Determination of Planck's constant using an LED

1 Aim

Determination of Planck's constant using an LED.

2 Introduction

In 1900, Planck derived the following formula for the spectral energy density of black-body radiation

$$u(\nu)d\nu = \frac{8\pi h}{c^3}\frac{\nu^3 d\nu}{e^{h\nu/kT}-1}$$

where h is a constant given by $h = 6.626 \times 10^{-34}$ J.s This implies that the oscillators in the cavity do not have a continuous distribution of possible energies by must have specific energies

$$\epsilon_n = nh\nu, \quad n = 0, 1, 2, ...$$

An oscillator emits radiation of frequency ν when it drops from a state with higher energy to a state with lower energy and jumps to the next higher state when it absorbs radiation of frequency ν. This discrete bundle of energy is called a quantum and h determines the size of the quantum.

3 The Experiment

We employ light emitting diodes (LEDs) to determine Planck's constant. The basic idea in this measurement is that the photon energy given by $E = h\nu$ is equal to the energy gap E_g between the valence and conduction bands of the diode. The gap energy E_g is equal to the height of the energy barrier that the electrons have to overcome to go from n-doped side of the diode junction to the p-doped side. This can be achieved by applying external voltage V_0, such that the electrons jump across the barier to the p-doped side and recombine with the holes releasing the energy E_g as photons with $h\nu = E_g = eV_0$.

The I-V equation for a diode is

$$I \propto exp(-V_0/V_1)[exp(V/V_1) - 1], \;\; V = V_m - RI,$$

where $V_1 = \eta kT/e$, k, T and e being Boltzmann constant, absolute temperature and electronic charge respectively. The voltmeter (in the external diode circuit) reading is given by V_m and R is the contact resistance. The constant η is the material constant which depends on the type of diode, location of recombination region etc. and is specific to the diode. The external voltage $V = V_m - RI$, V_m is the voltmeter reading in the external diode circuit and R is the contact resistance. Its value for an LED is usually around 1 ohm, while the overall internal resistance of the LED at applied voltage of approx. 1.8V is a few hundred ohms. Thus the term RI may therefore be neglected.
First, the constant η is determined from I-V characteristics of the diode at room temperature from the relation

$$\eta = \frac{e}{kT}\frac{\Delta V}{\Delta \ln I}. \tag{1}$$

In the second part of the experiment, the external voltage is kept fixed at some value lower than the barrier height V_0. The dependence of the diode current on the temperature is noted over a range of about 30 degrees at $V \approx 1.8$V. The slope of $\ln I$ vs. $1/T$ graph gives $e(V - V_0)/\eta k$. This determines the barrier height V_0. Finally, Planck's constant is obtained from the relation $h = eV_0/\nu$.

4 Apparatus in the Lab and Procedure

Carefully observe the switches and meters on the front panel of the set up. There is a two-way switch which can be set in V-I mode or T-I mode. The current digital panel meter (DPM) displays in units of μA in the V-I mode and in mA in the T-I mode.

1. **To draw I-V characteristics of LED**
   (a) Variable voltage source
      - Range: $0 - 1.95\ V$ Variable
      - Resolution: $1mV$
      - Accuracy= 0.2 %
   (b) Current meter
      - Range: $0 - 2000\mu A$
      - Resolution: $1\mu A$
      - Accuracy= 0.2 %
2. **Dependence of current on temperature at constant voltage**

Figure 1: The experimental setup.

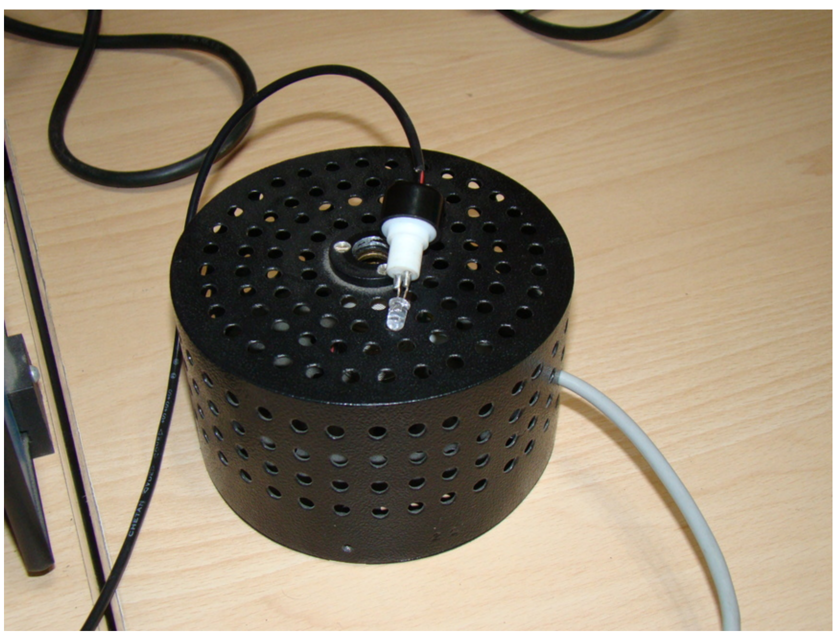

Figure 2: A close view of the LED.

(a) Current meter
   - Range: $0 - 20mA$
   - Resolution : $10\mu A$

(b) Temperature Controlled Oven
   - Range: Ambient to 65^0C
   - Resolution: 0.1^0C

Procedure

1. **To draw I-V characteristic of the LED**
   (a) Connect the LED in the socket and switch the power ON.
   (b) Switch the 2-way switch to $V - I$ position. In this position, the first DPM would read voltage across the LED and the second DPM will read current.
   (c) Increase the voltage gradually and tabulate the $I - V$ reading. There will be no current till about 1.5 volts. Plot: $ln\ I$ Vs V and determine η.

2. **Dependence of current (I) on temperature (T) at constant voltage.**
   (a) Keep the mode switch to $V - I$ and adjust the voltage slightly below he band gap of the LED ($1.8V$ for Yellow/Red and $1.95V$ for Green).
   (b) Switch the "MODE" switch to $T - I$.
   (c) Insert the LED in the oven and connect the oven to the socket. Before connecting, make sure the oven switch is ion OFF position and SET TEMP knob is in the minimum position. At this point the display will read the ambient temperature. Vary the temperature and the read the current.
   (d) Plot $ln\ I$ Vs $1/T$.

5 Precautions

1. The $V - I$ characteristics of the LED should be drawn at very low current (maximum being $\approx 1000\mu A$).
2. In T_I mode, make sure that the oven switch is "OFF" and "SET TEMP" knob is at its minimum position before connecting the oven.
3. At each temperature setting, allow sufficient time for the temperature to stabilise (typically 5-6 minutes).
4. Though the oven temperature can be as high as 70^0C, it is a good idea to restrict to a maximum of 60^0C.