31. Series and Parallel Circuits

Driving Questions

We know from Ohm's law how a circuit with one resistor behaves, but what happens when you combine resistors in a circuit?

Background

Ohm's Law identifies that the voltage drop across an electrical resistor is mathematically equal to the magnitude of the current through the resistor multiplied by the resistance.

$$V = IR$$

If voltage is held constant and resistance is doubled, the current would be half its original value. Likewise, cutting the resistance in half would double the current. When circuits have multiple resistors hooked up in either series or parallel, each resistor will have a voltage and a current associated with it. Can we simplify this complex circuit by substituting one resistor that behaves like the three resistors together? Using Ohm's law, we can measure individual components and compare them to the behavior of the whole circuit to experimentally determine if there is an *equivalent resistance* for a set of resistors.

Materials and Equipment

For each student or group:

- Data collection system
- Current sensor
- Voltage sensor
- Resistors (3-6), at least 3 different known values
- DC power supply, 10 V, 1A minimum
- Switch, single-pole single-throw
- Patch cord, 4 mm banana plug (10)
- Alligator clip adapters (10) (optional)

Safety

Add these important safety precautions to your normal laboratory procedures:

- Exercise caution when using the power supply: use only low voltages (10 VDC or less) and only make changes to the circuit when the circuit switch is open.
- To reduce chances of spills and subsequent electrical shock, do not allow food or beverages near the equipment.
- Be sure resistor ratings and power supplies settings are appropriate for your voltage and current sensors.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

○	○	○	○	○
Select three resistors, and identify their stated (color-coded) values (in Ω).	Set up another circuit of resistors in parallel, and repeat the process.	Apply a varying voltage to the circuit, and measure the different voltages and currents.	Set up a circuit of three resistors in series with a power supply.	Plot voltage versus current and determine the equivalent resistance in the circuit from the graph's slope.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

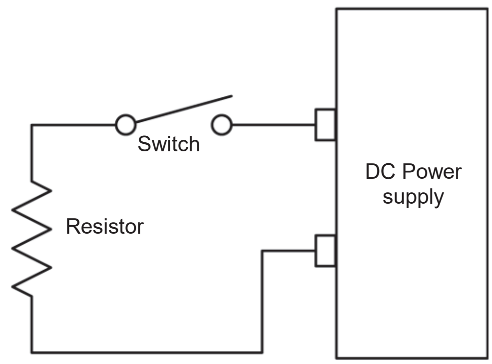
Part 1 - Resistors in Series

Set Up

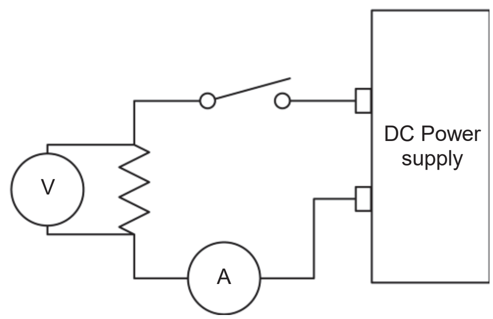
1. ☐ Start a new experiment on the data collection system. �(1.2)

2. ☐ Connect your voltage and current sensors to the data collection system. �(2.2)

3. ☐ With the power supply off, connect the first resistor and open switch in series to the power supply using the patch cords.



4. ☐ Connect the voltage sensor across the resistor, and then connect the current sensor in series with the resistor and switch. Be sure the switch is open.



5. ☐ Display voltage and current in a digits display. �(7.3.1)

6. ☐ Turn on your power supply, and set output voltage to the fixed voltage provided by your teacher, and record this value in the Data Analysis section; for example, 5 V.

Collect Data

7. ☐ Close the switch, and then record the voltage and current reading in Table 1 in the Data Analysis section. After recording the values, open the switch.

8. ☐ Add the second resistor in series with the first, and then move the voltage sensor leads to measure the total voltage across both resistors.

9. ☐ Close the switch, and then record the voltage and current reading in Table 1 in the Data Analysis section.

10. ☐ Move the voltage sensor leads to now measure the voltage across the first resistor by itself, and then record the voltage in Table 1 in the Data Analysis section.

11. ☐ Move the voltage sensor leads to measure the voltage across the second resistor by itself, and then record the voltage in Table 1 in the Data Analysis section. After recording the values, open the switch.

