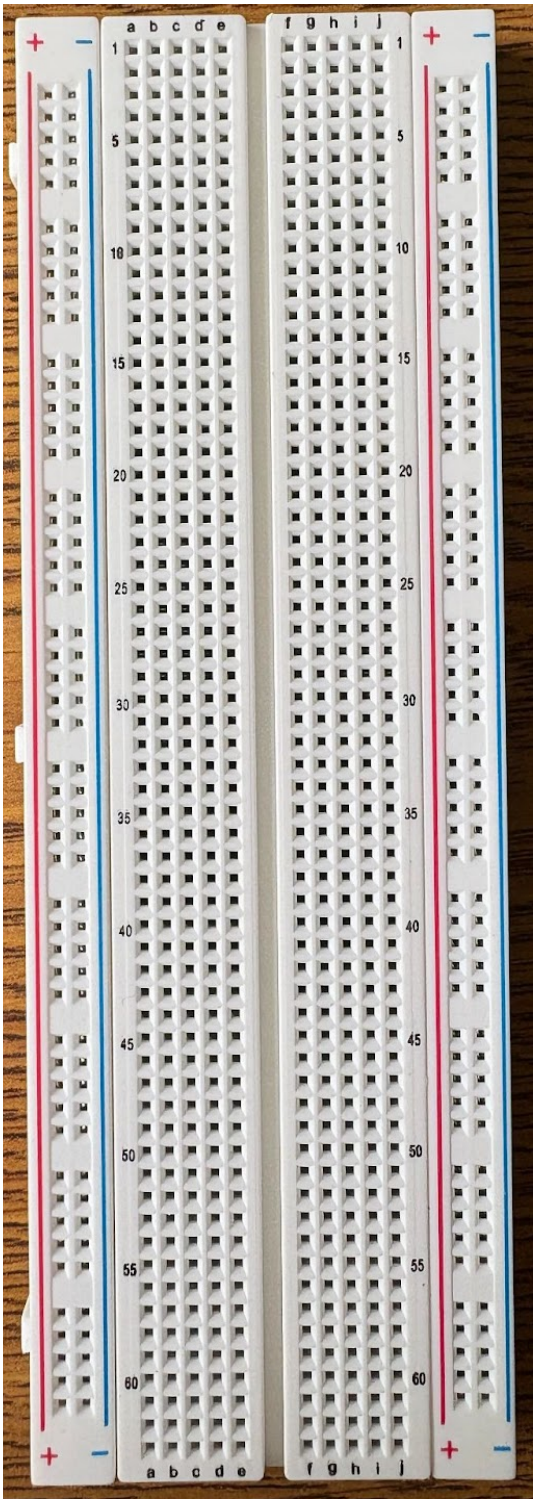
Lab 1: Breadboard Introduction

We will be using a “solderless breadboard” for many/most of our labs and projects in this class. This is a well-tested way for prototyping circuit designs used by amateurs and professionals. It allows us to make and change circuit connections securely and easily.



A key aspect of any solderless breadboard is that some parts of the breadboard are *electrically connected*, while others are *electrically isolated*. Using your multimeter in “Continuity” mode, your task is to map out the connected (and disconnected) parts of the breadboard. While you don’t need to try every combination of holes, you should come up with a working theory of which holes may or may not be connected and use that to test your ideas.

Some hints to help:

- The probes of your multimeter are too large to fit into the holes of the breadboard. However, any “electrically connected” wire is the same for a circuit, so you can use any combination of alligator clips, test leads, etc. to make electrical probes to test the continuity of your breadboard connections.
- The hole connections are *not* random; in general, either lines or columns are connected.

In your lab notebook:

1. Create a diagram of the breadboard, indicating which holes are connected to one another and which are isolated. This should include a sketch/diagram of the breadboard in addition to some text explaining the pattern that you discovered from your investigation.
2. Answer the following questions: Why is it useful to have some holes connected to each other electrically? How can your circuit take advantage of these connections? Should the separate legs of circuit elements be placed horizontally or vertically? What happens if you place them in the wrong orientation?

Lab 2: Ohm's Law

The fundamental relationship among the three important electrical quantities *current*, *voltage*, and *resistance* was discovered by Georg Simon Ohm. The relationship and the unit of electrical resistance were both named for him to commemorate this contribution to physics. One statement of Ohm's law is that the current through a resistor is proportional to the voltage across the resistor. In this experiment you will see if Ohm's law is applicable to several different circuits using a Current Probe and a Voltage Probe.

