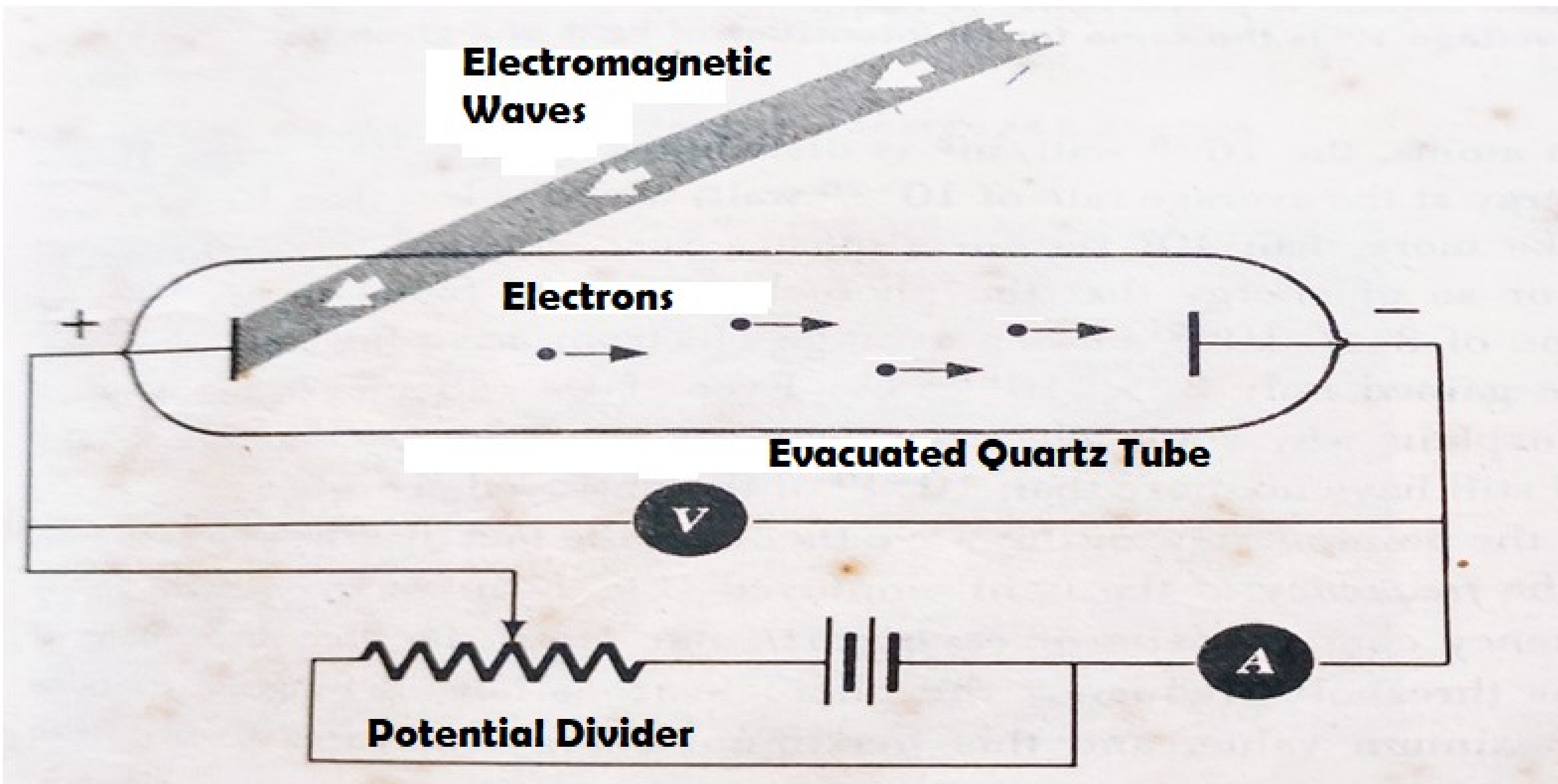
Photoelectric Effect

Photoelectric effect is the process of emitting the electrons from the a metal surface when the metal surface is exposed to an electromagnetic radiation of sufficiently high frequency. For example, ultraviolet light is required in the case of ejection of electrons from an alkali metal.



