

Simple Circuits (Parts 1 & 2)

✓ Learning goals

By the end of this unit, you should be able to:

- Use proposed models to make predictions and justify experimental design decisions such as how much data to collect and how to space data collection.
- Manage time by conducting pilot experiments and plotting as you go.
- Set up a simple circuit and troubleshoot the circuit by systematically isolating and testing different components (not "trial and error").
- Use results to propose new or modified models to explain and represent the phenomena being investigated.

Run this code cell to mount your Google Drive.

```
from google.colab import drive
drive.mount('/content/drive')
```

 Mounted at /content/drive

In the code cell below, fill in the "..." with the directory information where your utilities file is located on your Drive.

```
%run "/content/drive/My Drive/.../utilities.ipynb"
```

The first page provides information on a need-to-know basis. The aim is to give students comfort around terminology and equipment without giving away the physics. Keep this in mind as you guide them and discourage them from looking things up. The whole point is to try to figure things out experimentally.

From a modeling perspective, this lab is just like Stretchy Things—testing a system which should be linear and then a system which may not be. Remind them that have the tools to tackle this. The added layer here is that the phenomena are more unfamiliar so they can engage more authentically as scientists.

Note about the measurement: Even though the power supply displays voltage and current, students must use DMMs for their measurements.

In the first part of lab, the voltage supplied should be the same as the voltage across the resistor. But in the second part of the lab, the circuit will have resistor and LED/lightbulb in series so the voltage supplied will not be useful.

Additionally, the DMMs provide more precise measurements.

✓ Part 1: Getting started

As we move into experiments related to electricity and magnetism, we shift from testing models to building models. The goal is to explore the physical world and use our experimentation tools and skills to make sense of what may be happening. We are not seeking to verify textbook physics. We are seeking to discover physics from your experiments.

You are not expected to know anything about electricity to perform these experiments. The pioneers of the field in the 19th century didn't know much either and did experiments like these. You're in good company!

What is a circuit?

A circuit is a closed loop through which electricity flows. This closed loop consists of *circuit components* (things like batteries and light bulbs) and *wires* which connect circuit components together. Circuit elements either supply or absorb electrical energy, while wires transmit electrical energy (and absorb a little energy as well but usually a negligible amount).

In the circuit you will build, you will combine all of these elements. Your circuit will include

- a power supply, aptly named since it supplies electrical power/energy.
- a resistor, which absorbs electrical energy
- wires, which permit the flow of electricity through the circuit

If electricity feels unintuitive and unfamiliar, do not fear. It is! We cannot see electrons and often the behavior of electrical phenomena seems mysterious or complicated. While imperfect, a helpful analogy is the "water pipe" analogy. See details of this [analogy on HyperPhysics](#). If you're having trouble conceptualizing what a resistor does, try using the water pipe analogy.

Familiarizing yourself with the equipment

This first activity aims to familiarize you with equipment that will allow you to design and carry out experiments with circuits.

Check in with other groups if you need additional assistance with the set-up and refer to the sheet about as you work. If you

Check in with other groups if you need additional assistance with the set up and refer to the cheat sheet on your table. If you quickly get through this exercise, help out your peers in other groups. Your instructor is also available to help but there are more of you than there are instructors, so help each other out!

Your TA will draw a diagram of a circuit on the board for you to set up. Before setting up the physical equipment, [visit this simulation](#) and set up the same circuit using the simulated equipment.

After exploring the simulation a bit, read the information below carefully to understand what you'll be measuring and how. Then connect the physical circuit using the lab equipment.

Advise students not to turn on power supplies until they've spent some time with the simulation and have read up to the "Beware of excess current" note.

What are you measuring

So far we've mentioned a few ideas relevant to simple circuits. We've mentioned that electrical energy flows or is transmitted around a circuit. This flow of electricity is called **current**. The units of current are Amperes or Amps, denoted by A .

Current is a result of electrical potential energy, which is supplied by things like batteries and power supplies. We can measure this difference in electrical potential energy between distinct points in a circuit to get a sense of the "force" that drives the current between those points. This "force" that drives the current is called **voltage**. (Strictly speaking, voltage is not a force, which is why I've used scare quotes. Here we mean to imply the colloquial usage of "force" rather than the technical physics usage.) The units of voltage are Volts, denoted by V . Yes, the symbol for voltage is the same as the symbol for its units. Yes, this is bad notation. Sorry!

We will be introducing elements that absorb energy in our circuit, such as the resistor. To measure the extent to which a circuit element restricts current flow, we measure its **resistance**. Resistance is a property of the resistor itself; what material it's made of and its size and shape. Therefore you should measure the resistance of a resistor when it is not connected to a circuit. The units of resistance are Ohms, denoted by Ω .

Show students the decade box and show them how to change resistance without letting resistance go to zero.

How are measurements made

You will be using a handy tool called a Digital Multi-Meter (DMM). As its name implies, a multimeter measures multiple quantities (current, voltage, resistance, and more). But since these physical quantities are different, do not expect to use the multimeter in the same way for different measurements. Think of it this way—if you had an apparatus that measured both time and length, you'd probably expect to have to change the settings and the configuration depending on which quantity you were measuring. The same goes for the DMM.

