Laboratory 2 – Temperature measurement

Before starting:

- Read the rest this handout.
- For day 1: Review how to make difference amplifiers using op-amps and resistors.
- For day 2: Review 1-D heat conduction equation in spherical coordinates.

Main activities

First day exercise

- Weld a thermocouple
- Create a reference junction using an ice bath
- Build an amplifier for the thermocouple signal
- Use a LabView data acquisition system to measure the thermocouple voltage and convert it to temperature

Second day exercise

- Compare a thermistor's published R vs. T function to our observations
- Use self-heating in the thermistor to determine the thermal diffusivity of biological tissue
- Create a thermocouple reference junction using the thermistor
- Use the thermocouple for some interesting application.

Background:

A transducer is a device that converts some physical phenomenon into an electrical signal. A thermistor is a transducer for temperature measurement. Most thermistors are semiconductors whose resistance depends on the temperature. Measuring this resistance requires some heat to be dissipated ($q = Vi$) so the act of measuring the temperature can also change the temperature in the vicinity of the thermistor.

A thermocouple is a temperature transducer that uses bimetal junctions at different temperatures to create a voltage or current. Each junction between two dissimilar metals produces a small voltage across the junction. This voltage depends on the temperature of the junction. If the wires are connected at the other end, and both junctions are at the same temperature, then the voltages cancel out. However, if the junctions are at different temperatures, the net voltage is not zero. If there is a complete loop then the result is a current; if the loop is open (or connected to a high-impedance amplifier) then the result is a measurable voltage. This phenomenon is known as the Seebeck effect. Its corollary is the Peltier effect, in which one applies a voltage across a bimetal or semiconductor junction and produces heat flow through the junction. I think the Peltier effect is totally cool!

Because of the Seebeck effect, a thermocouple will measure the temperature difference between a pair of bimetal junctions. One junction is the probe, which is placed at the location where we wish to know the temperature. The other junction is the reference junction, which is held at some known temperature. A classic way to set up a thermocouple is to connect three strands of wire, metal A + metal B + metal A. One of the AB junction is placed in ice water, which is known to be 0° C. The other is the sensing junction. The voltage is read at the free ends of wires A1 and A2. Of course, the volt meter's probes should be made of the same metal and be the same temperature as each other, although they do not need to be the same kind of metal as the A. Otherwise, measuring the voltage would also change the voltage.

A common example is to use copper and constantan as the three wires. Constantan is a copper-nickel alloy. Copper and constantan together are called a type T thermocouple, which is effective in cold or moist applications. Iron and constantan, known as type J, is another common pair and is effective at higher temperatures. In both cases, constantan acts as the negative lead.

The following table 1 lists some properties of thermistors and thermocouples.

Thermistor	Thermocouple
Size range 1 mm – 1 cm	May be <u>very</u> small, e.g. < 0.1 mm
Easy to measure R as voltage / current	Resulting voltage is very small, order of mV
Strongly non-linear relationship between temperature and resistance	Approximately linear relationship between ΔT and voltage
Adds heat, may raise temperature of specimen	Operation does not add heat, but wires may conduct heat to/from the specimen
	Requires reference junction

Given that thermocouples produce tiny voltages (e.g. ~43 μV / °C for type T), and that they require a reference junction, why would we bother with them? Their small size, combined with the tendency of thermistors to change the local temperature, make thermocouples desirable in many applications. In addition, we can eliminate the ice bath by simply measuring the temperature at the reference junction with a thermistor. In fact, we can dispense with the third piece of wire entirely, as long as we know the composition of the metal we are connecting so we can calculate its impact on the observed voltage. Commercially available thermocouple-reading electronics use two wires and a thermistor at the reference junction.

For additional information…

🕮 Online reference: http://www.omega.com/thermocouples.html

DAY ONE

Equipment and Materials

Copper and Constantan wire
Thermocouple welding circuit
Power supply
High-precision digital voltmeter
Ice water

<u>Amplifier circuit</u>
Breadboard
Resistors
Standard multi-meter
Op-amp (e.g. μA741, LM301, or TL081)
Optional: Computer with DAQ interface and LabView

Procedures

Obtain some constantan and copper wire with which to make thermocouple junctions. Use the thermocouple welding station to create two junctions. Test the quality of the welds using an ohm meter. Add extension wires if necessary; if you do, make sure that they stay at the same temperature while you are taking measurements. Observe the behavior of your thermocouples using an ice bath and voltmeter. Create a difference amplifier to amplify the thermocouple output (may be completed next week).