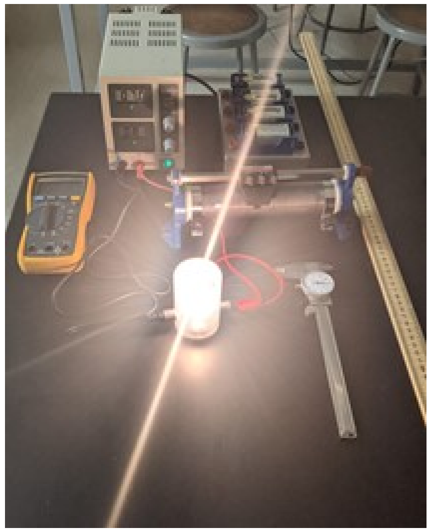
Lab 5

Resistance to Linear Fitting



Physical Models: Linear Response, Ohmic vs. non-Ohmic materials, Resistivity

Analysis Tools: Linear Fitting, Chi-Squared parameter

Experimental Systems: Rheostat, Lightbulb, D Battery Apparatus

Equipment: Extech Power Supply, Digital Multimeter

Safety Concerns: Be careful while handling the electrical equipment. Electrical currents can be harmful to some materials or dangerous to you.

Introduction

In the Prelab for this week you were introduced to a pair of models which characterize the electrical response of (at least some) systems to an applied voltage. Both models are linear, in the sense that they can be written in the form of:

$$y = mx \tag{5.1}$$

where y is variable you measure, x is a variable you can change, and m is some constant.

In this lab we'll test if these linear models genuinely do provide a good description of electrical effects in the real world. Unlike in the last lab, you may use Excel to determine m. However, **you must use the χ^2 technique** to determine if the model is accurate or not.

If the model is not accurate, or if the test is inconclusive, you may test different models instead:

$$y = mx + b \tag{5.2}$$

$$y = ax^2 + mx \tag{5.3}$$

$$y = ax^2 + mx + b \tag{5.4}$$

If you find one of these works better, you should state so and make sure to provide a hypothesis for why that might be (e.g. what do a and/or b physically represent?)

In this lab you are welcome to use excel to find the best fit curves, but must evaluate χ^2 for a given model yourself.

Part 1. Ohmic vs. Non-Ohmic Materials

When a system is subjected to a potential difference ΔV, and at least some of its electrons are free to move, the result is an electrical current (flow of charge) I. The precise details of how this works varies from material to material, but in many cases the relationship is linear:

$$\Delta V = IR \tag{5.5}$$

where R is a constant called the resistance. Materials that obey this relation are called "ohmic" while materials which are not are called "non-ohmic". In this part of the lab, we'll investigate a few items to see which category they fall into. If a material is non-ohmic you should determine if one of the equations in the introduction is a better explanation, and hypothesize why.

Quick Check: As usual let's first explore a bit. In this part of the lab, we'll use the Extech Power Supply. Hook the light bulb into the power supply using the banana cables. Turn on the power supply and set it to ~ 5 Volts; Let there be light!

As electrons travel through the light bulb, they experience friction with the bulb filament (internal wire). This dissipated energy is given off as light (and heat).

Try adjusting the power supply voltage and observing the brightness of the bulb. You can also read off the current directly from the power supply. Does the light bulb at least seem to be ohmic? Formulate a prediction.

Now replace the light bulb with the rheostat:

One cable should go into the red jack up top, and the other into the black jack on the other end. When current flows into the rheostat through the black jack on the bottom, it then travels through the cylinder until it reaches the metal flanges on the slider. Then the current flow up through the flanges, across the metal bar on top, and then out the red jack. By changing the position of the slider, we can change the distance the current flows through the cylinder, changing the resistance. In essence, a rheostat is a variable resistor.

A rheostat is an item designed by scientists and engineers to behave as exactly according to Ohm's law as possible. We will use the rheostat as a "model system" to begin our testing. Although we strongly suspect it is ohmic, we can use it as a chance to perfect our experimental methods.

