34
Planck's Constant

34.1 THE PHOTOELECTRIC EFFECT

Late in the nineteenth century, it was discovered that electrons are emitted from a metal surface when light of sufficiently high frequency falls upon it. This phenomenon is known as the *photoelectric effect*. The frequency of incident radiation above which the effect starts is known as the *photoelectric threshold*. Most solids emit electrons when this value is in the ultraviolet region of the spectrum although some metals like *sodium*, (Na) *Potassium* (K), *Cesium* (Cs) and *rubidium* (Rb) emit in visible and near ultraviolet region.

The characteristics features of the Photoelectric effects are:

1. The energy distribution in the emitted electrons is independent of the intensity of light and depends only on its frequency.
2. The number of photoelectrons emitted i.e., the photoelectric current is independent of the frequency of the incident light and depends only on its intensity.
3. There is no time lag between the arrival of light at the metal surface and the emission of photoelectrons.

34.2 PHOTOELECTRIC CELL

It is a device for converting light energy into electric energy. There are three types of photoelectric cells:

1. Photo-conductive cell,
2. Photo-voltaic cell and
3. Photo-emissive cell,

In this chapter, we are mainly concerned with a *photo-emissive cell*.

A vacuum-type photo-emissive cell consists of a glass or a quartz bulb. It consists of a cathode in the form of a semi-cylindrical plate which has emissive coating of alkali metal such as sodium, potassium on the side facing the anode. To increase the efficiency of the photocell, composite materials such as caesium on silver oxide or antimony caesium alloy are used as photo cathode materials. The Anode is in the form of a straight wire or a loop of wire of platinum.

The magnitude of the photocurrent in this type of photocell is small. To increase it, the cell is filled with an inert gas like neon or argon at a pressure of a few mm of mercury. Such a cell is called '*a gas-filled photo cell*'.

Experiment 34.1 **To determine the value of Planck's constant by using a photoelectric cell.**

Apparatus: A vacuum type photoelectric cell mounted inside a wooden box with a wide opening on the side opposite to the cathode, 6 Volt DC supply, a voltmeter (0-3 volt with a least count of 0.05 volt), a rheostat, a sensitive moving coil

5 V power supply.

galvanometer with lamp and scale arrangement, a key, a mercury lamp and few light filters.

Theory: When a photon of energy hν is incident on the emissive surface of the cathode, almost all of its energy is transferred to the electron inside the metal. If this energy is greater than the threshold energy W_0, the electron is emitted. W_0 is also called the *work function* of the metal. Above the threshold frequency, corresponding to the W_0 ($= h\nu_0$), photoelectrons have a range of energies from 0 to a certain maximum value, and this maximum energy increases linearly with increasing frequency. This is because, out of the total incident energy $h\nu$, a part W_0 is used up as the threshold energy and the rest is stored in the electron as it's kinetic energy.

Thus
$$h\nu = \frac{1}{2}mv_m^2 + W_0$$
$$= E_{\max} + W_0 \tag{34.1}$$

This Eqn. is called the *Einstein's Photoelectric Equation*

As W_0 remains constant for a given photoelectric cell, $E_{\max}$ varies linearly with the frequency.

In this experiment, to find out the maximum kinetic energy $E_{\max}$ of the emitted electrons, we reverse bias the photoelectric cell i.e., its anode is made negative. It, therefore, repels the emitted electrons and the current decreases. The negative potential on the anode is slowly increased till the *stopping potential* V_s is reached, when the current stops. When this happens

$$eV_s = E_{\max} \tag{34.2}$$

V_s is called the *stopping potential* or *the cut-off potential* because it just stops the electrons from leaving the surface.

From (34.2) and (34.1), we have

$$h\nu = eV_s + W_0$$
$$eV_s = h\nu - W_0$$
$$V_s = \frac{h}{e}\nu - \frac{W_0}{e} \tag{34.3}$$

Thus, if we make a graph with the frequency ν along the *x*-axis and the stopping potential V_s along the y-axis, it would be a straight line with slope equal to $\frac{h}{e}$* and negative intercept on *y*-axis equal to $\frac{W_0}{e}$.

Thus the Planck's constant *h* and the work function W_0 for a given photoelectric cell can be determined.

Procedure

1. Make the connections as shown in Fig. 34.1. *C* and *A* are respectively the cathode and anode of the photocell.
2. Arrange the mercury lamp just in front of the photocell and set the galvanometer so that the spot moves freely.

---

* $\frac{h}{e}$ is also called the photoelectric constant.

