# EXPERIMENT – 13

**Aim of the experiment:** Determination of Planck's constant using a photoelectric cell based experimental arrangement.

**Apparatus required:** Planck's constant setup having a photoelectric cell, a tungsten light source, an adjustable dc power supply (0 to 10 V dc, with polarity reversal switch), digital voltmeter (0 to 10 V) and a multirange ammeter (0 to 100 μA), Color filter set.

**Theory:** This experiment demonstrates wave-particle duality, where the particle-like behavior of light is clearly observed. When a light beam with a frequency higher than a certain threshold strikes the surface of a metal, the electrons in the metal absorb sufficient energy to become free and are ejected from the metal without any time lag. The minimum frequency required for this effect to occur is known as the threshold frequency, which is characteristic of the metal and is related to its work function. This phenomenon is particularly observable when the metal is in a vacuum or under very low pressure.

Photocurrent is produced only when the light of frequency $\nu > \nu_0$ (threshold frequency) is incident on the metal surface. The ejected electrons have a maximum kinetic energy given by Einstein's photoelectric equation,

$$KE_{max} = h\nu - \varphi$$

$$\frac{1}{2}mv_{max}^2 = h\nu - \varphi \qquad (1)$$

where,
$\varphi\ (= h\nu_0)$ - is the work function of the metal
$\nu$ - is the frequency of the incident light
$m$ - is the mass of the photoelectrons
$v_{max}$ - is the maximum velocity of photoelectrons
$h$ - is the Planck's constant

In order to measure the maximum kinetic energy $\left(\frac{1}{2}mv_{max}^2\right)$ the best way is to apply a retarding field to the electrons so that they are just prevented from reaching the other electrode. This is achieved by applying a voltage $V_s$ across the two electrodes. This voltage, that just prevents electrons from getting collected at the other electrode is known as *stopping voltage*. Consequently, we may write the energy relation as follows.

$$h\nu - \varphi = eV_s \qquad (2)$$

or, $$V_s = \left(\frac{h}{e}\right)\nu - \frac{\varphi}{e} \qquad (3)$$

The above equation is of the form $y = mx + c$, where the slope, $m = \left(\frac{h}{e}\right)$ and the intercept, $c = -\frac{\varphi}{e}$.

**Experimental setup description:** The experimental arrangement for the determination of Planck's constant has several devices and components, all housed in a single unit, duly wired and ready to be used, once powered on using the POWER button. A rail has been provided for positioning the light source against the photoelectric cell housing at a distance of our choice. This enables the adjustment of light intensity that the photoelectric cell receives. The intensity of light can also be altered using a LIGHT INTENSITY, rocker switch provided on the front panel. There is a single digital display unit that serves as a voltmeter as well as an ammeter by appropriately setting the DISPLAY MODE switch. While attempting to read current, the CURRENT MULTIPLIER knob is to be adjusted to a lower value making it more sensitive if it displays zero and is unable to read any current. However, if it shows a '1' at the left most end of the display, that signifies an overcurrent. The CURRENT MULTIPLIER knob needs to be adjusted for reduced sensitivity. The filters can be directly pushed and fitted onto the light input port of the photoelectric cell assembly. VOLTAGE DIRECTION switch and the VOLTAGE ADJUSTER knob can be used to appropriately bias the electrodes of the photoelectric cell.

