# DC Electric Circuits: Resistance and Ohm's Law

## Goals and Introduction

Our society is very reliant on electric phenomena, perhaps most so on the utilization of electric circuits. For much of our world to operate, we need electrical energy. In electric circuits, electrical energy is realized as flow of electric charge. This flow of charge, or current, can then cause materials to become warmer as the charges undergo collisions with each other and the atomic lattice of the material in which the current flows. When we think about the many ways in which electrical energy is generated, one theme that emerges is the need for a clever way to convert one type of energy, such as mechanical, solar, or geothermal, into electrical energy. As long as opposite charges can be physically separated from each other, or as long as a potential difference can be generated, we can convert much of the energy used to achieve that effect into electrical energy.

When you cause there to be a fixed potential difference, $\Delta V$, across a conducting material, like a wire, an electric current, $I$, will flow in the wire towards the lower potential. The magnitude of that current will depend on the amount of resistance, $R$, within the wire. This relationship is expressed Using Ohm's Law (Eq. 1). The potential difference is measured in units of volts, V, while the current is measured in amps, A, and the resistance in units of ohms, Ω.

$$\Delta V = IR \qquad \text{(Eq. 1)}$$

We can make a *direct current*, or DC, electric circuit by using some wire and a power source with a fixed potential difference, and connecting the wire across that difference. This is quite dangerous though because the resistance of the lone wire would likely be very low, causing the current to be greater, as can be deduced from Eq. 1. What is done to mitigate this issue in a circuit is to include a circuit component called a *resistor*. We say that a resistor has some resistance, $R$, and this is often much greater than the resistance of the wires that connect the resistor to the power source. An example of a *circuit diagram* is shown in Figure 1, where the fixed potential difference of the power source is shown (this is often used to symbolize a battery), and the resistor is indicated by the presence of the "zigzag" line. The convention in this kind of circuit is to model the current, or flow of charge, as moving from the higher electric potential (indicated by the "+" in the power source), through the resistor, and towards the lower electric potential (indicated by the "-" in the power source).

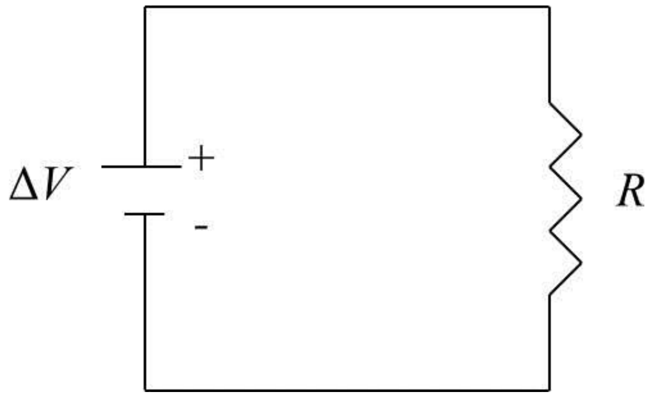


Figure 1

In truth a resistor is basically just “more wire.” It is a whole lot of wire crammed into a small package. Because the physical characteristics of a wire, such as length, cross-sectional area, and the resistivity of the material used to make the wire, are the factors that determine the magnitude of the resistance, we are able to engineer wires that have much greater resistance by adjusting these characteristics.

When a current flows through any resistor, Ohm’s Law (Eq. 1) can be used to express the potential difference that exists on either end of the resistor, even in a circuit more complicated than that in Figure 1. We find that this law works well in most settings, for most wires and materials, but it should not be thought of in the same way as Newton’s Laws of Motion. Most materials are said to be *ohmic*, and obey the law fairly well, though there are some materials that are *nonohmic*. It should also be noted that when used in this way, Ohm’s Law is expressing the potential difference across the resistor alone, based on the current that happens to be running through it at that time. We express this idea in Eq. 2. While it may seem identical to Eq. 1, realize that in Eq. 1 we are really saying that the current leaving and returning to the source depends on the potential difference of the source and the net resistance in the connected circuit.

$$\Delta V_R = IR \qquad \text{(Eq. 2)}$$

If we connect a single resistor to a fixed potential difference, we can measure the current through the resistor by using a device called an *ammeter*, and we can measure the potential difference across the resistor by using a device called a *voltmeter*. These are symbolized in Figure 2. Note that the voltmeter must be connected across the ends of the resistor, while the ammeter must in-line with the resistor. In technical terms, we say that the ammeter must be in the same *branch* of the circuit as the resistor, or *in series* with the resistor, while the voltmeter must be *in parallel* with the resistor.