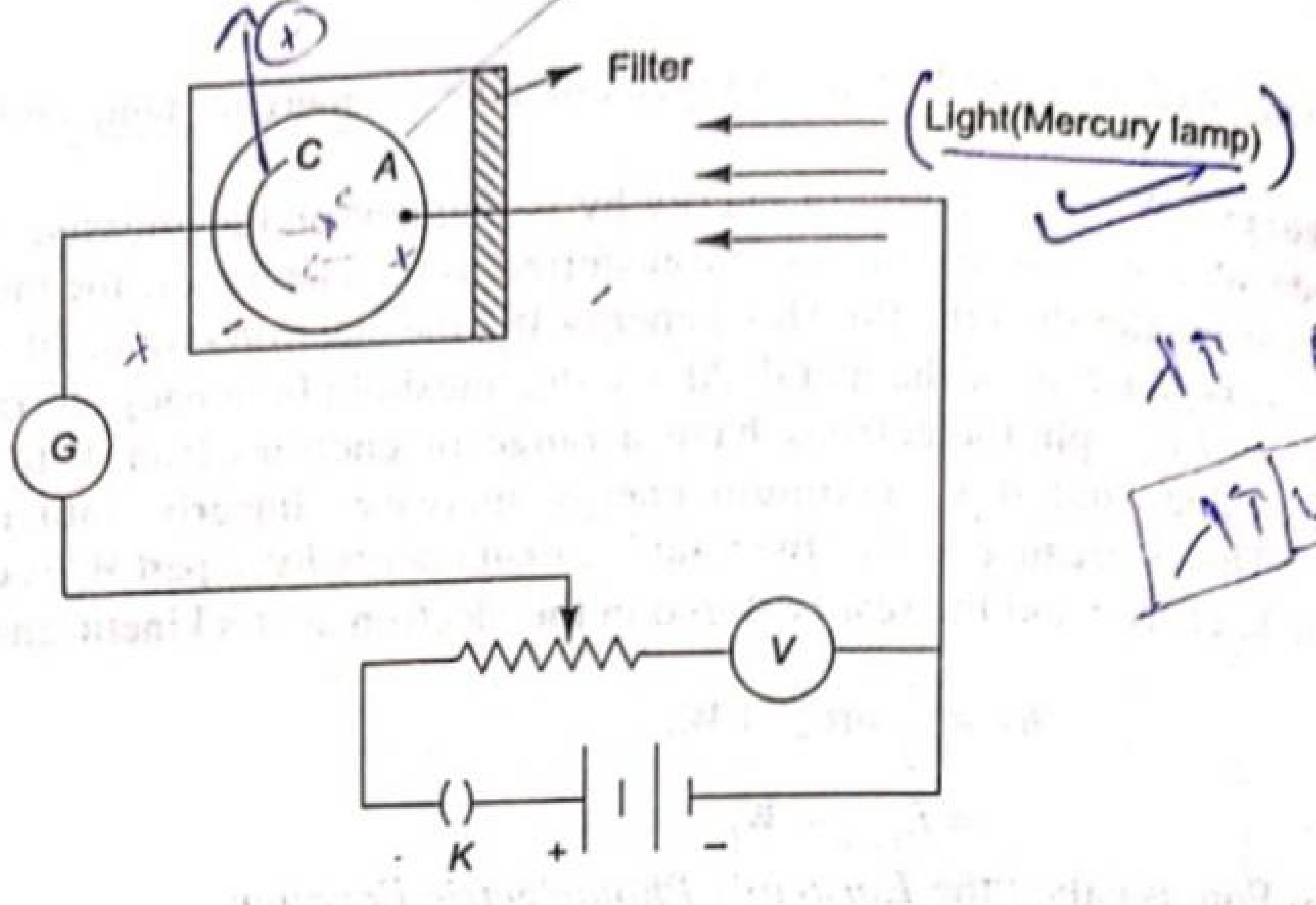

Fig. 34.1

λ↑ E↓

λ↑ V↓

3. With no light falling on the photocell, insert the key in *K*, adjust the voltage in the voltmeter to zero and adjust spot in the galvanometer to zero position. Remove the key.
4. Fit the violet filter in front of the photocell. Switch on the mercury lamp and plug in the key. The galvanometer will show deflection. Adjust the position of the mercury lamp so as to get maximum deflection. Do not move the lamp after this.
5. Increase the potential on anode slowly by the rheostat. The deflection in the galvanometer decrease. Go on increasing the negative potential applied to anode till the spot of light in the galvanometer comes back to zero position. Note down the potential
6. Repeat the observations and take three readings with the same filter.
7. Change the filter one by one from violet to red and repeat the experiment.
8. Make a graph with frequency of the filter ν along *x*-axis and the stopping potential V_s along *y*-axis.

Observations

Least count of the voltmeter = 0.05 V

speed of light, $c = 3 \times 10^8$ m/sec

Filter	*Violet*	*Blue*	*Green*	*Yellow*	*Red*
Wavelength λ(m)	4050×10^{-10}	4360×10^{-10}	5460×10^{-10}	5780×10^{-10}	6910×10^{-10}
Frequency $\nu = \frac{c}{\lambda}$ (*sec*$^{-1}$)					
Stopping Potential V_s (volts) 1					
2					
3					
Mean					

Calculations: The graph between the frequency ν along x-axis and the stopping potential V_s along y-axis is a straight line as shown in Fig. 34.2.

