PHYSICS
MERCER UNIVERSITY

Series and Parallel Resistive Circuits

Physics Lab VIII

Objective

In the set of experiments, the theoretical expressions used to calculate the total resistance in a combination of resistors will be tested experimentally. In addition, the expected distribution of the voltage and current to each resistor in a network will also be tested.

Equipment List

DC Voltage Source, Three Resistors with resistance between 100 Ω and 900 Ω, Two Multimeters, Various Connecting Leads.

Theoretical Background

According to Ohm's Law, the current and voltage in a resistor are related by the resistance of the resistor,

$$V = IR, \tag{1}$$

where V is the voltage across the resistor, I is the current flowing through the resistor, and R is the resistance of the resistor. In this lab, combinations of resistors will be considered. There are two ways in which a pair of resistors can be connected to a battery. The first way is to connect the resistors one after the other, as shown in Figure 1. This type of arrangement is known as a *series* arrangement of the resistors.

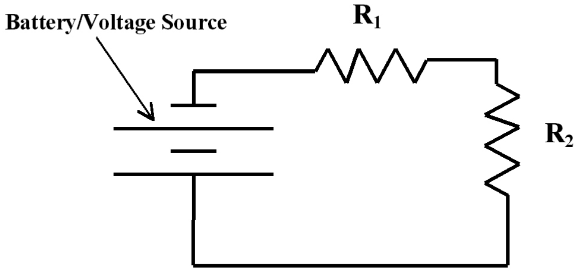

Figure 1: Series Combination of Resistors

In this case, the same current flows through both resistors while the voltage from the battery is split between the two resistors,

$$I_{total} = I_1 = I_2 \ , \ V_{total} = V_1 + V_2. \tag{2}$$

In this equation, I_1 is the current through the first resistor, I_2 is the current through the second resistor, V_{total} is the total voltage supplied by the battery, V_1 is the voltage across the first resistor, and V_2 is the voltage across the second resistor. Substituting Ohm's Law into the voltage condition, and noting that the same current flows through the circuit, gives

$$I_{total}R_{total} = I_1R_1 + I_2R_2 \Longrightarrow R_{total} = R_1 + R_2. \tag{3}$$

In this equation, R_1 is the resistance of the first resistor and R_2 is the resistance of the second resistor. For more than two resistors, the total resistance is just the sum of the individual resistances,

$$R_{total,series} = R_1 + R_2 + R_3 + \ldots = \sum_{i=1}^{N} R_i. \tag{4}$$

The other possible combination of two resistors involves connecting the ends of the resistors to the battery. This arrangement, shown in Figure 2, is known as a *parallel* combination.

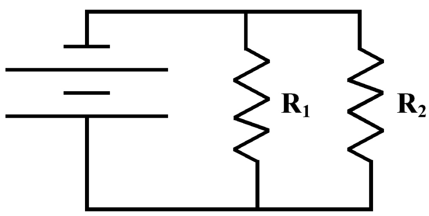

Figure 2: Parallel Combination of Resistors

In this case, the voltage across each resistor is equal to the voltage of the battery while the total current in the circuit is split between the two resistors,

$$V_{total} = V_1 = V_2 \ , \ I_{total} = I_1 + I_2. \tag{5}$$

Substituting Ohm's Law into the current condition, and noting that all of the voltages are the same, yields,

$$\frac{V_{total}}{R_{total}} = \frac{V_1}{R_1} + \frac{V_2}{R_2} \Longrightarrow \frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2}. \tag{6}$$

For more than one resistor in parallel, based upon this relation, the inverse of the total resistance is the sum of inverses of the individual resistors,

$$\frac{1}{R_{total,parallel}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots = \sum_{i=1}^{N} \frac{1}{R_i}. \tag{7}$$

In this set of experiment, these theoretical expressions for the total resistance of a combination of resistors will be tested, along with the conditions that were used to derive them.

Procedure

Individual Resistors

In this section, the resistance of the individual resistors will be determined.

1. The colors on each resistor indicate, roughly, the resistance of each resistor. The color of the band closest to the end of the resistor gives the first digit of the resistance. The color of the next band gives the second digit of the resistance. The third band color is the power of ten that multiplies the digits indicated by the first two bands. The last band indicates the error, as a percentage, in the resistance. Use this information, along with Table 1, to determine the resistance of each resistor, and the uncertainty in the resistance, based upon the color code. Record the value of the resistance and the uncertainty on your data table.

Color	Number	Multiplier	Tolerance (%)
Black	0	1	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5 %
Silver		10^{-2}	10 %
Colorless			20 %

Table 1: Color Code for Resistors

2. **Before making any connections, make sure the power supply is turned off.** Connect the first resistor first to the voltage supply, next to the multimeter being used as an ammeter, and then to the multimeter being used as a voltmeter. Your circuit should be similar to the circuit diagram in Figure 3. It may be of some use for you to connect the voltmeter last when wiring the circuit.

