PHOTO-ELECTRIC EFFECT

Photo electric emission is the phenomenon in which a good number of substances, mainly metals, under the influence of suitable radiations, such as γ-rays, X-rays, ultraviolet light and even visible light, emit electrons. By different experiments and observations, following characteristics regarding photoelectric emission were noted:

1. Photoelectrons are negatively charged particles. They are nothing but electrons as the value of e/m for these particles is the same as that for electrons.
2. The possibility of photo emission from a given surface is determined by the frequency of the incident radiation. Of the frequency is less than a certain limiting value, called "**threshold frequency**" ϑ_0, no photo-emission will take place.
3. The value of the threshold frequency ϑ_0 depends upon the nature of the emitter.
4. The intensity of incident radiation does not at all determine whether photo-emission will take place or not. A weak radiation of frequency greater than ϑ_0 is capable producing photoelectric effect, while a radiation of frequency less than ϑ_0 fails to affect photo emission however intense the incident radiation may be.
5. For a given emitter and for a given monochromatic radiation, the photo-electrons will have speeds ranging continuously between zero and a maximum value v_{max} (say).
6. The value of v_{max} is independent of the intensity of the incident radiation but depends on the frequency of the incident radiation.
7. If V_s is the magnitude of the least **retarding potential** (negative potential) which prevents the photo current to flow, then ---- $eV_s = \frac{1}{2}mv_{max}^2$; here "e" and "m" are the charge and mass of an electron.
8. The value of V_s, known as **Stopping potential**, is found to vary linearly with ϑ as indicated by $V_s = k(\vartheta - \vartheta_0)$, where k is a constant independent of the nature of the material.
9. For a given material, as the frequency of the incident radiation increases, the value of the stopping potential (V_s) also increases negatively i.e. decreases [Fig. 1].
10. When a curve is drawn by plotting the number of photo electrons (n) emitted against the corresponding energy, a distribution curve of the adjoining form is obtained [Fig. 2]. It shows that, maximum numbers of photoelectrons are emitted with the average energy and the number of photo electrons emitted with very high or low energy is zero.

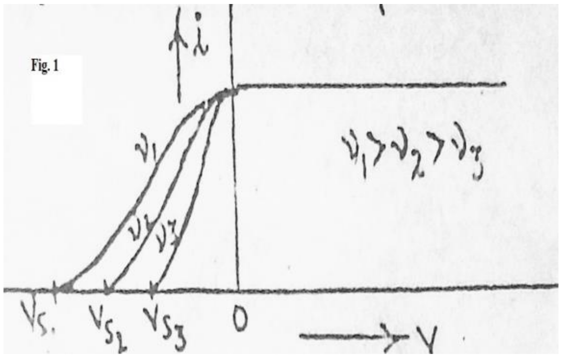
Fig. 1

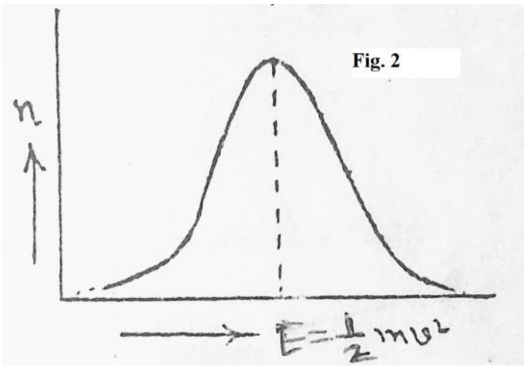
Fig. 2

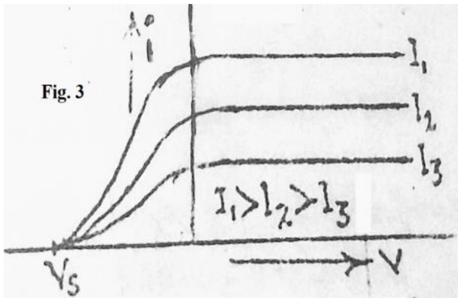
Fig. 3

11. If the frequency of the incident radiation is above ϑ_0, the photoelectric effect i.e. photo current I is found to be directly proportional to the intensity (I) of the incident radiation [Fig. 3].
12. The photoelectric emission is an instantaneous process. The time lag between irradiation and emission of photo electrons is of the order of 10^{-9} sec.
13. Photo emission process is highly selective. Very few atoms of the emitter actually participate in the emission process. For Na, the best material for photoemission, only 1 in 10^3 atoms takes part in this process.

