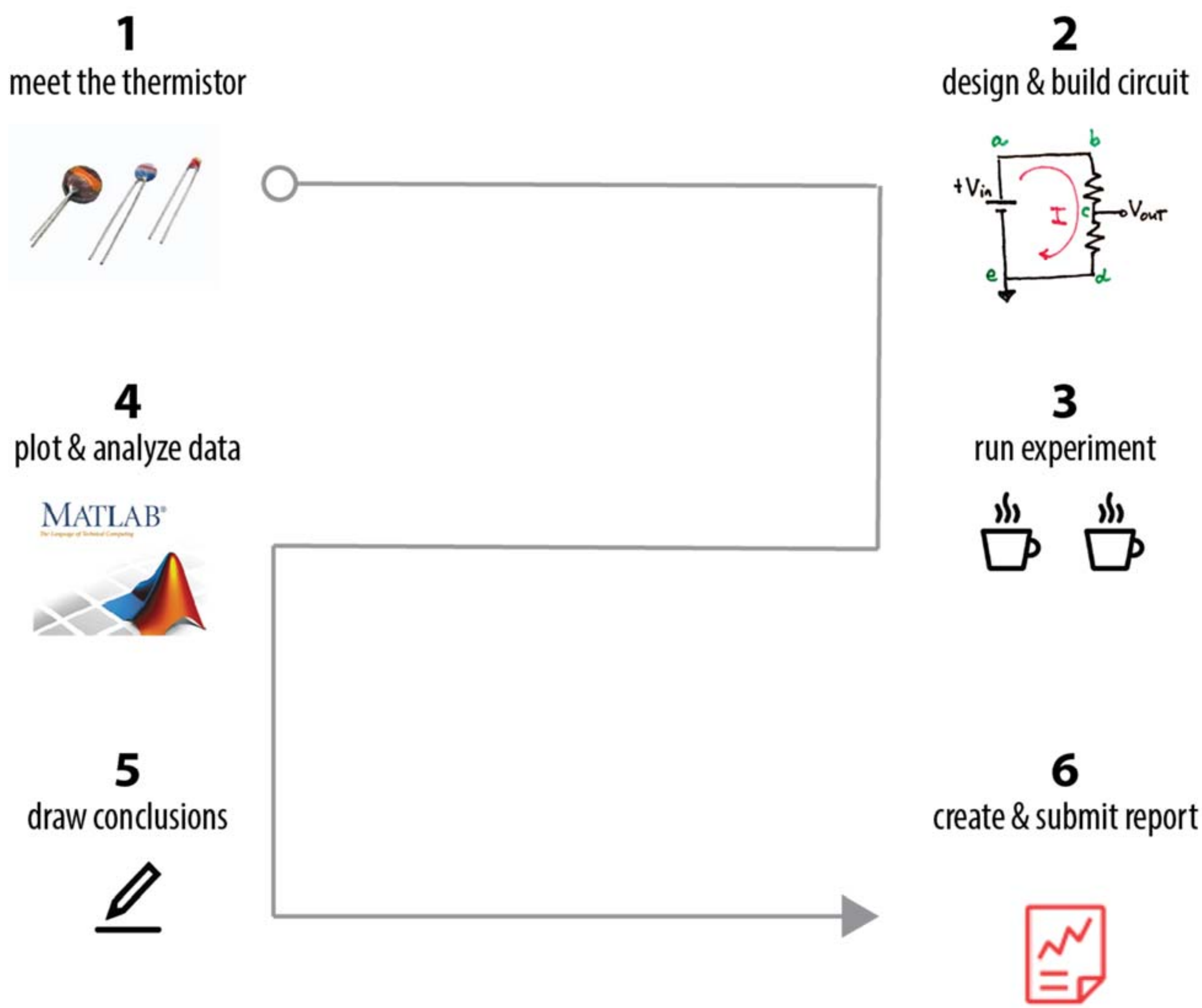
Lab 2: Monitoring temperature

Goal: Use a thermistor to monitor the changes in temperature in a cooling liquid.

