D2: Electric Circuits II

GOALS

- To examine Ohm's Law: the pivotal relationship between voltage and current for resistors
- To closely study what current does when it reaches a junction
- To observe Kirchhoff's Loop Rule in practice for some circuits

EQUIPMENT

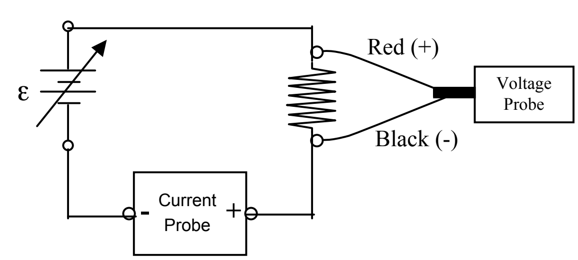
- variable-voltage power supply (0-6 V), battery eliminator
- multimeter
- 1 switch
- 3 light bulbs (6 V) and holders
- 5 different resistors (10-100 ohms)
- color coded resistors, resistor charts
- Several alligator clip wires
- Several banana plug wires
- Two Differential Voltage probes
- Two Current probes
- Computer interface
- LoggerPro software
- Experiment file: OHMSLAW

Activity 1: Ohm's Law

For this week's lab we will use constant voltage power supplies (the voltage remains fixed) and variable voltage power supplies (the voltage can be varied).

Locate your variable power supply. It's a gray box with an adjustment knob on the front. Connect a black banana plug wire to the black plug of the power supply, then into the COM (common) input on your multimeter. Connect a red wire to the red plug of the power supply, then into the "Volts" input on your multimeter. Turn on the power supply and the multimeter. Put the multimeter in "DC Volts" mode. Turn the adjust knob on the power supply and verify that the output voltage changes as you turn the knob. Turn the power supply voltage to zero and then turn it off.

1. <u>Build the circuit shown below.</u> The symbol for the adjustable power supply is just like the symbol for a battery, but there's an "adjustment arrow" through the symbol that represents the knob. The vertical "zig-zag" is a resistor. A resistor impedes (or resists) the flow of charge. It is a device that stubbornly always adds a fixed amount of resistance to the flow of current, wherever it is inserted in your circuit.



Use four labeled resistors (10-100 Ω).

In this circuit, you are measuring the current through the circuit and the voltage across the resistor, hence the placement of the voltage and current probes.

2. Open the file **OHMSLAW**, LoggerPro will start automatically. You should see three plots on the screen. One is voltage versus time, the second is current versus time, and the third is voltage versus current.
3. Turn the power supply on and click the green “Collect” button.
4. Now, slowly increase the power supply voltage from 0 V to 6 V.

5. Turn the power supply voltage back down to zero. Click the green “Collect” button and turn the voltage adjust knob on the power supply up and down. Ideally, your graph should look like a straight line that goes through (or very close) to the origin. If your graph looks ragged try this: go to “Experiment” menu, click on “data collection”, set sampling rate to 15 samples per second and turn oversampling on. Take new data. If the graph still looks bad, try other sampling rates or get help from your instructor. When you are satisfied with your plot, **perform a linear fit (there is a button for this).** Take note of the slope and intercept of the trend line and interpret.

- Q1.1: As you increased the voltage from the power supply, what happened to the current through the circuit?

- Q1.2: In particular as you rapidly changed the power supply voltage, what did you notice about the "Voltage versus Current" graph?

- Q1.3: What do you conclude about the relationship between voltage and current for this circuit?

6. Store this data for later comparison by choosing “Store latest run” from the Experiment menu.
7. Repeat the above steps for each of the resistors you have. You should generate one V vs. I data set for every resistor you have. Store the data after each run. Keep track of which resistor goes with which plot. You may want to label them: R_1, R_2, …
8. Print out the plot with the *all the resistor data on the same graph*. Title this “Activity 1: ΔV vs. I -all resistors”

- Q1.4: Based on your observations, propose an empirical relationship between the applied voltage across the resistor and the current through it.

Ohm’s law states that $I = \dfrac{\Delta V}{R}$ or $\Delta V = IR = RI$, where R is the resistance of the circuit element.

- Q1.5: Is Ohm’s law consistent with your empirical relationship? Explain.

- Q1.6: What are the units of resistance?