Schematic Diagram of Photoelectric Effect Set Up



Apparatus Description

- An evacuated tube has two electrodes connected to an external circuit.
- The metal plate whose surface is to be irradiated acts as the anode.
- Some of the photoelectrons that emerge from the radiated surface have sufficient energy to reach the cathode despite its negative polarity and they constitute the current.
- As the retarding potential is increased fewer and fewer electrons are able to reach the cathode and the current drops. When V exceeds a certain value V_0 no further electrons are able to strike the cathode and the current drops to zero.

Laws of Photoelectric Emission

- There is no time lag between the irradiation of the surface and the ejection of the electrons.
- At a particular fixed frequency of incident radiation the rate of the emission of photo electrons i.e. the photocurrent increases with increase in the intensity of the incident light.
- Photo electric effect does not occur at frequency less than threshold frequency.
- At the frequency above the threshold frequency, the kinetic energy of the ejected electrons depends only on the frequency of the exposed radiation and not on its intensity.

Explanation of Photoelectric Effect

i. The photoelectric effect cannot be explained on the basis of electromagnetic theory.
ii. In 1905 Einstein proposed that the photoelectric effect could be understood through the idea proposed by the German theoretical physicist Max Planck in 2000.
iii. Planck was seeking to explain the characteristics of the radiation emitted by hot bodies.
iv. Plank assumed that while the radiation is emitted continuously as little bursts of energy called quanta but propagated continuously in space as electromagnetic waves.
v. Einstein proposed that light not only was emitted as quanta at a time but also propagated as individual quanta, sufficiently small to be absorbed by the electron.

vi. Planck found that the quantity associated with a particular frequency ν of light all had the same energy and that this energy was proportional to ν that is

$$E = h\nu$$

vii. Photoelectric effect can be explained by the following equation

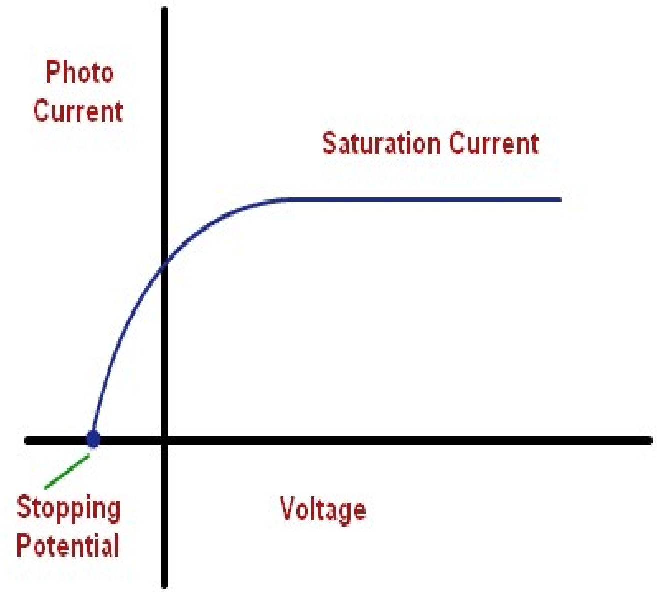
$$E(=h\nu) = h\nu_0 + T_{max}$$

Here E is the total energy of the photon incident on the metallic surface, ν is the frequency of the incident radiation, ν_0 is the threshold frequency of the metal and T_{max} is the maximum kinetic energy with which the electron moves after ejection from the surface.

In wave mechanics the intensity of radiation is defined as the total continuous energy falling normal to a surface per second per unit area. In quantum mechanics intensity should be considered to be related to the number of photons falling per second per unit area. In this way, increase in intensity implies increasing the number of photons leading to increase in number of collisions with the electrons and their subsequent ejection from the surface. This then should increase the photocurrent. Thus increase in intensity should increase the photocurrent.

