Lab 1: Thermistor

Thursday, February 11, 2021 4:30 PM

started @ 3:20

w/ m.7K: 190mL

w/o m.1K: 180mL

Lab1_
Thermistor

isim1

isim2

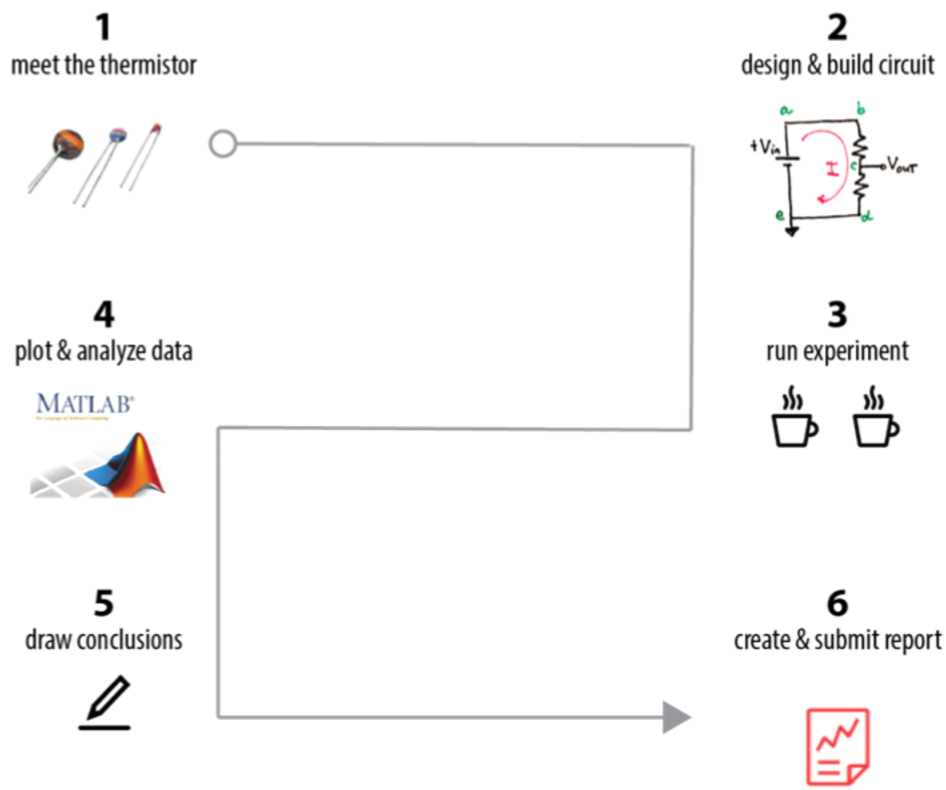
Lab 2: Monitoring temperature

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



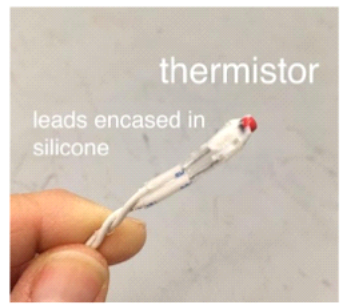
1. Meet the thermistor

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 have seen 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, wait until I get to work, or add the milk at some point in between?

We will conduct an experiment similar to the ModSim problem. You should save this data as you can later use it to check how your ModSim model matches experimental results.



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

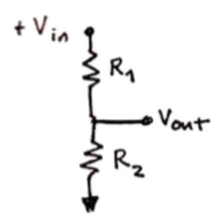
$$R = 1000\ \Omega \times e^{-3528\left(\frac{1}{298}-\frac{1}{T}\right)}$$

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: sketch the circuit on paper first.

What is V_{in} for your circuit? ~5V

What will you use for R_1 and R_2? How does your choice for either affect the result? R_1 = As small as possible, so voltage drop can vary as much as possible

R_2 = Thermistor NOPE!

R_1 = 1kΩ (same as therm.)

Connect the Measuring Instrument

Let's connect the instrument 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:

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

$R_1 +$ $R_2 -$ $\qquad\qquad$ $R_2 +$ $R_2 -$

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.