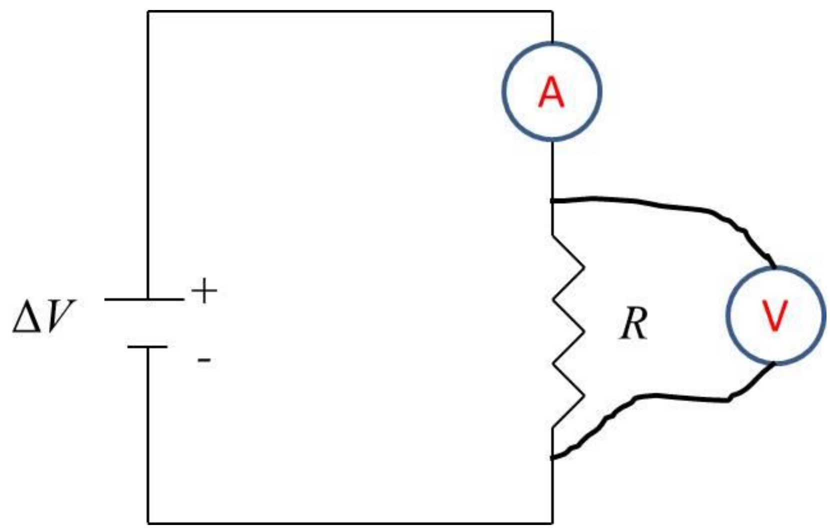


Figure 2

In today's lab, you will explore the conversion of mechanical energy into electrical energy by use of a hand-crank generator. At first, you will observe the brightness of a lightbulb, which is a resistor that converts the electrical energy into light, when a current runs through it. You will then show that similar characteristics are present for a resistor, when it replaces the bulb in the circuit. Lastly, you will conduct a series of measurements to test the validity of Ohm's Law for a resistor.

*Goals*: (1) Confirm the conversion of mechanical energy to electrical energy
(2) Observe the electrical measurements for a lightbulb and a resistor to confirm the similar electrical energy aspects they exhibit in a circuit.
(3) Test and confirm Ohm's Law for a resistor connected to a fixed potential difference.

**Procedure**

*Equipment* – electric connection board, 5 wires, 0 – 30 V DC 1 A wall power source, hand-crank generator, resistor with a resistance between 20 and 50 Ω, lightbulb, ammeter with a 0 – 500 mA scale, digital multimeter, two alligator clips

NOTE: When turning the hand-crank generator during this experiment, you will be asked to vary the speed at times, but please do not attempt to turn them so fast that you end up ripping the handle off the end. You should have fun and explore the effects of altering the rotational speed but be mindful for the care of the equipment.

NOTE: When you use the wall power supply, do not leave the voltage applied for long periods of time. If you do, you will heat up the resistors and potentially damage them. If you smell an odor, during the experiment, it is probably the resistor heating (hopefully not your lab partner). You should immediately turn the knob on the power supply all the way counter-clockwise and let the resistor cool.

1) Before connecting anything to the hand-crank generator, both you and your lab partner should take turns turning the hand-crank generator. Make note of the effort needed to turn the crank while no bulb, or resistor, is connected to the leads.

2) Now, clip either end of the hand-crank generator to either end of the lead wires from the lightbulb. Be sure to clip to the exposed metallic portion of each wire. Both you and your partner should take turns rotating the hand-crank generator and make note of the effort needed to turn the crank.

**Question 1:** How did the effort required to turn the crank differ when the bulb is now connected versus when nothing was connected across the leads of the generator. Hypothesize as to why there is a difference.

3) Try to turn the crank slowly at a constant rate and observe the brightness of the bulb. Then turn the crank at a faster constant rate and observe the brightness of the bulb.

**Question 2:** How did the brightness of the bulb vary compared to the rate of rotation of the generator? Hypothesize as to what causes the difference in terms of electrical energy.

4) Now follow this procedure to build the first circuit:

a) Partially unscrew two of the adjacent posts on the circuit board and plug the wire leads from the lightbulb into the top of the two posts. If you do not have plugs on the ends of the bulb's wire leads, thread one lead wire from the light bulb into one post, and the second lead wire through the other post. Leave some of the metallic end of each wire sticking out the side of each post. Be sure that when you tighten down the post, it will be pinning only the exposed metallic portion of the wire.

b) (IF YOU COULD NOT PLUG YOUR BULB INTO THE TOP OF THE POSTS ONLY) LIGHTLY tighten the posts by screwing them back down. Just make sure the wires are secure. You don't need to tighten the screws severely; just enough to keep the wires from sliding around.