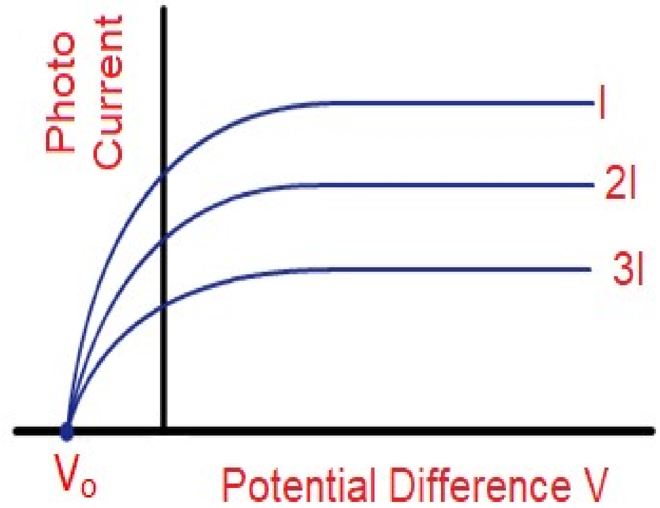
When frequency is increased the energy of individual photons increases. The work function is fixed. Hence, the any increase in the energy of individual photons results in increase in maximum kinetic energy of the ejected electrons.

Even when V is zero there is some current. This is due to some of the electrons coming out have sufficient energy to reach the cathode all by themselves. When V is increased the electrons not having sufficient KE are also pulled by the cathode and hence current increases. For a given intensity when all the ejected electrons are pulled by the cathode there are no more electrons left to reach the cathode. After this even if V is increased the current does not increase. This is the saturation current.



When V is made negative and increased the electrons are repelled. However, some electrons having sufficient energy are still able to reach the cathode and constitute the current. The value of V when even the most energetic electron is not allowed to reach the cathode is known as stopping potential and the current now becomes zero.

If the frequency of the incident radiation is fixed T_{max} will not change. Hence, the stopping potential will remain the same even if the intensity is increased or decreased.



If the intensity of radiation is increased, keeping the frequency fixed, the number of photons per second will increase leading to more collisions per second and transfer of photon energy to more electrons. Thus the number of electrons coming out per second will increase leading to increase in photocurrent.

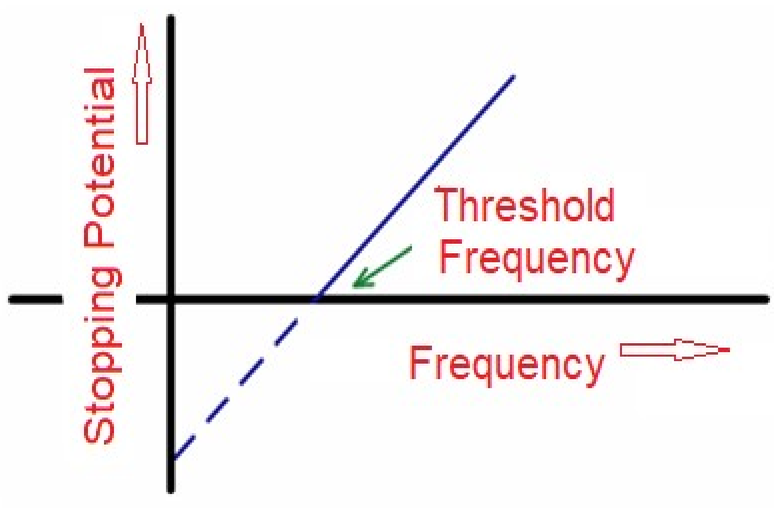
The Linear Equation

The photoelectric equation may be written as follows

$$h\nu = h\nu_0 + T_{max}$$

$$h\nu = h\nu_0 + eV$$

$$V = (h/e)\nu - (h/e)\nu_0$$



Compare this to the standard linear equation

$$y = m\,x + c$$

The intercept on the X-axis will give the threshold frequency. The slope of the curve will give h/e.