Experimental Study of Photoelectric Effect

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***Abstract*: The photoelectric effect is widely studied in schools and institutions. It is common knowledge that in order for photoelectrons to be emitted, the energy of the incoming photons must be greater than the work function of the irradiated metal (i.e. hv > hv0). This paper provides experimental evidence for the effect of intensity of light, effect of stopping potential on photoelectrons. The number of photoelectrons emitted per second is proportional to the intensity of incident radiations. When incident light falls on the metal with suitable frequency then, photons are emitted. It is found that the photoelectric current increase with the increase in accelerating potential till a stage is reached when the photoelectric current becomes maximum and does not increase further with the increase in the accelerating potential. According to Einstein's theory, if v <v0, then kinetic energy of photoelectrons becomes negative. So, photoelectric emission does not occur below the threshold frequency. K.E. of electron increase linearly with the frequency of the incident radiations and independent of the intensity of incident radiation. There is no time lag between the incidence of a photon and the emission of photo electrons.**

***Keywords*: Glass tube, metal plate, voltmeter.**

1. Introduction

In recent years, the rapid development of electronic technology, also led to the development of a variety of weak physical measurement, such as weak light, weak current, micro wave, micro vibration and so on. Detection method for most of its electricity conversion through the sensor, the measurement object is converted into electricity, method of measuring points are many, such as coherent measurement, computer processing method, discrete signal statistical average method. The photoelectric effect plays a prominent role in helping students build their understanding of the photon model of light. According to Hertz's observations the high voltage spark passed across metal electrodes of the detector loop more easily when the cathode was illuminated by ultraviolet light from the lamp. This UV light caused emission of electrons from the metal surface. We had earlier developed inquiry-based instructional material of this topic for A-level physics [1]. Through our interactions with teachers and analyzing the student reasoning difficulties, we realized that the information presented in typical A-level and introductory undergraduate textbooks on the topic was not sufficient to address and resolve some of the more intricate questions from teachers and students. This motivated us to seek ways to bridge the gap by explaining the finer aspects of the photoelectric effect in a manner that was accessible to teachers and students at A-level [2]. Among the ideas discussed were the angular distribution of photoelectrons and its effect on the I–V curve [3], and the possibility of multi-photon photoelectric emission [4, 5]. The idea most intriguing for us, however, was the fact that the often quoted Einstein photoelectric effect was actually misleading and incorrect! In this paper, we seek to experimentally investigate the validity of the more correct but non-intuitive form of the photoelectric equation $eVs = h\nu - \varphi_{collector}$. From this point on, we use the term 'emitter' instead of anode to represent the metal electrode or plate that is subjected to direct radiation and the term 'collector' instead of cathode to represent the other electrode. This is done to avoid confusion as the potential of the emitter may be higher or lower than that of the collector. In addition, it should also be noted that the plate called emitter does not necessarily always emit.

2. Experimental study of photo electric effect

In the following study, the explanations of (i) the effect of intensity of light on photoelectric current, (ii) potential on photoelectric current, and (iii) frequency of incident radiation on stopping potential.

- *Effect of intensity of light on photoelectric current:* If we allow radiations of a fixed frequency to fall on plate P and the acceleration potential difference between the two electrodes is kept fixed, then the photoelectric current is found to increase linearly with the intensity of incident radiation. Since the photoelectric current is directly proportional to the number of photoelectrons emitted per second, this implies that the number of photoelectrons emitted per second is proportional to the intensity of incident radiation.
- *Effect of potential:* (Fig. 2) If we keep the intensity I1 and the frequency of incident radiation fixed, and increase the positive potential on plate A. It is found that the photoelectric current increases with the increase in acceleration potential till a stage is reached when the photoelectric current becomes maximum and does not increase further with the increase in the accelerating potential. This maximum value of the photoelectric current is called the saturation current. At this stage, all the electrons emitted by the plate C are collected by the plate A. Now, if we apply a negative potential on plate A with respect to plate C (Fig.1) and increase its magnitude gradually, it is seen that the photoelectric current decreases rapidly until it

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becomes zero is called cut off or stopping potential.

- For a given frequency of incident radiation, photoelectrons are emitted with all velocities ranging from zero to a certain maximum value v_{max}. At the stopping potential v_0, when no photoelectrons are emitted, the work done by stopping potential on the fastest electron must be equal to its kinetic energy. Hence

$$K_{max} = mv^2_{max}/2 = eV_0$$

- *Effect of frequency of incident radiation on stopping potential:* (fig. 3 & 4). To study the effect of frequency on photoelectric effect, the intensity of incident radiation at each frequency is adjusted in such a way that the saturation current is same each time when the plate A is at a positive potential. The potential on the plate A is gradually reduced to zero and then increased in the negative direction till stopping potential is reached. The experiment is repeated with radiations of different frequencies.

