(For Counsellor's use only)

Grade . . . . Name . . . .

Evaluated by . . . . Enrolment Number . . . . .

EXPERIMENT 2

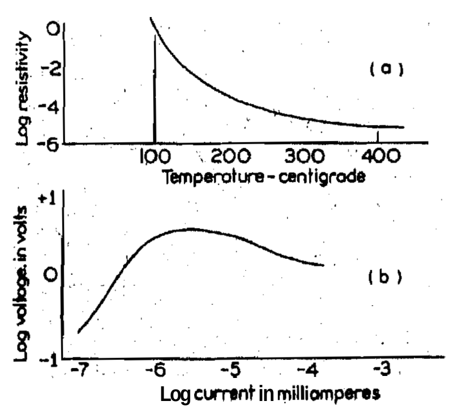
CALIBRATION OF A THERMISTOR AND DETERMINATION OF ITS ENERGY GAP.

Structure

2.1 INTRODUCTION

The electrical resistance of materials generally increases with increase of temperature. This increase is usually very small (<1% degree C). The discovery of semiconducting materials and the techniques used in modifying their electrical properties have resulted in materials for which the variation in electrial resistance with tempature is large (as high as 3 to 10%). Such devices have very many applications in measurement and control of temperatures of objects. Thermistors are semiconductor devices, with a high (usually negative) temperature coefficient of resistance. Some thermistors have their mom temperature resistance decrease 5% per degree rise in temperature. This high degree of sensivity to temperature change, makes it possible to use the thermistorin temperature measurement and control etc. Thermistors are generally used in the temperature range of -100°C to 300° C. Thermistors have generally three important characteristics (Fig 2.1) which are extremely useful in measurement & control applications.

i) Resistance vs Temp. characteristics (Fig.2.1 (a))
ii) Voltage vs Current characteristics (Fig.2.1 (b))



In this experiment you will find the resistance temperature characteristics of a thermistor, which has a high temperature coefficient of resistance. This property is used in making temperature transducers. Thermistors are used in other fields also. Some of the important applications of transducers are in remote measurement or control, temperature controller circuits, compensator circuits and in thermal conductivity measurements etc. For example the temperature inside a vacuum furnace, measurement of superheated steam inside a turbine of a thermal power station.

In the first part of the experiment you will calibrate the given thermistor using a thermocouple in the temperature range 30°C - 150°C. As you know that the thermistors are made of materials called semiconductors, we will calculate the band gap energy (See Fig.2.2) of the semiconducting material.

OBJECTIVES

The student will be able to:

* calibrate the given thermistor using a thermocouple.
* calculate the band gap energy, Eg of the thermistor material (semiconductor).

2.2 APPARATUS:

Thermo couple (copper - constantan)
Thermistor (7 K ohms at room temperature)
Water bath
Oil bath
Ice bath
Burner or stove or an electric hot plate
Wire gauze
Stands
Resistance Boxes (of different ranges 1K ohm to 3K ohm)
Low voltage D.C source (battery or power supply 0-4 volts)
Galvanometer / head phone
Millivoltmeter (0 to 10 mv)
Multimeter
Soldering iron , soldering rosin, and solder.
Connecting wires.

2.3 - STUDY MATERIAL

The thermistor is a made of a semiconducting material. Its resistance generally decreases when the temperature is increased . The relation between resistance and temperature is given by :

$$R_T = R_o \exp(E_g / 2\,kT)$$

Here R_T = resistance at temparature T in Kelvin degrees.
R_o = resistance at 0 Kelvin.
E_g = the energy difference between the filled valence and the empty conduction band of the particular semiconductor (Fig.2.2).