9. From your data find the resistance of each of your resistors and complete the table below.

Resistor #	Resistance (measured using ΔV vs. I)
1	
2	
3	
4	
5	

10. Label each of the curves on your "Activity 1: ΔV vs. I-all resistors" plot with the appropriate resistance value.

- Q1.7: At a fixed voltage, if the resistance in this circuit is halved, the current will ______________________. (You can use the Examine function to move around.)

- Q1.8: At a fixed voltage, if the resistance in this circuit is doubled, the current will ______________________.

Circuit elements that obey Ohm's Law are said to be **ohmic**. Your resistors should have been ohmic.

11. Replace the resistor in your circuit with a light bulb and repeat the experiment. **DO NOT EXCEED 6 V with the bulbs!** *The data is best if you start at 6 V and then go down.* Plot Volts versus Current. Label this graph "Activity 1: ΔV vs. I – bulb."

- Q1.11: Compare and contrast the relationship between the voltage and current for the light bulb with that of the resistor.

- Q1.12: Is the light bulb an "ohmic" device? Why or why not?

Activity 2: Color Codes and Ohmmeters

Resistors come with a color code to specify the resistance or they are labeled. Typically the labeled resistance is within +/- 10%. For a more exact resistance measure, the resistance can be measured with an ohmmeter.

Prepare one of the multimeters at your station to measure the resistance of circuit element. Check the inputs to the meter and the dial settings. Be sure they both involve "Ohms" or the electrical symbol for resistance, Ω. Like Voltage and Current measurements, the black lead will still go into the black, ground, or "COM" (for common) input.

1. Take a resistor and connect the leads from your meter to the leads of one of your resistors. The ohmmeter should indicate the resistance of your resistor. Resistance =______________.

- Q2.1: How does the resistance value measured with the ohmmeter compare to the value you found from the color code or label?

2. Measure the resistance of all of your resistors using the ohmmeter. Put this data in the following table with your color code or labeled values.

Resistor	Resistance (ohmmeter)	Resistance (color code or label)	% difference
1			
2			
3			
4			
5			

- Q2.2: Are your measured values within 10% of the color code or the labeled value?

Activity 3: Combining Resistors in Parallel and Series

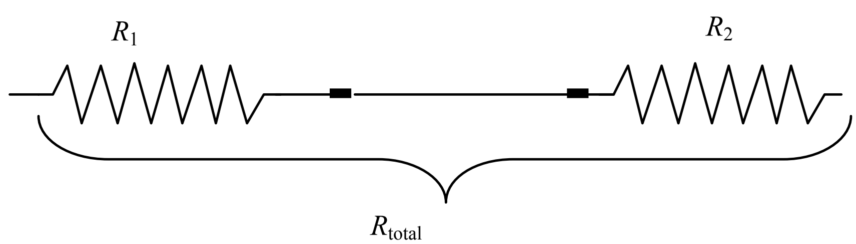
Series

3. Get two of your known resistors. Record each resistance below.

   The resistance of R_1 = ________

   The resistance of R_2 = ________

4. Connect the two resistors together in series with an alligator clip wire, like this:



Connecting electrical elements end-to-end like this is called a "series" connection. Circuit elements in series have the same current flowing through them.

- Q3.1: How many junctions (optional "turns" or alternate paths current can take) do you find when circuit elements are connected in series?

5. Measure the resistance of the combination of R_1 and R_2 in series: ____________

6. Place 3 or 4 resistors in series and find the total resistance.

- Produce an algebraic law that predicts how the total resistance depends on the individual resistances for resistors connected in series.

