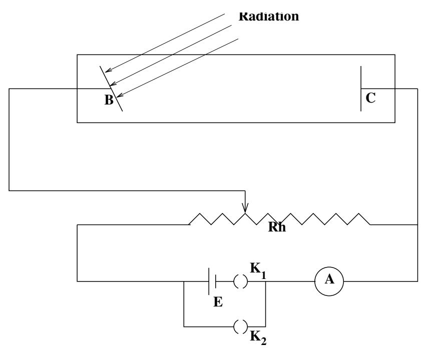
# Photoelectric effect

Photoelectric effect refers to the electric current that is caused when certain metals are illuminated with light. Metals like Ni, Na etc are known to display this phenomenon for various values of frequency of the incident light. Photoelectric effect could be understood by considering the configuration below.




Two plates B and C made of the same metal, fixed at the ends of a vacuum tube are held at a potential difference $V$ by means of an external source E of e.m.f. through a key $K_1$. Another key $K_2$ is connected in parallel to the source E. If $K_1$ is closed and $K_2$ is open, there is a potential difference between the plates A and C. If $K_2$ is closed and $K_1$ is open, A and C are at the same potential. The rheostat Rh helps to regulate the current in the circuit and the ammeter A measures the current **i**.

We begin by keeping $K_2$ closed and $K_1$ open. We shine electromagnetic radiation of various frequencies, including visible light, on plate B. It is found that the ammeter reads a current $i$ for incident electromagnetic radiation with frequency $\nu$ above a certain *threshold frequency* $\nu_0$. For frequencies below $\nu_0$, there is no current. This frequency is different for different materials. The current **i** in the circuit is found to increase in direct proportion to the intensity $\mathcal{I}$ of the incident radiation.

Now we close $K_1$, open $K_2$ and maintain the the plate B at a positive potential with respect to the plate C. It is found that at a particular potential difference $V_0$ the current through the circuit stops completely. This proves that the current flow is caused by the emission of negatively charged electrons from the metal plate B when radiation is incident on it. Further, it is found that the velocity inside the tube of these electrons is directly proportional to frequency of the incident radiation.

The explanation for the photoelectric effect was provided by Albert Einstein using Planck's hypothesis stated at the end of the previous section - the energy of an electromagnetic radiation of frequency $\nu$ is in quanta of $h\nu$. A quantum of radiation energy was called a *photon*.

When electromagnetic radiation of frequency $\nu$ falls on plate B, the electrons present in the material gains energy by absorbing a photon. Higher the energy of the photon, the higher the energy gained by the electron. When the electrons are supplied sufficient energy so as to free them from the atoms to which they are otherwise bound. The minimum energy that is required to free the electron is called the *work function*. Work function is different for different materials. For instance, work function for Ni is approximately 5 eV while that of Na is about 2.4eV. The frequency of the electromagnetic radiation that provides this minimum energy is the threshold frequency for that material. The energy of the radiation that is in excess of the work function, provides kinetic energy for the electron that is liberated from the material. Thus

$$h\nu - h\nu_0 = \mathrm{KE} \tag{1}$$

Thus the larger the frequency of the radiation incident on plate B, the higher the kinetic energy and the velocity of the emitted electrons.
Moreover, the intensity $\mathcal{I}$ of the radiation is proportional to the number of photons $n$ in the radiation. Thus higher the intensity $\mathcal{I}$ of the radiation, the more number of electrons emitted and higher the current in the circuit is.
If we keep the plate B at a higher potential $V$ compared to the plate C, we see a decrease in kinetic energy of the electrons that reach plate C. This is because the relative negative potential of plate C decelerates the electrons emitted by plate B, by the time they reach plate C. When the potential $V = V_0$, is the stopping potential absolutely no electron reaches plate C and the flow of current is stopped. The electron just manages to be free from the plate B but stays there as it has no kinetic energy to reach plate C. All of its energy is now potential energy being equal to $eV_0$. If the potential were zero this would have become the kinetic energy of the electrons. Thus

$$\mathrm{KE} = eV_0$$
$$h\nu - h\nu_0 = eV_0 \tag{2}$$

From this we can find the work function for the material to be

$$h\nu_0 = h\nu - eV_0 \tag{3}$$

Thus photoelectric effect provided an independent verification of the Planck's hypothesis used to explain the black body radiation spectrum.