

How Does it Flow? Electricity, Circuits, and Motors

In this lab, we will investigate the behavior of some direct current (DC) electrical circuits. These circuits are the same ones that move electrons from wind turbines and solar panels to our electrical grid. We will explore how voltage, current, and resistance are related to one another, how motors are powered, and how a turbine can generate a voltage. We will also explore charging and discharging behavior of capacitors. These exercises will assist you in the wind and solar labs later this week.

By the end of the lab, you should be able to:

- identify the components of a circuit;
- understand the relationships that occur between the components;
- be able to use all variables associated with Ohm's Law (\mathbf{V} , \mathbf{I} , \mathbf{R});
- examine the use of capacitors in electrical circuits;
- understand the relationship between electricity and a motor or turbine

Before we start the lab, we will talk about electrical charge, voltage, current and resistance, to make sure that you are familiar with these concepts and terms, and the units we use to measure them. Electrical circuits usually have a power source such as a cell or battery, and one or more resistance sources, such as a light bulb or resistance coil. A circuit is a path along which electrons can flow. If the circuit is closed, there is a continuous flow of current until the power source is exhausted. Current does not flow in an open circuit, much like an outlet in your house. A circuit in which there is a single pathway is known as a *series* circuit whereas a circuit that has multiple (more than one) possible paths is known as a *parallel* circuit.

Voltage is the energy between two points and is a measure of the “push” of electrons through a circuit. It is measured in units of volts (V). The more fundamental SI unit is $(\text{kg} \cdot \text{m}^2/\text{C} \cdot \text{s}^2)$. For a reference, a standard AA battery is 1.5 volts, a car runs on 12V, and standard AC systems in the U.S. run on 120 V.

Current differs from voltage in that it is a measure of the flow of electrons through a wire, like water flowing through a pipe. Current is measured in units of amperes (amps) and is symbolized by the letter I (e.g. mA).

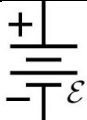




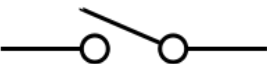
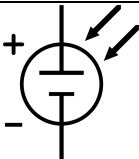

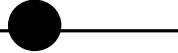
Resistors provide resistance to the flow of current in a circuit, similar to friction in a classical mechanics. Many resistors obey Ohm's Law ($\mathbf{V} = \mathbf{IR}$), which states that the current I through a resistance R is proportional to the voltage V across the resistor. Resistance is the functional basis of incandescent light bulbs, electric stoves, and electric heaters.

Capacitors are energy storage devices, but unlike batteries, capacitors function by means of storing static charge (electrons) between two parallel plates. Once the charge builds, it can then be discharged as needed, usually for short bursts of power.

Very importantly, there are various symbols used to easily and quickly identify parts of a circuit such as voltage, current, power source, wires, resistors, and capacitors:

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Table 1. Common circuit symbols.

 DC voltage	 Resistor/load	 Capacitor
 Voltmeter	 Ammeter	 Switch
 Solar cell	 Wire	 Wire connection

Materials

- One 9V cell with connector
- One “D” or “C”-type cell
- Set of “alligator” leads
- Resistance decade box
- Single throw switch
- LabQuest with current/voltage probes

Getting started

Measurements will be obtained using standard multimeters as well as Vernier systems with current and voltage probes. Using the LabQuest interface, connect the voltage probe to channel 1 and the current probe to channel 2. Current and voltage readings should be displayed on the meter. Set the LabQuest module to collect Events with Entry, meaning that it will save data when you click “keep” and you must input a value. You can name the cell “Ohms”. Connect the current probe to itself and the voltage probe to itself and click the Potential and Current meters. Click “zero” on each to zero both current and voltage sensors when there is no applied voltage with no current flowing before starting any measurements.

Simple Circuits and Resistance:

1. Make a simple circuit using the cell (and its holder), the decade box set to 22Ω , single-throw switch, and some of the connecting leads.
 - a). Using the symbols shown above in Table 1, draw a circuit diagram representing your new circuit:

b). Use Voltage probe to measure the voltage across the resistor, and the current passing through it. In order to measure the voltage *across* a component, place the two probe tips on either side of the component, placing the voltage probe in *parallel*. In order to measure the current *through* a component, the probe is placed so it is part of the current path, so connect the probe in *series*.

- Close the switch and observe the values. What is the voltage across the resistor? What is the current through the resistor? Open the switch when done so you do not drain the battery.

c). Fill in the table below, measuring the voltage across the 22Ω resistance, and the current through it. Use Ohm's Law ($V = IR$) to calculate the resistance from these two values. You do not need to “keep” and of the values.

Resistance	Measured voltage (V)	Measured current (A)	Calculated resistance (Ω)
22Ω			

Ohm's Law

You will determine the quantitative relationship among current, voltage and resistance.

- Connect the simple series circuit, using the decade box as the resistor and 9V cell as the source. You should not need to zero the readings again.
- Click the Graph icon on the top right, followed by graph options. Set the X-axis to “Ohms” or whatever you named your Entry cell and Run 1 to Current. Click “OK”, followed by clicking Graph again and selecting Show Graph → Graph 1.
- Placing the resistance at 22Ω , click “Collect” and observe the current value. Press “keep” to store the values.
- Increase the resistance to 47 Ohms. Press “Keep”. Repeat this for 100, 330, 470, and 680 Ohms. Click “Stop”, turn the resistance to 22Ω , and open the circuit with the switch.
- View the on-screen graph. Are the current and resistance values proportional? You will need to now perform some data manipulation to determine a relationship.
- Click the Table icon on the top right. Then click Table → New Calculated Column and name the column “V x I”. Under Equation Type, select “XY” and choose CH1: Potential for X and CH2: Potential for Y. Click OK. Compare the Calculated values to the values for Ohms. What do you observe?
- Add another Calculated Column named “1/R”, select “A/X” and select “Ohms” as the Column for X, A=1. Click OK. Go back to the graph icon and go to Graph → Graph Options. This time, select 1/R for the X-Axis and “I” for Y data. Click “OK” and change to the Graph view. The plotted line is I vs. 1/R. Is this linear? Check by going to Analyze → Curve Fit → Current. Choose Linear fit and click OK. What is the slope of the line? Compare this to the Voltage value from above. Record the slope and y-intercept of the regression line in the data table, along with their units.