Failure of Classical Theory:

1. According to the classical theory, electrons of all atoms have the same possibility in taking part in the process of photo emission. But, only a very few atoms actually take part in the process.
2. Classically, of the intensity of the incident beam increases, the energy of the emitted photo electrons must also increase which in direction contradiction with the experimental results.
3. Classically, the process of photo electric emission must take an appreciable time. But, practically, this is an instantaneous process.
4. The time required during the photo electric emission process must decrease with the increase of intensity of the incident beam according to the classical theory which is not observed experimentally.
5. Classically, number of photo electrons emitted must not change with the change in intensity of the incident radiation. However, reversed results are observed experimentally.

Thus classical theory i.e. electromagnetic theory of light is not able to explain the phenomena in connection with photo-electric emission.

EINSTEIN'S PHOTO-ELECTRIC EQUATION

Einstein applied Quantum theory of light to the problem of photo-electric emission. According to this theory, radiant energy is propagated in terms of photons each having energy E = h ϑ, where "h" is Planck's constant and ϑ is the frequency of radiation.

Einstein assumed that when a radiation falls on the surface of an emitter, an inelastic collision takes place between a photon and an electron of the atoms and the energy of the photon is completely absorbed by the electron.

Now the electron may exist in millions of energy states inside the substance (say, a metal). Let W_i be the initial energy of such an electron lying in an energy state. When this electron absorbs a photon of energy h ϑ, its energy becomes (W_i +h ϑ). If W be the energy required to liberate the electron from zero initial energy level, the K.E. of the emitted photo-electron will be given by;

$W_i + h\vartheta = W + \frac{1}{2}mv_e^2$; where v_e is the emission velocity of the photo-electron.

Therefore, $\frac{1}{2}mv_e^2 = h\vartheta - (W - W_i)$

Depending upon the value of W_i, ejection velocity v_e of the electron will vary, being maximum when $(W-W_i)$ is minimum i.e. W_i is maximum.

Therefore, $\frac{1}{2}mv_{(e)max}^2 = h\vartheta - (W - W_{imax})$

Where W_{imax} is the energy of the highest energy level. if $(W-W_{imax}) = h\vartheta_0$, where ϑ_0 is the threshold frequency, then

$$\boldsymbol{\frac{1}{2}mv_{(e)max}^2 = h(\vartheta - \vartheta_0)}$$

This is known as Einstein's photo-electric equation.

<u>Characteristics of Photo-Electric Equation:</u>

1. If, $\vartheta < \vartheta_0$, $(v_e)_{max}$ is imaginary. So no photo-emission will occur.
2. Now, $\vartheta_0 = \frac{W-(W_i)max}{h}$. As W and $(W_i)_{max}$ vary from matter to matter, the value of ϑ_0 varies with emitter.
3. As intense beam means more supply of photons and the energy of photons depends only on the frequency of the incident radiation, photo-emission will not take place whatever be the intensity if $\vartheta < \vartheta_0$.
4. Due to almost continuous variation in energy state in an emitter, $(W - W_i)$ varies almost continuously. As most of the electrons have energy less than $(W_i)_{max}$ in normal condition, their velocity will vary from zero to maximum.
5. As W is constant for a given emitter, the energy and hence the velocity (v_e) of the photo-electron varies proportionately with the frequency ϑ of the radiation.
6. As the increase in intensity means more photons, the number of collisions resulting photo-electric emission would increase but the nature of collision will remain unaltered. Therefore, each electron would require same energy and hence acquire the same velocity regardless of the intensity.
7. Above the threshold frequency, the increase in intensity of radiation means the involvement of larger number of photons and atoms. So assuming a constant value for the probability of absorption of photons by an atom, the photoelectric current increases with the increase of the intensity of radiation.
8. As this is a collision process between a photon and an electron, the process is instantaneous.
9. Since photons are distributed in some discrete points, they cannot initiate all the atoms of the emitter surface. Hence photo-electrons will be emitted only by some particular atoms of the emitter.