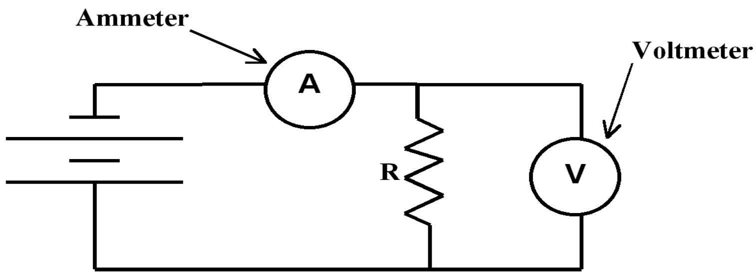

Figure 3: Circuit Diagram for Individual Resistor Measurements

3. With the power supply turned off, turn the current control on the power supply to half its maximum value. Turn the voltage control completely down to zero before turning the power on. The voltmeter should be set to the 20 V (DC) maximum scale, and the ammeter should be set to the 200 mA (DC) maximum scale.

4. Turn the power on, and increase the voltage slowly until one volt is displayed on the voltmeter. Record the voltage and the current displayed from each meter on your data sheet.

5. Continue slowly increasing the voltage until you have voltage and current measurements for 2 V, 3 V, 4 V, and 5 V.

6. Reset the voltage to zero and turn the power supply off. Disconnect the first resistor. Connect the second resistor to the power supply and multimeters. Repeat the process outlined above for the second resistor.

7. After obtaining the current and voltage measurements for the second resistor, repeat the above process for the third resistor.

8. For each of the resistors, use the voltage and current measurements, and Ohm's Law, to calculate the resistance of each resistor. For each resistor, calculate and record the average resistance values. The average resistance will be used to calculate the theoretical value of the resistance for combinations of resistors.

9. For each resistor, calculate the percent variation in the resistance.

$$\%\, Variation = 100 \times \frac{Largest\ Value\ -\ Smallest\ Value}{2 \times Average\ Value} \tag{8}$$

Series Combinations

In this set of experiments, the total resistance of resistors in a series combination will be measured. In addition, measurements will be made to check the validity of the assumptions used to derive the theoretical expression for the total resistance of a series combination.

1. **Before making any connections, make sure the power supply is turned off.** Connect the first and second resistors in series. Connect the series combination first to the voltage supply, next to the multimeter being used as an ammeter, and then to the multimeter being used as a voltmeter. Your completed circuit should be similar to the circuit diagram in Figure 4. It may be of some use for you to connect the voltmeter last when wiring the circuit.

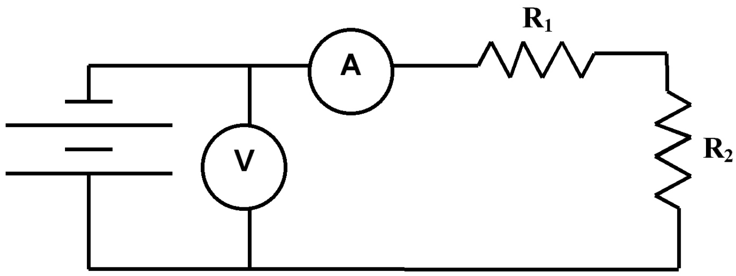

Figure 4: Circuit Diagram for Series Resistors Measurements

2. With the power supply turned off, turn the current control on the power supply to half its maximum value. Turn the voltage control completely down to zero before turning the power on. The voltmeter should be set to the 20 V (DC) maximum scale, and the ammeter should be set to the 200 mA (DC) maximum scale.

3. Turn the power on, and increase the voltage slowly until one volt is displayed on the power supply. Record the voltage and the current displayed on each meter on your data sheet.

4. Continue slowly increasing the voltage until you have voltage and current measurements for 2 V, 3 V, 4 V, and 5 V.

5. Disconnect the voltmeter. Use the voltmeter to measure the voltage drop across each individual resistor for the last trial, when the total voltage is about 5 V. Record these voltages on your data sheet. In addition, record the total voltage V_{Total} and the total current I_{Total} in the circuit.

6. Reset the voltage to zero and turn the power supply off. Disconnect the resistors, and connect the second and third resistors in series. Connect the series combination to the power supply and multimeters according the circuit diagram above. Repeat the process outlined above for this second series combination.

Parallel Combination

In this set of experiments, the total resistance of resistors in a parallel combination will be measured. In addition, measurements will be made to check the validity of assumptions used to derive the theoretical expression for the total resistance of a parallel combination.

1. **Before making any connections, make sure the power supply is turned off.** Connect the first and second resistors in parallel. Connect the parallel combination first to the voltage supply, next to the multimeter being used an ammeter, and then to the multimeter being used as a voltmeter. Your completed circuit should be similar to the circuit diagram in Figure 5. It may be of some use for you to connect the voltmeter last when wiring the circuit.

