Experiment No. 1

PLANCK'S CONSTANT

I. OBJECTIVE

Determine Planck's constant 'h' by photocell and demonstrate the inverse square law of radiation.

II. APPARATUS

Vacuum phototube, halogen tungsten lamp, colour filters, regulated power supply, current meter and optical bench.

III. THEORY

Late in the nineteenth century a series of experiments revealed that electrons are emitted from a metal surface when it is illuminated with light of sufficiently high frequency. This phenomenon is known as the photoelectric effect. It was found that the energy distribution of the emitted electrons (called photo-electrons) is independent of the intensity of the light. A strong light beam yields more photoelectrons than a weak one of the same frequency, but the average electron energy is the same. The maximum photoelectron energy was found to depend on the frequency of the light. At frequencies below a certain critical frequency characteristic of the metal surface being illuminated, no electrons are emitted. Above this frequency the maximum photoelectron energy, KE_{max}, increases linearly with increasing frequency.

$$KE_{max} = h(\nu - \nu_o) = h\nu - h\nu_o$$

where ν_o is the threshold frequency below which no photoemission occurs, and h is a constant. The value of h, Planck's constant, (6.626×10^{-34} J·s = 4.136×10^{-15} eV·s), is always the same, Φ whereas ν_o varies with the particular metal being ϕ illuminated. The quantity $h\nu_o$ is equal to e, where e is the magnitude of electron charge and is called a work function which is the minimum energy required to remove an electron from the metal surface being illuminated.

$$hv = \frac{1}{2}mv^2 + e\Phi$$

Also, within the limits of experimental accuracy, there is no time lag between the arrival of light at the metal surface and the emission of photoelectrons. These observations cannot be explained by the electromagnetic wave picture of light.

The kinetic energy of emitted photoelectrons is measured by retarding potential technique and the potential at which the photocurrent drops to zero is termed as stopping potential.

$$\frac{1}{2}mv^2 = eV_z$$

$$V_z = \frac{h}{e}v - \Phi$$

So when the stopping potential V_s is plotted against the frequency, the slope yields the value of 'h' and the intercept on y axis gives the work function. Figure-1 shows the schematic of the photoelectric effect.

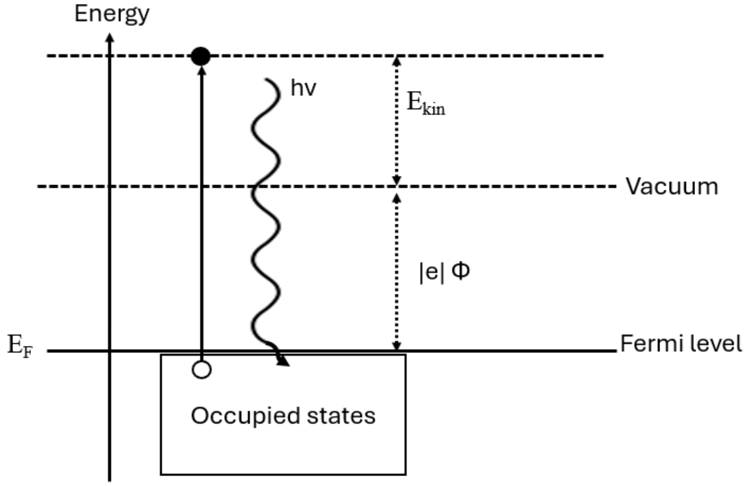

Figure 1: Photoelectric effect

If L is the luminous intensity of an electric lamp and E is the luminescence at point 'r' from it then, **E=L/r²**. Since the light is allowed to fall on the photocathode, the photocurrent 'I' is proportional to E, i.e. **E=CI= L/r²** , where C is a constant. A plot between I and $1/r^2$ should be a straight line.

IV. EXPERIMENTAL SETUP AND APPARATUS DETAILS

The schematic diagram of the setup is shown in Figure-2 and the actual picture of the setup is shown in Figure-3.

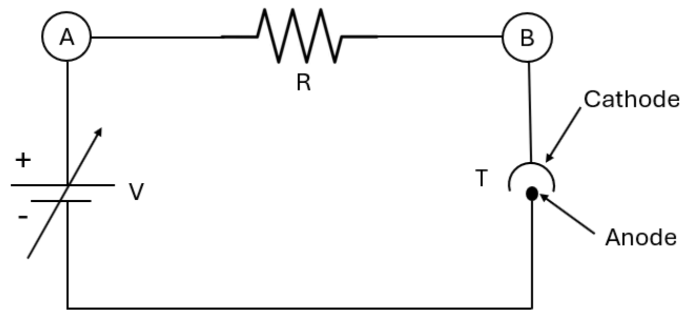

Figure 2: Schematic Diagram of circuit used for Photoelectric effect

The setup consists of a halogen tungsten lamp (12V/35W) whose intensity can be continuously varied. Light, from this source falls on a cathode of vacuum phototube mounted inside a closed chamber. The drawtube attached to the front side of the chamber can hold colour filters at one end and a lens at the other end to focus light onto the photocathode. Five colour filters are provided with the central frequency mentioned on them. Magnitude of the voltage between the anode and cathode can be continuously varied using a ± 15V multi-turn pot and the polarity can also be switched using a switch button. Photocurrent can be read using a digital nano-ammeter. Both the source as well as phototube is mounted on an optical bench of length 40 cm. The source can be moved along this bench to adjust the distance between it and the phototube (which is fixed).