You may see or hear the terms **ammeter** or **voltmeter** which refer to tools that measure current or voltage, respectively. Your multimeter measures both and therefore can be used anywhere an ammeter or voltmeter is required.

The DMM will connect to your circuit either in **series** or in **parallel** with some circuit element depending on whether you are measuring voltage (parallel) or current (series). Your TA will show you how to make these connections.

To measure voltage and current, electricity needs to be flowing which means your circuit should be on.

To measure resistance, no electricity should be flowing through your resistor.

✓ Check your understanding.

Answer the following questions based on the simulation, the real equipment, and conversation with your TA. You may come back and revise your answers as you learn more throughout the session.

How do you set up the multimeter to measure the voltage supplied by the power supply? What does the multimeter read when the power supply is turned off? What does the multimeter read when the power supply is turned on?

[Your response here]

What do the voltage settings on the multimeter do (e.g. the ones that say 200m, 2, 20, etc)?

[Your response here]

What happens if you swap the terminals on the multimeter while measuring voltage?

[Your response here]

Beware of excess current

Applying the water pipe analogy rather loosely, imagine blowing a hole in your water pipe so that all the water rushes out. This is what happens there is not enough resistance in your circuit to prevent a current surge. When current surges, components can become damaged. Do not let the resistance in your circuit go below $20k\Omega$!

To protect circuits from too much current, many devices contain **fuses**. When too much current flows, the fuse takes the hit and blocks current from passing. If the multimeters seem to not be working, check the fuse. There is a screw driver in the toolbox. Unscrew the four screws on the back and pop off the front part. Check the bottom fuse for a sear mark. If it looks seared, pop it out, throw it in the garbage, and replace it with one in the baggy at the front of the room. Ask your TA for help if you are not sure how to locate/remove the fuse.

✓ Begin Your Experiment: Testing Ohm's Law

Say you have a circuit component with some resistance R . According to a model called Ohm's Law, the ratio of the *voltage across* that component to the *current through* that component is equal to its resistance, or $V/I = R$. Put another way, $V = IR$.

There are all sorts of circuit components that exist (resistors, thermistors, capacitors, diodes, transistors,...). We will begin by testing Ohm's Law for resistors by collecting current and voltage data. Later, we'll test Ohm's Law for other types of circuit components.

If Ohm's law applies to a system under investigation, what do you predict a plot of the current, I , on the y -axis and voltage, V , on the x -axis will look like?

[Your prediction here]

Work with your group to design an experiment to test your prediction for the relationship between the current, I through your circuit and voltage, V , across the resistor.

Questions to consider in your design:

- You have three variables, V , I , and R . Which are dependent, independent, or constant variables? Please explain your reasoning based on your experience measuring them in the previous exercises.
- What are your dominant sources of uncertainty? How will you characterize, quantify, and minimize those sources?
- What ranges of values will you explore? How many data points will you collect within that range, given the minimum allowable resistance ($20k\Omega$)? How many repeated trials for each value of the independent variable will you need? Justify your choice in each case.
- How will you plot and analyze the data to evaluate whether the system is consistent with the model?

[Your design here]

#Create as many code cells as you need

[Your iterations here]

#More analysis here

#more analysis here

As always, iterate on your design informed by preliminary analyses (plot as you go!!).

A few technical notes:

- Always start with your power supply at zero and *slowly* increase the voltage to check how quickly the current is changing.
- Always check that there is at least $20k\Omega$ resistance in your circuit. To change resistances, add resistance before removing resistance so you never have zero resistance.
- Use Ohm's Law to predict the current through your circuit to give you a safe upper bound on the voltage.
- If your experiment requires greater than $50mA$, then first discuss your plan with your instructor.

End of session 1

✓ Part 2: Building models for other resistive materials

For the next part, design an investigation to explore the electrical behavior of light bulbs and/or light-emitting diodes (or LEDs). The goal here is to move from model testing (e.g., does Ohm's Law apply?) to model building (e.g., what's the new model?).

Set up a simple circuit with a light bulb or LED **in series** with a resistor.

REMINDER: Keep an at least $20k\Omega$ resistance in your circuit at all times so that you do not draw current greater than 50 mA through your circuit components. Note that a different range of resistor values may be acceptable depending on which type of light source you are using.

Choose your resistive material (either a light bulb or LED). Then design and carry out your investigation using strategies learned from Part I.

[Your design here]

#Your analysis code here

Use your observations and results and those of other groups to develop and refine models for the electricity through your object. You may want to build from the water pipes analogy linked above, construct a new analogy that better represents what you're seeing in your data, or focus on specific sub-pieces of the process (such as assumptions of the original model that may be limited). Justify each model that you develop using your previously collected data. Use the model(s) to make a prediction(s) about a new result and carry out investigations to test those prediction. You can also try another material if that seems justifiable.

[Your ongoing train of thought documentation of your various investigations should keep getting created here and below]

#Create as many of these as necessary

Before submitting, make sure your lab notes include all of the following information:

- Description of experimental design
- Uncertainty estimation
- Raw data
- Analyzed data
- Interpretation of results
- Concluding remarks including remaining questions and discussion of the physical significance of your results

You can delete this cell once you've checked off all the items on this list!

We will also have students present to each other at the end of the second session, as in Lab 3.