M_1: Determination of the threshold frequency for the material of a photocathode and hence find the value of the Planck's constant

The experiment is based on the phenomenon of the photoelectric effect.

Photoelectric effect

When light or any other electromagnetic radiation of suitable wavelength (or frequency) falls on metal surfaces, electrons are ejected from these metals. This phenomenon is called the photoelectric effect. Although electrons emitted in this process are not different from ordinary electrons, they are usually referred to as photoelectrons.

From experimental studies, the following characteristics of the photoelectric effect were established.

i. Photoelectric current is directly proportional to the intensity of radiation.

ii For every metal there is a limiting or critical value of the frequency of the incident radiation, below which no photoelectrons are emitted. This limiting frequency is called the threshold frequency whose value depends on the nature of the material irradiated, i.e. different for different materials.

iii. The stopping potential is independent of the intensity of the incident radiation but is directly proportional to the frequency of the radiation. The stopping potential is defined as that value of the retarding potential difference between the two electrodes with the photocathode positive, which is just sufficient to halt the most energetic photoelectrons emitted i.e., to reduce the photoelectric current to zero.

Theory:

Einstein's photoelectric equation

Einstein explained the photoelectric effect based on Planck's quantum theory of light. According to quantum theory, light consists of energy quanta

$$E = h\nu \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

where ν is the frequency of the light and h is the Planck's constant. These quanta are known as photons. Thus, according to Einstein, radiation is regarded as a shower of photons each of energy $h\nu$ moving in space with the speed of light. When a single photon is incident on a metal surface, it is completely absorbed by atom. The energy is subsequently imparted to one of the electrons of the atom. This energy is utilized for two purposes;

(1) Partly for getting the electron free from the atom. This energy is known as photoelectric work function of the metal and is represented by $\phi = h\nu_0$ or W_0.
(2) The balance of the photon energy is used by the free electron to gain a Kinetic energy of $\frac{1}{2}mv^2$, where, m is the mass of electron and v is the velocity of electron.

Einstein expressed this assumption in his photoelectric equation as

$$h\nu = \phi + \frac{1}{2}mv^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

where,

$h\nu$	=	energy of the incident photon
ϕ	=	work function of the photocathode material
$\frac{1}{2}mv^2$	=	maximum kinetic energy of the emitted electrons.

Now, if ν_0 is the threshold frequency for the material of the photocathode, then it can be shown that $\phi = h\nu_0$. And, if V_s is the stopping potential for the frequency ν of the incident radiation, then the maximum kinetic energy of the emitted photoelectrons is,

$$\frac{1}{2}mv^2 = eV_s \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

where, e is electronic charge.

So, $$h\nu = h\nu_0 + eV_s$$

or, $$V_s = (h/e)\nu - (h/e)\nu_0 \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (4)$$

Experimental arrangement for the photoelectric effect:

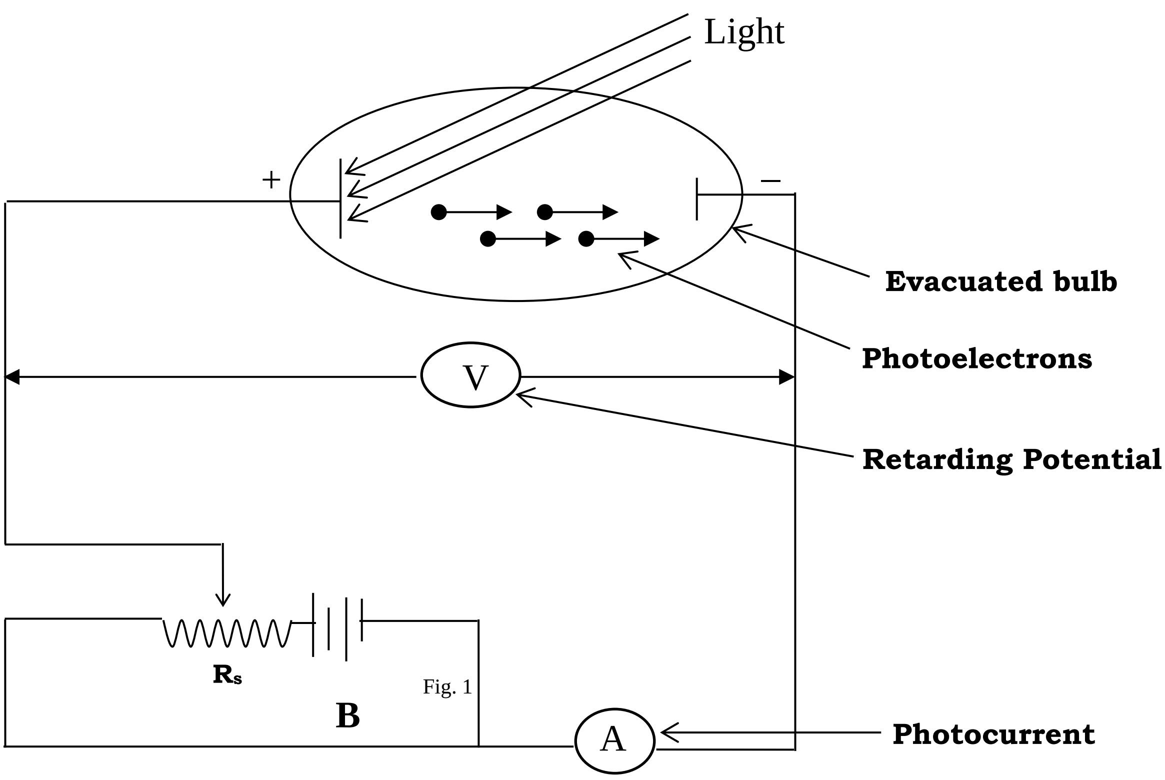

Fig. 1: Experimental arrangement for the photoelectric effect

Apparatus

Photocell:

The photocell consists of a photo-metal as the cathode (Photocathode) and another electrode as the anode enclosed in an evacuated glass bulb. When light is allowed to fall on the photocathode, electrons are emitted by the photocathode. These are drawn towards the positively charged anode. This flow of electrons from the cathode to anode constitutes what is known as the photoelectric current which can be measured by an ammeter.

Procedures:

1. a) Initially when the ‘Power Switch’ and ‘Indicator’ are switched off, set the ‘Current Multiplier’ in ×0.01 position.
   b) Set the ‘Display Mode’, ‘Light Intensity’ and ‘Voltage Adjustor’ in the extreme left position. Keep the light source at a fixed distance (~20cm).
   c) Now set the ‘Voltage Direction’ in the (-) ve direction and insert the light shielding plate in the filter inlet. Connect the power cord to the main source and then turn on the power switch. Switch on the ‘Indicator’ and wait until the reading of the current (μA) displays as zero.
2. Replace the light shielding plate with a filter of known wavelength.
3. Keep the Light Intensity at its lowest (I_1). Then record the value the of current from ‘Display Mode’.
4. Now rotate the ‘Voltage Adjustor’ in such a way that the value of the current becomes zero. In this case, change the position of ‘Display Mode’ to the extreme right and record the value of voltage as stopping potential.
5. Now repeat the above procedures described in 4 & 5 for higher intensities. Thus, you will get stopping voltages for different intensities. Each time change the ‘Voltage Adjustor’ to the extreme left position before taking the reading of current for different intensities.
6. Repeat the above procedures described in 4, 5 & 6 for different filters and obtain the corresponding values of current and stopping potentials.
7. Draw a curve taking the frequency of the radiation in the X-axis and the stopping potential in the Y-axis. The resulting curve will be a straight line (Fig. 2). When the straight line is produced backwards, the intercept with the X-axis gives the value of the threshold frequency ν_o. Now from equation 4, you have,

   $$h = e\frac{V_s}{\upsilon - \upsilon_o} = e\frac{\Delta V_s}{\Delta \upsilon} = e\frac{m}{n} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (5)$$

   Where m and n are the values to be taken from Fig. 2 as shown. Knowing the value of electronic charge e, Plank’s constant h, can be calculated.

Table: Data for the determination of threshold frequency and Plank's constant

Intensity of the light	Name of the filter	Wavelength of the filter, λ(Å)	Frequency, ν (Hz)	Photocurrent, i (μA)	Stopping potential, V_s (V)	Average stopping potential, ν_s (V)	Threshold Frequency, (Hz) (from graph)
I_1 I_2 I_3 I_4							
I_1 I_2 I_3 I_4							
I_1 I_2 I_3 I_4							

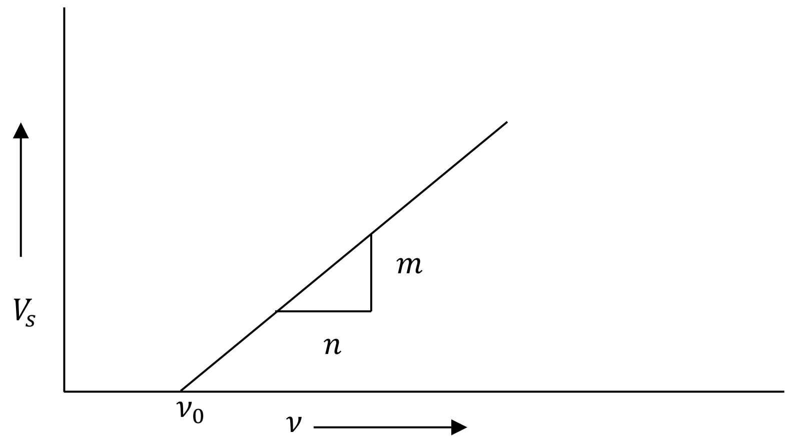

Fig. 2: Frequency ν vs V_s graph

Precautions

[a] Handle the filters very carefully.
[b] You have to take experimental data at four different intensities of light. Start the experiment from the lowest intensity of the light.