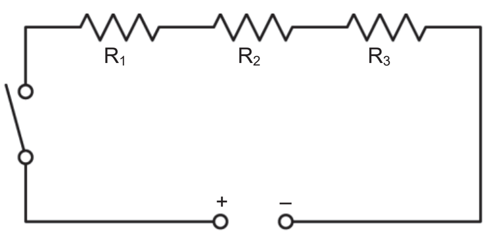
12. ☐ We have measured the voltage for each component. Why are we not measuring the current for each component as well?

13. ☐ Add the third resistor in series with the first, and then repeat the previous steps recording the voltage and current across all three resistors, then the voltage for each individual resistor in the circuit. Record the values in Table 1 in the Data Analysis section.

Note: Be sure to open the switch in the circuit after you have finished making each measurement.

Part 2 - Combined Resistors in Series

Set Up



14. ☐ Use the series circuit that you have created to determine if the behavior of a series circuit is Ohmic. Ensure the sample rate on your data collection system is set to 10 samples per second. �(5.1)

15. ☐ Display Voltage on the y-axis of a graph with Time on the x-axis. �(7.1.1)

16. ☐ Change the variable on the x-axis from Time to Current. �(7.1.9)

17. ☐ Make sure the switch is open, and set a low voltage on the power supply; for example, 1 V.

18. ☐ Connect the voltage sensor to measure the total voltage drop across all three combined resistors.

19. ☐ Connect the current sensor to measure the total current in the circuit.

Collect Data

20. ☐ Start data recording. �(6.2)

21. ☐ Close the switch, and then gradually change the voltage of the power source, both increasing and decreasing the voltage, but not to exceed the limit specified by your teacher.

22. ☐ Once you have swept through a range of voltages, stop data recording. �(6.2)

23. ☐ Open the switch, turn off the power supply, and disconnect the resistors.

Analyze Data

24. ☐ How would you describe the Voltage versus Current graph? Is this considered Ohmic behavior?

___

___

25. ☐ Apply a linear curve fit to the Voltage versus Current graph. �(9.5)

26. ☐ Sketch your Voltage versus Current graph in the space provided in the Data Analysis section. Be sure to include the slope of the linear fit in your sketch.

Part 3 - Resistors in Parallel

Set Up

27. ☐ With the power supply off, connect the first resistor and switch (open) in series to the power supply using the patch cords.

28. ☐ Connect the voltage sensor across the resistor, and then connect the current sensor in series with the resistor and switch. Be sure the switch is open.

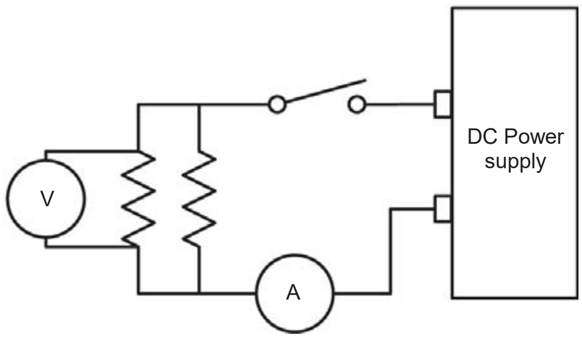
29. ☐ Display voltage and current in digits displays. �(7.3.1)

30. ☐ Turn on your power supply, and set the output voltage to the fixed voltage specified by your teacher, and record this value in the Data Analysis section; for example, 5 V.

Collect Data

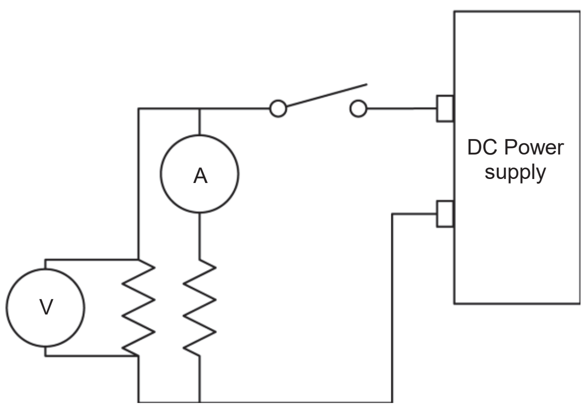
31. ☐ Close the switch, and then record the voltage and current reading in Table 2 in the Data Analysis section. After recording the values, open the switch.

32. ☐ Add the second resistor in parallel with the first.



33. ☐ Close the switch, and then record the voltage and current reading in Table 2 in the Data Analysis section. After recording the values, open the switch.