Learning objectives

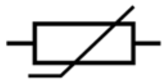
- Design a circuit to use with a thermistor, based on the voltage divider;
- Construct the circuit that is needed to sense the temperature
- Use the transfer function of the t sensor (thermistor) to compute temperature
- Graph temperature v. time and determine a fitting parameter, tau

Visual Summary



1. Meet the thermistor

Thermistor symbol



In this lab, you will make measurements of temperature using a device called a thermistor. A thermistor is nothing more than a resistor whose resistance changes with temperature. You will conduct an experiment that you will revisit from the modeling perspective in a few weeks in ModSim. In ISIM you will try out the problem experimentally, to get an empirical answer to the question, as stated by Allen Downey in his ModSim Python book:

> Suppose I stop on the way to work to pick up a cup of coffee, which I take with milk. Assuming that I want the coffee to be as hot as possible when I arrive at work, should I add the milk at the coffee shop or wait until I get to work?

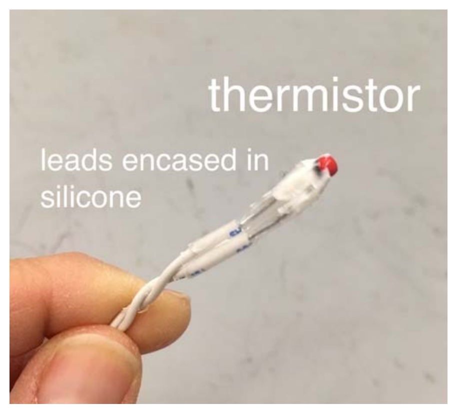
We will conduct an experiment similar to a ModSim problem that you may discuss in class. You can even save your data and use it to check how your ModSim model matches experimental results (if you build the coffee model in ModSim).

The thermistor* we will use has the following relationship between resistance and temperature

$$R = 1000\ \Omega \times e^{-3528\left(\frac{1}{298}-\frac{1}{T}\right)}$$

where T is the absolute temperature in Kelvin.

This equation is the *transfer function* of the thermistor; you might say it is a mathematical *function* of the *transfer* of T to R. At room temperature (defined as 25 C or 298 K) the thermistor we are using has a resistance of 1000 Ω (Ohms).

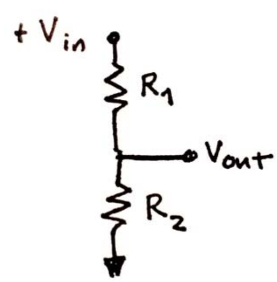


*For the curious, thermistors are made of semiconductors. Thermal energy increases the number of electrons that are free to conduct; in semiconductors, as T↑, R↓.

2. Design and build the instrumentation circuit

Design a circuit using the voltage divider concept. This circuit should give you a V_{out} that you can use to determine the voltage drop *across* your thermistor. Suggestion: Choose a resistor that is less than 50kΩ.

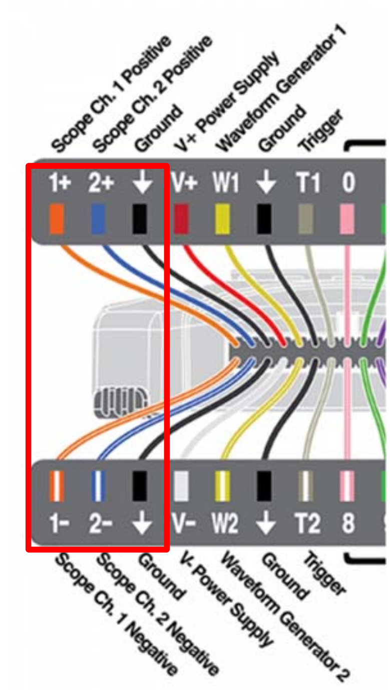
Suggestion: sketch the circuit on paper first.



What is V_{in} for your circuit?

What will you use for R_1 and R_2? How does your choice for either affect the result?

Connect the Analog Discover (AD)



Let's connect the AD so that you can read the voltage output of your thermistor. Recall that Channels 1 and 2 will measure a ΔV *across* each channel's +1 and -1 probes:

$Ch1 = Ch1^{+} - Ch1^{-}$ $\qquad$ $Ch2 = Ch2^{+} - Ch2^{-}$

Where should you connect Ch1+ and Ch1- to measure the ΔV <u>across</u> the thermistor?

Check that your system seems to be working by squeezing the thermistor to heat it up. You should notice a change in the voltage.

Once you think it is working, make a copy of the circuit on your breadboard so that you can make two simultaneous temperature measurements. You will measure both "cooling coffee" scenarios simultaneously.