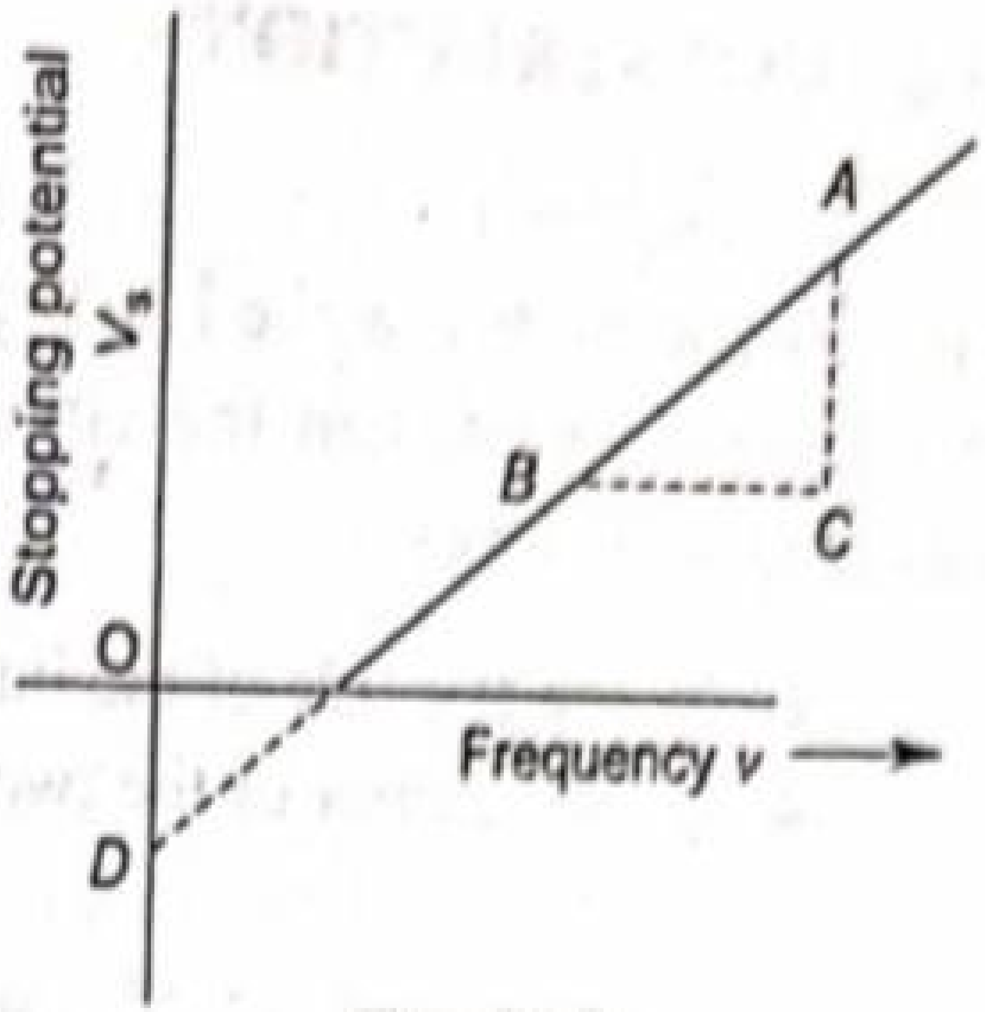

Fig. 34.2

$$\text{Slope of the line} = \frac{AC}{BC} = \ldots$$

$$\frac{h}{e} = \text{slope}$$

$$\therefore \quad \text{Planck's constant } h = e \times \text{slope}$$
$$= 1.6 \times 10^{-19} \times \text{slope}$$
$$= \ldots\text{. J sec.}$$

Negative intercept on y-axis $= OD = \ldots$. Volts

$$\text{Work function } W_0 = OD \text{ eV}$$
$$= e \times \text{OD Joule}$$
$$= 1.6 \times 10^{-19} \times \text{OD Joule}$$

Result: (*i*) The Planck's constant h = ... Joule sec

Actual value = ... Joule sec

% Error = ... %

(*ii*) Work function W_0 for the given photoelectric cell = ... eV

Precautions and Sources of Error

1. Care should be taken to ensure that when no light is falling on the cathode, the deflection in the galvanometer is zero.
2. The position of the mercury lamp should not be changed during the experiment.
3. Care should be taken to note down the stopping potential. The voltage across the photocell should be increased very slowly and three readings should be taken for each filter.

Weak Points

A sharp cut-off may not be obtained due to ionization of the residual air in the cell and due to secondary emission and photoelectric emission from the anode *A*.

34.3 LIGHT EMITTING DIODES (LED'S)

The phenomenon of light emission by electrical excitation of a solid was first observed in 1907 by H.J. Round using Silicon Carbide (SiC). This phenomenon is called *electro luminescence* and is the inverse of Einstein's well known photoelectric effect. The effect can be seen in the light emitting diodes.

LED's or the 'Light Emitting Diodes' are special diodes that emit light when connected in a circuit. LED's that emit visible light are widely used in instrument display indicators, digital watches, calculators etc. LED's that emit invisible infrared light find applications in remote control schemes, object detectors, burglar alarm systems etc.