Einstein in 1905, explained photoelectric effect on the basis of planck's quantum theory according to which a light radiation travels in the form of photons. The energy of each photon is $h\nu$, where h is planck's constant [6] and ν is the frequency of light. This theory showed that:

- Photoelectric emission is the result of interaction of two particles- one a photon of incident radiation and the other an electron of photosensitive metal.
- The free electrons are bound with in the metal due to force on the surface. The minimum energy required to liberate an electron from the metal surface is called work function W_0 of the metal
- Each photons interact with the one electron. The energy $h\nu$ is used in two parts: a) a part of energy liberated electrons from photons which is equal to W_0 of the metal, b) remaining energy of the photon used in kinetic energy for ejected electron

Energy of the incident photon = maximum K.E. of photoelectron + work function.

$h\nu = mv^2_{max}/2 + W_0$

$K_{max} = mv^2_{max}/2 = h\nu - W_0$ (1)

If threshold frequency is ν_0, then photon energy $h\nu_0$ is sufficient to free the electron from the metal surface. So, $h\nu_0 = W_0$. Then equation 1 becomes,

$K_{max} = h\nu - h\nu_0$ (2)

Equation 1 and 2 can be used to explain the law of photoelectric effect are:

- *Effect of intensity:* the increase of intensity means the increase number of photons striking the metal surface per unit time. Each photon ejects only one electron. So, the number of ejected electrons increase with increase in intensity of incident radiations.
- *Threshold frequency:* If $\nu < \nu_0$, then kinetic energy of photoelectrons becomes negative. So, photoelectric emission does not occur below the threshold frequency.
- *Kinetic energy:* K.E. of electron increase linearly with the frequency of the incident radiations and independent of the intensity of incident radiation.
- *Time lag:* there is no time lag between the incidence of a photon and the emission of photo electrons.

3. Figures

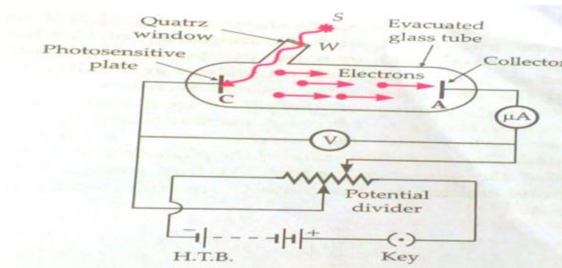

Fig. 1. Experimental arrangement to study photo electric effect

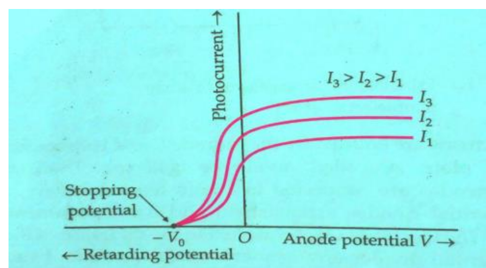

Fig. 2. Variation of photoelectric current with the anode potential

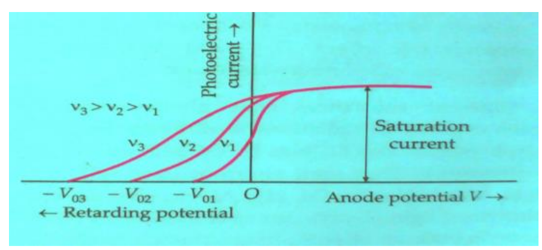

Fig. 3. Variation of photoelectric current with anode potential for different frequencies of incident radiation

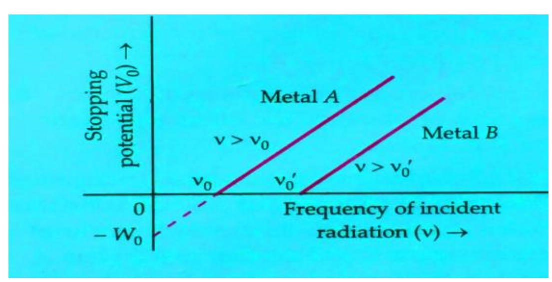

Fig. 4. Variation of stopping potential with frequency of incident radiation

4. Conclusion

This paper presented an experimental study of photoelectric effect.

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