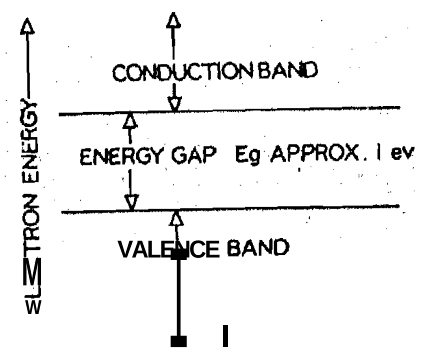


Fig.2.2

Energy band diagram of a **semiconductor**

Electrons in a free **atom have** discrete energy levels. But when atoms are brought **together to** form **molecules and** solids the electronic energy levels became almost continuous over **certain** ranges. These **ranges** are separated **by** regions of energy **values** that **electrons cannot possess. The** energy of the **electrons** in a semiconductor is represented on a one-dimensional **energy** diagram (see **Fig.2.2),** showing ranges of energies the electrons are **allowed** to have **and the ranges** of energies in between the **allowed** bands where electrons are forbidden to exist.

The highest occupied band corresponds to the groundstate of the outmost or valence **electrons** in the atom. For this reason the upper occupied band is called the valence band. In a semiconductor, the **valence** band is **full** or nearly so. In addition the width of the forbidden energy gap (Eg, **the** band gap energy) between the top of the valence band **and** the **bottom** of **the next** allowed band, **called** the conduction band is of the order of 1 ev **(e.g.** for Ge = 0.7 **ev,** and for **Si = 1.1ev).**

SAQ

What.do you mean by **the** energy gap in a semiconductor?

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The resistance of a thermistor may be determined at various **temperatures** with the **help of** some type of bridge circuits. In these circuits we required the use of a,galvanometer or head phone as a **balancing indicator.** All these bridges work on the principle of Wheatstone's bridge. The circuit arrangement is shown in **Fig.2.3.**

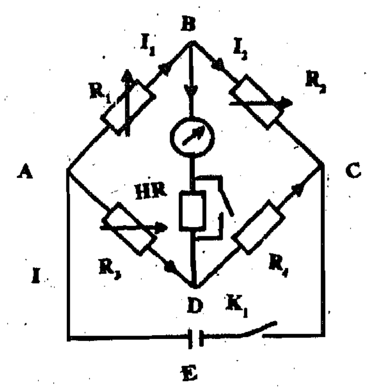

Fig.2.3

Wheatstone's bridge consists of four resistances R_1, R_2, R_3 and R, connected **as shown in Fig.2.3** to **form** a network. **A** battery is connected between **one** pair of opposite junctions, A and C. A , galvanometer G of resistance *R*, is connected across the other pair of junctions B and D as a balancing indicator along with a **high resistance HR.** Let I be the current from the **battery** entering at the junction *A*. **Let** I_1, I_2, I_3, I_4 and I_g *be* the currents through the **resistances** R_1, R_2, R_3, R_4 and galvanometer G **respectively.** By **Kirchoff's** first law (The **algebraic** sum of the currents flowing into a **junction** is zero) we have the following relations.'

For the junction A, $I - I_1 - I_3 = 0$ ....(1)
For the junction B, $I_1 - I_2 - I_g = 0$ ....(2)
For the junction D, $I_3 + I_g - I_4 = 0$ ....(3)

If the bridge is balanced, the voltage at point B and D is the same. So no current flows through the galvanometer, i.e. Ig= 0. It can be shown that the following equation is true.

$R_1/R_2 = R_3/R_4$ ....(4)

If three resistances (R_1,R_2,R_3) are known, the value of the fourth can be calculated.

The resistance of the thermistor (R_T) at various temperatures (T° Kelvin) can be measured using the bridge circuit.

If we plot a graph between 1/*T* along the x axis and $\ln(R_T)$ along the y axis it will be a straight line since the following is true.

$\ln(R_T) = \ln(R_o) + (E_g/2k)*(1/T)$..(5)

The slope of the line is (E_g/2k.)

If the graph is between 1/*T* and $\log 10 R_T$, then the slope of the straight line is given by the following.

