DC Electric Circuits: Resistors in Combination

Goals and Introduction

Assuming you performed the lab activity “DC Electric Circuits: Resistance and Ohm’s Law,” you saw how the potential difference across a resistor is related to the current through that resistor (Ohm’s Law for a resistor, Eq. 1). In a simple circuit, such as those examined in that lab, there was only one resistor connected to the power source. Thus, the fixed potential difference of the source was the same as the potential difference across the resistor. In more complicated circuits, this may or may not be true. And yet, the potential difference across any single resistor must still be related to the current through that resistor, as in Eq. 1.

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

Given two resistors to be connected to the power source, one possible way this can be achieved is to connect the resistors directly on one end and connect the remaining free ends of each resistor to the power source (Figure 1). These resistors are said to be connected in *series*. Realize that there can only be one value for the current in the branch, or pathway in a circuit. This entire circuit is one branch, since there is no place for the current to split off and travel a different path. Conventional current flow would proceed towards the lower fixed potential on the power source - the same current through both resistors! The amount of current drawn from the power source (and through the source) should be a function of the *equivalent resistance* of the circuit.

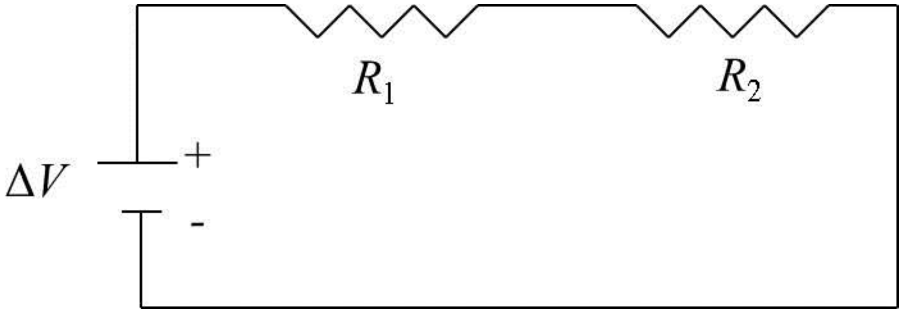

Figure 1

We can imagine that from the perspective of the power source, there is some kind of *net* or *equivalent* resistance that is connected across its ends. Thus, we imagine that we could theoretically replace the two separate resistors with a single resistor that had the right value of resistance to cause the same current to be drawn from the power source – the same current as when the two resistors were connected. A drawing of the equivalent circuit is shown in Figure 2.

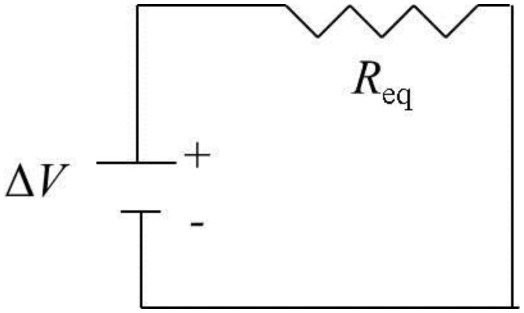

Figure 2

It is the equivalent circuit that allows us to apply Ohm's law for the current through the source (Eq. 2).

$$\Delta V = IR_{\text{eq}} \qquad \text{(Eq. 2)}$$

When resistors are connected in series, it must be true that the sum of the changes in electric potential across each individual resistor must equal the fixed potential difference of the source. This is an expression of Kirchoff's loop rule, which you should learn about in lecture. The result of this idea is that there is a formula that can be applied to resistors in series to find the equivalent resistance. This equation is shown below (Eq. 3). The sum of the resistances that are in series is equal to the equivalent resistance. In this lab, we will limit ourselves to two resistors in series, but we could have more and still apply the rule in Eq. 3.

$$R_{\text{eq}} = R_1 + R_2 + \cdots \qquad \text{(Eq. 3)}$$

Another way to connect two resistors to the power source is to connect both left ends of the resistors together and both right ends of the resistors together (Figure 3). These resistors are said to be connected in *parallel*. Here, as current travels through the source and into the rest of the circuit, there are two possible paths for the current. Some of the current would pass through the first resistor and the rest would pass through the second resistor. This leads to what is called the junction rule: The sum of the currents entering a point where branches connect must be equal to the sum of the currents leaving that point. Still, as before, the amount of current drawn from the power source (and through the source) should be a function of the *equivalent resistance* of the circuit.

