Experiment 30

Object. To study the temperature dependence of total radiation and to verify the Stefan's law.

Apparatus Required. 6V battery, key, a D.C. voltmeter of range 0-10 V, a D.C. ammeter of range 0-1 A, an electric bulb of tungsten filament of rating 6V, 6W, a rheostat of resistance 100 Ω and connection wires etc.

Theory. According to Stefan's law, the total radiation emissivity of a black body (*i.e.*, the total radiant energy emitted per unit area per second by a black body) is directly proportional to the fourth power of absolute temperature T of that body. *i.e.*,

$E \propto T^4$ or $E = \sigma T^4$, where σ is Stefan's constant. ...(i)

Now if the tungsten filament of the electric bulb is assumed to be the black body, according to Stefan's law, the total radiant power emitted by it

$$P \propto T^{\alpha} \text{ or } P = CT^{\alpha}$$

Taking logarithm on both sides,

$$\log_{10}P = \log_{10}C + \alpha \log_{10}T \quad \text{...(ii)}$$

Hence a graph plotted between $\log_{10}P$ versus $\log_{10}T$ will be a straight line with a slope α (= nearly 4).

The temperature of filament of bulb is determined by measuring its resistance. The variation of its resistance with temperature is given by the following relation

$$R_t = R_0(1 + \alpha t + \beta t^2) \quad \text{...(iii)}$$

where R_0 = resistance of filament at 0°C, R_t = resistance of filament at t°C and α and β are the temperature coefficients of resistance.

For the tungsten filament, $\alpha = 5{\cdot}21 \times 10^{-3}$ °C^{-1} and $\beta = 7{\cdot}2 \times 10^{-7}$ °C^{-2}, hence assuming the temperature of filament at just glow to be 530°C, the value of the quantity $\alpha t + \beta t^2$ comes out to be 3·96. Then

$$R_0 = \frac{R_g}{3{\cdot}96} \quad \text{...(iv)}$$

where R_g is the resistance of filament at just glow.

From Ohm's law, $$R_g = \frac{V_g}{I_g} \quad \text{...(v)}$$

where V_g and I_g are respectively the voltage applied across the ends of the bulb and the current flowing in it, at just glow of its filament.

Thus knowing R_g, the value of R_0 can be calculated. Then the resistance R_t of the filament of bulb is measured by finding the ratio of voltage and current, at any temperature *t*. After this, the value of R_t/R_0 is calculated and then from the calibration curve plotted for R_t/R_0 versus *t* for the tungsten filament, the temperature *t* of the filament corresponding to that value of R_t/R_0 is obtained.

Formula used. The resistance of filament of bulb at any temperature *t* is $R_t = \frac{V}{I}$ where V is the potential difference applied across the filament of the bulb and I is the current flowing in the filament.

Resistance of filament of bulb at just glow $R_g = \frac{V_g}{I_g}$

where V_g is the potential difference applied across the filament and I_g is the current flowing in the filament, when it just glows.

Resistance of filament of bulb at 0°C is $R_0 = \frac{R_g}{3 \cdot 96}$

According to Stefan's law, if the absolute temperature of filament of bulb is T, the total radiant power P emitted by it is given as

$$\log_{10}P = \log_{10}C + \alpha \log_{10}T$$

Hence, a graph plotted for $\log_{10}P$ versus $\log_{10}T$ will be a straight line with a slope α (= 4 nearly).

Procedure. First the apparatus is arranged as shown in Fig. 30·1. For this, a battery, rheostat, key and ammeter are connected in series with the bulb and a voltmeter is connected in parallel across the bulb. Take care that the +ve marked terminals of ammeter and voltmeter are connected with the positive terminal of the battery and no socket is used with the bulb, otherwise additional resistance will get added with the filament of bulb. Hence at the base of the bulb, its terminals are soldered at two different points with the wires.