Current and voltage can be difficult to understand, because they cannot be observed directly. To clarify these terms, some people make the comparison between electrical circuits and water flowing in pipes.

Electrical Quantity	**Description**	**Unit**	**Water Analogy**
Voltage or Potential Difference	A measure of the Energy difference per unit charge between two points in a circuit.	Volt (V)	Water Pressure or Drop in altitude between ends of the pipe
Current	A measure of the flow of charge in a circuit.	Ampere (A)	Amount of water flowing
Resistance	A measure of how difficult it is for current to flow in a circuit.	Ohm (Ω)	A measure of how difficult it is for water to flow through a pipe.

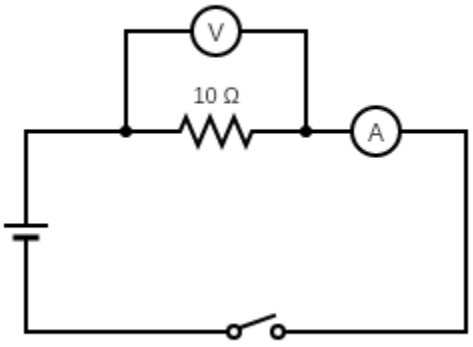


Figure 1

OBJECTIVES

- Determine the mathematical relationship between current, potential difference, and resistance in a simple circuit.
- Compare the potential *vs*. current behavior of a resistor to that of a light bulb.

PRELIMINARY SETUP

1. Connect the Current Probe to Channel 1 and the Differential Voltage Probe to Channel 2 of the computer interface.

2. Open the file "22 Ohms Law" in the *Physics with Vernier* folder. A graph of potential (i.e. Voltage) *vs*. current will be displayed. The meter displays potential and current readings.

3. Using the continuity feature of your multimeter, determine the function of the switch you're using. Which terminals are always connected? Which terminals are disconnected when the switch is "open" (i.e. the button isn't pushed)? Which terminals are connected when the switch is closed (i.e. the button pushed)? Draw the switch in your notebook and indicate its function.

4. **With the power supply turned off**, connect the power supply, 10 Ω resistor, wires, and switch as shown in Figure 1. Take care that the red terminals of the Vernier Current & Voltage probes are closest to the "positive" side of the power supply.

Since this is the first circuit you're building in this class, please have me check your circuit before proceeding beyond this point!

5. Click Zero. A dialog box will appear. Click OK to zero both sensors. This sets the zero for both probes with no current flowing and with no voltage applied.

6. Turn the control knob on the DC power supply to 0 V and then turn on the power supply. Slowly increase the voltage to 5 V, making sure to push the switch to complete the circuit every time you want to make a measurement. Monitor the meter in Logger *Pro* and describe what happens to the current through the resistor as the potential difference across the resistor changes. If the voltage doubles, what happens to the current? What type of relationship do you believe exists between voltage and current?

PROCEDURE

1. Record the value of the resistor in the data table.

2. Make sure the power supply is set to 0 V. Click Collect to begin data collection. Monitor the voltage and current. Click Keep.

3. Increase the voltage on the power supply to approximately 0.5 V. Push (and hold) down on the switch button and click Keep.

4. Increase the voltage by about 0.5 V. Push (and hold) down on the switch button and click Keep. Repeat this process until you reach a voltage of 5.0 V.

5. Click Stop and set the power supply back to 0 V.

6. Print a copy of the graph. Are the voltage and current proportional? Click the Linear Fit button, . Record the slope and *y*-intercept of the regression line in the data table, along with their units.

7. Repeat Steps 1 – 6 using a different resistor.

8. Replace the resistor in the circuit with a light bulb. Repeat Steps 2–5, but this time increase the voltage in 0.1 V steps up to 5.0 V (between 2V and 4V, you can go in steps of 0.2 V to save time, if you like).

9. To compare slopes of data at different parts of the curve, first click and drag the mouse over the first 3 data points. Click the Linear Fit button, , and record the slope of the regression line in the data table. Be sure to enter the units of the slope.

10. Click and drag the mouse over the last 10 points on the graph. Click the Linear Fit button, , and record the slope of the regression line in the data table.