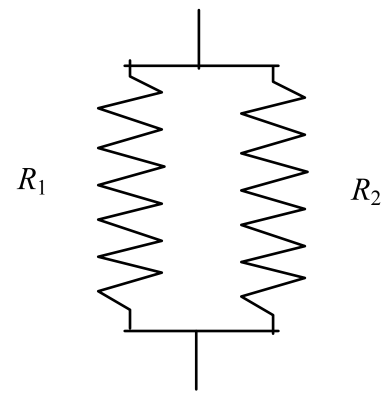
Parallel

7. Measure, or be sure you know the individual resistances for two resistors.

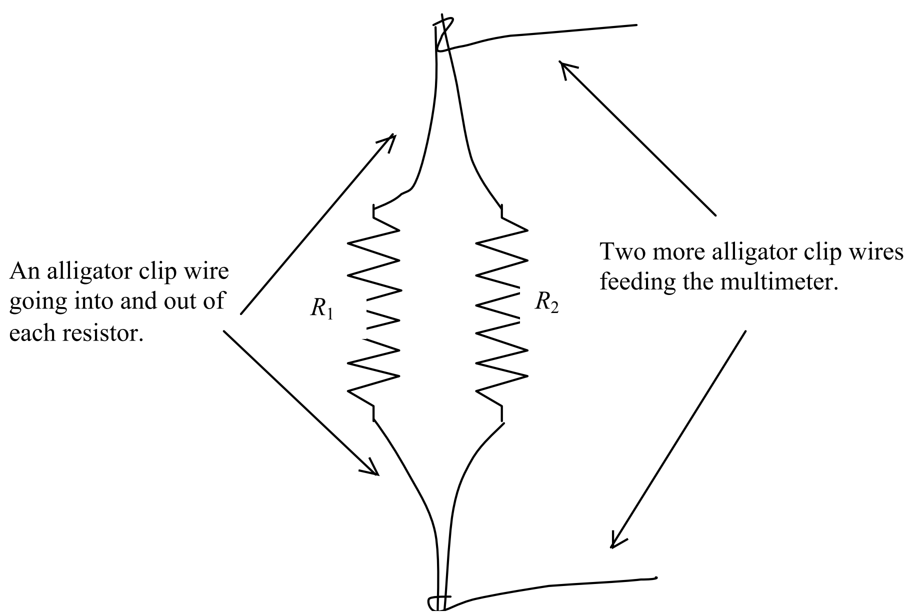
   The resistance of R_1 = ________

   The resistance of R_2 = ________

8. Connect the two resistors as shown.



You'll have to be very careful with your connections to get this right. You might try something like this:



Connecting electrical elements end-to-end like this is called a "parallel" connection. Circuit elements in parallel have the same voltage across them and their corresponding ends are connected together.

- Q3.2: How many junctions (optional "turns" or paths current can take) do you find when circuit elements are connected in parallel?

9. Measure the total resistance of the combination of two resistors in parallel.

   Combined resistance of R_1 in parallel with R_2: _____________

10. Place 3 or 4 resistors in parallel and find the total resistance.

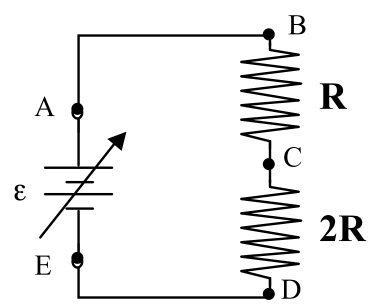
- Q3.3: Produce an algebraic law that predicts how the total resistance is related to the individual resistances for resistors in connected in parallel.

11. Test your law using two different resistor value combinations.

Activity 4: Kirchhoff's Loop Rule

Two resistors-series

1. Build the following circuit using two resistors that have different resistance, one about twice the resistance of the other.



2. Turn on the variable power supply and turn it up to 6 volts.
3. Measure the potential difference across the power supply using a voltage probe and placing the red lead at point A and the black lead at point E. Record your value in the table below.
4. Next, "slide" the leads around the circuit. Place the black lead at point A and the red lead at point B. Record the potential difference. Record your value in the table below.
5. Place the black lead at point B and the red lead at point C. Record your value in the table below.
6. Place the black lead at C and the red lead at D. Record your value in the table below.
7. Place the black lead at D and the red lead at E. Record your value in the table below.

Points compared	**Measured ΔV**
$\Delta V_{AE} = V_A - V_E$	
$\Delta V_{BA} = V_B - V_A$	
$\Delta V_{CB} = V_C - V_B$	
$\Delta V_{DC} = V_D - V_C$	

$\Delta V_{ED} = V_E - V_D$	
$\Delta V_{AE} + \Delta V_{BA} + \Delta V_{CB} + \Delta V_{DC} + \Delta V_{ED} =$	

- Q4.1: What is the sum of all of the potential differences around the loop ABCDEA? Is it 0V as expected? Explain why 0V is the expected value and whether your measurement disagrees significantly.

- Q4.2: Why was it important to preserve the relative orientation of the black and red leads in this measurement? or Why was it important for the red lead to advance first around the circuit?

- Q4.3: Why is the potential difference between points A and B so small? Use Ohm's law in your explanation.

- Q4.4: What does your answer to the last question imply about the resistance of our wires?