$E_g/(2k * 2.303)$..(6)

The energy gap is calculated from the slope of the straight line.
E_g = 4.606 * k * (slope of the straight line)..(7)

Here E_g is expressed in electron volts.

SAQ

1. List a few metals, semiconductors, and insulators that you are familiar with.
2. Distinguish between metals, semiconductors and insulators in terms of energy gap.

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2.4 PRECAUTIONS

(a) Care should be taken not to damage the balancing instrument. You can do this by using a high resistance in series with the galvanometer when the bridge is too for away from the balance. You can then remove this when the bridge is near the balance condition, by short circuiting the high resistance.

(b) Care should be taken to keep the thermocouple and thermistor in the same location during the calibration.

2.5 EXPERIMENT

2.5.1 Calibration of thermistor.

APPARATUS:

As in Section 2.2.

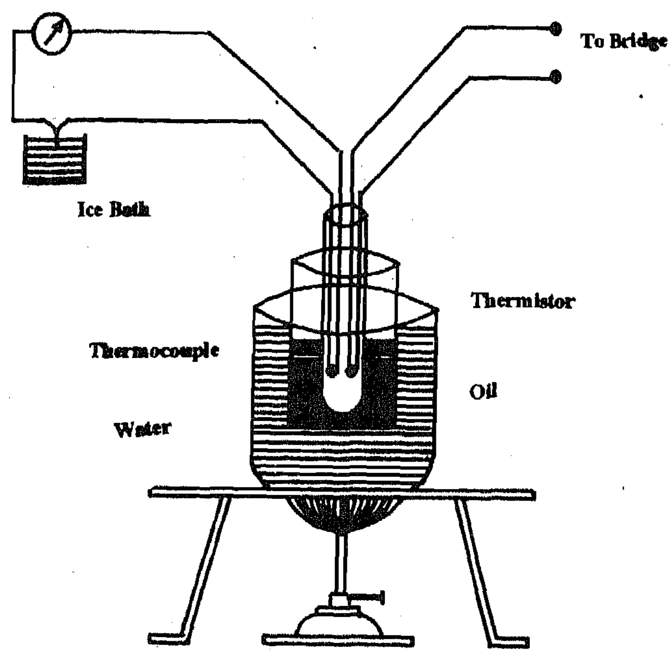

Fig.2.4

PROCEDURE:

Take the given thermistor, and measure its resistance with the help of a **multimeter** at room temperature. Solder its ends to long connecting wires. Connect this **thermistor** to one arm of **the** bridge (between C & D of **Fig.2.3)** and place known resistance boxes in the other three **arms.** The **voltage source** (battery), with a plug key in series, is **connected** across one diagonal of the four-sided arrangement. A sensitive galvanometer or null detector or headphone and a high resistance (about 5000 ohms) is connected across the other diagonal as shown **Fig.2.3.** Now you can **measure** the resistance of **the thermistor** with the help of this bridge as follows:

Make R_1 and R_2 **each** equal to 1k ohm and $R_3 = 0$, and close the key K_1 and then K_2, the key K_3 in the safety resistance being left open. The high resistance is then included in series **with** the balancing indicator and it cuts down the current to a low value. Note to which side the pointer moves on closing K_3. **Repeat** by having in R_3 the largest possible resistance or say 10000 **ohm.** Note the direction **of** the deflection. The galvanometer needle must deflect in the opposite direction for $R_3 = 0$ and $R_3 =$ infinity. If it is so, the network is connected correctly. Otherwise check the connection again.

Now **take** $R_1 = R_2 = 1$K ohm. Vary R_3 **till** this deflection is brought to zero. When the deflection is almost nil, short-circuit the high resistance. Now. the measuring instrument becomes more sensitive and a large deflection is seen. Make final adjustment **of** R_3 needed for **perfect balance (no movement** of pointer). **Then** R3 **is** equal **to** R_4 **at** room temperature. In this way you determine the value of the **thermistor** resistance at a given tempera**ture.** Now compare the resistance of this **thermistor** as measured by a digital ohm-meter and the value from the **above** bridge measurement. Is there any difference? Give reasons.