DATA TABLE

	Slope of regression line (V/A)	Y-intercept of regression line (V)
Resistor ____ Ω		
Resistor ____ Ω		
Light bulb (first 3 pts)		
Light bulb (last 10 pts)		

ANALYSIS

1. As the potential across the resistor increased, the current through the resistor increased. If the change in current is *proportional* to the voltage, the data should be in a straight line and it should go through zero. In these two examples how close is the *y*-intercept to zero? Is there a proportional relationship between voltage and current? If so, write the equation for each run in the form potential = constantcurrent. (Use a numerical value for the constant.)

2. Compare the constant in each of the above equations to the resistance of each resistor.

3. Resistance, *R*, is defined using $R = V/I$ where *V* is the potential across a resistor, and *I* is the current. *R* is measured in ohms (Ω), where 1 Ω = 1 V/A. The constant you determined in each equation should be similar to the resistance of each resistor. However, resistors are manufactured such that their actual value is within a tolerance. For most resistors used in this lab, the tolerance is typically 5% or 10%.

Calculate the range of values for each resistor. Does the constant in each equation fit within the appropriate range of values for each resistor?

4. Do your resistors follow Ohm's law? Base your answer on your experimental data.

5. Describe what happened to the current through the light bulb as the potential increased. Was the change linear? Since the slope of the linear regression line is a measure of resistance, describe what happened to the resistance as the voltage increased. Since the bulb gets brighter as it gets hotter, how does the resistance vary with temperature?

6. Does your light bulb follow Ohm's law? Base your answer on your experimental data.

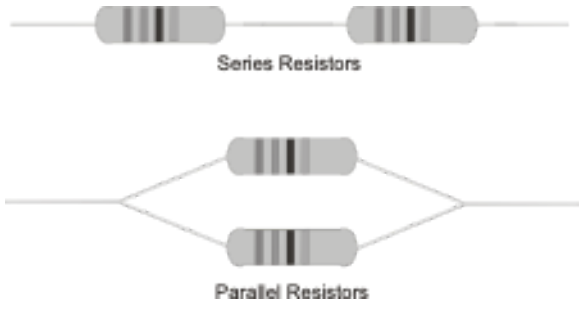
Lab 3: Series and Parallel Circuits

Components in an electrical circuit are in *series* when they are connected one after the other, so that the same current flows through both of them. Components are in *parallel* when they are in alternate branches of a circuit. Series and parallel circuits function differently. You may have noticed the differences in electrical circuits you use. When using some decorative holiday light circuits, if one lamp burns out, the whole string of lamps goes off. These lamps are in series. When a light bulb burns out in your house, the other lights stay on. Household wiring is normally in parallel.

You can monitor these circuits using a Current Probe and a Voltage Probe and see how they operate. One goal of this experiment is to study circuits made up of two resistors in series or parallel. You can then use Ohm's law to determine the equivalent resistance of the two resistors.

OBJECTIVES

- To study current flow in series and parallel circuits.
- To study voltages in series and parallel circuits.
- Use Ohm's law to calculate equivalent resistance of series and parallel circuits.



PRELIMINARY QUESTIONS

1. Using what you know about electricity, predict how series resistors would affect current flow. What would you expect the effective resistance of two equal resistors in series to be, compared to the resistance of a single resistor?

2. Using what you know about electricity, predict how parallel resistors would affect current flow. What would you expect the effective resistance of two equal resistors in parallel to be, compared to the resistance of one alone?

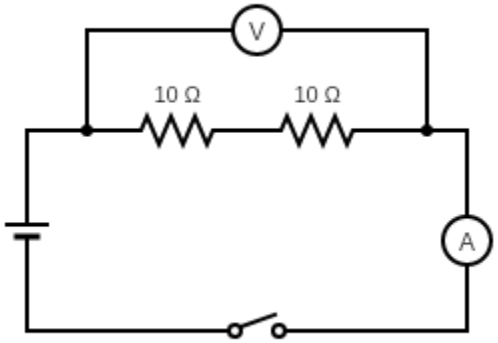
PROCEDURE

Part A – Series Circuits

1. Connect the Current Probe to Channel 1 and the Differential Voltage Probe to Channel 2 of the interface.

2. Open the file “23a Series Parallel Circ” in the *Physics with Vernier* folder. Current and voltage readings will be displayed in a meter.

3. Connect together the two voltage leads (red and black) of the Voltage Probe. Click Zero, then click OK to zero both sensors. This sets the zero for both probes with no current flowing and with no voltage applied.



