Experiment III

Thermistors and the Wheatstone Bridge

Introduction

By the use of the Wheatstone bridge, a type of null comparator, the temperature versus resistance behavior of a thermistor is plotted. Using this calibration curve, one's body temperature is determined.

Equipment

Galvanometer, 2-known resistors, 0 - 999 **Ù** decade resistance box, thermistor, wires, rubberbands, Bunsen burner, beaker, and thermometer .

Note: Bring linear graph paper.

Theory

When a meter is used for measuring electrical circuits, the meter must draw some power from the circuit to make the measurement. This effect is known as "loading" of the circuit by the meter.

For an ammeter the loading has the effect of adding a series resistance to the circuit. For a voltmeter the effect is of a parallel resistance. Thus, for a voltmeter, the greater its input resistance (or impedance in the A.C. case), the better the measurement. However, even the best PET-digital meters, with input impedances greater then 10 M**Ù** or 10 x 10^6 **Ù**, pull *some* power, though usually negligible, from the circuit.

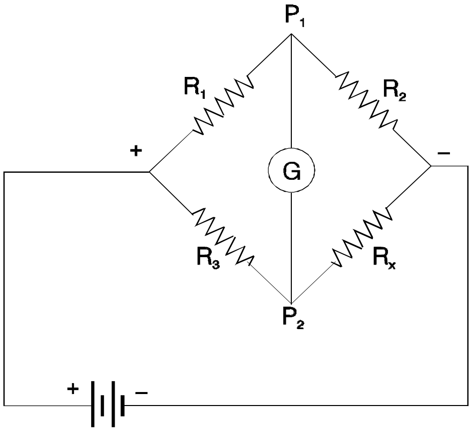

Figure 3.1 - Wheatstone bridge

To circumvent the loading problem, null comparators are used. Null comparators make a measurement by comparing two quantities, one of known value, the other unknown. The known value is adjusted till it equals the unknown. When they are equal, a detector placed across them will give a zero reading. Hence the term, null comparator.

A voltmeter, or a galvanometer can be used as the detector, as when two points are at the same voltage, no current will flow between them. As the measurement is made when the meter is nulled, no loading occurred. Hence the accuracy of the measurement is limited only by the knowledge of the known quantity, and the sensitivity of the nulled detector.

The Wheatstone bridge is a null comparator used for very accurate measurement of resistance.[1]

In the Wheatstone bridge of Figure 3.1, R_1, R_2, and R_3 are known resistances, R_x is the unknown. The bridge is said to be balanced when P_1 is at the same potential as P_2. Thus, no current will flow through the galvanometer. For this to happen, the ratio of resistance in the R_1 - R_2 path must equal the ratio in the R_3 - R_x path:

Thus, if R_2, is twice the value of R_1, then R_x is twice R_3, or

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} \tag{3.1}$$

Figure 3.2 - Circuit diagram for measuring R_x.

A thermistor is a metal oxide semiconductor whose resistance varies with temperature. For a conductor, as its temperature is increased, its resistance will increase. However, the resistance of a semiconductor will decrease with an increase in temperature. Over a wide range of temperature, this change in resistance is very non-linear. However, in a restricted range of 10°C or less, it may appear fairly linear. Because of this, thermistors are employed in a wide range of applications as temperature sensors.

In this experiment, you will measure the resistance of a thermistor with a Wheatstone bridge, for different temperatures, in a water bath. Then you will plot a calibration curve and use the thermistor to find your body temperature.

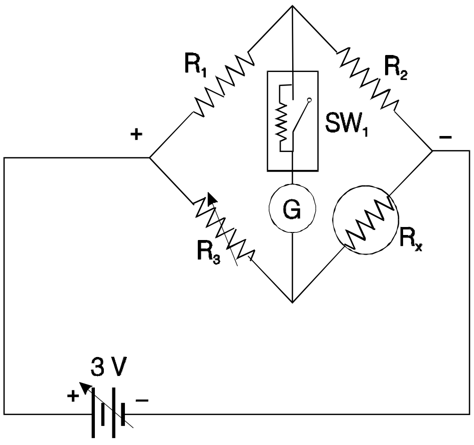

Figure 3.3 - R_1 = 200 **Ù**, R_2 = 300 **Ù**.

Procedure

Wire the circuit as in Figure 3.3, using the 0-999 **Ù** decade box for R_3:

You will balance the bridge by varying the decadebox, till the galvanometer indicates no current is flowing. For the initial rough balancing, the resistor switch SW_1 should be *open*. This adds a series resistance to the galvanometer to protect it from too much current when unbalanced. Once the bridge is roughly balanced, fine-balance it by closing SW_1. This shorts around the resistor, giving full

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[1] A bridge in electrical terminology is four components connected in a diamond configuration.

sensitivity of the galvanometer.

Attach the thermistor to the Hg thermometer with a rubber band. Place in a water bath brought to 0 °C with a little ice. *DO NOT* stir with the thermometer, as it is fragile, and will break.

Heat the bath slowly with the Bunsen burner. Be careful not to melt the wires in the flame. *DO NOT* place the thermistor in the flame to see what happens! To do so will ruin the thermistor and your chances of passing this course.

Record the resistance of the thermistor in 10 °C steps, from 0 °C to 100 °C. Use the computer program “Quattro Pro” and plot your data with temperature on the abscissa and resistance on the ordinate.

You may find it difficult to fit a straight line to your data. This is because, as many things in nature, the resistance varies as an exponential. For a semiconductor, the resistivity depends on the inverse of the *absolute temperature* (Kelvin), or

$$\tilde{\mathbf{n}} \propto e^{K/T}$$

If the thermal expansion in the thermistor is neglected, then the above equation can be written in terms of resistance, or

$$R \propto e^{K/T}$$

To make an equation of this relationship, multiply by a constant to yield

$$R = Ce^{K/T}$$

By taking the natural log of both sides, we have a linear equation in ln R and 1/T:

$$\ln R = \ln C + K\frac{1}{T}$$

Redefining C' to be the constant ln C, we have

$$\ln R = C^{/} + K\frac{1}{T} \tag{3.2}$$

or $y = b + mx$.

Plot the log of the resistance versus the inverse of the temperature (*in Kelvin*) using the “Quattro Pro” template. Follow the instructions given in the template and draw a "best-fit" straight line to your data. Measure the resistance of the thermistor by holding the thermistor between your lower and upper arms. *Then, using this calibration curve, determine your body temperature, giving your answer in °C and °F.*

The slope of the semi-log plot is related to the energy gap (E_g) of the semiconductor (thermistor). (The semiconducting gap is the region where no electrons are allowed and is between the valence and conduction bands.) Find the slope, m, and calculate the semiconducting gap using the following relation.

$$m = E_g/2k_B$$

where $k_B = 1.38\times10^{-23}$ J/K is the Boltzmann's constant. Give your answer in J and in eV where $1 \text{ eV} = 1.6\times10^{-19}$ J. (Note: The slope of the semi-log plot is obtained by performing a “linear regression fit” to your data points. Question: What is the unit of the slope?)

Answer the following questions and include with your report:

1. What are the major factors limiting the accuracy of a null Comparator?

2. If you wished the Wheatstone bridge to be direct-reading, *i.e.*, the value given by the decade box R_3 to be the same as R_x, what must be the values of R_l and R_2?

3. If a RTD (Resistive Thermal Device, made of ordinary conductor) were used instead of a thermistor, how would the calibration curve differ?