We can imagine replacing the parallel circuit in Figure 3 with an equivalent resistance (Figure 2), just like we did with the series circuit, and we can again apply Ohm's law to the source (Eq. 2).

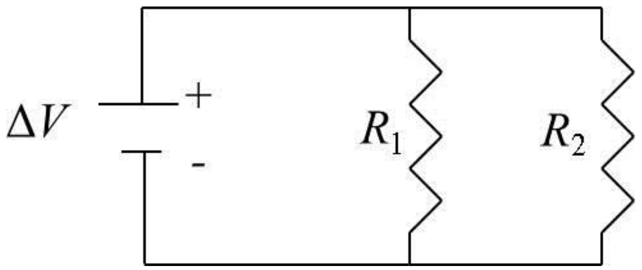

Figure 3

When resistors are connected in parallel, it must be true that the potential difference across each resistor must equal the fixed potential difference of the source. This is again an expression of Kirchoff's loop rule, which you should learn about in lecture. The result of this idea, in combination with the junction rule for the current in the branches of the circuit, is that there is a formula that can be applied to resistors in parallel to find the equivalent resistance. This equation is shown below (Eq. 4). The sum of the reciprocal the resistances that are in parallel is equal to the reciprocal of the equivalent resistance. In this lab, we will limit ourselves to two resistors in parallel, but we could have more and still apply the rule in Eq. 4.

$$\frac{1}{R_{\mathrm{eq}}} = \frac{1}{R_1} + \frac{1}{R_{\mathrm{eq}}} + \cdots \qquad \text{(Eq. 4)}$$

In today's lab, you will explore the effect of resistors being in series and parallel and perform measurements that confirm the expected behavior of the electric current in both types of circuits – series and parallel. You will also confirm Kirchoff's loop rule for each type of circuit by measuring the potential difference across each resistor and the fixed potential difference of the source.

Goals: (1) Observe the behavior of resistors in parallel and series via the use of lightbulbs, acting as resistors in a series and parallel circuit
(2) Perform measurements to test and confirm Kirchoff's loop rule for a circuit
(3) Perform measurements to test and confirm the behavior of currents in a series and parallel circuit, and confirm the junction rule for a parallel circuit.

Procedure

Equipment – electric connection board, 7 wires, 0 – 30 V DC 1 A wall power source, hand-crank generator, 2 resistors of different resistance, 2 lightbulbs, 2 digital multimeters, 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.

1) Plug one wire into the “COM” port on one of the multimeters and another into the “V- - -” port. Attach the alligator clips to the free ends of the wires plugged into the multimeter, and clip them across the two ends of one of the resistors. Turn the knob on the multimeter to the area marked with Ω and set the dial at “2K.” Note that when you are on a setting with a “K”, the meter is reading in thousands of Ohms. If the meter shows a one with a line next to it, this means the resistance is larger than the current setting. If this is the case, turn the dial one click counter-clockwise until you can get a reading of the resistance. **Record** the resistance of the resistor, being sure to convert your measurement to ohms.

2) Unclip the first resistor and clip the meter to the other resistor. Turn the dial on the meter to the best possible setting for precision, and **record** the resistance of the second resistor, being sure to convert your measurement to ohms. Make note of which resistor is which (one will have a greater resistance than the other)! Repeat this process to **measure and record** the resistance of each of the lightbulbs, separately (remember which is which!), and then, remove the alligator clips.