c) Plug a wire into the top of the post on the right and run it to the digital multimeter. Plug the other end into the port on the bottom labeled “VΩ.”

d) Plug a wire into the top of the other post and run it to the digital multimeter. Plug the other end into the port on the bottom labeled “COM.” Then, turn the dial on the digital multimeter so that it points to “20” in the section labeled as “V- - -” on the outer edge of the meter.

e) Plug a third wire into the top of the post on the right and plug its other end into the ammeter labeled “COM.”

f) Then, clip one end of the hand-crank generator to the post (or lightbulb wire) at the post not connected to the ammeter. Unscrew the “500 mA” post on the ammeter, just enough so that you can clip the other end of the generator to that post. See Figure 3. This builds the circuit described by Figure 2. Check the connections to see if you can follow the wire-paths and verify that this mimics Figure 2, where the resistor is the lightbulb. If you are unsure, check with your TA. **Record** any nonzero reading on your multimeter. This value must be treated as the zero reading for this meter. If you have one, your measurements in this part of the experiment must be corrected for this offset.

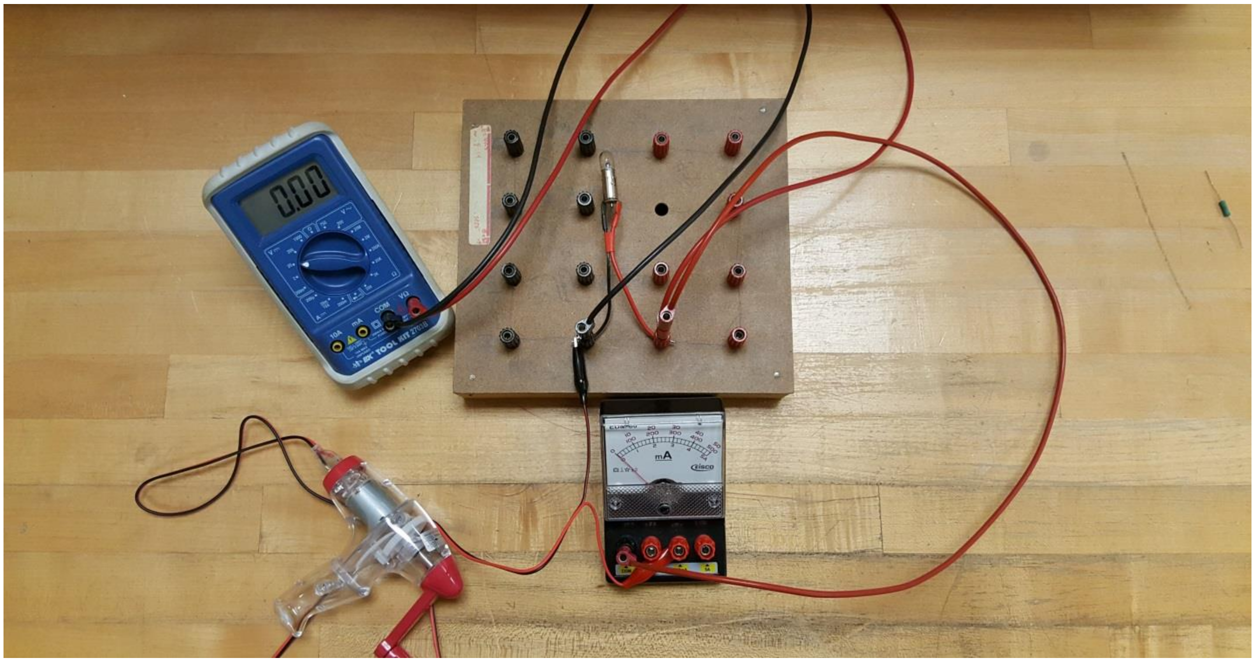


Figure 3

5) Now, try to rotate the crank slowly, at a constant rate, and observe the readings on the two meters. Be sure to rotate in a direction so that the voltmeter reading is positive. **Record** what you perceive to be the average values for the potential difference across the bulb and the current through the bulb. Note that when you are reading the digital multimeter, your reading will currently be in units of volts. On the ammeter, you must use the middle scale along the dial, which has a maximum value of 500 mA. Your reading on that meter will thus be in milliamps.

6) Rotate the crank more quickly, at a constant rate, and observe the readings on the two meters. **Record** what you perceive to be the average values for the potential difference across the bulb and the current through the bulb. Also, note if the brightness of the bulb is different than in step 5 and how so.

7) Rotate the crank the opposite direction and observe the readings on the voltmeter and the ammeter. Also note the behavior of the bulb.

