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 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 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 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

$$E = h\nu \qquad \ldots \qquad \ldots. \qquad (1)$$

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 $\Phi = h\nu_o$ or W_o.
(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

$$h\nu = \Phi + \tfrac{1}{2}mv^2 \quad \ldots \quad \ldots \quad (2)$$

Where,

$h\nu$ = energy of the incident photon

Φ = work function of the photocathode material

$\tfrac{1}{2}mv^2$ = 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

$$\tfrac{1}{2}mv^2 = e.V_s \quad \ldots \quad \ldots \quad (3)$$

where, "e" is electronic charge.

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

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

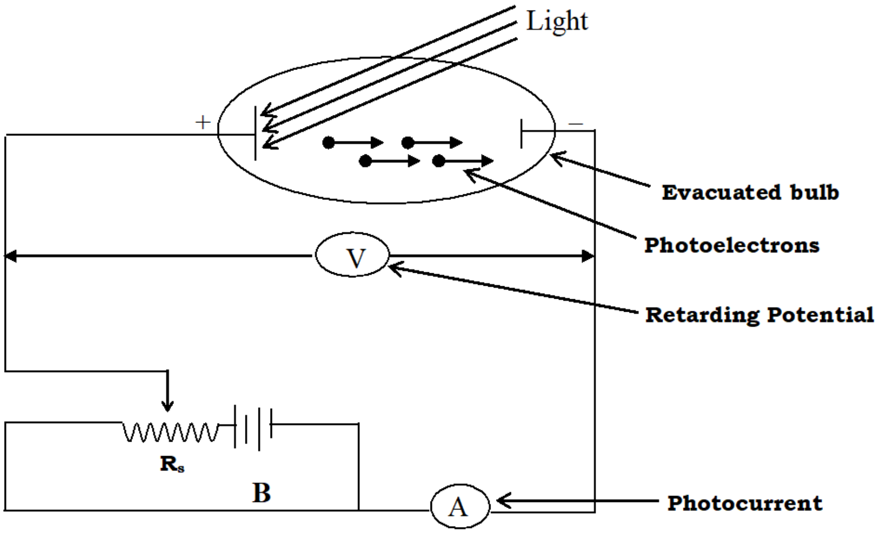

Fig. 1 Experimental arrangement for the photoelectric effect

Apparatus

Photocell:

The photocell consists of a photo-metal as the cathode (Photocathode) and another electrode as anode enclosed in a 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 cathode to anode constitutes what is known as photoelectric current which can be measured by an ammeter.

Procedure:

1. (a) Before connecting the power switch, turn off both the power switch and the sensitivity select switch.

   (b) Turn the anode voltage adjusting dial and the light adjusting dial to the extreme left position.

(c) Insert light shielding plate in the filter inlet.

2. Now connect the power cord with main source and then turn on power switch.
3. Set the Inter./Exter. switch of the micro ammeter to "inter", the sensitivity select switch to 0.1 or 1, and Meas./Calib, Switch "Meas". If the indicator of micro ammeter does not point 0, at this time, adjust it to 0 by using the zero-adjusting dial.
4. As the next stage, change the meas./calib, switch to calib', if the indicator of the micro ammeter pointer does not read 100, adjust it to 100 by turning gain the adjusting dial.
5. Set the 'Meas'. 'Calib.' 'Switch to Meas' again.
6. Replace the light shielding plate with a filter and keep the intensity of the bulb in its lowest position.
7. When the micro ammeter is actuated after setting the light adjusting dial to ON to light the lamp, the photo current can be measured. By turning the anode voltage adjusting dial to the right, you will get a stopping voltage when the current in the ammeter becomes zero.
8. Now repeat the above procedure for higher intensities. Thus, you get stopping voltages for different intensities.
9. Now change the filter and repeat the above procedure described in 7 & 8.
10. Before turning off the apparatus, keep the intensity knob in its lowest intensity position.
11. 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,

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

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.

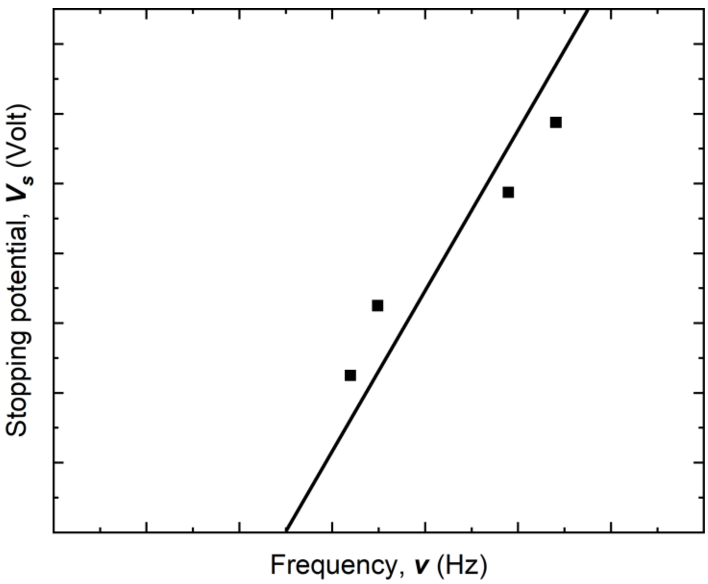

Fig. 2

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)	Photo current I (mA)	Stopping potential V_s (V)	Average stopping potential V_s (V)	Threshold Frequency, ν_o (Hz) (From graph)
I_1	L-39	4046.56					
I_2							
I_3							
I_4							
I_1	L-44	4347.5					
I_2							
I_3							
I_4							
I_1	L-54	5460.74					
I_2							
I_3							
I_4							
I_1	L-58	5769.59					
I_2							
I_3							
I_4							

Calculations:

The intercept with the x-axis =

Slope from graph = $\frac{\Delta V_s}{\Delta \upsilon}$

$$h = e\frac{V_s}{\upsilon - \upsilon_o} = e\frac{\Delta V_s}{\Delta \upsilon} = e\frac{m}{n} =$$

Results:
The threshold frequency for the material of the photocathode is ……………

Planck's constant is ………………….

Error analysis:

Discussion:

Precautions

[a] Handle the filters very carefully.
[b] Your have three different intensities of the light, start the experiment from the lowest intensity of the light.