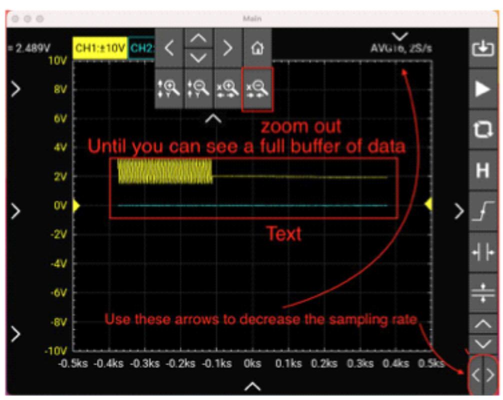
Since the experiment will take about fifteen minutes you will want to make sure that you have everything working before you actually start collecting data.

3. Conduct the experiment

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

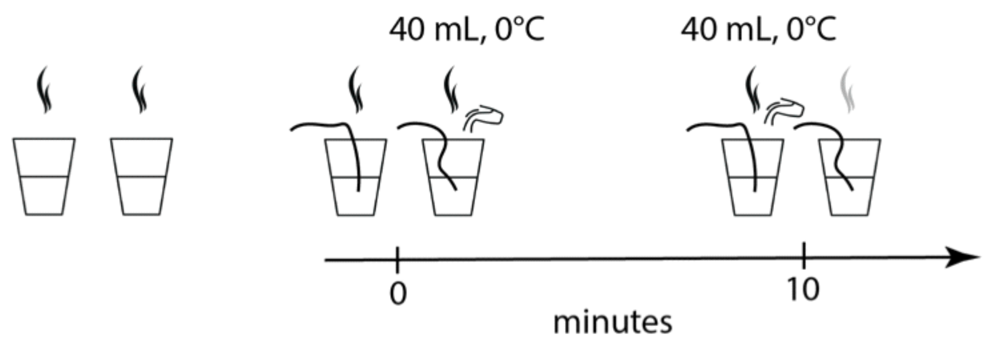
Use extra caution setting up and cleaning up the experiment.

Decrease the sampling rate of the scope to 2S/s. Disable the continuous sweep button. You will need to zoom out in time so that you can see the entire sample buffer.



Procedure (read before starting):

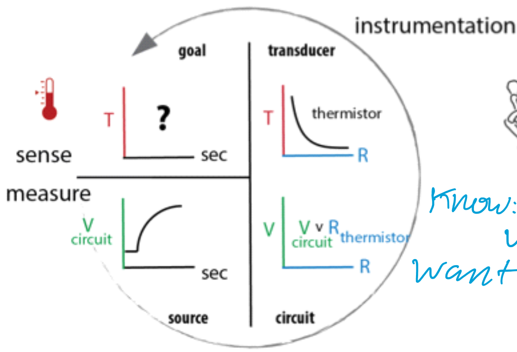
- Get two coffee cups. Partially fill with boiling water from the tea kettle to equal volume and leave enough room to add the "milk" (ice water).
- Take the cups to your desk, place them carefully and out of the way, and hit run on the instrument oscilloscope.
- Plunge a thermistor in each cup of "coffee" (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 cold 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 the O-Scope App 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.

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****?*

Know: V

$V = IR$

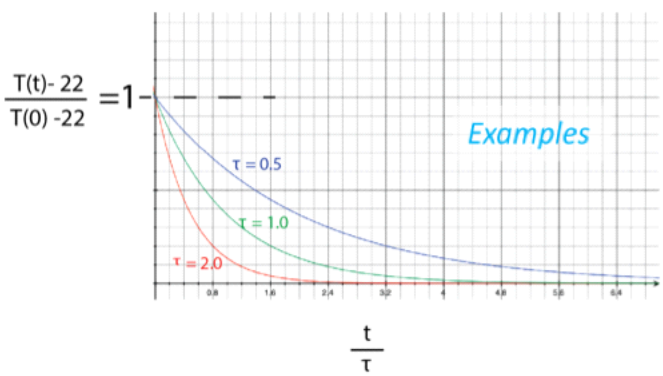
Want: R

$R = \frac{V}{I}$ $T = f\left(\frac{V}{I}\right)$

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, wait until I get to work, or add the milk at some point in between?

