Today's lab has two parts: First, you will calibrate a thermistor by measuring its resistance at two known temperatures (freezing and boiling points of water). Then, you will use several different temperature sensors, including the calibrated thermistor, to measure the temperature of a simple heat sink and calculate its thermal resistance.

Objectives:

- Learn about several types of temperature sensors and their underlying theory of operation.
- Gain an understanding of proper temperature-measurement technique.
- Practice your calibration skills.

Equipment provided:

- Heat sink (3x4" metal plate with a resistor and a "washer"-style thermocouple bolted on)
- HP 6236 power supply
- Fluke 8846A benchtop meter
- Fluke 52 thermocouple temperature meter
- Ice bath (at each bench) and boiling-water bath (at one station)
- Several temperature sensors:
  - Bead thermistor (Omega 44032) mounted in a pen handle with gold-colored cable
  - K-type bead thermocouple
  - K-type surface-probe thermocouple
  - K-type "washer" thermocouple (bolted to heat sink)
  - Fluke 65 infrared temperature meter

Part 1

A simple model for thermistor resistance vs temperature is

$$R = R_0 \exp\left(\beta\left(\frac{1}{T} - \frac{1}{T_0}\right)\right)$$

where

- β is a parameter
- T_0 is a reference temperature (in Kelvin)
- R_0 is the thermistor resistance at T_0
- T is the temperature we are measuring (in Kelvin)
- R is the thermistor resistance at T

To solve for β it is necessary to measure the thermistor resistance at two known temperatures, obtaining T_0, R_0, T, and R. T_0 and T could be any two temperatures, although for best accuracy T_0 should be chosen close to the temperatures where the thermistor will actually be used.

For this calibration we only have two convenient temperature references: the ice point and the boiling point of water. Define T_0 as the ice point (0 °C = 273.15 K). The measurement in the ice bath provides T_0 and R_0. The measurement in the boiling-water bath provides T and R.

Procedure:

1. Assemble your ice bath. Add ice and water to a styrofoam cup, keeping water to the minimum required to fill the gaps between ice chunks. Let sit for a few minutes.
2. Connect the bead thermistor (in the plastic pen) to the Fluke 8846A meter and set it to measure resistance. Immerse the thermistor in the ice bath and stir while waiting for the resistance value to settle. Record the resistance.
3. Bring your thermistor to the boiling water bath station to have it measured. (You may want to work ahead if this station is busy.) Record this resistance.
4. Calculate T (the boiling-water bath temperature) with corrections for barometric pressure and elevation. (See https://www.thermoworks.com/bpcalc. Your elevation is approximately 820 feet above sea level.) Remember to convert into Kelvins.
5. Find β for your thermistor. Don't forget that this number has units!

Part 2

Heat sinks are often needed to help remove heat from electrical and mechanical systems. If the thermal resistance between a given heat sink and ambient air is known, the cooling that will be achieved can be calculated. In this experiment we seek to empirically determine thermal resistance between an electronic component (a resistor) mounted on a 3"x4" 1/16" thick aluminum sheet and ambient air. The heat sink will be heated by a resistor, in what is called a TO-220 package, screwed to the aluminum heat sink. The amount of energy to be dissipated, and hence the temperature of the heat sink, can be controlled by adjusting the voltage supplied to the resistor. Recall Ohm's power law:

$$P = IV = I^2R = V^2/R$$

where P is power in watts, V is voltage across the resistor, and I is current through the resistor. Heat sink temperature will be measured in six ways:

- with the "washer" thermocouple bolted to the heat sink, and a Fluke 52 temperature meter.
- with a surface-probe-type thermocouple and the Fluke 52.
- with a bead-type thermocouple and the Fluke 52.
- with the calibrated thermistor and the Fluke 8846A in resistance mode.
- with an infrared thermometer.
- with the "washer" thermocouple and the ice bath, using the Fluke 8846A in voltage mode.

Procedure:

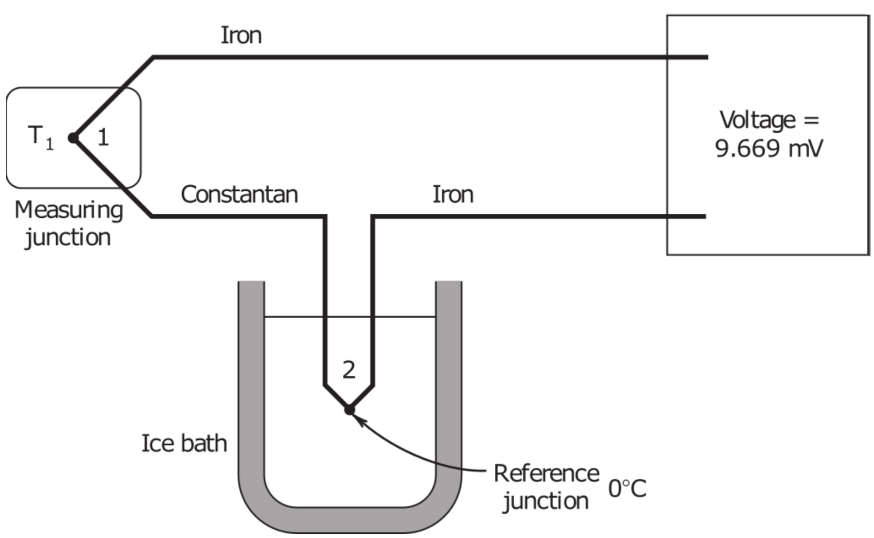
6. Measure the actual resistance of the 75 Ω power resistor mounted on the heat sink using clip leads attached directly to the resistor leads. Measure the resistor, then short your test leads together and measure the resistance of the test leads. Subtract test lead resistance from the first measurement to get true resistor value. Record.