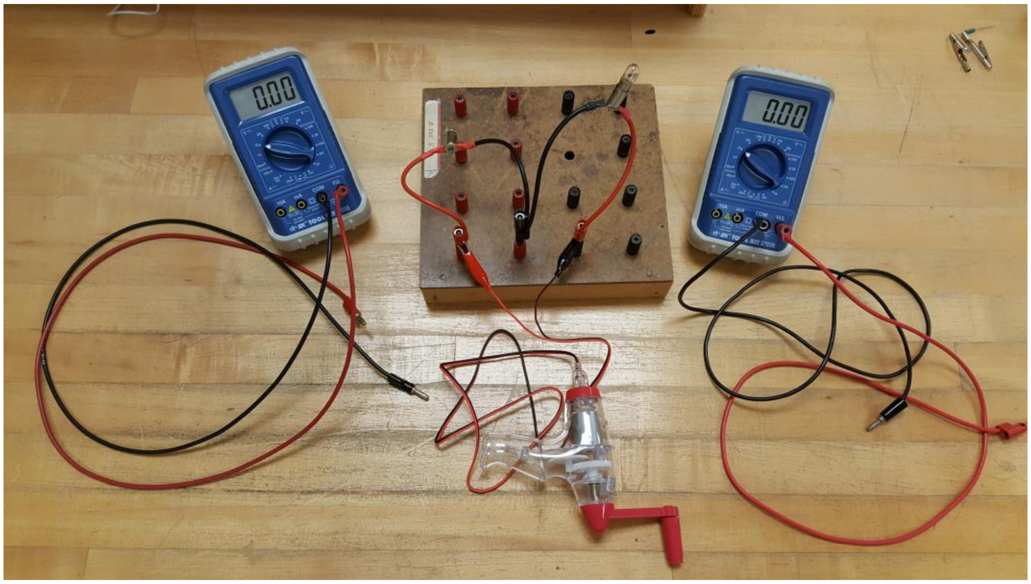

Figure 4

3) Use three of the posts on the connection board to connect the two lightbulbs in series. Pin, or plug, a lead wire from each lightbulb into a center post and then connect the remaining free ends of each lightbulb into separate, nearby posts. Then, clip the leads from the hand-crank generator

onto the two outer posts. You should also plug one wire into the “COM” port on the other multimeter and another into the “V- - -” port. Turn the dial on both meters so that they point to “20” in the section labeled as “V- - -” on the outer edge of the meter. See Figure 4 above.

4) Plug the “COM” wire from the left multimeter into the center post and the other wire into the left-most post. Then, plug the “COM” wire from the right multimeter into the right-most post and the other wire into the center post. The goal is to try and arrange these connections so that you measure positive potential differences in each case. If you find that is not the case in future steps, reverse the connections on the multimeter, or call over your TA! Your circuit should now look like that seen in Figure 5.

