Structure

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1.1 INTRODUCTION

From your school physics curriculum you may recall that transmission of thermal energy (heat) takes place from one point to another by conduction, convection and radiation. Thermal energy from the sun reaches the earth through radiation. Similarly, when we stand near a fire, we feel heat due to radiation. From your +2 physics, you may be aware that in radiation, energy is transported without active participation of the intervening medium. Do you know that radiation is the main mechanism for energy transfer in large systems such as the solar system, interstellar space and galaxies?

You now know that all bodies radiate by virtue of temperature at the expense of their internal energy. However, the intensity and the rate of emission increase with temperature. For instance, at room temperature, most of the energy is radiated in the far infrared region but at the temperature of the outer surface of the Sun (6000K), it lies in the visible region. You may have seen a blacksmith heating a piece of iron in his furnace to create different implements. The colour of iron changes from dull red to reddish yellow and ‘white’ as it is heated continuously.

You may also recall from your school classes that thermal radiations are electromagnetic in nature and akin to light but for the wavelength, which lies in the infra-red region (> 800 nm) and produces sensation of warmth in human body. That is why an enclosure maintained at a constant temperature can be considered to be filled with electromagnetic radiation in thermal equilibrium with the walls. The electromagnetic radiation trapped in a cavity is called black body radiation and constitutes a simple thermodynamic system.
A complete understanding of the behaviour of black body radiation required scientific creativity of the highest order; it changed physicists’ view of nature and opened totally new perspectives. You will agree that physics is an experimental science and our vast knowledge pool has genesis in the confirmation of theoretical predictions by experiments. Theory is invariably modified in the light of experimental evidences. This happened in the case of blackbody radiation also.

In the early days of blackbody radiation, theoretical explanations were given by Wien and Rayleigh-Jeans based on laws of thermodynamics and the principle of equipartition of energy, which favours continuous energy exchange. These had limited success in explaining the observed results for complete range of wavelengths. In this scenario, Planck made a drastic assumption that radiation involves discontinuous energy exchange. He based his argument on the following two postulates:

- exchange of energy between matter (walls) and radiation (cavity) takes place in bundles of a certain size, and

- the quantum of exchange is directly proportional to its frequency. That is, the energy of an oscillator having frequency \( \nu \) could only be an integral multiple of \( \hbar \nu \), where \( \hbar \) is known as Planck’s constant.

Planck presented the following formula for energy density and succeeded in explaining experimental results of blackbody spectrum in their entirety:

\[
\psi_d = \frac{8\pi \nu^2}{c^3} \left( \frac{\hbar \nu}{\exp(\hbar \nu / k_B T) - 1} \right) d \nu
\]

We can determine the value of Planck constant using a method based on blackbody radiation as well as by using a light emitting diode (LED). For ease and convenience, here we will use the method based on light emitting diodes.

**Expected Skills**

After performing this experiment, you should be able to:

- appreciate internal consistency of concepts in physics;
- plot a graph and identify dependent and independent variables; and
- determine Planck’ constant using LEDs.

### 1.2 THEORY

A light emitting diode is a semiconductor device which emits light when current flows through it. (Infra-red LEDs were first produced in 1962 and used in remote control circuits. The first visible light LEDs were of low intensity and limited to red light. Now-a-days, LEDs are available corresponding to visible, ultra-violet and infra-red wavelengths as well. White light LEDs are used to light our homes.) Essentially an LED is a p-n junction diode made of gallium arsenide or indium arsenide for which energy of **direct band gap** is more than 1.8eV, value necessary for emission of light in visible range. When an electron
combines with a hole, it is accompanied by release of energy in the form of photons. The colour of light is determined by the energy required for electrons to cross the band gap of the semiconductor.

In a forward biased p-n junction with voltage \( V \), electrons gain extra energy \( (= eV) \), and flow across the junction from n region and re-combine with holes in p-region leading to emission of photons. If minimum voltage required for emission of light photon is \( V_0 \), we can write

\[
e V_0 = R + h\nu \quad (1.1)
\]

where \( R \) signifies the energy lost in non-radiative recombination and \( \nu \) is frequency of the emitted photon. Do you know what non-radiative recombination is? It is a process in which electrons and holes combine without emission of a photon. (It means that energy available to the electrons is less than the threshold energy.)

In general, \( R << h\nu \) and we can rewrite Eq. (1.1) as

\[
e V_0 = h\nu = hc / \lambda \quad (1.2)
\]

Note that we have replaced \( \nu \) by \( c/\lambda \); \( \lambda \) being wavelength of emitted radiation.