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.

ISIM_Lab_1

ISIM Lab 1: An Analysis of Dairy Addition Strategies for Thermal Management of Coffee

Ari Porad

February 19, 2021

Abstract

Two approaches for when to add cream to coffee were studied, with the goal of maximizing the temperature of the coffee at a fixed time after brewing. Each approach was evaluated by pouring a cup of coffee and monitoring the temperature of the liquid with a thermistor in a voltage divider circuit, while adding cream at the appropriate time. Adding the milk immediately after brewing resulted in significantly higher coffee temperatures at t = 15 minutes post-brew. Combined with the fact that pouring the milk immediately significantly simplifies the logistics of coffee production, it appears the clear favorite coffee creaming method.

1 Methodology

Each day, millions of people drink at least one cup of coffee. Of those coffee drinkers, a substantial portion add some form of cream[1] to their coffee. However, cream must be refrigerated to prevent spoilage and food-borne illness, meaning that it is cold when added to the coffee and thereby acts to cool the coffee. If the coffee is to be drunk immediately, this is rarely a significant issue–immediately after brewing, the coffee is too hot to drink anyways, so cream serves to cool the coffee to a drinkable temperature. However, many coffee drinkers make coffee at home before commuting to work,[2] and wish to drink their coffee upon arrival. This presents a conundrum for the coffee drinker, who must decide whether to add cream before departure or post-arrival. Which will ultimately result in a hotter cup of coffee at drinking time?

For this experiment, we set out to answer the above age-old question. We studied two different coffee creaming regimes, each simulating a 15 minute brew-to-drink time window:

1. Adding cream to the coffee immediately after brewing, before the commute (n = 1).
2. Adding cream to the coffee after arriving at work (t = 10 minutes post brew), 5 minutes before drinking the coffee (n = 1).

For each trial, we poured the 100C coffee (represented by water: 150 mL for Regime 1 and 140 mL for Regime 2) into a paper cup and inserted a thermistor. For Regime 1, we immediately added 40 mL of 20C cream (also represented by water). For Regime 2, we added an identical 40 mL of 20C cream, but after 10 minutes. The temperature of all trials was measured for 15 minutes after pouring the coffee.

[1] Many different additives are commonly used in addition to or instead of cow-dairy cream. Popular alternatives include regular cow milk, almond milk, and soy milk.

[2] Notwithstanding the ongoing coronavirus pandemic, which has been hugely problematic for introductory undergraduate electrical engineering project pretexts.

1.1 Data Collection

Figure 1 shows a diagram of the circuit used to measure the coffee's temperature. It consists of two identical voltage divider circuits, each dividing 5V of V_{in} across a 1000 Ω upper resistor and the lower thermistor. Leads for a channel of an O-Scope were connected across each thermistor, and the voltage measured can be calculated as follows:

$$V_{out} = V_{in}\frac{R_{thermistor}}{R_{upper} + R_{thermistor}} \tag{1}$$

The thermistor's resistance can be calculated from the following formula, where T is the temperature of the coffee in Kelvin:

$$R_{thermistor} = 1000\,\Omega \times e^{-3528(\frac{1}{298}-\frac{1}{T})} \tag{2}$$

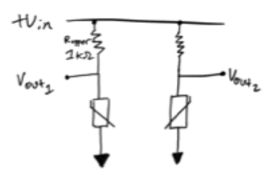


Figure 1: A diagram of the double voltage divider circuit used to measure the temperature of the coffee. Each voltage divider is connected to 5V of V_{in}, with a upper resister and the thermistor as the lower resistor.

2 Results

2.1 Temperatures

Regime 1, where cream was added to the coffee immediately after brewing, resulted in significantly warmer temperatures at t = 15 minutes (51C vs. 46C, see Figure 2). From this, it can be determined that immediately creaming coffee is the thermally ideal coffee creaming regime. Additionally, the immediate-cream regime is logistically far simpler, and eliminates the possibility that a coffee drinker forgets to add cream to their coffee. The author of this paper can see no reason why anyone would ever follow Regime 2.