**Question 3:** What is different about the readings when you rotate the meter in the opposite direction? Explain what is happening in terms of the potential difference from the generator, the potential difference across the resistor, and the current through the resistor. Is the bulb receiving energy? How can you tell?

8) Replace the bulb with the resistor. This will require you to loosen the posts to get the bulb wire leads out and put the resistor wire leads in. Remember to not overtighten the posts! Be sure to connect the hand-crank generator to the one end of the resistor, just as it was for the bulb. The circuit should be identical to that from Figure 3, except with the resistor in place of the bulb.

9) Now, try to rotate the crank slowly, at a constant rate, and observe the readings on the two meters. Be sure to rotate in a direction so that the voltmeter reading is positive. **Record** what you perceive to be the average values for the potential difference across the resistor and the current through the resistor.

10) Rotate the crank more quickly, at a constant rate, and observe the readings on the two meters. **Record** what you perceive to be the average values for the potential difference across the resistor and the current through the resistor.

**Question 4:** How are the values observed similar or dissimilar to those you recorded for the lightbulb? Hypothesize as to the cause of these differences. With regard to energy, does the lightbulb behave like a resistor and vice-versa? What else would we want to check, or measure, to verify further (if we could)?

11) We will now create a different version of the same circuit. Follow these steps:

a) Unclip the hand-crank generator from the bulb and the ammeter. Screw down the post on the ammeter. You may place the hand-crank generator off to the side (we are done with it for this lab).

b) Locate the "0-30 V DC 1A" wall power supply and be verify that the knob is turned all the way counter-clockwise, and that the switch is "off."

c) Using another wire, plug one end into the top of the "500 mA" post on the ammeter, and plug the other end into the red post on the wall power supply ("0-30 V DC 1A").

d) Using another wire, plug one end into the post on the circuit board where the ammeter is not connected, and plug the other end of the wire into the black post on the wall power supply ("0-30 V DC 1A"). Your figure should look like that seen in Figure 4. **Record** any nonzero reading on your multimeter. This value must be treated as the zero reading for this meter. If you have one, your measurements in this part of the experiment must be corrected for this offset.

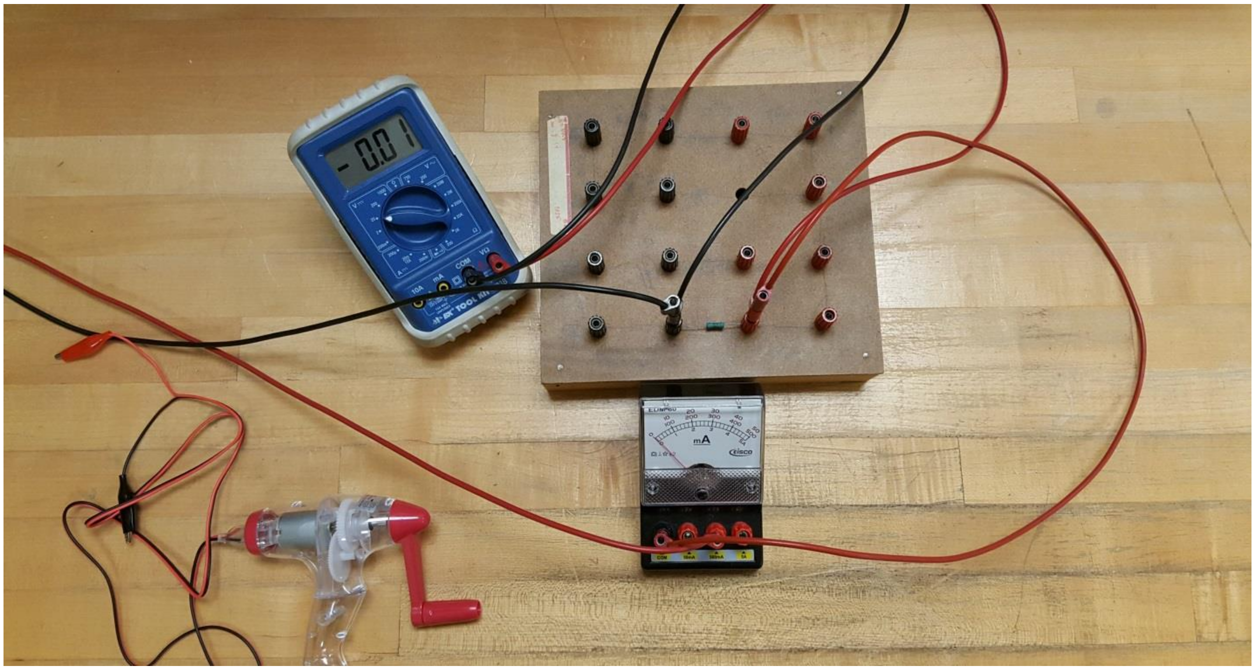


Figure 4

12) Observe that there is no current when the potential difference across the resistor is 0. This is your first data point for **recording** $\Delta V_R$ and $I$.