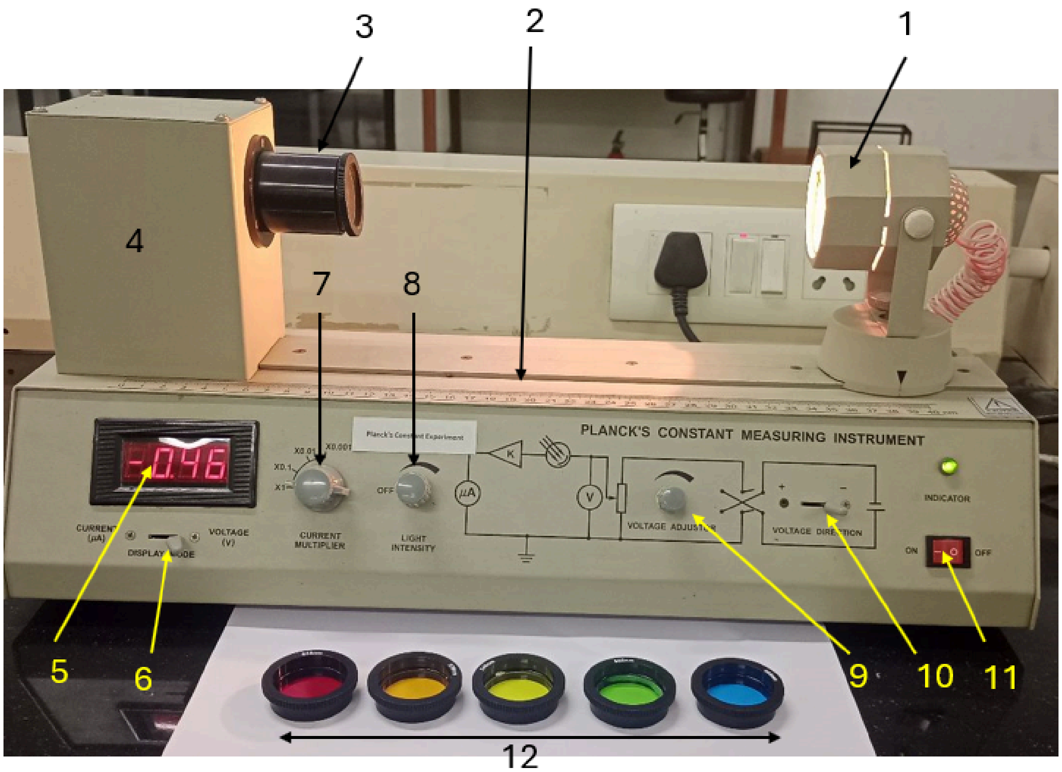

Figure 3: Apparatus for Planck's constant experiment

1.	Halogen tungsten lamp	7.	Current multiplier
2.	Optical bench	8.	Light intensity adjusting knob
3.	Drawtube	9.	Voltage adjusting knob
4.	Cover chamber containing phototube	10.	Voltage direction switch
5.	Display meter (current or voltage)	11.	Power switch
6 .	Display mode switch	12.	Colour filters (#5)

Wavelength of Colour filters in nm:

1.	Blue	480
2.	Green	520
3.	Yellow	565
4.	Orange	590
5.	Red	670

V. PROCEDURE

Part-I: Determination of Planck's constant

(1) Insert the red filter (670 nm) and increase the light intensity to the maximum. Adjust the distance between the source and the photocathode to 25cm. Set the voltage direction switch at '-V' and display mode switch at current display.

(2) Increase the de-accelerating voltage such that the photocurrent drops to zero value. Switch the display mode to Voltage and note down the stopping potential where the photocurrent is zero

(3) Repeat the steps 1 and 2 for all the remaining filters. Make sure that every time when you are changing the filter, light must be switched off. Prepare a table describing central wavelength of the colour filter, the frequency corresponding to it and the stopping voltage.

(4) Set all the knobs to their minimum position and switch off the set-up.

Part-II: Demonstration of inverse square law of radiation

(1) Turn on the setup and insert the red filter(670nm) and set the voltage direction switch to +V and Set the voltage to +0.1 V

(2) Place the source at 40cm from the detector, maximize the intensity of the lamp.

(3) Move the source towards the photocathode in intervals of 2 cm(till the distance between the source and detector is 20cm) and take down readings of photocurrent.

VI. RESULTS AND CALCULATIONS

(1) From Part-I, plot a graph of magnitude of stopping voltage as a function of frequency of filter. Draw a straight line passing through the data points and thus find out the value of 'h' from the slope and the work function, Φ from the intercept on y-axis.

(2) From Part-II, plot a graph of photocurrent as a function of $\frac{1}{r^2}$ and draw a straight line passing through it.

(3) Using the least square fitting method, determine the value of 'h' and Φ and estimate their corresponding errors.

VII. PRECAUTIONS

(1) Phototube is a light sensitive device and its sensitivity decreases with exposure of light. While changing the colour filter, either minimize the intensity of the lamp or block the light directly falling onto the photocathode.
(2) After the experiment is over, minimize the lamp intensity to zero and cover the drawtube with the lens cover provided.
(3) Turn down the applied voltage to zero.

VIII. LEARNING OUTCOMES

(1) Demonstrate photoelectric effect and how to determine the value of Planck's constant using phototube.
(2) Study I-V characteristics of phototube.
(3) Demonstrate inverse square law of radiation.

IX. REFERENCES

1) R.A. Millikan, *Phys. Rev.* **7** 18 & 355 (1916).
2) Arthur Beiser: Perspectives of modern physics.