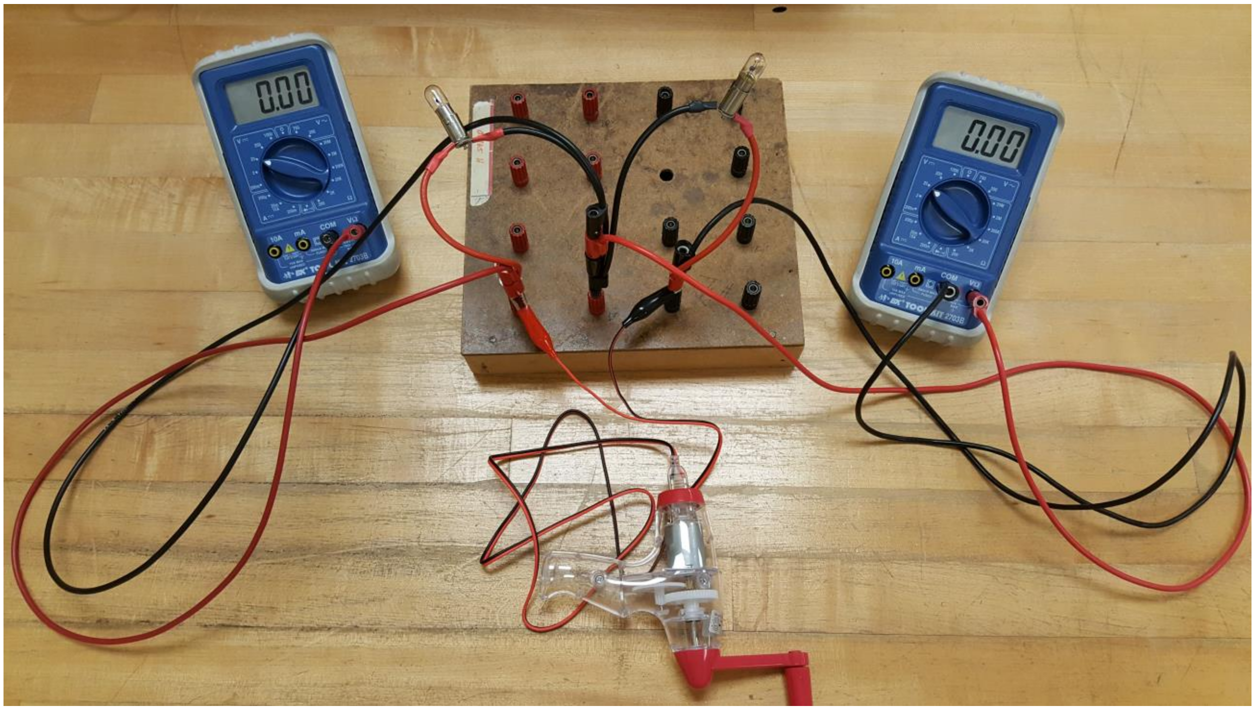

Figure 5

5) 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. Make note of the difficulty in turning the generator.

Question 1: How did the brightness of the bulbs compare to each other in each case? Explain your observations.

6) Try to turn the generator at a constant rate and **record** the potential difference across each lightbulb. Be sure to note which bulb experienced each potential difference (the bulbs likely had different resistances).

7) Disconnect the generator and the wires from the posts. Disconnect the bulbs from the posts. Then, use four posts on the connection board to connect the bulbs in paralle to the hand crank generator. Connect one bulb into two adjacent posts, and then connect the other bulb into two other separate, but nearby, posts (connect the second bulb in the row above the first). You can then plug both wires from the “COM” ports on the meters to the posts on the right side and both wires from the “V- - -” ports to the posts on the left side. Clip the generator to the left and right posts of the first bulb. Lastly, connect a wire to both left posts of the bulbs and another wire to both right posts of the bulbs. Verify that this is a circuit with two resistors in parallel. Ask your TA if you are not sure. An example of this circuit is shown in Figure 6.