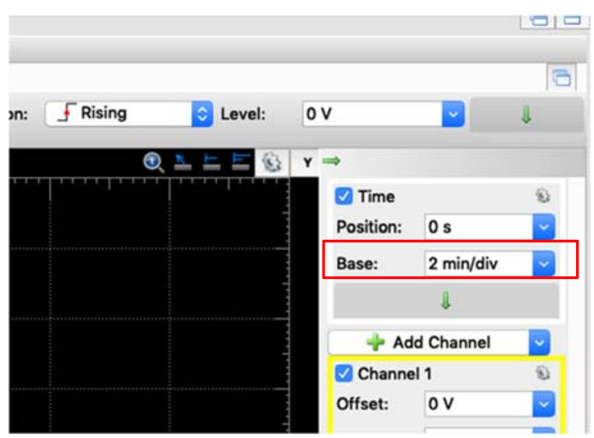
Since the experiment will take about fifteen minutes you will want to make sure that you have everything working before you actually start collecting data.

3. Conduct the experiment

WARNING – the experiment involves boiling water next to your laptop.

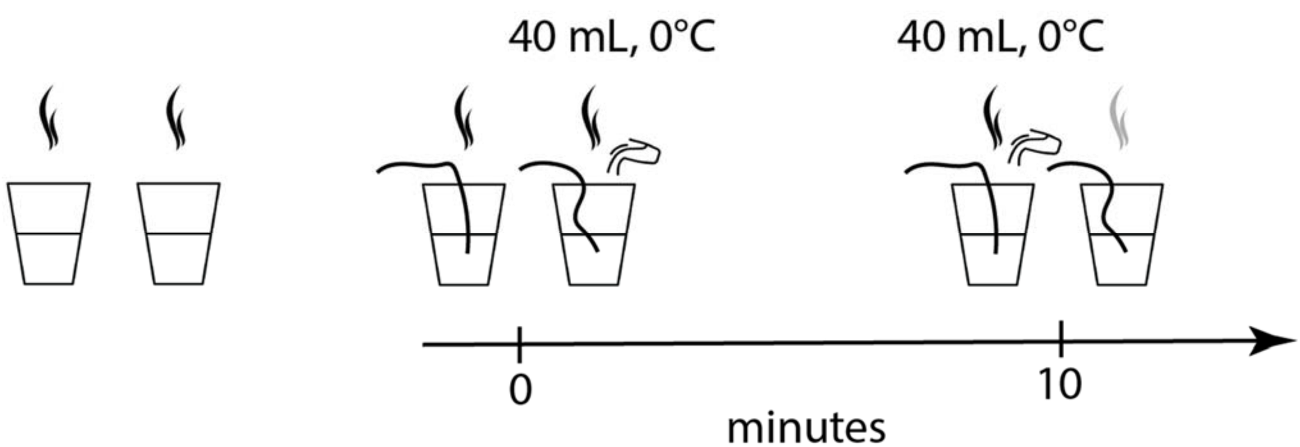
Use extra caution setting up and cleaning up the experiment**.**

Set the time base in Scope to be 2 minutes per division. This will allow you to collect a long enough time series of data.



Procedure (read before starting):

- Get two coffee cups. Partially fill with boiling water from the tea kettle to equal volume and leave enough room to add the “milk” (ice water).
- Take the cups to your desk, place them carefully and out of the way, and hit run on the Analog Discovery Scope.
- Plunge a thermistor in each cup of “coffee” (without pulling the wires from the breadboard). Place the thermistors so they are well submersed. Try to place the thermistors in approximately the same location and depth – i.e. either the center of the cup, near the wall, near the bottom. The location doesn’t matter much, but both cups should be about the same location for an equal comparison.
- You should see the measured voltage change fairly rapidly as the thermistor heats.
- Now, relatively quickly before the coffee cools much, go get 40 mL of ice water from the front of the room (this is the "milk" in this experiment). This water should be very close to 0 C. Dump this 40 mL of ice water into **one** of the cups of coffee. Mark which one got the cold water so you don’t forget.

