Thermo e.m.f. by Thermocouple

Object. To study the variation of thermo e.m.f. with temperature, for copper-iron thermocouple with the help of potentiometer.

Apparatus. Potentiometer, thermometer, battery, copper-iron thermocouple, high resistance box, two beakers, cold water at room temperature, heater, hot water, high resistance rheostat, key, galvanometer, connection wires etc.

Description of the apparatus. Potentiometer-A potentiometer is a wire of high specific resistance and low temperature `coefficient of resistance, such as the alloy of manganin or constantan of uniform cross-sectional area. The wire is spread on a rectangular wooden board parallel to its length. The total length of wire is divided into ten equal parts of one metre each. The end of each wire is connected to the starting end of other wire by thick copper plates. In this way, all parts of wire are connected in series. The starting terminal A of first wire last terminal B of tenth wire is connected to the terminals of the potentiometer. A metre scale is provided parallel to the length of wire. The zero of the scale starts from the starting terminal of first wire. A jockey J is connected on a rod provided which can slide on the given wire. By pressing the jockey, contact can be made with any wire according to need.

Theory. When two junctions are made by joining the wires of two different metals (such as copper and iron) and they are placed at different temperatures, an e.m.f. is developed in the circuit which is called the thermo e.m.f. Due to this thermo e.mf., a thermo electric current flows in the circuit from the copper wire to the iron wire through the hot junction. The value of thermo e,m.f., depends on the nature of metals and the difference in temperatures of the junctions. On increasing the temperature of the hot junction, the thermo e.m.f. increases and it becomes maximum at a particular temperature t_n. This temperature is called the neutral temperature. For copper-iron thermocouple, the neutral temperature is nearly 270°C. On further increasing the temperature of hot junction, the thermo e.m.f. begins to decrease and at a particular temperature t_i, which is called the temperature of inversion, the thermo e.m.f. becomes zero. Then on further increasing the temperature of hot junction, the direction of thermo e.m.f. reverses. If the temperature of cold junction is 0°C, $t_i = 2t_n$. The value of neutral temperature is constant for a given thermocouple (i.e., its value does not depend on the temperature of cold junction), but the temperature of depends on the temperature of cold junction. Remember that the value of thermo e.m.f. is of the order of micro-volt, hence a potentiometer is used to measure it. Fig .1 shows the variation of thermo e.m.f. *e* with the temperature of the hot junction when the temperature of cold junction is 0°C.

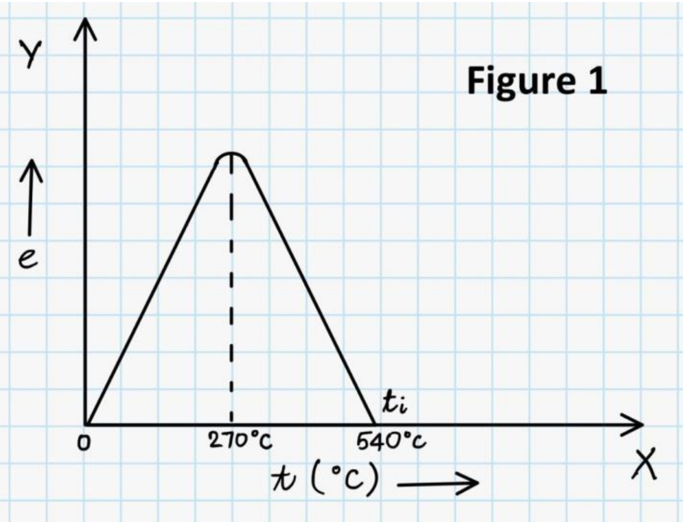

Fig. 2 shows the electric circuit used in the experiment. Here the ten wires of potentiometer are shown by a single wire AB. Let E volt be the e.m.f. of the battery used in the primary circuit of the potentiometer, R ohm be the resistance applied by the resistance box, *r* ohm be the resistance of the potentiometer wire AB, L cm be the length of the potentiometer wire and *l* cm be the balancing length on the potentiometer by the thermocouple when the deflection in galvanometer G is zero.