Equation of line: _____

Slope: _____

y-intercept: _____

The voltage of a battery does not vary under normal conditions since it is governed by a chemical redox reaction. As the resistance of a circuit is increased, however, less current is able to travel through the resistor for a given voltage, thus obeying Ohm's law. If the change in current is inversely *proportional* to the resistance, the data for I vs. $1/R$ should be in a straight line and it should go through zero. Why is this true? In these two examples how close is the y -intercept to zero? Is there a relationship between voltage, current, and resistance? What is it?

Using this information, predict what the current of the circuit will be when the resistance is set to 33Ω . Test your hypothesis. Is it correct? Why or why not?

Voltage of cell	
Resistance of decade box	
Predicted current of circuit	
Actual current of circuit	
Percent error from predicted value	

- Typical resistors have an accuracy of $\pm 5\%$. Are your measurements within this error?

Building a Motor/Turbine

You will now construct a simple motor/turbine. The physical principles in this model are basis of all electrical generators and electric motors.

- Using a "D"-style battery, make several windings of enameled wire around the battery, leaving about 1.5" of wire exposed before you begin to wind the coil. Eight windings should be sufficient. Leave another 1.5" of wire exposed at the other end. Remove the wire from the battery and loop the excess wire around the coil as shown in figure 1.

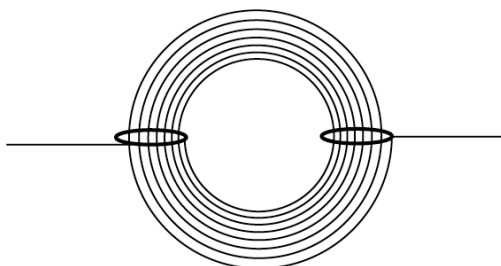


Figure 1. Copper coil with 8 windings made around a "C"-cell battery.

- Obtain a piece of wood and place the ceramic magnet in the pre-drilled hole. Un-bend a small paperclip, making a support for the exposed wire ends on the coil and tack the paperclip to the wood using a thumbtack. Place the coil on the supports and connect the 9V battery leads to the paperclip supports. Give it a slight push. Does anything happen? Interestingly, the wire you are using is enamel-coated, meaning that it is not conductive. To complete the circuit, you must have a conductive wire between the terminals of the 9V battery.

The insulation on the two ends of the copper wire must be removed so that the current can flow. This can be done with sandpaper, scissors, or blade of a razor. You will not want current to flow in the coil all the time, or else there will be no “push” in the motor. If you remove the insulating material all around the wire, the loop will have a constant force through it. You will need to make what is called a "commutator" which is a mechanism to make the flow of current intermittent. One simple solution is to only remove the insulating material on one "half" of the wire as shown below.



- Place the wire coil in the vertical direction, so the loop is up and down, not flat. Sand the ends of each wire *only on the top half of the wire*. Place the coil back on the paperclip support, connect the 9V leads (if necessary) and give the coil a slight push. What do you observe? If the wire is perpendicular to the magnetic field, then the force is along the wire and can do some work, in this case cause rotational motion.

You have successfully built an electric motor! The laws of electricity and magnetism dictate that any charge (electron) moving through a magnetic field experiences a force (N). In this case, the 9V battery supplies a current and aligns the direction of magnetic spins, making the coil an electromagnet. When the coil is in a position that gives it the same polarity as the magnet (conducting), opposing forces push the coil away, thus creating motion.

At this point the motion may be irregular since the wire only receives a “push” half of the time it is spinning. To build a truly fast motor, you need to have the push occur all the time. In this case, the current needs to reverse, so the north pole of the electromagnet became the south pole, and vice versa. And since it is already going in one direction that is the direction it will choose to continue going (due to the inertia and momentum of the coil).

- Place the motor in front of you, so that the axle goes left to right. Now scrape a piece of the enameled wire so it is completely exposed. Attach the wire on the right side with a pushpin and let it rest on the right axle, just past the right support. Do the same thing with the right support and the left axle.
- Connect the bare wire on the right to the left axle support with an alligator clip. Do the same with the bare wire on the left, connecting it to the right axle support.

On one half of the cycle, the bare half of the axle will face down and touch the bare wire of the support, just like before. On the other half of the cycle, the bare half of the axle will touch the new wires that are resting on top of the axle. Since these wires are connected to the opposite supports, the current will flow in the opposite direction. The motor will get two kicks per cycle instead of one, and will never be coasting. It will always have power and should go twice as fast, neglecting friction.

- Re-connect the clips on the leads from the battery to the paper clips, and your "motor" should run; it may need a small push to get going, but that is all.

Like many principles in science, you should be able to run the reaction in reverse: That is, use the magnet and coil to *generate* power. This is a turbine.

- Begin by disconnecting the 9V battery and connecting the Vernier voltage probe to the paperclips. Begin to spin the coil. Do you see any change in voltage? If this is not observable, simply try to push the magnet back and forth across the wire. All the work you did in constructing the wire coil, magnet assembly, and commutator can be used as both a motor and a turbine. This has interesting dual-purpose possibilities.

In what capacity does a wind turbine fit into this experiment? A solar cell? Other forms of energy?