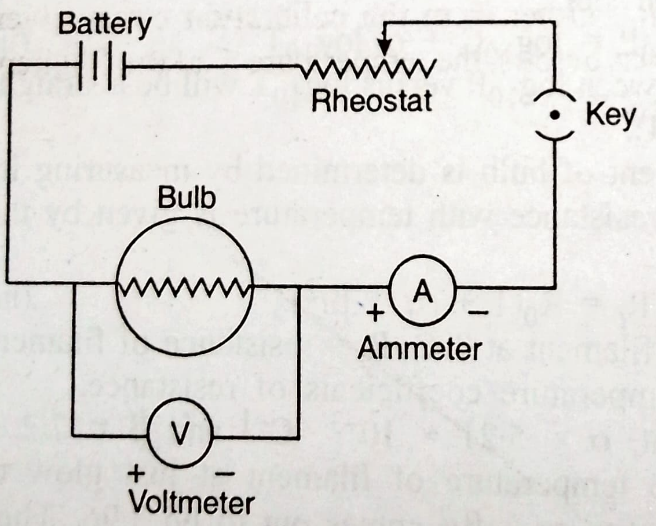

Fig. 30·1

Now the experiment is performed in the following two parts :

(i) To find the resistance of filament of bulb at 0°C, (ii) To find the absolute temperature (in kelvin) of the filament of bulb and the total radiant power emitted by it.

(i) To find the resistance of filament of bulb at 0°C

1. By inserting the plug in the key, the rheostat is adjusted to its maximum value so that a very feeble current flows in the bulb. Then the

sliding terminal of the rheostat is gradually moved to decrease the resistance till the bulb gets just glow (*i.e.*, the filament appears faint red). In this situation, the reading I_g of ammeter and the reading V_g of voltmeter are noted.

2. Now the resistance of circuit is much decreased so that the bulb glows with white illuminance. Then sliding the variable terminal of the rheostat, the resistance of circuit is increased till the bulb again appears faint red. Again the reading I_g of ammeter and the reading V_g of voltmeter are noted.

3. Repeat the above steps 2-3 times.

4. For each observation, calculate $R_g = V_g/I_g$ and then find the mean value of R_g.

5. Then calculate the resistance R_0 of the filament at 0°C using the relation $R_0 = R_g/3{\cdot}96$.

(ii) To find the temperature T (in kelvin) of the filament of bulb and the total radiant power emitted by it

1. After inserting the plug in the key, the current in circuit is gradually increased from its low value with the help of rheostat and each time the reading V of voltmeter and the reading I of ammeter are noted. This is done till the bulb illuminates with white glow.

2. For each observation, $R_t = \frac{V}{I}$ is calculated and then R_t/R_0 is determined.

3. For each value of R_t/R_0, either from the calibration curve given in Fig. 30·2 (or from the table given below), the temperature T of the filament of bulb (in kelvin) is determined.

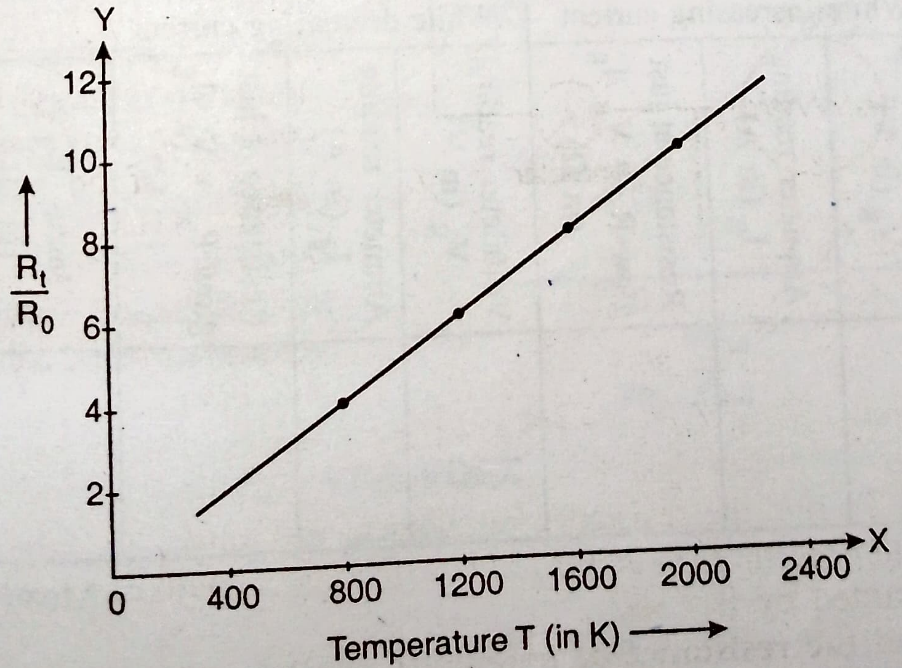

Fig. 30·2. Calibration curve for the temperature T of the tungsten filament and R_t/R_0