34. ☐ Move the current sensor leads to measure the current through the first resistor by itself.



35. ☐ Close the switch, and then record the current in Table 2 in the Data Analysis section. After recording the value, open the switch.

36. ☐ Move the current sensor leads to measure the current through the second resistor, close the switch, and then record the current reading in Table 2 in the Data Analysis section. After recording the value, open the switch.

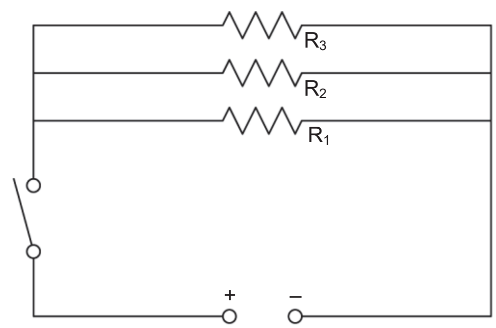
37. ☐ We have measured the current for each component, why are we not measuring the voltage too?

38. ☐ Add the third resistor in parallel with the first two, and then repeat the previous steps recording the voltage and current across all three resistors, then the current for each individual resistor in the circuit. Record the values in Table 2 in the Data Analysis section.

Note: be sure to open the switch in the circuit after you have finished making each measurement.

Part 4 - Combined Resistors in Parallel

Set Up



39. ☐ Use the parallel circuit that you have created to determine if the behavior of a parallel circuit is Ohmic. Ensure the sample rate on the data collection system is set to 10 samples per second. �(5.1)

40. ☐ Make sure the switch is open, and set a low voltage on the power supply; for example, 1 volt.

41. ☐ Connect the voltage sensor to measure the total voltage drop across all tree combined resistors, and then connect the current sensor in series to measure the total current in the circuit.

42. ☐ Display Voltage on the y-axis of a graph with Time on the x-axis. �(7.1.1)

43. ☐ Change the variable on the x-axis from Time to Current. �(7.1.9)

Collect Data

44. ☐ Start data recording. �(6.2)

45. ☐ Close the switch, and then gradually change the voltage of the power source, both increasing and decreasing the voltage, but not to exceed the limit specified by your teacher.

46. ☐ Once you have swept through a range of voltages, stop data recording. �(6.2)

47. ☐ Open the switch, turn off the power supply, and disconnect the resistors.

Analyze Data

48. ☐ How would you describe the Voltage versus Current graph? Is this considered Ohmic behavior?

____

____

49. ☐ Apply a linear curve fit to the Voltage versus Current graph. �(9.6)

50. ☐ Sketch your graph of Voltage versus Current in the space provided in the Data Analysis section. Be sure to include the slope of the linear fit in your sketch.

51. ☐ Save your experiment as instructed by your teacher. �(11.1)

Data Analysis

Voltage from Power Supply: ____________

Table #1: Series Circuit

# of Resistors	Resistor	Voltage across resistor (V)	Current through the resistor (A)	Voltage/Current	Resistor Rating (Ω)
1	First				
2	First				
	Second				
Total voltage for two resistors = __________					
3	First				
	Second				
	Third				
Total voltage for three resistors = __________					