4. Connect the series circuit shown in the above figure using the 10 Ω resistors for resistor 1 and resistor 2. Notice the Voltage Probe is used to measure the voltage applied to both resistors. The red terminal of the Current Probe should be toward the + terminal of the power supply (the exact voltage of the power supply is not critically important, but ~5V is reasonable).

5. For this part of the experiment, you do not even have to click on the Collect button. You can take readings from the meter at any time. To test your circuit, briefly press on the switch to complete the circuit. Both current and voltage readings should increase. If they do not, recheck your circuit.

6. Press on the switch to complete the circuit again and read the current (I) and total voltage (V_{TOT}). Record the values in the data table (*Note*: example data tables immediately follow the *Procedure* section, but you should create your own in your lab notebooks).

7. Connect the leads of the Voltage Probe across resistor 1. Press on the switch to complete the circuit and read this voltage (V_1). Record this value in the data table.

8. Connect the leads of the Voltage Probe across resistor 2. Press on the switch to complete the circuit and read this voltage (V_2). Record this value in the data table.

9. Repeat Steps 5–8 with a 51 Ω resistor substituted for resistor 2.

10. Repeat Steps 5–8 with a 51 Ω resistor used for both resistor 1 and resistor 2.

Part B – Parallel circuits

11. Connect the parallel circuit shown below using 51 Ω resistors for both resistor 1 and resistor 2. As in the previous circuit, the Voltage Probe is used to measure the voltage applied to both resistors (so, although it’s not shown in the diagram, make sure that you hook it up to measure the Voltage difference across the two resistors combined). The red terminal of the Current Probe should be

toward the + terminal of the power supply. The Current Probe is used to measure the total current in the circuit.

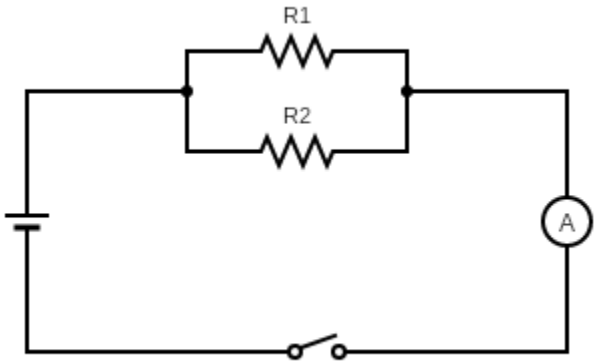


Figure 3

12. As in Part A, you can take readings from the meter at any time. To test your circuit, briefly press on the switch to complete the circuit. Both current and voltage readings should increase. If they do not, recheck your circuit.

13. Press the switch to complete the circuit again and read the total current (I) and total voltage (V_{TOT}). Record the values in the data table.

14. Use your multimeter (set in "Voltage" mode) to measure the voltage drop across resistor 1. Press on the switch to complete the circuit and read the voltage (V_1) across resistor 1. Record this value in the data table.

15. Use your multimeter (set in "Voltage" mode) to measure the voltage drop across resistor 2. Press on the switch to complete the circuit and read the voltage (V_2) across resistor 2. Record this value in the data table.

16. Repeat Steps 13–15 with a 68 Ω resistor substituted for resistor 2.

17. Repeat Steps 13–15 with a 68 Ω resistor used for both resistor 1 and resistor 2.

Part C – Currents in Series and Parallel circuits

18. For Part C of the experiment, you will use two Current Probes. Open the experiment file "23b Series Parallel Circ." Two graphs of current *vs.* time are displayed.

19. Disconnect the Voltage Probe and, into the same channel, connect a second Current Probe.

20. With nothing connected to either probe, click Zero, then click OK to zero both sensors. This adjusts the current reading to zero with no current flowing.

21. Connect the series circuit shown in Figure 4 using the 10 Ω resistor and the 51 Ω resistor. The Current Probes will measure the current flowing into and out of the two resistors. The red terminal of each Current Probe should be toward the + terminal of the power supply.