Table. Values of R_t/R_0 at different temperatures for the tungstan filament

Temperature T (in K)	R_t/R_0	Temperature T (in K)	R_t/R_0
273	1·00	1273	6·94
373	1·53	1373	7·60
473	2·07	1473	8·26
573	2·13	1573	8·90
673	3·22	1673	9·70
773	3·80	1773	10·43
873	4·40	1873	11·17
973	5·00	1973	11·42
1073	5·64	2073	12·69
1173	6·37	2173	13·50
		2273	14·30

4. For each observation, calculate power P radiated by the filament using the formula P = VI. Then a graph is plotted by taking $\log_{10}P$ on Y-axis and $\log_{10}T$ on X-axis which comes out to be a straight line. The slope of the line is determined.

Observations.

1. For finding the resistance R_0 of the filament of bulb at 0°C

S. No.	While increasing current: Voltmeter reading V_g (in V)	Ammeter reading I_g (in A)	Resistance at just glow $R_g = V_g/I_g$ (in Ω)	While decreasing current: Voltmeter reading V_g (in V)	Ammeter reading I_g (in A)	Resistance at just glow $R_g = V_g/I_g$ (in Ω)	Mean R_g (in Ω)	$R_0 = R_g/3{\cdot}96$ (in Ω)
1.								
2.								
3.								

Mean R_0 = ...Ω

2. For finding the temperatures T (in K) of filament and the power P radiated by it

S.No.	Voltmeter reading V (in V)	Ammeter reading I (in A)	Resistance $R_t = V/I$ (in Ω)	$\frac{R_t}{R_0}$	Temperature of filament T from calibration curve (or table) (in K)	Power radiated P = VI (in W)	$\log_{10}T$	$\log_{10}P$
1.								
2.								
3.								
4.								
5.								
6.								

Calculations. Slope of the straight line obtained in graph (Fig. 30·3) plotted between $\log_{10}P$ versus $\log_{10}T$

$$s = \frac{\Delta \log_{10} P}{\Delta \log_{10} T} = \frac{AB}{CD} = \text{.........}$$

Result. The graph plotted between $\log_{10}P$ and $\log_{10}T$ is a straight line as shown in Fig. 30·3, hence it verifies the relation $P = CT^{\alpha}$. Moreover the slope of the straight line s = 4(nearly), hence it verifies the Stefan's law.

Precautions. 1. The bulb should not be fixed in the holder, otherwise an additional resistance of the holder comes in the circuit.

2. The readings of voltmeter and ammeter while measuring the resistance of filament at just glow should be noted only when the filament of the bulb appears to be faint red.

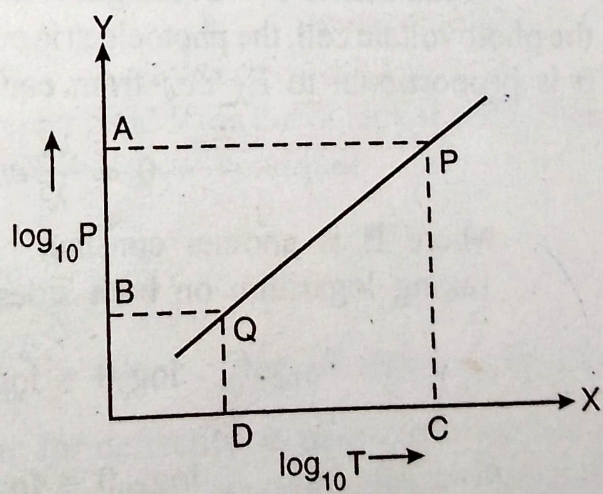

Fig. 30.3

VIVA-VOCE

Refer Experiment no. 29 and 31.