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Now you take the thermocouple, connect it to a millivoltmeter, or you can connect it with a digital multimeter in millivolt range. Mount the thermistor and thermocouple at the same location with the help of insulation tape. Insert them into a test tube. Dip this test tube in an oil bath and fix it on a stand. Now, immerse the oil bath (the test tube with the thermistor and thermocouple) into a large vessel of water and heat the water to boiling point, with the help of a burner. Now measure the voltage across the thermocouple in steps of 0.1 volt and measure corresponding thermistor resistance using the bridge as described above.

In case the change in the resistance of the given thermistor is very small, then you can connect an OPAMP configuration as shown in Fig.2.5 (For detailed discussion see the experiment on Operational Amplifiers.)

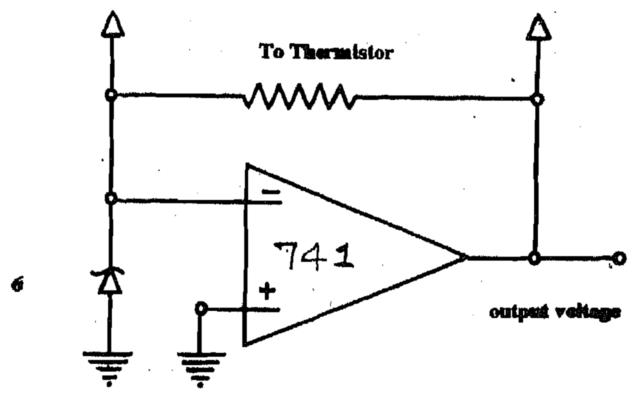

Fig.2.5

Record your data in Table I .

TABLE I

Resistance of the thermistor at room temperature = ...

S.NO	Voltage across the Thermocouple		Resistance across the thermistor	
	WHEN HEATING	WHEN COOLING	WHEN HEATING	WHEN COOLING

The values of thenno-emf for different temperatures for a copper-Constantan thermocouple is given in Table II.

TABLE II

Thenno-emf of Copper-Constantan thermocouple. Temp. in ^{0}C.
EMF in millivolts.

TEMP	0	10	20	30	40	50	60	70	80	90	100
EMF	0	0.39	0.79	1.19	1.61	2.03	2.47	2.91	3.36	3.81	4.28

With the help of the Table II you can plot a graph between voltages and temperatures of the thermocouple. From this graph, you will note tbe temperatures corresponding to the voltages which you have recorded earlier.

Record temperature and resistance data in tbe Table III.

TABLE III

S.NO	Temperature (T) of tbe thermistor(T)	Resistance (R)

Plot a graph between temperature vs resistance on the following graph.

This is the calibration chart of the given thermistor.

2.5.2 Calculation of Band Gap Energy of a Thermistor.

PROCEDURE

Take temperature vs resistance data of the given semiconductor. In this case we will use the data of the previous part of this experiment. Use the data from the observation Table III. Now, find the reciprocal of temperature and $\log_{10} R$. Record these values in observation Table IV.

TABLE IV

S.NO.	1/T	$\log_{10} R$

Now plot a graph between $1/T$ on the X-axis and $\log_{10} R$ on Y-axis. Plot this graph in space given below :

You will find this to be straight line. Calculate the slope of this line. Put the value of this slope in Equation (7) and calculate the value of E_g.

RESULT

The band gap energy Eg of the given thermistor is ...... ev.

SAQ

'What do you mean by the energy gap in a semiconductor? Can you calculate this gap in a metal or an insulator ? If not, why not?

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2.6 CONCLUSIONS

In this experiment you have studied how a thermistor can be used as a temperature transducer and also some of the material properties of the thermistor materials, resistance-temperature characteristics and the energy gap of the semiconducting material. Is this energy band gap temperature-dependent or not? Can you think of using this thermistor for temperature measurements in any real-life situation? Write some examples

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