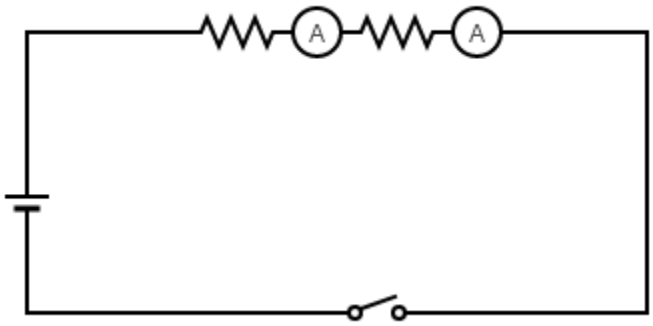


Figure 4

22. For this part of the experiment, you will make a graph of the current measured by each probe as a function of time. You will start the graphs with the switch open, close the switch for a few seconds, and then release the switch. Before you make any measurements, think about what you would expect the two graphs to look like. Sketch these graphs showing your prediction. Note that the two resistors are not equal.

23. Click on the Collect button, wait a second or two, then press on the switch to complete the circuit. Release the switch just before the graph is completed.

24. Select the region of the graph where the switch was on by dragging the cursor over it. Click on the Statistics button, , and record the average current in the data table. Determine the average current in the second graph following the same procedure.

25. Connect the parallel circuit as shown in Figure 5 using the 51 Ω resistor and the 68 Ω resistor. The two Current Probes will measure the current through each resistor individually. The red terminal of each Current Probe should be toward the + terminal of the power supply.

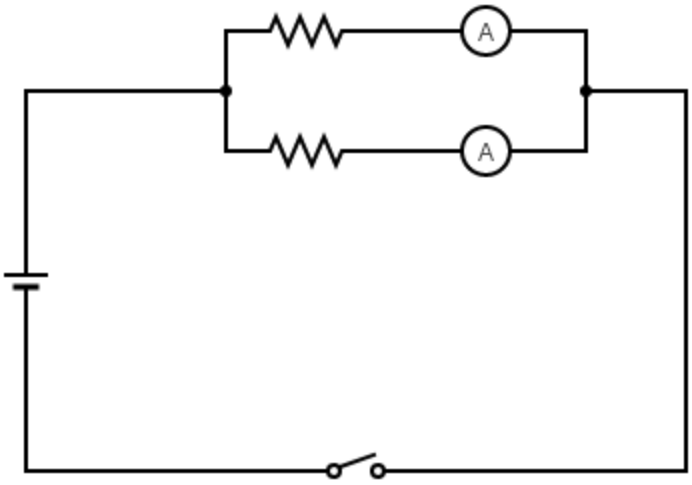


Figure 5

26. Before you make any measurements, sketch your prediction of the current *vs.* time graphs for each Current Probe in this configuration. Assume that you start with the switch open as before, close it for several seconds, and then open it. Note that the two resistors are not identical in this parallel circuit.

27. Click Collect and wait a second or two. Then press on the switch to complete the circuit. Release the switch just before the graph is completed.

28. Select the region of the graph where the switch was on by dragging the cursor over it. Click the Statistics button, , and record the average current in the data table. Determine the average current in the second graph following the same procedure.

DATA TABLES

Part 2A: Series circuits							
	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (Ω)	V_{TOT} (V)
1	10	10					
2	10	51					
3	51	51					

Part 2B: Parallel circuits							
	R_1 (Ω)	R_2 (Ω)	I (A)	V_1 (V)	V_2 (V)	R_{eq} (W)	V_{TOT} (V)
1	51	51					
2	51	68					
3	68	68					

Part 2C: Currents				
	R_1 (Ω)	R_2 (Ω)	I_1 (A)	I_2 (A)
1	10	51		
2	51	68		

ANALYSIS

1. Examine the results of Part A. What is the relationship between the three voltage readings: V_1, V_2, and V_{TOT}? What does this relationship tell you about how resisters work in series?

2. Using the measurements you have made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three series circuits you tested. Use your answer to devise a rule for equivalent resistance of any combination of resistors in series.

3. Using the measurements you have made above and your knowledge of Ohm's law, calculate the equivalent resistance (R_{eq}) of the circuit for each of the three parallel circuits you tested.

4. Study the equivalent resistance readings for the parallel circuits. Devise a rule for the equivalent resistance of a parallel circuit of two resistors.

5. Examine the results of Part B. What do you notice about the relationship between the three voltage readings V_1, V_2, and V_{TOT} in parallel circuits?

6. In part C, how does the current flow differ between the parallel and series circuits?

7. If the two measured currents in your parallel circuit were not the same, which resistor had the larger current going through it? Why?