Q.1. (a) What is photoelectric effect? How it is experimentally studied ?
(b) What are the major features of photoelectric effect?
(c) Discuss the failure of classical physics and the success of Einstein's photon concept in explaining photoelectric effect.

(a) PHOTOELECTRIC EFFECT

The phenomenon in which electrons are emitted from a metal surface (photo sensitive plate) when it is illuminated with a high frequency of electromagnetic radiations is called photoelectric effect and the process is called photoelectric emission. The electrons emitted in this process are called photoelectrons and the current produced due to these photo electrons is called photoelectric current.

Modern applications of the photoelectric effect are automatic door openers, burglar alarms, television cameras, exposure meters and many other photo-electronic devices.

Explanation

The photoelectric effect was first observed by Hertz in 1887.Atypical arrangement for the study of photoelectric effect is shown in the fig (1.1).

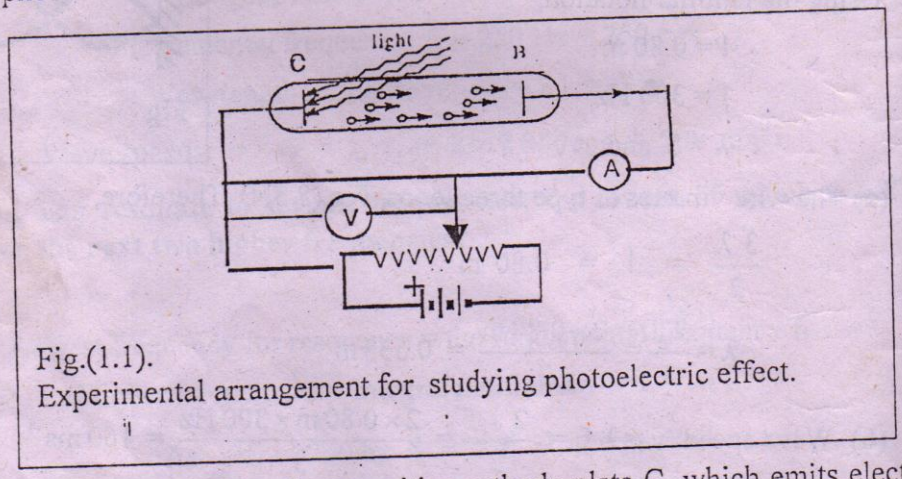


Fig.(1.1).
Experimental arrangement for studying photoelectric effect.

Light from a source shines on a photosensitive cathode plate C, which emits electrons. Another plate B at a positive potential with respect to the cathode acts as a collector of photoelectron ejected from the cathode. The two plates are sealed in an evacuated tube and are connected externally to a variable voltage source and a sensitive galvanometer or an ammeter. These photo electrons move across the tube to the positive collector and carry current (photoelectric current) through the tube. When the light is switched off then the current through the circuit will be stop.

Photoelectric current is found to depend on two factors :

1 **The intensity of the incident light (Note First it depends on intensity and then frequency)**

2 The frequency f of the light.

(b) Experimental results of Photoelectric Effect :

The experimental findings about photoelectric effect are the following:

(i) Threshold Frequency :

The minimum frequency required to initiate photoelectric effect is called threshold Frequency or cut off frequency (f_o).

No matter how intense the light may be, no photoelectron are emitted, if the frequency of the light is less than a certain minimum frequency f_o. The value of the threshold frequency depends on the nature of the photosensitive cathode. For most metals f_o is in the blue or ultraviolet region of the electromagnetic spectrum.

(ii) Instantaneous Effect :

Photoelectric effect is an instantaneous process. No matter how weak the beam of light is, if its frequency $f > f_o$, electrons are emitted at the instant the light strikes the cathode; the photoelectric effect occurs at once with no time delay.

(iii) Dependence on Light Intensity :

With $f > f_o$, the number of photo electrons emitted from the cathode is directly proportional to the intensity of the light beam. The number of photoelectrons ejected depends upon the intensity of incident light. The maximum kinetic energies of the photo electrons do not depend on the intensity of the light. It depends on the frequency of the incident light.

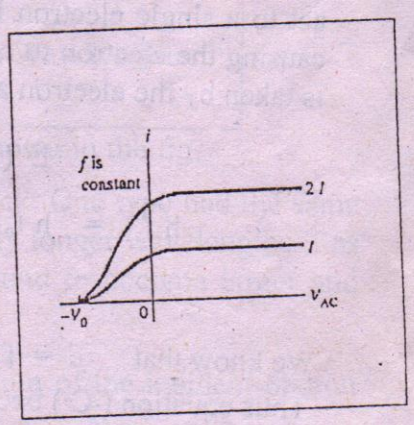
(iv) Maximum Kinetic Energy :

The maximum kinetic energy $(KE)_{max}$ of the ejected electrons is determined by reversing the battery in the circuit and making the cathode C negative with respect to the collector B. As C is made more and more negative the current rapidly decreases and stops at some definite retarding potential V_o which is called the stopping potential (stopping voltage) detected by the voltmeter.

The maximum kinetic energy lost by an electron of charge (e) in moving up the retarding potential (V_o) is given by :

$$(KE)_{max} = \frac{1}{2} m v_{max}^2 = e V_o \quad \text{------ (A)}$$

(v) The maximum kinetic energy is measured for light of different frequencies. The graph of KE_{max} against the frequency of the light is found to be a straight line as shown in Fig. (19.10).



The equation of the line is

$$(KE_{max}) = eV_o = hf - hf_o$$

$$(KE_{max}) = h(f - f_o) \text{ ------- (B)}$$

where , h is the slope of the line and f_o is the threshold frequency.

(c) Failure of the Classical Wave Theory to explain photo electric effect

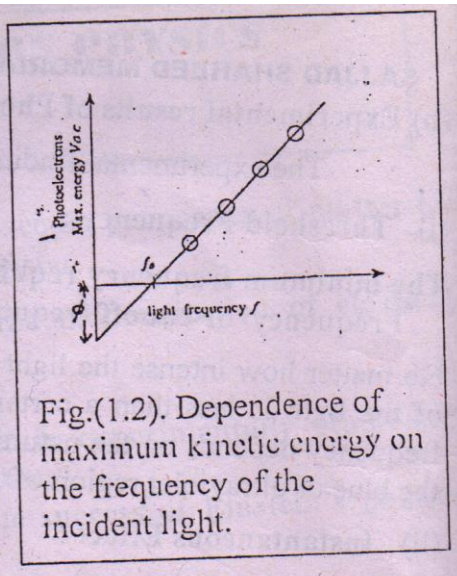


Fig.(1.2). Dependence of maximum kinetic energy on the frequency of the incident light.

According to the classical electromagnetic wave theory , light consists of oscillatory electric and magnetic fields that carry electromagnetic energy. When light wave strike qa metal surface , they transfer energy to electrons in the metal. These electrons , after acquiring energy from light waves, escape out of the metal. The classical electromagnetic theory failed to explain :

1. Why photoelectrons cannot be ejected if the frequency of incident light is less than threshold frequency. Because the classical electromagnetic theory predicts the emission of electrons after absorbing sufficient energy from light waves irrespective to its frequency .

2. Why emission of photoelectrons take place instantaneously even for a very weak intensity of light if its frequency is greater than threshold frequency. While it should not have been possible according to the classical electromagnetic theory.

3. Why the kinetic energy of photoelectrons depend upon the frequency of incident light rather than the intensity of light. Because according to classical wave theory, the velocity of photoelectrons should depend upon the amplitude of incident waves and therefore upon the intensity of light rather than the frequency of light.