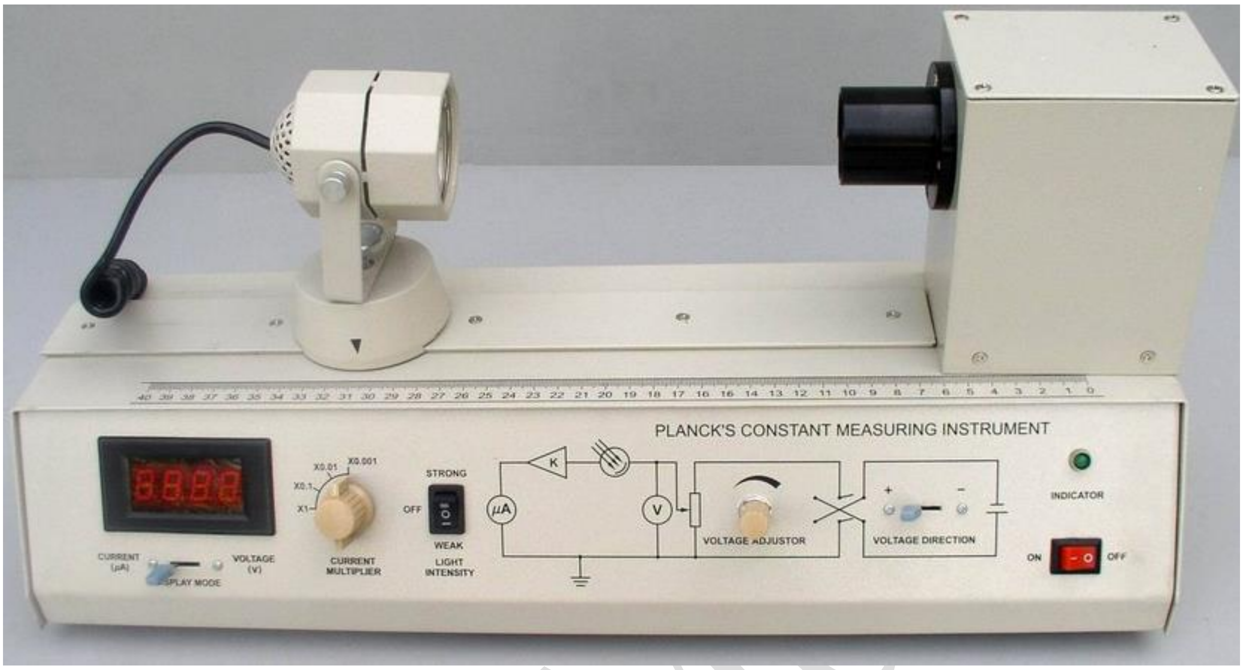



Fig-1: Actual experimental unit for the determination of Planck's constant.

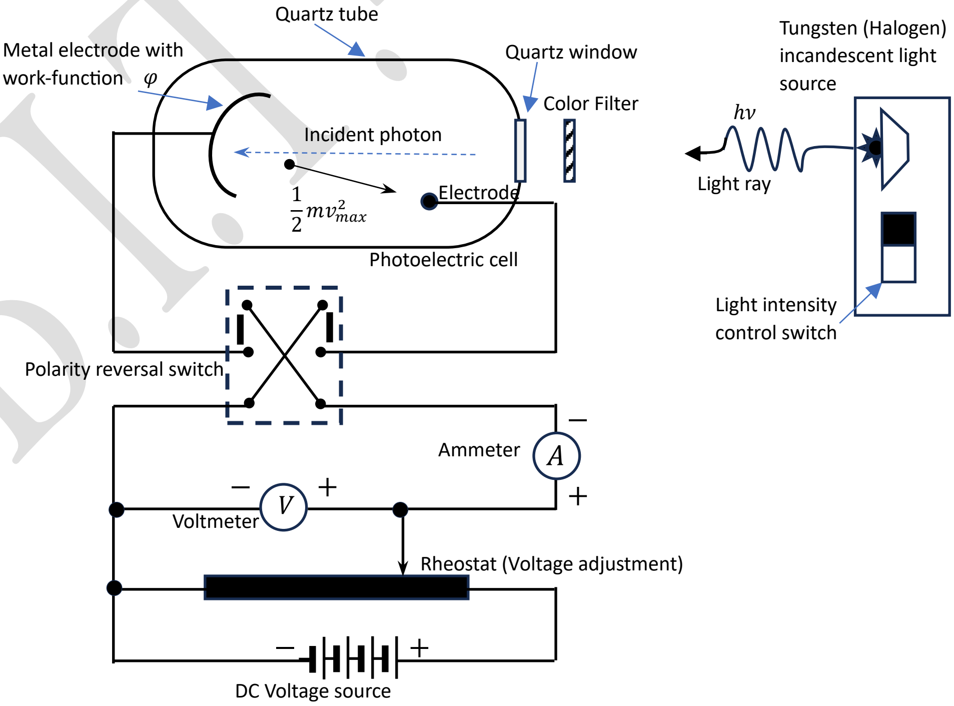



Fig-2: Experimental arrangement for the determination of Planck's constant and work function of the metal inside the photoelectric cell.

**Procedure and precautions:**

For determination of Planck's Constant and work function:

1. Place the setup at a location such that almost no light enters the photo-tube light entrance port.
2. Cover the photo-tube light entrance port so that the light source on the setup also gets shielded.
3. Switch on the light source by powering on the setup and allow the setup some time for all its components to stabilize.
4. Place the red filter on the light entrance port of the photocell, set the intensity control knob at a fairly high level.
5. Push the voltage direction switch towards [ - ], this will be the decelerating voltage for the ejected photoelectrons and the display mode switch towards [CURRENT].
6. Adjust to decelerating voltage to 0 V and set the current multiplier knob at [x 0.001].
7. Increase the decelerating voltage gradually and notice that the photo-current decreases.
8. Adjust the decelerating voltage make the photocurrent just zero. Record the value of this decelerating voltage ($V_s$) which is the stopping voltage for a particular color filter that you have used.
9. Repeat the process for all the color filters that you have been provided and record the data in the relevant columns.
10. Plot a graph of stopping voltage against frequency of light (color of light used). Draw a best fit line for the data points. Obtain its slope and intercept.