7. Connect the power resistor to the +20 and -20 terminals of the HP 6236 power supply (no connection to the common terminal). Connect voltmeter clip leads directly to the resistor leads and adjust voltage to about 20 volts across the resistor (10 volts on the power supply meter). Measure and record the voltage right at the resistor.

8. While the resistor and plate are heating check calibration of the Fluke 52 temperature meter. Use a bead type thermocouple connected to the T1 connector and measure the temperature of boiling water. Also check to see if it reads close to zero when placed in your ice bath.

9. A washer-style thermocouple is mounted on the heat sink. Connect the thermocouple to the T1 connector of a Fluke 52 temperature meter. Turn on the meter, make sure the T1 button is pressed, and monitor temperature. Wait to proceed until the heat sink reaches equilibrium temperature; i.e., wait until the temperature ceases to increase, but note that it may drift a bit as room temperature and air motion changes. Note that any changes in the orientation of the heat sink from this point on—vertical or horizontal, shiny side up or down, etc.—will change the equilibrium temperature, due to changes in convection and radiation from the plate. Try to keep it in a consistent orientation with the shiny side up.

10. Do the most challenging measurement first, because your ice bath is melting: Use a bead thermocouple in the ice bath as a reference, together with the washer-style thermocouple mounted to the plate, and measure the resulting thermocouple output voltage with the Fluke 8846A. Use the K-type thermocouple chart to determine temperature. You need to think through how to make good connections for this measurement.



11. Re-connect the washer thermocouple to the Fluke 52 temperature meter at socket T1. Record the plate temperature as read by this meter.

12. Connect the surface-probe thermocouple (tube-shaped device with black pastic cap) to socket T2 of the Fluke 52, and press T2 to select that input. Measure temperature by pressing the probe against the shiny side of the heat sink, close to the resistor. Hold steady for a few seconds until the value stabilizes. Record the temperature and the location on the plate where you took it, then replace the plastic probe cover. Switch to T1 and record the washer thermocouple temperature alongside this measurement.

13. Connect the bead thermocouple to socket T2 of the Fluke 52. Press T2 to select that input and measure the temperature by pressing the probe against the heat sink in the same place as the surface-probe measurement. Hold steady for a few seconds until the value stabilizes, then record. Switch to T1 and record the washer thermocouple temperature alongside this measurement.

14. Connect the calibrated bead thermistor to the Fluke 8846A and set the meter to read resistance. **Gently** press the probe against the heat sink in the same place as the previous measurements. When the resistance value stabilizes, record it alongside the washer thermocouple temperature. Solve the thermistor equation for T and calculate the temperature reported by the thermistor.

15. Use a Fluke 65 IR temperature meter to measure the temperature at the same place on the heat as previous measurements. Note the 8:1 distance-to-measurement-diameter ratio of the Fluke 65, and choose your distance so the diameter of measurement approximates the diameter of the surface probe. Repeat using the black side of the plate. Record these measurements alongside the washer thermocouple temperature.

16. Calculate the thermal resistance of the heat sink. Thermal resistance has units of K/W (or equivalently °C/W because the size of one degree is the same). For a heat sink with known power input P it is calculated as $(T_{\text{sink}} - T_{\text{ambient}})/P$. The higher the thermal resistance, the hotter the heat sink must get to dissipate a given amount of power.

Report guidelines:

Present your measurements and explain how and under what conditions each was taken. Use hand-drawn figures as needed. Show all formulas used, with derivations. State and justify your assumptions (e.g. which temperature measurements to use when calculating the heat-sink thermal resistance). Comment on any measurements which appear to be outliers, and see if you can find reasonable explanations for them. In particular:

- Which measurement do you think has a lower uncertainty: The washer thermocouple read on the Fluke 52, or the washer thermocouple with ice-bath reference junction, read on the Fluke 8846A? Justify your answer.
- Why does the bead thermistor (in the pen holder) give a poor result? (Hint: think geometry)

Remember to include units with all measurements, and pay close attention to SI prefixes—e.g. there is a big difference between Ω and kΩ!