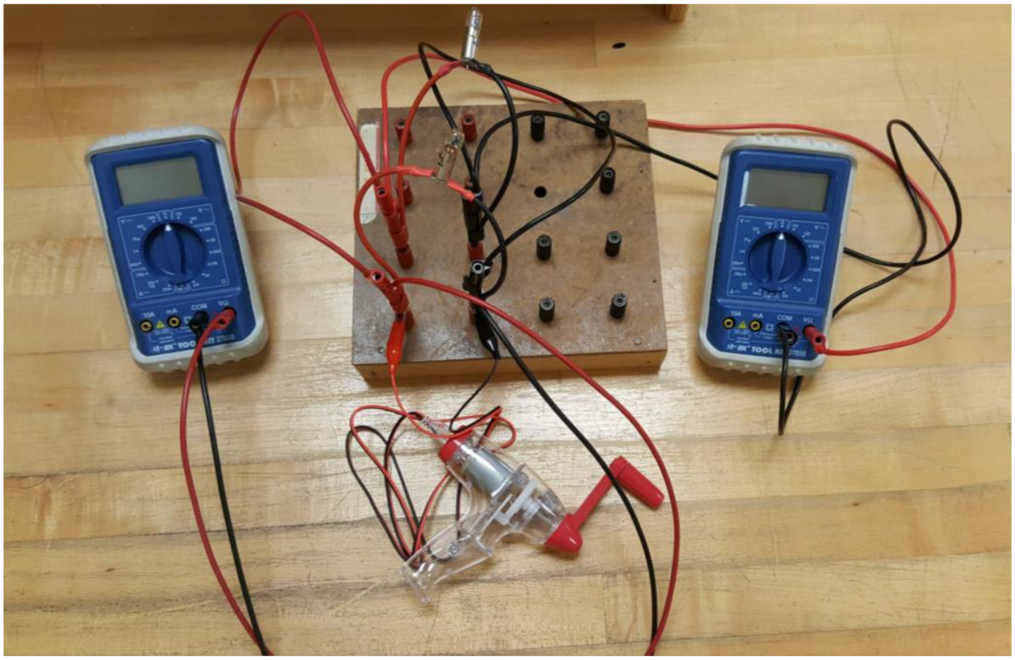

Figure 6

8) With the meters set to the same “20” in the section labeled as “V- - -” on the outer edge of the meter, try to turn the generator at a constant rate and **record** the potential difference across each lightbulb. Be sure to note which bulb experienced each potential difference. Make note of the difficulty in turning the generator.

Question 2: How did the brightness of the bulbs compare to each other in each case? Explain your observations.

Question 3: How did the difficulty of turning the generator compare to that for the bulbs connected in series? Explain why this might be different in terms of equivalent resistance in the series and in the parallel circuit.

9) Disconnect the circuit from step 8 and place the hand-crank generator off to the side. Check that the wall power supply (0 – 30 V DC 1A) is turned off and that the knob is turned all the way counter-clockwise.

10) Build a series circuit with the two resistors, just as that for the bulbs from steps 3 and 4, where the wall power supply will replace the hand crank generator. Use a wire to connect the black port on the wall to the right-most post on the resistor combination, and a second wire to connect the red port on the wall to the left-lost post on the resistor combination. Verify that you have built a series circuit, and check with your TA if you are unsure! See Figure 7.