Designing Your Experiment: Now design a high precision experiment to systematically investigate whether the light bulb and rheostat are ohmic or non-ohmic. Keep in mind:

- It's best if you start by testing the rheostat, then try the light bulb afterwards, since the rheostat is designed to be ohmic (but... take nothing for granted).
- The more measurements you take, and wider the range of measurements you take, the more confident you can be in your conclusion.
- For the equation $\Delta V = IR$, think carefully about what should correspond to y, x, and m. There's more than one way to do this (but there are also wrong ways).
- You'll need to reduce uncertainty sufficiently in order to get conclusive results. You can only measure one value with the multimeter at a time. Think about what values to measure with what device to reduce your uncertainty.

Refer to the "Statistical Methods Summary Lab5" if you need a reminder on how to evaluate a model using the χ^2 method.

If you not sure how to use the multimeter, be sure to refer to the "Multimeter Instructions."

Conducting Your Experiment: Go for it. Above all, try to minimize uncertainty as much as you can so that you can be confident in your conclusions.

Forming a Conclusion: Does your data support your predictions? If so, how well? If not, which model works better, and what's a physical explanation for why that might be?

Check in with Another Group: Check with another group to see if they got similar results.

Part 2. Resistance and Wire Length

If you found the rheostat was non-ohmic in Part 1, ask your TA for a replacement that is. We need an ohmic rheostat for this part.

In addition to being ohmic, rheostats can be adjusted to different effective lengths. For a fixed ΔV, a power supply must move charges over a larger/smaller distance if a wire is longer/shorter. This is represented by the equation:

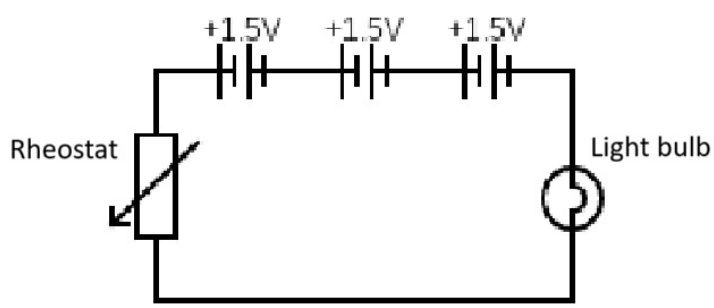
$$R = cL \qquad c = constant = \frac{\rho}{A} \tag{5.6}$$

where L is the length, and ρ/A is a constant that depends on the area A and the intrinsic properties of the material (the "resistivity") ρ. Notice this also has the form of $y = mx$ but this time R is y!

In this part of the lab we'll test if this relation is accurate for the rheostat.

Quick Check: Disconnect the Extech power supply. We'll instead use the D battery apparatus.

1. Start by connecting the D battery apparatus to the red jack on the rheostat.
2. Then attach the black jack on the other end of the rheostat to into the light bulb.
3. Finally, attach the other end of the light bulb back into the D battery apparatus.



Try adjusting the length of the rheostat. The light bulb should get more or less bright. (This is similar to how a dimmer works). Make a prediction: does the rheostat appear to be behaving as expected?

Note: the light bulb may only light up for very small values of L. If you don't see the light bulb light up, try setting L to 0.

To measure the current, replace the light bulb with the Digital MultiMeter (DMM). Make sure the wires going into the multimeter and the center dial are properly set up to measure current from a DC source.

Designing Your Experiment: Design a high-precision experiment to test the model or identify an alternative. Keep in mind the following:

- The battery voltage is constant and the total is the sum of the individual voltages. Each is 1.5 ± 0.1 volts.

- Make sure to test the whole range of L and to be as precise as possible. Think carefully about how and from where you'll measure L.
- It is not necessary to find R by plotting I and ΔV for every value of L. You may simply compute $R = \Delta V/I$ for each L. But remember to propagate uncertainty if you do so.

The partial derivatives you may need (from $R = \Delta V/I$) are:

$$\frac{\partial R}{\partial \Delta V} = \frac{1}{I} \qquad \frac{\partial R}{\partial I} = -\frac{\Delta V}{I^2} \tag{5.7}$$

Conducting Your Experiment: Conduct the experiment as planned. As always, make sure to minimize uncertainty. If you decide one of the alternative models is better, make sure to provide an explanation for why that might be. Even better: is there a way to check it quickly?

Forming a Conclusion: Does your data support your predictions? If so, how well? If not, which model works better, and what's a physical explanation for why that might be?

Writing Up Your Lab Notes for Submission

Write up your notes for Part 1 and Part 2 in an organized way according to the rubric provided.