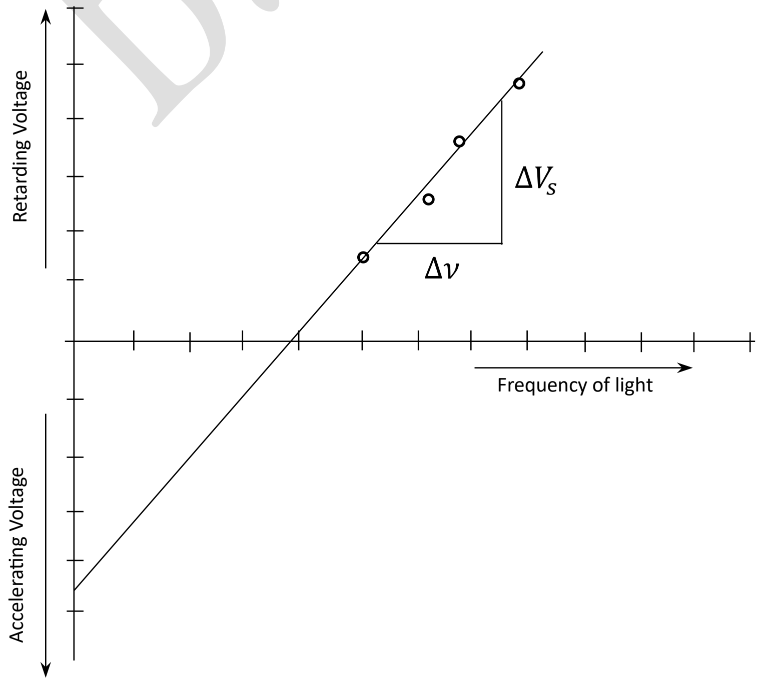
**Observations**

Table-1: Readings for stopping voltage corresponding to each color filter, for the determination of Planck's constant and work-function

| S.No. | Filter (Wavelength) | $\nu\ (\times 10^{14}\ Hz)$ | Stopping Voltage $V_s$ (in Volts) | | |
|---|---|---|---|---|---|
| | | | d = 20 cm | d = 10 cm | d = 5 cm |
| 1 | Red (635nm) | 4.72 | -0.35 | -- | -- |
| 2 | Yellow I (570nm) | 5.26 | -0.54 | -- | -- |
| 3 | Yellow II (540nm) | 5.56 | -0.66 | -- | -- |
| 4 | Green (500nm) | 6.00 | -0.84 | -- | -- |
| 5 | Blue (460nm) | 6.50 | -1.07 | -- | -- |

**Plot and Calculation:**

Mark all the data points on a graph sheet showing $V_s$ along the y-axis and $\nu$ along the x-axis and draw a best fit line. Get the slope, intercept and standard deviation from the plot.



As you can see from equation that, $\frac{h}{e}$ corresponds to the slope $m$ of the straight-line equation, it is easy to determine $h$ as follows

$$h = e \times slope\ of\ the\ plot\ (Joule\ sec)$$

or,
$$h = e \times \frac{\Delta V_s}{\Delta \nu}\ (Js)$$

Standard value of Planck's constant is $h = 6.63 \times 10^{-34}\ (Js)$

The % error in the determination of $h = \frac{|Value\ obtained\ from\ plot - 6.63\times10^{-34}|}{6.63\times10^{-34}} \times 100\%$

The intercept is $\frac{\varphi}{e}$, that is the work-function in electron·volts

**Results and discussion:**

$$Planck's\ constant, \quad h = \_\_\_\_\_\_\_\_\_\_\_\_\ Js$$

$$workfunction, \quad \varphi = \_\_\_\_\_\_\_\_\_\_\_\_\ eV$$

[*discuss your obtained results here!*]

**Conclusion:**

By changing the distance between the photoelectric cell and the light source we actually alter the intensity of light. It is quite evident from the data in table-1, that intensity of light has no bearing on the stopping voltage or in turn on the maximum kinetic energy of the photoelectrons. Intensity can only influence the photocurrent i.e., the number of photoelectrons emitted per unit time, provided the incident light is of frequency higher than the threshold.

The photoelectric effect provides evidence for the particle nature of light.

The photoelectric effect shows that there is a minimum frequency of light, known as the threshold frequency, below which no electrons are emitted from a metal, regardless of the intensity of the light. The kinetic energy of the emitted electrons depends exclusively on the frequency of the incident light and not its intensity.

Intensity of light influences the number of electrons and has no bearing on its energy.

The emission of photoelectrons occurs almost instantaneously, which indicates that the energy of the photons is absorbed by the electrons in a one-to-one interaction.

**Questions for viva:**

1. What is photoelectric effect? What are its key features?
2. What is a photoelectric cell?
3. What is work-function?
4. Write the Einstein's photoelectric equation.
5. What is stopping potential?
6. How can one measure the maximum kinetic energy of photoelectrons inside a photoelectric cell?
7. What is the pressure inside a photoelectric cell?
8. How do you bias the electrodes of a photoelectric cell?

9. What is the effect of intensity on the number of generated photoelectrons and on their energy?