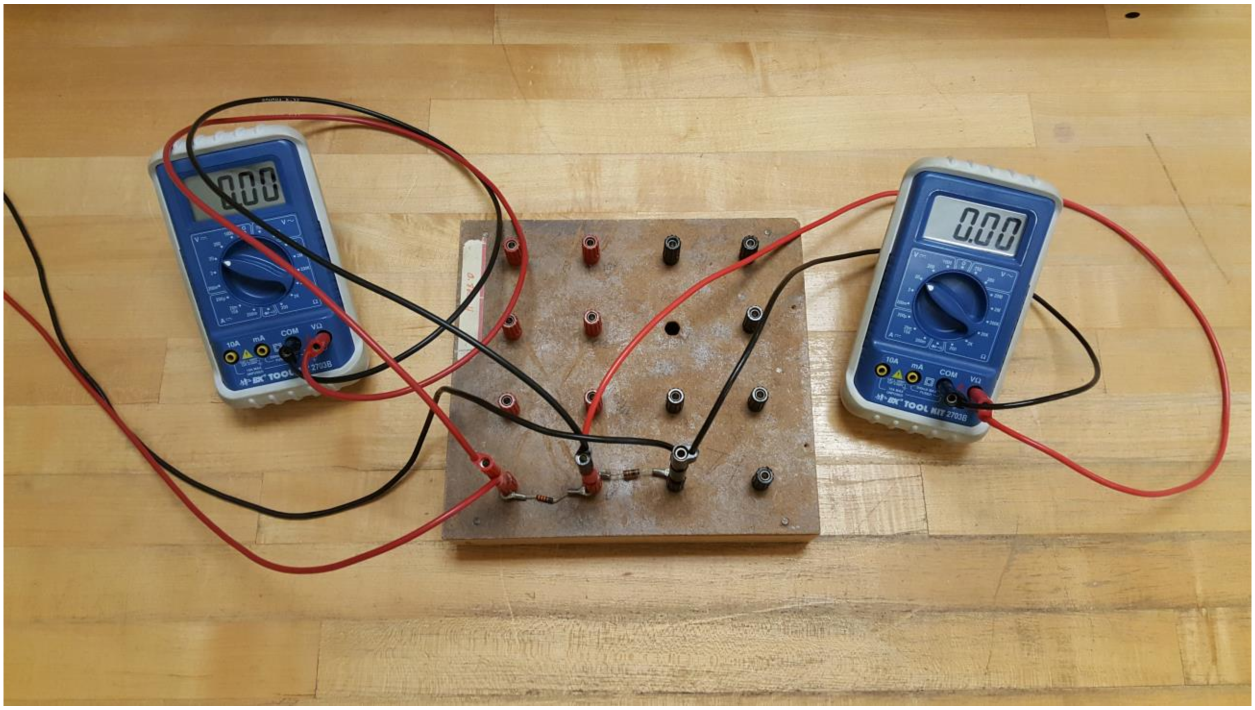

Figure 7

11) Turn on the wall power supply and begin to increase the voltage until the wall power supply reads about 10 V. **Record** the value shown on the voltmeter next to the knob on the wall power supply. Then, **record** the reading on each multimeter, noting which meter is connected to which resistor.

12) Repeat the measurements in step 11 after turning the knob on the power supply to set the potential difference at the wall to read about 15 V. **Record** your results. Remember to note which meter reading applies to which resistor.

13) Now, turn the knob on the power supply all the way counter-clockwise, turn off the power supply, and disconnect the circuit. Build a circuit with the resistors in parallel, similar to that built in step 7 for the bulbs. Verify that you have built a parallel circuit and check with your TA if you are not sure! An example is shown in Figure 8.

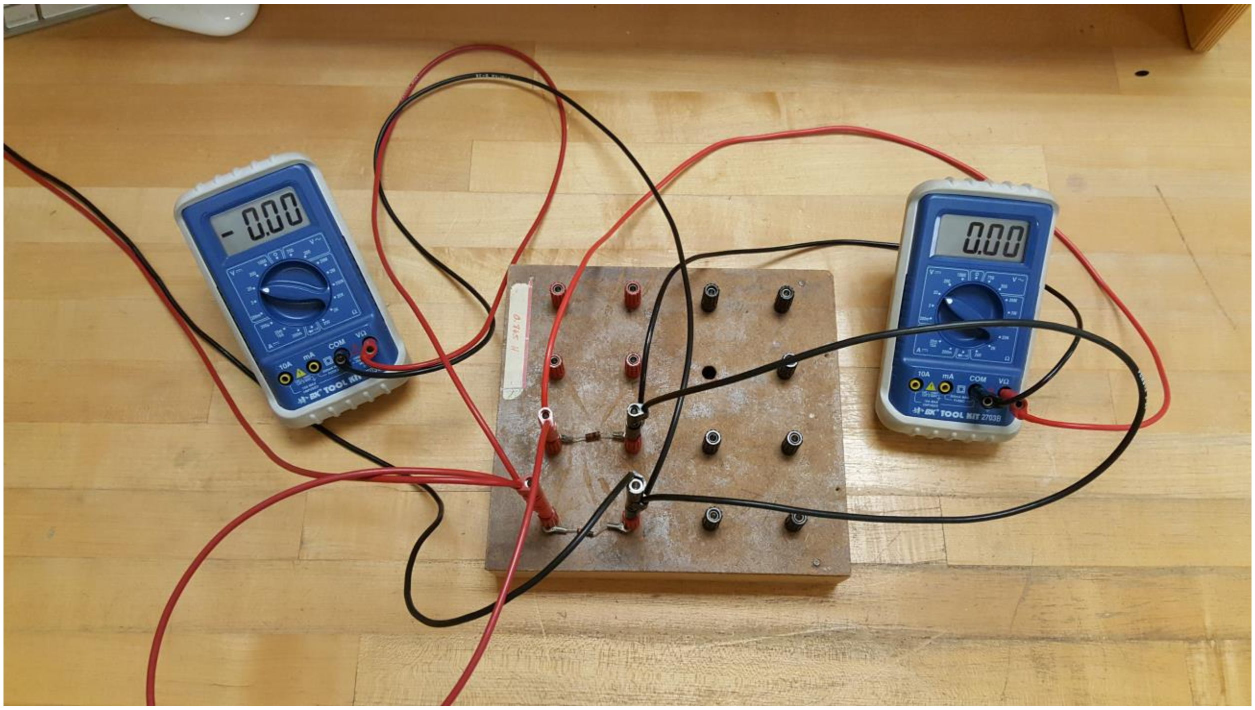

Figure 8

14) Turn on the wall power supply and begin to increase the voltage until the wall power supply reads about 10 V. **Record** the value shown on the voltmeter next to the knob on the wall power supply. Then, **record** the reading on each multimeter, noting which meter is connected to which resistor.