13) Turn on the wall power supply and turn the knob slowly while watching the digital multimeter. Set the potential difference across the resistor to be approximately 0.50 V and **record** the potential difference across the resistor and the current through the resistor at that moment.

14) Repeat step 13 by increasing the potential difference by 0.50 V for each measurement until you reach 6.0 V. **DO NOT** leave the wall power supply on for very long. Get these measurements in a timely and efficient manner, and then turn the knob all the way counter-clockwise and turn off the wall power supply.

15) Once the power is off, disconnect the circuit, except the wires that were plugged into the digital multimeter. Attach the alligator clips to the free ends of the wires plugged into the multimeter, and clip them across the two ends of the resistor. Turn the knob on the multimeter to the area marked with Ω and set the dial at "200." This causes the meter to measure the resistance of the resistor. **Record** the resistance of the resistor.

As always, be sure to organize your data records for presentation in your lab report, using tables and labels where appropriate.

## Data Analysis

Remember to convert your currents to amps, A, as necessary!

When you rotated the crank slowly, while attached to the lightbulb, you recorded values for the potential difference and the current. Use these to calculate the resistance of the lightbulb.

Repeat the above calculation using the data from when you rotated the crank more quickly.

Use the data you recorded in step 9, when using the hand-crank generator with the resistor, to calculate the resistance of the resistor.

Use a software package, such as Microsoft Excel, to plot your data for the potential difference across the resistor versus the current ($V$ vs. $I$) from steps 13 and 14. Remember to include (0 A, 0 V) as a point.

Find a best-fit line for your data and display this equation on the graph, including it in your lab report.

The slope of the best-fit line should be representative of the resistance. Note the value of the slop of the line.

**Question 5:** How well did the resistance of the resistor you found from the hand-crank data match that from the best-fit line? What would account for any differences you see here?

## Error Analysis

Calculate the percent error between the resistance you found from the best-fit line and the resistance you measured in the last step using the digital multimeter. Treat the value from the multimeter as the accepted value.

$$\%error = \frac{\left|R_{\text{experimental}} - R_{\text{accepted}}\right|}{R_{\text{accepted}}} \times 100\%$$

Calculate the percent difference between the two resistances you calculated for the lightbulb.

$$\%diff = \frac{\left|R_1 - R_2\right|}{\left(R_1 + R_2\right)/2} \times 100\%$$

**Question 6:** What would you claim the resistance of the light bulb to be, based on the available data? How would you design an experiment to measure the resistance of the lightbulb more exactly? Would this design work for any resistance?

## Questions and Conclusions

Be sure to address Questions 1 through 6 and describe what has been verified and tested by this experiment. What are the likely sources of error? Where might the physics principles investigated in this lab manifest in everyday life, or in a job setting?

## Pre-Lab Questions

Please read through all the instructions for this experiment to acquaint yourself with the experimental setup and procedures, and develop any questions you may want to discuss with your lab partner or TA before you begin. Then answer the following questions and type your answers into the Canvas quiz tool for “DC Electric Circuits: Resistance and Ohm’s Law,” and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) Tyrell measures the current through a resistor to be 0.30 A while the potential difference across the resistor is 6.0 V. What is the resistance of the resistor? Answer in units of ohms, Ω.

PL-2) Increasing the potential difference across a resistor will cause the current to

A) increase.

B) decrease.

C) stay the same.

D) approach zero.

PL-3) Laurie found that the slope of the best-fit line for her data had a value of 35.6 Ω. She had used the multimeter to measure the resistance and found that it was 33.0 Ω. What is the percent error in her results? Answer as a percent without the “%” symbol.

PL-4) Tyrell knows that he has a resistor with a 200-Ω resistance. He wants to cause a current of 3.0 A to run through the resistor. What potential difference must he apply to the resistor to cause this to happen? Answer in units of volts, V.

PL-5) Suppose that while performing this activity, Laurie begins to smell an odor that might be due to the resistor heating up. She should

A) turn the knob on the power supply completely counter-clockwise.

B) unscrew the posts holding the resistor.

C) blow on the resistor to cool it off.

D) increase the potential difference across the resistor.