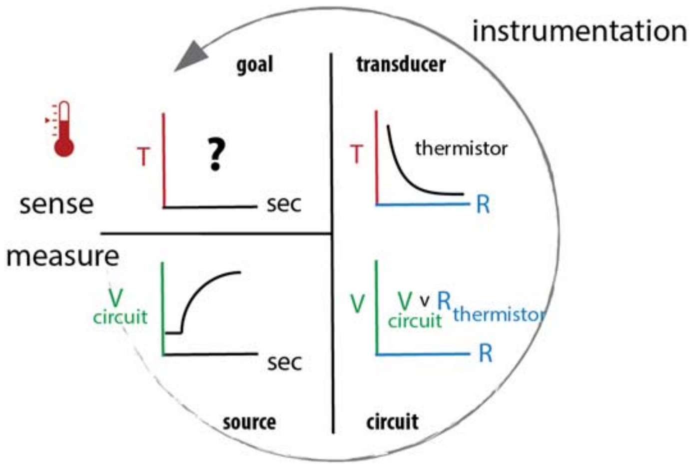


- Set a timer for 10 minutes.
- After about 10 minutes (the exact time doesn’t matter so much), go get another 40 mL of ice water, and dump that in the other cup of coffee.
- Set a timer for 5 minutes.
- Hit stop on the Scope and **export the data from Waveforms to a CSV file**. Confirm that the data was saved and open the file in Excel or some other program before closing Waveforms – just to make sure you have the data and don’t need to repeat the experiment. Don’t close waveforms until you make sure the data is saved.
- Use one of the beakers at the front of the room to measure the volume of water in both cups. The initial volume will be that value minus 40 mL of cold water. Record these numbers and make sure you keep them for your lab report and have them for your later

ModSim work.

4. Plot and analyze the results

For your analysis, you will need to convert measured voltage to resistance of the thermistor to temperature. Let's think about how to transform this data:



The transfer function of the transducer gives T v. $R_{thermistor}$.

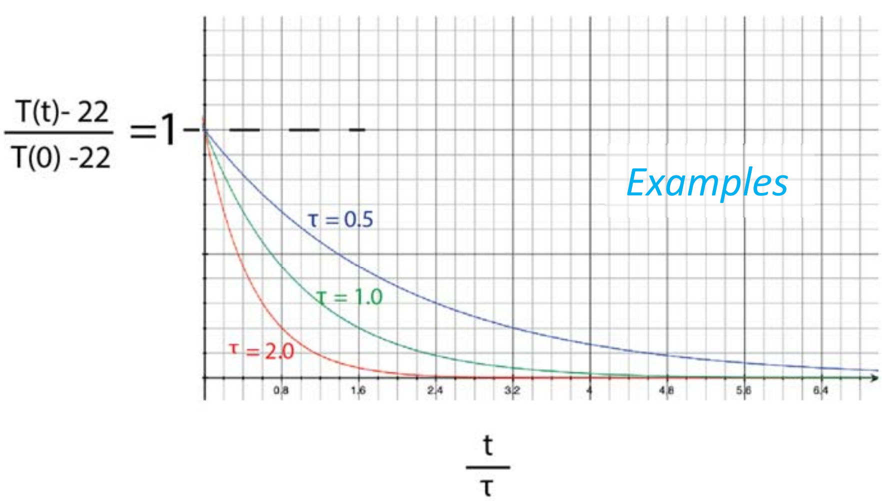
Your circuit design gives V v. $R_{thermistor}$.

What is the equation for V v. $R_{thermistor}$ for ***your circuit design****?*

Use Matlab (or other means) to plot the Voltage v. time for both "coffee" simulations. 

For the data where you dump the cold water in at the beginning, try to fit the measured data just after the cold water has been added with a function,

$$T(t) = 22\,C \;+\; (T(t=0) - 22\,C)e^{-t/\tau}$$



What is the effect of τ?

Where here we are assuming that the room is at 22 C, T(t=0) is the temperature at time 0 (defined as just after the cold water is poured), and the parameter tau, τ, is the experimentally determined constant which has units of seconds.

You will learn later in ModSim how this single parameter relates to the physics of the problem. In this class we will see this same functional form governs the dynamics of one of our key future circuits. In your lab report, also include a plot with the fit of your data to this function and report what the value of tau is.

5. Draw a conclusion about the question

You've just created an experimental model to answer this question:

> Suppose I stop on the way to work to pick up a cup of coffee, which I take with milk. Assuming that I want the coffee to be as hot as possible when I arrive at work, should I add the milk at the coffee shop or wait until I get to work?

What's your conclusion?

6. Create and submit report

Lab report containing at least:

- a plot of temperature vs time for the two experiments below, superimposed on the same graph.
- all the parameters used in your experiment – i.e. volumes of water, etc.;
- some conclusions about the original question;
- a plot with the fit of your data to

$$T(t) = 22°C + (T(t=0) - 22°C)e^{-t/\tau}$$

- the value of tau, τ.