<u>Thermistor</u>

In this experiment, the characteristics of a thermistor will be investigated. Thermistors are semiconductor devices that exhibit a drastic resistance change as a function of temperature. This high sensitivity to temperature makes them useful as a sensor. The relationship between thermistor resistance and temperature is highly nonlinear but is predictable and repeatable so they are widely used in industry as temperature sensors in environments where the temperature is less than about 300°C. The thermistor used in this lab exhibits a resistance that *decreases* as the temperature *increases*. This type of thermistor is therefore classified as having a *negative temperature coefficient* or NTC type. Positive temperature coefficient (PTC) thermistors are also commercially available.

The nonlinear behavior of the thermistor resistance can be approximated over given ranges of temperature by a polynomial function called the Steinhart-Hart equation:

$$\frac{1}{T} = A + B[ln(R)] + C[ln(R)]^3 \qquad \textbf{(1)}$$

Where,

T is the temperature of the thermistor in **<u>Kelvin</u>**.

R is the thermistor resistance in Ohms, at temperature T.

A, B, and C are the Steinhart-Hart equation coefficients typically provided by the thermistor manufacturer or determined experimentally.

Recall that the temperature in Kelvin is related to the temperature in Celsius as…

$$\mathrm{T}(\mathrm{K}) = \mathrm{T}(°\mathrm{C}) + 273.15$$

To determine the coefficients, A, B, and C, a *minimum* of three pairs of temperature-resistance data points are required.

$$\frac{1}{T_1} = A + B[ln(R_1)] + C[ln(R_1)]^3$$
$$\frac{1}{T_2} = A + B[ln(R_2)] + C[ln(R_2)]^3$$
$$\frac{1}{T_3} = A + B[ln(R_3)] + C[ln(R_3)]^3$$

In matrix form:

$$\begin{bmatrix} \frac{1}{T_1} \\ \frac{1}{T_2} \\ \frac{1}{T_3} \end{bmatrix} = \begin{bmatrix} 1 & ln(R_1) & [ln(R_1)]^3 \\ 1 & ln(R_2) & [ln(R_2)]^3 \\ 1 & ln(R_3) & [ln(R_3)]^3 \end{bmatrix} \begin{bmatrix} A \\ B \\ C \end{bmatrix} \qquad \textbf{(2)}$$

$$\mathbf{Y} = \mathbf{MX}$$

Then, using the inverse of **M** to solve for A, B, and C…

$$\begin{bmatrix} A \\ B \\ C \end{bmatrix} = \begin{bmatrix} 1 & ln(R_1) & [ln(R_1)]^3 \\ 1 & ln(R_2) & [ln(R_2)]^3 \\ 1 & ln(R_3) & [ln(R_3)]^3 \end{bmatrix}^{-1} \begin{bmatrix} \frac{1}{T_1} \\ \frac{1}{T_2} \\ \frac{1}{T_3} \end{bmatrix}$$

$$\mathbf{X} = \mathbf{M}^{-1}\mathbf{Y}$$

If more than three measurements are available, a least-squares best estimate can be obtained by extending the matrix equations,

$$M = \begin{bmatrix} 1 & ln(R_1) & [ln(R_1)]^3 \\ \vdots & \vdots & \vdots \\ 1 & ln(R_N) & [ln(R_N)]^3 \end{bmatrix} \quad \text{and} \quad Y = \begin{bmatrix} \frac{1}{T_1} \\ \vdots \\ \frac{1}{T_N} \end{bmatrix} \qquad \text{N} > 3$$

and using the *pseudoinverse* of the **M** matrix,

$$\mathbf{X} = (\mathbf{M}^T\mathbf{M})^{-1}\mathbf{M}^T\mathbf{Y}$$

Thermistor Static Sensitivity

To obtain a range of temperature measurements, a hot plate will be used to heat water from near freezing to about 50ºC. Measurements of thermistor resistance and water temperature are to be made at approximately 5ºC increments.

Procedure

Caution: The hot plate you are about to use is hot!

1. Carefully attach the thermistor-under-test to the Fluke temperature probe with a rubber band or two.
2. Connect a DMM to the leads of the thermistor to measure its resistance throughout the experiment.
3. Pour about 100ml of water into the large beaker provided.
4. Add enough ice to the liquid water to produce a level of about 200ml in the beaker.
5. Submerse the thermistor/temp probe pair into the ice water mixture and gently stir until the thermistor resistance reading stabilizes. If the ice melts completely, add enough to get the temperature below 5ºC. Record the temperature and thermistor resistance.
6. Place the beaker on the hotplate, turn on the hotplate and set the knob to about the “7” setting. Keep the thermistor/temp probe pair submerged and keep stirring.

7. Continue to stir the water while monitoring the temperature probe reading and the thermistor resistance.
8. Record temperature and thermistor resistance readings in 5ºC increments (or smaller if desired) as the water warms up to 50ºC.
9. Turn off the hot plate.
10. Remove the thermistor/temp probe pair from the water. Leave the beaker of water on the hotplate until it cools for 10 – 15 minutes before removing it and pouring the water into the bucket provided. **Do not pour any water back into the source bottle.**

Homework Submission

1. Include a table of your resistance vs. temperature measurements.
2. Determine the experimental values of the Steinhart-Hart equation coefficients as described earlier in this handout. Record the values for A, B, and C.
3. Check your calculated values for A, B, and C against those in the data sheet posted on Canvas. Hopefully they are similar.
4. Make a graph of the measured resistance vs T(K). Does it look like what you expect for an NTC thermistor?
5. Make a new table. The dependent variable will be 1/T, while the independent variable will be R. The first column should have your measured resistance values. The second column should have your measured values of 1/T for each resistance in the first column.
6. Add a third column. Use equation 1 and the data sheet values for A, B, and C to calculate 1/T for each resistance in the first column.
7. Add a fourth column. Use equation 1 and your calculated values for A, B, and C to calculate 1/T for each resistance in the first column.
8. Make a graph that includes three curves of 1/T vs. R with the data from your new table. Graph your raw data from the experiment, graph 1/T calculated using the data sheet Steinhart-Hart equation coefficients, and graph 1/T calculated using the Steinhart-Hart equation coefficients calculated from your measured data. (All three curves should essentially lie on top of each other, right?)

The following link might be useful: https://en.wikipedia.org/wiki/Thermistor