Eq. (1.2) shows that if we plot a graph by taking \( V_0 \) along y-axis and \( 1/\lambda \) along x-axis, we will obtain a straight line whose slope \( m = hc / e \). Since, velocity of light \( c = 3 \times 10^8 \text{ms}^{-1} \) and electronic charge \( e = 1.602 \times 10^{-19} \text{C} \) are standard known constants, you can easily calculate the value of Planck constant using the relation

\[
h = me / c \quad (1.3)
\]

Before discussing the procedure, we list the apparatus required to perform this experiment.

**Apparatus Required**

LEDs which can emit light of different colours (wavelengths), 5V battery, a rheostat, a voltmeter (0-3V), a milli-ammeter, connecting wires and sand paper.

### 1.3 PROCEDURE

1. Take connecting wires and clean their ends using sand paper. Do you know why connecting wires are made of copper and why should you clean their ends? It is because copper offers almost zero resistance to flow of current and cleaning minimises external resistance.

2. Now refer to Fig. 1.1. It shows the circuit diagram for the determination of \( h \) using LEDs. Here rheostat is being used as a potential divider. In many circuits, rheostat is used as a variable resistor. You would have learnt about the action of a rheostat as a potential divider or a variable resistor and how it is connected in a circuit in these cases. (It is discussed in...
detail in Experiment 10.) You may like to discuss it with your peers or the counsellor so as to refresh your knowledge.

Fig. 1.1: Circuit diagram for determination of Planck’s constant using LEDs.

3. Note that a voltmeter is connected in parallel with the device across which you wish to measure the voltage (LED in our case), whereas the ammeter is connected in series. The voltmeter measures the voltage across the LED while ammeter gives the value of current flowing through it.

4. In Fig. 1.1, several LEDs that can emit light of different colours are shown. These are connected in the circuit one by one by joining point O with 1, 2, 3, 4 or 5, at a time.

5. Initially adjust the rheostat so that maximum resistance is included in the circuit, i.e. keep the slider near point P. Switch on the power supply and connect O with 1.

6. Now increase voltage across the LED slowly (say, in steps of 0.1 V) by moving the sliding contact (towards Q) and note values of voltage across the diode and current $I$ passing through it. Record the readings in Observation Table 1.1. Now slowly decrease the voltage to zero.

7. Next connect O with LED 2 and repeat steps 5 and 6.

8. Continue step 7 for other LEDs and record readings in Observation Table 1.1.

9. When you complete taking observations, plot $V-I$ characteristic for each LED. You should obtain the plots as shown in Fig. 1.2. Extrapolate the

Fig. 1.2: $V-I$ characteristics for different LEDs.
linear portions of the curves backward to meet x-axis, as shown for one LED. These will define the minimum voltage at which a particular LED would start to glow. This is known as turn-on voltage or threshold voltage. Note the values of turn-on voltage for each LED from your graph. Alternatively, you can determine turn-on voltage by gradually increasing voltage across the LED under reference and noting the value at which it just begins to glow. It may be mentioned here that this method may not give correct value due to limitations of an individual as well as of the equipment.

**Observation Table 1.1: Variation of Current with Voltage across an LED**

<table>
<thead>
<tr>
<th>LEDs</th>
<th>Infrared</th>
<th>Red</th>
<th>Yellow</th>
<th>Green</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL.No.</td>
<td>V (volt)</td>
<td>I (mA)</td>
<td>V (volt)</td>
<td>I (mA)</td>
<td>V (volt)</td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
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<td>3.</td>
<td></td>
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</table>

**Observation Table 1.2: For $1/\lambda$ vs. $V_0$**

<table>
<thead>
<tr>
<th>No. of Obs.</th>
<th>Colour of light emitted</th>
<th>$\lambda$ (nm)</th>
<th>$1/\lambda$ (m⁻¹)</th>
<th>$V_0$ (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
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<td>5.</td>
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</table>
1.4 CALCULATIONS

1. Note the wavelength corresponding to threshold voltage from table available in your physics laboratory. (Wavelengths corresponding to typical colours of LED are also listed in Table 1.1) Enter these values in Observation Table 1.2 along with corresponding values of $V_0$. 

2. Plot a graph by taking $1/\lambda$ along x-axis and $V_0$ along y-axis. It should be a straight line as shown in Fig. 1.3. Calculate the slope of the straight line. You should use the maximum span of the graph to minimize errors. Now you can easily calculate the value of Planck constant using Eq. (1.3).

![Graph of threshold voltage vs. wavelength](image)

**Fig. 1.3:** Plot of threshold voltage with corresponding wavelength.

**Result:** The calculated value of Planck constant = ....................... Js.