2.2 Model

Additionally, we fitted a theoretical model of thermal convection cooling to our data (see Figure 4). The model is described by the following equation:

$$22 + (T(0) - 22)e^{\frac{-t}{tau}} \tag{3}$$

We found the model to be relatively accurate. We only compared the model to Regime 1 (immediate milking), as the model would not have been able to predict the addition of cream at t = 10 minutes. During the experiment, the coffee was left undisturbed to eliminate any thermal effects from mixing. We calculated a parameter value of $\tau = 1752$ seconds.

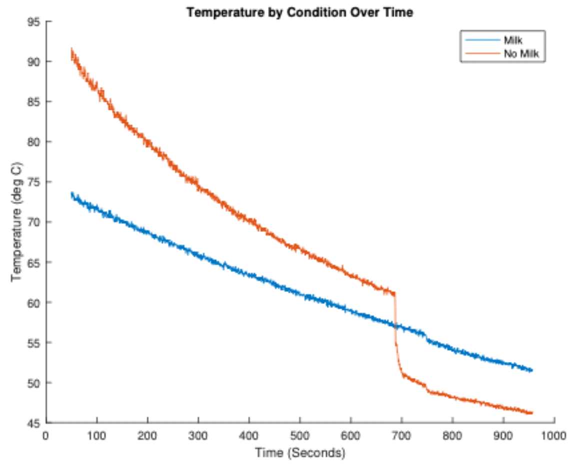


Figure 2: Temperature over time by condition (creaming regime). Where cream was added immediately, the final temperature was much higher. Both regimes resulted in coffee that was barely above lukewarm.

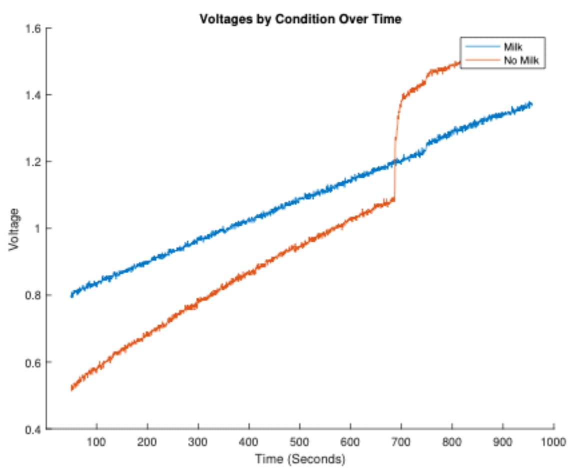


Figure 3: Voltage over time by condition (creaming regime). Voltage is inversely proportional to temperature. Where cream was added immediately, the final voltage was much lower.

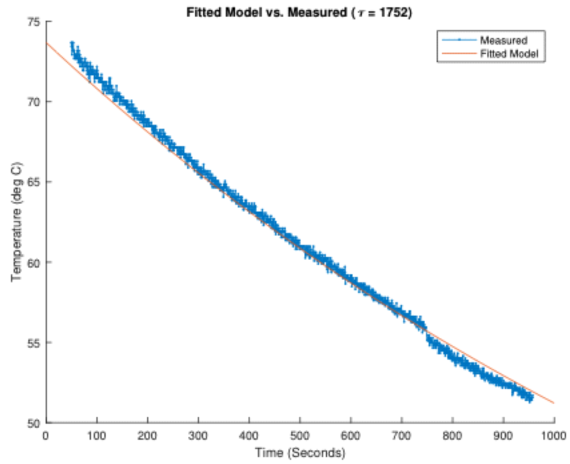


Figure 4: Measured temperature (from the regime where the cream was added immediately vs a fitted theoretical model. The model does a reasonably good job of predicting the coffee's temperature. $\tau = 1752$

3 Finishing Remarks

This experiment revealed several interesting conclusions about proper coffee creaming regimes. While the author has no doubt that this was a pedagogically useful lab, one cannot help but not that this absolutely constitutes "overthinking" one's morning coffee.[3]

[3]The other of this paper is from Seattle. Do you know what it takes to be "overthinking coffee" in Seattle?