CHAPTER 9

SOME MISCELLANEOUS EXPERIMENTS

9.1(A) To Determine the band gap by measuring the resistance of a thermistor as a function of temperature :

• **Theory :** Thermistors or thermally sensitive resisters are devices made of semiconductors whose electrical condutivity varies rapidly with temperature. The thermal variation of the electrical resistivity (ρ) of an intrinsic semiconductor is given by the relation

$$\rho = A \, . \, e^{\frac{E_g}{2kT}} \qquad \text{... (9.1-1)}$$

where E_g is the energy gap between valence and conduction bands and

$$A^{-1} = 2e \, . \left(\frac{2\pi kT}{h^2}\right)^{\frac{3}{2}} (m_e^* \, . \, m_h^*)^{\frac{3}{4}} \, . (\mu_e + \mu_h) \qquad \text{... (9.1-2)}$$

Here e is the magnitude of electronic charge, k is the Boltzmann constant, h is the Planck constant, T is the temperature in absolute scale, m_e^* and m_h^* are the effective masses of electrons and holes respectively, μ_e and μ_h are the mobilities of electrons and holes respectively. At moderate temperatures the variation of A with temperature is relatively slow compared to that of the exponential term and hence can be considered as a constant.

Now the resistance (R) of a specimen of length (l) and cross-sectional area (a) is given by

$$R = \rho \, . \frac{l}{a} = A' e^{\frac{E_g}{2kT}}$$

where $\quad A' = A \cdot \frac{l}{a}$

Taking log of both sides we get

$$\log_{10} R = \log_{10} A' + \frac{1}{2.3026} \cdot \frac{E_g}{2kT} \qquad \text{... (9.1-3)}$$

Thus a plot of $\log_{10} R$ with $\frac{1}{T}$ gives a straight line. If m be the slope of the line then

$$E_g = 4.6052 \times k \times m \qquad \text{... (9.1-4)}$$

where $k = 1.381 \times 10^{-23}\ J.K^{-1} = 8.620 \times 10^{-5}\ eV.K^{-1}$

The resistance R of the specimen is measured by passing a current I from a constant current source and noting the resulting voltage drop V. Thus

$$R = \frac{V}{I} \qquad \text{... (9.1-5)}$$

• **Apparatus :** (*i*) A thermistor (rod or disc form having resistance ~ 100 Ω), (*ii*) an electrically controlled thermostat (room temperature to 200°C), (*iii*) a constant current *dc* source (typically 0 – 1A), (*iv*) a thermo-meter, (*v*) a *dc* milliammeter (0 – 100 mA) and (*vi*) a *dc* voltmeter (0 – 10V).

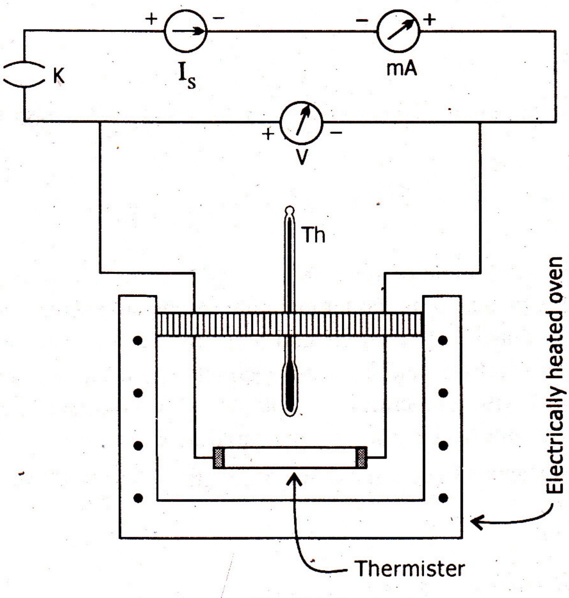

Fig. 9.1-1

N.B. The ranges of the meters depend on the resistance of the thermistor available.

• **Procedure :** (*i*) Set up the circuit arrangement as shown in Fig. 9.1-1. Here I_S is a constant current *dc* source, *mA* is a *dc* milliammeter, *V* is a voltmeter, *Th* is a thermometer. The specimen (a thermistor) is placed inside a small electrically controlled oven.

(*ii*) Switch on the constant current source and pass a small current (in the *mA* range) through the thermistor. Allow sufficient time for the voltage recorded by the voltmeter *V* to attain a steady value. Note this steady voltage (*V*), current (*I*) recorded by the milliammeter *mA* and the temperature of the oven recorded by the thermometer *Th.* Calculate the resistance *R* of the specimen at this (room) temperature as $R = \frac{V}{I} \times 10^3 \Omega$.