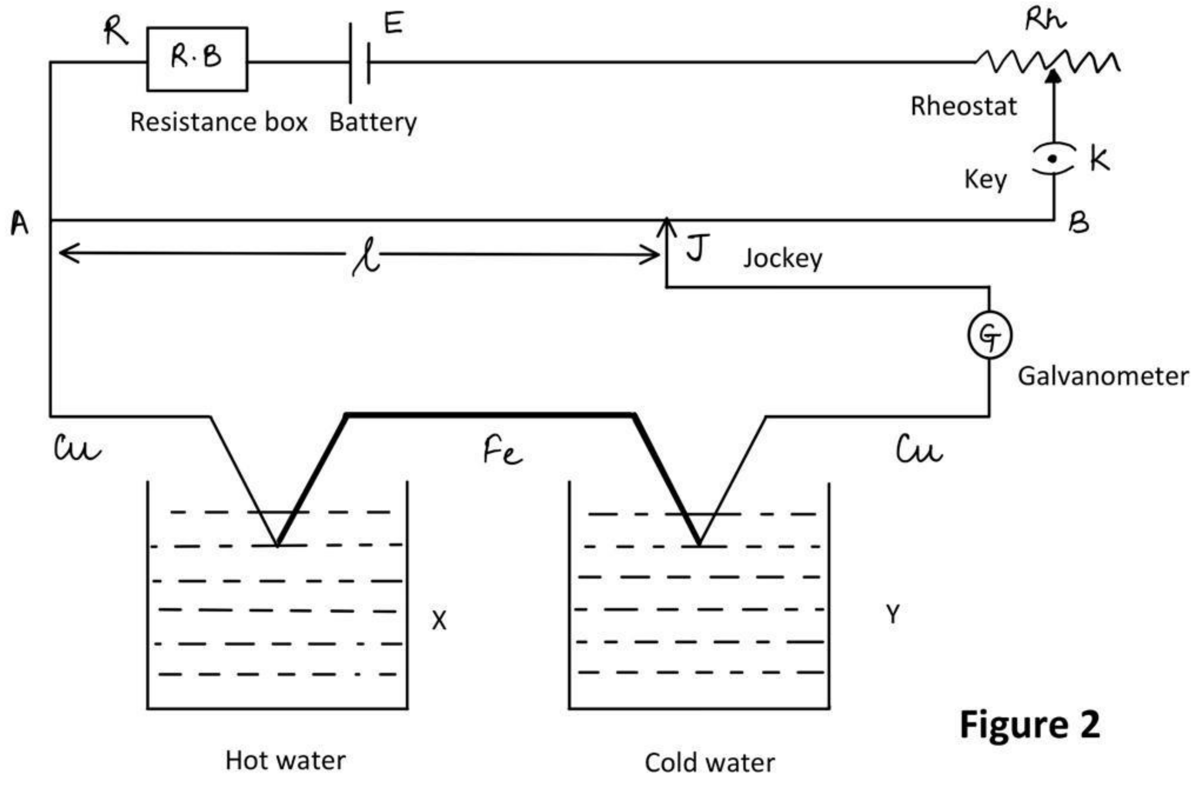

Figure 2

Then, the current flowing in the potentiometer wire AB due to the e.m.f. E applied in the primary circuit is I = $\frac{E}{R+r}$

In the balanced condition,

Potential difference across the balancing length l (i.e., wire AJ) of the potentiometer wire = Thermo e.m.f. e

∴ e = I * resistance of I length of potentiometer wire

$$= I * \frac{r}{L} * l = \left(\frac{E}{R+r}\right) \frac{rl}{L} \text{ volt}$$

Formula used. At a given temperature of hot junction of the thermo-couple, thermo e.m.f.

$$e = \left(\frac{E}{R+r}\right) \frac{rl}{L} \text{ volt}$$

where,

E = e.m.f. of the battery used in the primary circuit,

R = resistance connected in series with the potentiometer wire from the resistance box, resistance of the potentiometer wire AB,

L = length of the potentiometer wire AB,

l = balancing length for the thermocouple when there is zero deflection in the galvanometer.

Procedure. (Not to be written in copy)

1. First, complete the electric circuit shown in Fig. 2 for which across the potentiometer wire AB, a resistance box R.B., a battery E, rheostat Rh and a key K are connected in series to form the primary circuit. Take care that the positive

terminal of the battery is joined at the end A of the potentiometer wire. Then the copper and iron wires are joined together to form two junctions and as shown in Fig. 2, one junction is kept immersed in the beaker X of cold water, while the other junction is kept immersed in the beaker Y of the hot water. The beaker Y is placed on the heater. The end of copper wire of the junction kept in cold water is then joined at the terminal A of the potentiometer, while the end of copper wire of the junction kept in hot water is joined to a galvanometer G and then to the jockey J of potentiometer.

2. When the water in beaker Y begins to boil, the heater is removed.

3. Now introduce a resistance of the order of 1000 ohm in the circuit from the resistance box and insert the plug in the key.

4. Note the temperature of cold junction (which is at room temperature) by means of a thermometer.

5. Then note the temperature of hot junction and slide the jockey on the potentiometer wire AB to adjust it in a position when no deflection is obtained in the galvanometer G. In this position, note the distance l of the jockey from the end A of the potentiometer wire (i.e., the balancing length).