- Q4.5: Is it necessary to measure the potential between A & B and D & E?

- Q4.6: How do the voltages across each resistor compare to each other? Explain why this is so.

8. Given that the voltage at point E is zero, label the voltage at points A, B, C, and D on the diagram above.

9. Measure the current in the circuit: __________

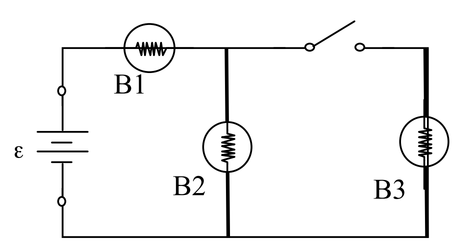
10. Calculate the expected potential difference across each resistor using Ohm's Law and complete the table below.

Resistance	Current	Calculated ΔV ($\Delta V=IR$)	Measured ΔV	% difference

- Q4.7: Do your resistors obey Ohm's Law? Explain.

Activity 5:
Imagine that we hook up circuit shown.

- P4.1: Predict the order of the brightnesses of the bulbs when the switch is open?



- P4.2: Predict the order of the brightnesses of the bulbs when the switch is closed?

- P4.3: Predict, when the switch is closed, whether the brightness of bulb B1 will increase, decrease, or stay the same?

- P4.4: Predict, when the switch is closed, whether the brightness of bulb B2 will increase, decrease, or stay the same?

Now build the circuit above and then test your predictions.
Use a power supply with a fixed voltage and do not exceed 6 V.

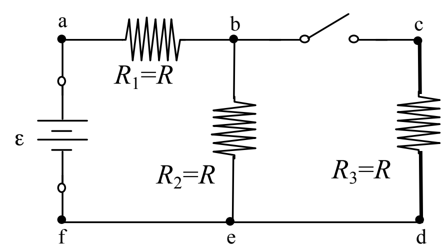
- R4.1: Rank the brightness of the bulbs when the switch is open?

- R4.2: Rank the brightness of the bulbs when the switch is closed?

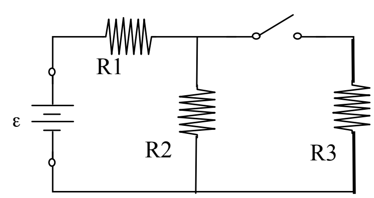
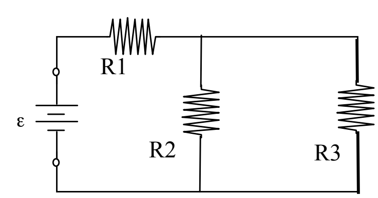
- R4.3: When the switch is closed did the brightness of bulb B1 increase, decrease, or stay the same?

- R4.4: When the switch is closed did the brightness of bulb B2 increase, decrease, or stay the same?

We have seen that light bulbs do not have a constant resistance so to get quantitative we will now replace the bulbs with resistors that all have the same resistance. Rebuild the circuit. It should look like the figure.



Make the appropriate measurements so that you can fill in the following table. (You will need to use current and voltage probes to do this.)

	Switch open	**Switch closed**
		
I_1		
I_2		
I_3		
ΔV_1		
ΔV_2		
ΔV_3		

- Does current through resistor R_1 increase, decrease, or stay the same when the switch is closed? Explain.

- Does the potential difference (voltage) across resistor R_1 increase, decrease, or stay the same when the switch is closed? Explain.

- Does current through resistor R_2 increase, decrease, or stay the same when the switch is closed? Explain.

- Does the potential difference (voltage) across resistor R_2 increase, decrease, or stay the same when the switch is closed. Explain.

There are three possible complete loops when the switch is closed.

1. Symbolically write down the equation for summing the change in potential using ε or IR terms. *Note:* be very careful to have the correct sign for each term, and subscript for each variable.
2. Experimentally verify that Kirchhoff's loop rule is satisfied for each loop when the switch is closed.

Symbolic **Experimental**

Loop abcdefa:

Loop abefa:

Loop bcdeb:

There are two possible current junctions when the switch is closed.