(*iii*) Keep the current constant. Switch on the oven and adjust its temperature to a value of about room temperature + 20°C. Allow sufficient time for the voltage recorded by the voltmeter *V* and temperature recorded by the thermometer *Th* to attain steady values. Now note the temperature and readings of the voltmeter *V* and milliammeter *mA*. Calculate the resistance at this temperature.

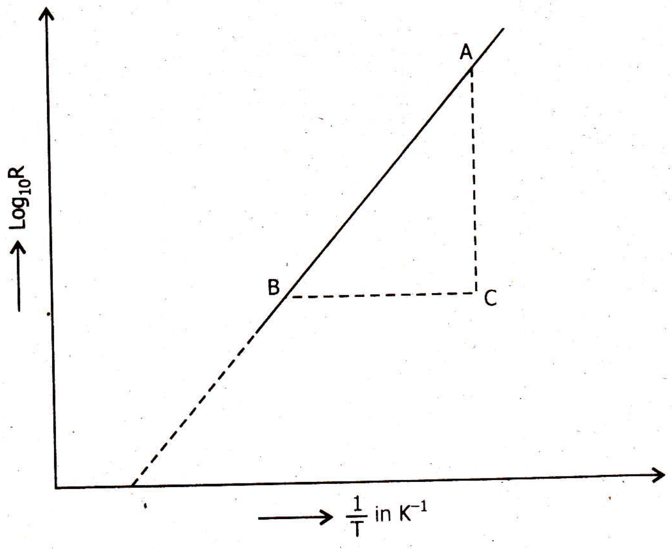

Fig. 9.1-2

(iv) Keeping the current constant increase the temperature of the oven in suitable steps and in each step calculate the resistance and note the temperature of the specimen following the process *(iii)*.

(*v*) Decrease the temperature of the oven in similar steps, allow sufficient time in each step for attaining steady state and then note temperature, *p.d.* (*V*) across the specimen and current *I*. Hence obtain the value of *R* at different temperatures. Obtain the mean of the two values of *R* for each temperature.

(*vi*) Repeat the experiment for a different constant value of the current (*I*
For each temperature calculate the value of $\frac{1}{T}$ in K^{-1} and the mean value of $10 \log_{10} R$.

(*vii*) Draw a curve by plotting $\frac{1}{T}$ in K^{-1} along *x*-axis and $\log_{10} R$ alon
y-axis. The nature of the curve will be as shown in Fig. 9.1-2. From the curv
find the slope $m = \frac{AC}{BC}$ and then calculate E_g from (9.1-4).

- **Experimental data :**

(A) *Measurement cf resistance at different temperatures :*

TABLE I

Set no.	No. of obs.	Temp. in °C	Current *I* in mA	P.D. in *V* across the thermistor when: Temp. is increasing	Temp. is decreasing	Mean *V* in volts	*R* in Ω $= \frac{V}{I} \times 10^3$
I	1	...					
	2	...					
	3	...	...				
	4	...					
	5	...					
	6	...					
II	1	...					
	2	...					
	3	...	...				
	4	...					
	5	...					
	6	...					

(B) *To draw* $\log_{10} R$ *vs.* $\frac{1}{T}$ *graph :*

TABLE II

Temp (t) in °C						
$\frac{1}{T} = \frac{1}{(t+273)}$ in K^{-1}						
R in Ω (Set-I)						
R in Ω (Set-II)						
$\log_{10} R = \log_{10} \frac{R_I + R_{II}}{2}$						

(C) *Calculation of E_g :*

$$k = 1.381 \times 10^{-23}\ J.K.^{-1} = 8.620 \times 10^{-5}\ e.V.\ K^{-1}.$$

From graph		Slope $m = \frac{AC}{BC}$	E_g in eV
BC in K^{-1}	AC	in K	$= 4.6052 \times k \times m$
...	...	...	...

• **Precautions and Discussions :** (*i*) The resistance of the thermistor changes rapidly with temperature. This makes it useful for the measurement of unknown temperature.

(*ii*) After each temperature change sufficient time should be allowed for the voltage to attain a new steady value.

(*iii*) For accuracy the p.d. across the specimen can be measured by using a potentiometer.

(*iv*) To provide electrical insulation and at the same time good thermal contact the thermistor can be wrapped round by a mica cover.

(*v*) The four-probe method of determining the resistivity of a semiconductor is superior to the present method.

• **Maximum proportional error :** From (9.1-4)

$$\left.\frac{\delta E_g}{E_g}\right/_{\max} = \frac{\delta m}{m} = \frac{1}{m}\delta\left(\frac{AC}{BC}\right) \qquad \text{[from Fig. 9.1-2]}$$