6. Now repeat the step (5) described above for the different decreasing temperatures of the hot junction (since now heating of the beaker Y by the heater

has been stopped) to find the balancing length of the potentiometer wire corresponding to each temperature.

7. Then measure and note the e.m.f. E of the battery used in the primary circuit with the help of voltmeter (or multimeter).

8. Now measure and note the resistance r of the potentiometer wire AB with the help of multimeter.

9. Then measure and note the total length L of the potentiometer wire AB.

Observations.

1. E.m.f. of the battery used in the primary circuit E = ……… volt (measure using multimeter).
2. Resistance of the potentiometer wire = 40 Ω
3. Length of the potentiometer wire = 1000 cm
4. **For thermo e.m.f. corresponding to different temperatures of hot junction**.

S. No.	Temperature of cold junction (room temperature) t_1 ^{0}C	Temperature of hot junction t_2 ^{0}C	Difference in temperatures t ^{0}C	Balancing length l (cm)	Thermo e.m.f . $e = (\frac{E}{R+r})\ \frac{rl}{L}$ volt
1.					
2.					
3.					

4.					
5.					
6.					

Graph. From the above observation table, a graph is plotted by taking the thermo e.m.f *e* on Y-axis and difference in temperatures *t* of the junctions on X-axis which comes out to be nearly a straight line as shown in Fig. 3

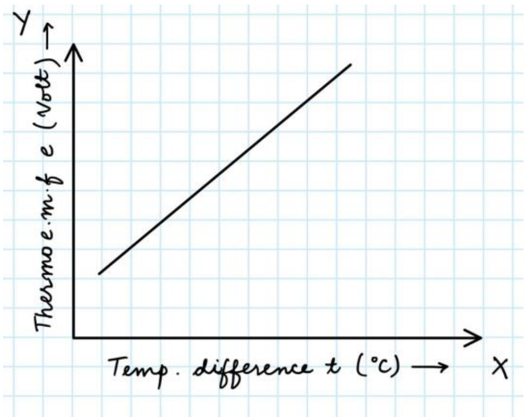

Figure 3

(since the neutral temperature for copper-iron thermo-couple is 270°C while in experiment, the maximum- temperature difference is of the order of 70°C -75°C, hence only the initial straight line part of the parabola shown in Fig. 1 is obtained in the experiment).

Result. The variation in thermo e.m.f. with temperature difference for the copper-iron thermocouple is shown graphically.

Precautions.

1. In the primary circuit of potentiometer, the resistance introduced from the resistance box must be of the order of 1000 Ω, because the thermo e.m.f. to be measured by it is of the order of micro-volt, hence the potential gradient in the wire of potentiometer must be of the order of micro-volt/cm.

2. The copper wire of the cold junction of thermocouple must be connected at the terminal of the potentiometer which is connected to the positive terminal of the battery used in the primary circuit.

3. All the connections must be tight.

4. Current should not flow in wire for longer duration (i.e., plug should be removed from key immediately after taking observation), otherwise potential gradient of wire will change due to heating.

5. During the experiment, the resistance of rheostat in primary circuit should not change.

6. Jockey should not be firmly pressed or rubbed on potentiometer wire, otherwise diameter of wire will not remain uniform throughout. Also, the jockey should not be pressed for longer duration on potentiometer wire (otherwise potentiometer wire will get heated and potential gradient will change).

7. Shunt must be used with galvanometer and should be removed only near the null point.

8. As soon as the temperature of hot junction is recorded, the balancing length corresponding to that temperature in the potentiometer wire should be determined at the same instant, otherwise the temperature of hot junction will change.

Viva -Voce

Q. What is your experiment?

Ans. To study the variation of thermo e.m.f. with temperature for the copper-iron thermocouple with the help of potentiometer.

Q. We can measure potential difference by voltmeter, what is the advantage of using potentiometer then?

Ans. As a voltmeter draws some of the current flowing in circuit, its reading is always less than the actual potential difference. Hence a voltmeter cannot measure the actual potential difference between two points. Whereas, at zero deflection position, no current flows through the circuit of potentiometer connected to galvanometer, hence it measures the accurate potential difference.

Q. What is the material of potentiometer wire and why?

Ans. Potentiometer wire is made of constantan or manganin because its temperature coefficient of resistance is lesser and specific resistance is high.

Q. Why copper wire is not used in potentiometer?

Ans. Because temperature coefficient of resistance of copper is more and specific resistance is less.

Q. What is meant by the sensitivity of potentiometer? How can its sensitivity be increased?

Ans. A potentiometer is said to be highly sensitive when there is enough change in balancing length on changing the potential difference a little. Potential gradient of wire should be as low as possible to make the potentiometer more sensitive. To reduce potential gradient of wire, length of wire should be more.