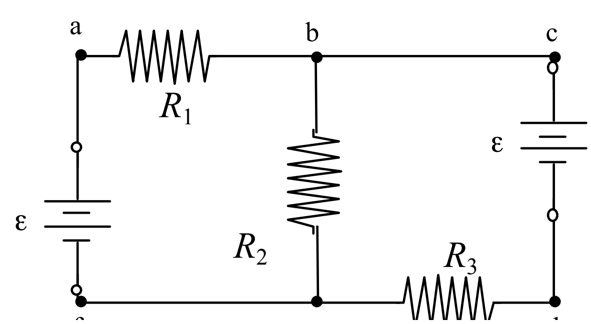
3. Using the junction rule, $\sum I_{\text{in}} = \sum I_{\text{out}}$, symbolically write down the sum of the currents at each junction when the switch is closed.
4. Experimentally verify that Kirchhoff's current rule is satisfied for each junction when the switch is closed.

Symbolic **Experimental**

Junction b:

Junction e:

Activity 6: Apply what you've learned.



Build this circuit. Use a fixed power supply and a variable power supply set to the same voltage. **Do not exceed 6 V.** Choose any three *different* resistors.

There are three possible complete loops.

1. Identify the three loops, and draw them.
2. Symbolically write down the sum of the change in potentials for each loop ($\Delta V_{\text{battery}} + \Delta V_1 + \ldots$) in going around the loop.
3. *Measure* and verify that Kirchhoff's loop rule is satisfied for each loop when the switch is closed.

	Symbolic	**Loop Circuits**
Loop 1:		
Loop 2:		
Loop 3:		

There are two possible current junctions.

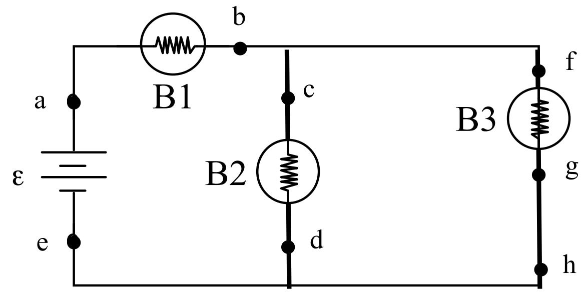
4. Identify the two junctions.
5. Symbolically write down the sum of the currents at each junction.
6. *Measure* and verify that Kirchhoff's junction rule is satisfied for each junction.

Junction 1:

Junction 2:

Electric Circuits 2 Post Lab

Three identical bulbs are hooked up to a battery in the following manner.



1) How does the brightness of each of the three bulbs compare to each other? Explain your reasoning.

2) Bulb B2 is unscrewed and removed from its socket.

a) In the space to the right, draw the equivalent circuit for the situation when B2 is removed.

b) Once bulb B2 is removed, how do the relative brightness of each of the remaining bulbs compare to each other? Explain your reasoning.

c) What happens to the brightness of each of the bulbs when bulb B2 is removed? Explain your reasoning.

d) What happens to the potential difference between points "c" and "d" (or equivalently between "f" and "h") when bulb B2 is removed? Explain your reasoning.

3) Bulb B2 is screwed back into its socket. A wire is connected from point "a" and to point "f."

a) In the space to the right, draw the equivalent circuit for the situation when the wire is connected from "a" to "f".

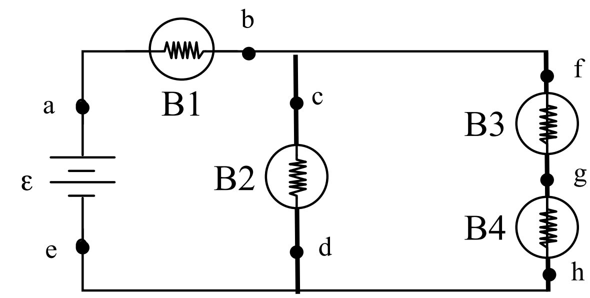
b) Once the wire is connected, how does the brightness of each of the remaining bulbs compare to each other? Explain your reasoning.

c) What happens to the brightness of each of the bulbs when the wire is connected? Explain your reasoning.

d) What happens to the potential difference between points "c" and "d" when the wire is connected? Explain your reasoning.

e) The wire connected between points "a" and "f" is now removed. A new wire is connected from point "h" to point "e". Describe what happens.

4) In the following circuit, the battery has an emf of 5 V and the light bulbs all have the same resistance, 3 Ω. Determine the current through and the voltage across each bulb.



5) In the following circuit, the battery has an emf of 9 V and the resistors all have a different resistance: R_1 = 80 Ω, R_2 = 20 Ω, R_3 = 30 Ω, and R_4 = 60 Ω. Determine the current through and the voltage across each resistor.