Series Circuit Voltage versus Current

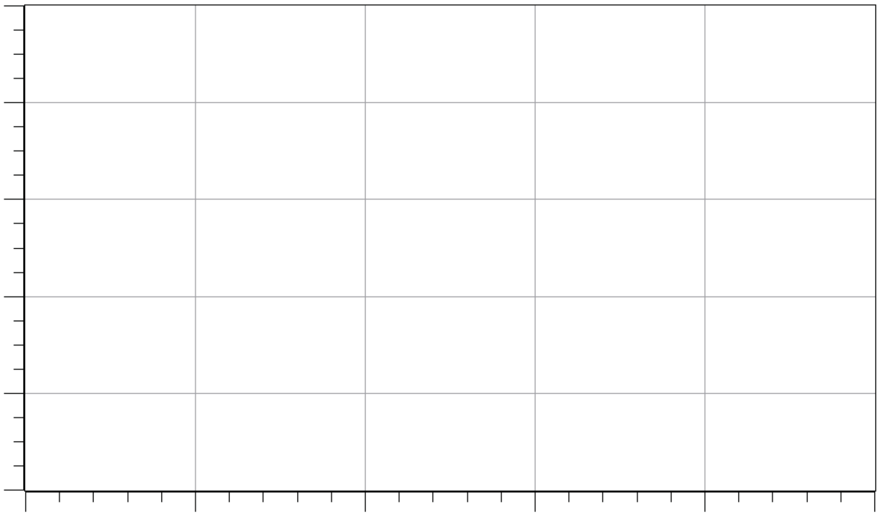
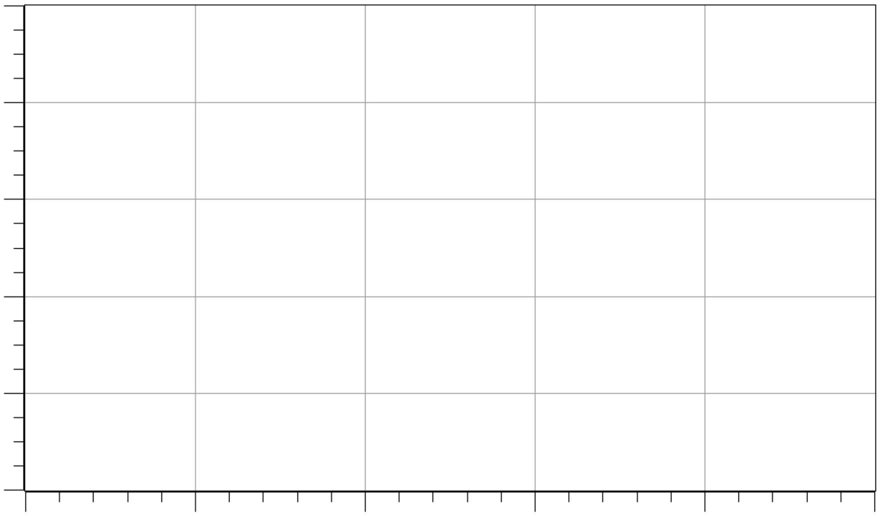


Table #2: Parallel Circuit

# of Resistors	Resistor	Voltage across resistor	Current through the resistor	Voltage/Current	Resistor Rating
1	First				
2	First				
	Second				
Total current for two resistors = ________					
3	First				
	Second				
	Third				
Total current for three resistors = ________					

Parallel Circuit Voltage versus Current



Analysis Questions

1. What does the slope of each graph represent, and what values for the slope did you get for each graph you made?

2. Add up the resistance values of the three resistors in the series circuit. How does this total resistance compare to the slope of your series circuit graph?

3. Add up the resistance values of the three resistors in the parallel circuit. How does this total resistance compare to the slope of your parallel circuit graph?

4. **Add up the inverses of the resistance values of three resistors for the parallel circuit, and then take the inverse of that sum (use this equation to solve for R_{eq}):**

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

How does R_{eq} compare to the slope of your parallel circuit graph?

Synthesis Questions

Use available resources to help you answer the following questions.

1. **If one of the bulbs in a parallel circuit goes bad (or is disconnected), what happens to the brightness of the other bulbs?**

2. **What happens to the brightness of other bulbs if a single bulb goes bad in a series circuit? Explain your answers.**

3. **Many houses display colored lights during winter holiday season, and occasionally one of the bulbs goes out. Does the entire string of lights go out with it? Explain what this tells you regarding series and parallel circuits? Student answers will vary, but the general idea is to identify that bulbs in series will go out and bulbs in parallel will remain lit.**

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. What would happen to the current from a power supply if you added more resistors to a series circuit?

- **A.** The current increases
- **B.** The current decreases
- **C.** The current stays the same
- **D.** Not enough info provided

2. What would happen to the current from a power supply if you added more resistors to a parallel circuit?

- **A.** The current increases
- **B.** The current decreases
- **C.** The current stays the same
- **D.** Not enough info provided

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. There is a predictable relationship between current, ____________, and resistance: For a circuit with constant resistance, as voltage increases or decreases, ____________ increases or decreases respectively. Thus, they are said to be ____________ proportional. For the same circuit, when resistance increases, current decreases, and visa versa. Thus, they are said to be ____________ proportional. This relationship is called ____________.

2. The formula for Ohm's law can be written as: $R = V/I$. When the plot of voltage versus current is a ____________ line, the circuit obeys Ohm's Law with a slope about the same value as the total circuit ____________, or the ____________ resistance of the ____________.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
Circuit	C=q/V
Current	Circuit
Directly	Equivalent
Hertz	R=V/I
Inversely	Resistance
Ohm's law	Straight
Voltage	Voltage