Q. Why do you use ten wires in potentiometer in your experiment?

Ans. To increase the sensitivity of potentiometer.

Q. What is meant by potential gradient? What is its unit?

Ans. The rate of change of potential with length of potentiometer wire is called the potential gradient. Its unit is volt/cm.

Q. If potential gradient of potentiometer wire is doubled, how will it affect the position of null point?

Ans. Null point is at half a distance.

Q. If e.m.f. of the cell in primary circuit used in your experiment is reduced, how will it affect the position of null point?

Ans. Null point will move ahead i.e., the balancing length will increase.

Q. How will the position of null point be affected if current through the potentiometer wire is reduced?

Ans. Potential gradient will reduce if current flowing through the potentiometer wire is reduced, therefore null point will move ahead.

Q. If length of potentiometer wire is doubled, what will be its effect on the position of null point?

Ans. On doubling the length of potentiometer wire, potential gradient will be reduced to half, hence null point will be obtained at almost double the distance.

Q. If some resistance is connected in series with the experimental cell, how will it affect the position of null point?

Ans. As the potential difference to be measured will remain same, therefore null point will be unaffected.

Q. Can a voltmeter be used to measure e.m.f. of a cell? Give reason for your answer.

Ans. No, because the resistance of voltmeter is not infinite and hence it draws some current from the cell.

Q. What is the use of key in your experiment?

Ans. As current should not flow for longer duration, so to avoid change in potential gradient due to heating, therefore, by inserting or taking out the plug-in key, flow of current from cell to the potentiometer wire can be switched on or off as required.

Q. Why do you use storage battery in primary circuit in your experiment instead of a primary cell?

Ans. As internal resistance of storage cell is low, high current can be drawn from it and almost steady or constant potential difference can be maintained for longer duration.

Q. If you get deflection in galvanometer only in one direction for the entire length of potentiometer wire, what may be the probable error in circuit?

Ans. (i) All the positive terminals may not be connected at one end of potentiometer wire.

(ii) It may be possible that e.m.f. of cell in primary circuit is less than e.m.f. to be measured.

(iii) Some connections may be loose or connecting wire may have broken in between.

Q. When do we get null point? Is there some current flowing through galvanometer in this situation?

Ans. When potential difference on potentiometer wire between the terminal A and jockey terminal J is equal to the e.m.f. to be measured, we get null point. In this situation, no current flows through the galvanometer.

Q. What is thermo-electric effect?

Ans. When two junctions A and B are made by joining the ends of wires of two different metals (such as copper and iron) and one junction say, A is kept hot while the other junction B is kept cold, a current begins to flow in the circuit which is called the thermoelectric current and this effect is called the thermoelectric effect.

Q. What do you mean by a thermocouple?

Ans. The circuit obtained by joining the ends of wires of two different metals is called the thermocouple. One junction of it is kept hot while the other is kept cold.

Q. State two uses of thermocouple.

Ans. (i) Measurement of high temperature, (ii) Detection of heat radiations.

Q. What is Peltier effect?

Ans. When current flows in a circuit formed by the wires of two different metals, there is formation of heat at one junction and absorption of heat at the other junction. As a result, the temperatures of junctions change. This is called the Peltier effect.

Q. What is Joule's effect?

Ans. When current flows in a conducting wire, it gets heated. This is called the Joule's effect.

Q. What is neutral temperature?

Ans. The temperature of hot junction at which the thermo e.m.f, is maximum, is called the neutral temperature.

Q. What is temperature of inversion?

Ans. The temperature of hot junction at which thermo e.m.f. becomes zero and on further increasing its temperature, the thermo e.m.f. changes its direction, is called the temperature of inversion.

Q. At temperature of inversion of a thermocouple, what is the magnitude of current in circuit?

Ans. Zero.

Q. Does the temperature of inversion of a thermocouple depend on the temperature of its cold junction?

Ans. Yes.

Q. Does the neutral temperature of a thermocouple depend on the temperature of its cold junction?

Ans. No.

Q. What is the neutral temperature of copper-iron couple?

Ans. 270°C.

Q. On what factor does the direction of thermoelectric current in a thermocouple depend?

Ans. On the metals of the thermocouple.

Q. What is the direction of current in the copper-iron couple?

Ans. At the hot junction, from copper to iron.

Q. What is the direction of current in the antimony-bismuth couple?

Ans. At the cold junction from antimony to bismuth.

Q. How are the neutral temperature t_n, and temperature of inversion t_i, of a thermocouple related?

Ans. $t_i - t_n = t_n - t_0$

where t_0 is the temperature of cold junction.

If temperature of cold junction $t_0 = 0°C$, then $t_i = 2t_n$.