15) Repeat the measurements in step 14 after turning the knob on the power supply to set the potential difference at the wall to read about 15 V. **Record** your results. Remember to note which meter reading applies to which resistor.

16) Turn the knob on the power supply all the way counter-clockwise and then turn the power supply off. Disconnect your circuit and turn off the multimeters.

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

Data Analysis

Use the resistances for the lightbulbs and their respective potential differences to calculate the current through each lightbulb when they were connected in series.

Question 4: Was the expected behavior of current in a series-resistance circuit verified? Explain why or why not.

Use the resistances for the lightbulbs and their respective potential differences to calculate the current through each lightbulb when they were connected in parallel.

Question 5: Was the expected behavior of current in a series-resistance circuit verified? Explain why or why not. Did the potential difference across each bulb confirm Kirchoff's loop rule – that the sum of the changes in electric potential around a closed path in the circuit equals zero? Explain why or why not.

Consider the circuit with the resistors connected in series. Calculate the equivalent resistance of the circuit.

Using the data from step 11, determine the current in each resistor. Then, use the potential difference of the power supply and the equivalent resistance to calculate the current through the power supply.

Using the data from step 12, determine the current in each resistor. Then, use the potential difference of the power supply and the equivalent resistance to calculate the current through the power supply.

Consider the circuit with the resistors connected in parallel. Calculate the equivalent resistance of the circuit.

Using the data from step 14, determine the current in each resistor. Then, use the potential difference of the power supply and the equivalent resistance to calculate the current through the power supply.

Compare the current through the power supply to the sum of the current through each of the resistors.

Using the data from step 15, determine the current in each resistor. Then, use the potential difference of the power supply and the equivalent resistance to calculate the current through the power supply.

Compare the current through the power supply to the sum of the current through each of the resistors.

Question 6: Was the junction rule verified for the parallel circuit? Explain your answer.

Error Analysis

For the data from the series circuit in step 11, calculate the percent difference between the current through the power supply and the current through the first resistor. Then repeat the is calculation for the current through the power supply and the current through the second resistor.

For the data from the parallel circuit in step 14, calculate the percent difference between the current through the power supply and the sum of the currents through both resistors.

$$\%diff = \frac{\left|I_1 - I_2\right|}{I_1 + I_2 \ /2} \times 100\%$$

Question 7: How did your percent differences in each case reflect upon your responses to the previous questions? Explain, referencing your results.

Questions and Conclusions

Be sure to address Questions 1 through 7 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: Resistors in Combination,” and submit it before the start of your lab section on the day this experiment is to be run.

PL-1) Maha measures the potential difference across a 1000-Ω resistor to be 5.50 V. What is the current through this resistor? Express your answer in amps, A.

PL-2) When resistors are connected in parallel to a fixed potential difference, the current through each should

A) equal the current through the power source.

B) be the same.

C) subtract from each other to equal the current through the power source.

D) add together to equal the current through the power source.

PL-3) Max finds that the potential difference across the first resistor in a series circuit is 9.75 V and the potential difference across the second resistor in a series circuit is 9.75 V. What is the potential difference of the power source, assuming there are only two resistors in series? Express your answer in volts, V.

PL-4) Maha finds that the potential difference across the first resistor in a parallel circuit is 9.75 V and the potential difference across the second resistor in a parallel circuit is 9.75 V. What is the potential difference of the power source, assuming there are only two resistors in parallel? Express your answer in volts, V.

PL-5) When resistors are connected in series to a fixed potential difference, the current through each should

A) be zero.

B) be the same.

C) subtract from each other to equal the current through the power source.

D) add together to equal the current through the power source.