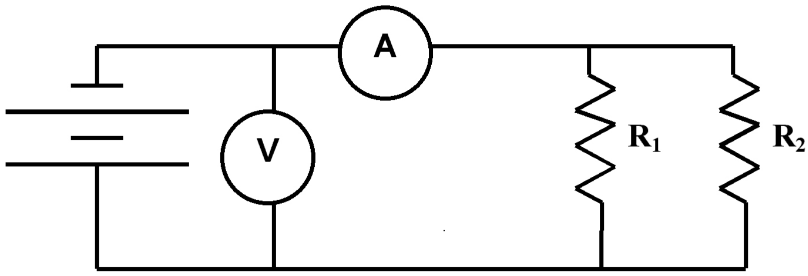

Figure 5: Circuit Diagram for Parallel Resistors Measurements

2. With the power supply turned off, turn the current control on the power supply to half its maximum value. Turn the voltage control completely down to zero before turning the power on. The voltmeter should be set to the 20 V (DC) maximum scale, and the ammeter should be set to the 200 mA (DC) maximum scale.

3. Turn the power on, and increase the voltage slowly until around one volt is displayed on the voltmeter. Record the voltage and the current displayed on each meter on your data sheet.

4. Continue slowly increasing the voltage until you have voltage and current measurements for about 2 V, 3 V, 4 V, and 5 V.

5. Disconnect the voltmeter. Use the voltmeter to measure the voltage drop across each individual resistor for the last trial, when the total voltage is about 5 V. Record these voltages on your data sheet. In addition, record the total voltage V_{Total} and the total current I_{Total} in the circuit.

6. Reset the voltage to zero and turn the power supply off. Disconnect the resistors, and connect the second and third resistors in parallel. Connect the parallel combination to the power supply and multimeters according the circuit diagram above. Repeat the process outlined above for this second parallel combination.

Series and Parallel Combination

In this set of experiments, the total resistance of resistors in a parallel and series combination will be measured. In addition, measurements will be made to check the validity of assumptions used to derive the theoretical expression for the total resistance of this combination.

1. **Before making any connections, make sure the power supply is turned off.** Connect the first, second, and third resistors in a series and parallel combination as indicated in Figure 6. Connect the combination first to the voltage supply, next to the multimeter being used an ammeter, and then to the multimeter being used as a voltmeter. Your completed circuit should be similar to the circuit diagram in Figure 6. It may be of some use for you to connect the voltmeter last when wiring the circuit.

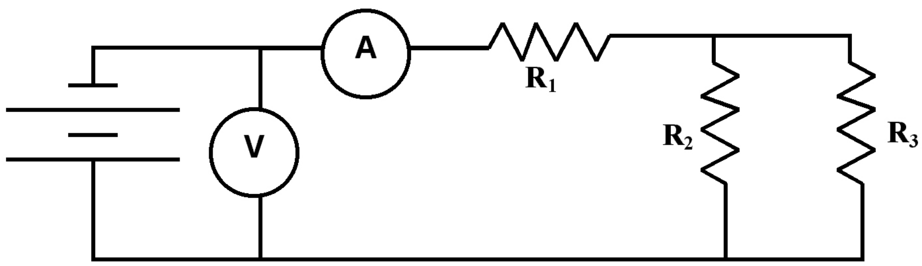

Figure 6: Circuit Diagram for Parallel and Series Resistor Combination Measurements

2. With the power supply turned off, turn the current control on the power supply to half its maximum value. Turn the voltage control completely down to zero before turning the power on. The voltmeter should be set to the 20 V (DC) maximum scale, and the ammeter should be set to the 200 mA (DC) maximum scale.

3. Turn the power on, and increase the voltage slowly until around one volt is displayed on the power supply. Record the voltage and the current displayed on each meter on your data sheet.

4. Continue slowly increasing the voltage until you have voltage and current measurements for about 2 V, 3 V, 4 V, and 5 V.

5. Disconnect the voltmeter. Use the voltmeter to measure the voltage drop across each individual resistor for the last trial, when the total voltage is about 5 V. Record these voltages on your data sheet. In addition, record the total voltage V_{Total} and the total current I_{Total} in the circuit.

6. Estimate the measurement uncertainty in the current I and the voltage V measurements. Use these values and the smallest measured value of each to calculate

the percent uncertainty in each.

$$\%\ Uncertainty = 100 \times \frac{Measurement\ Uncertainty}{Smallest\ Measured\ Value} \tag{9}$$

7. Use the largest percent variation in the individual resistor measurements as the percent uncertainty in the resistance.

8. Record the largest percent uncertainty in the experiment in the space provided.

Data Analysis

Individual Resistors

1. For each resistor, graph the voltage V as a function of the current I. Draw a straight line that comes closest to the data points, and determine the slope and y-intercept of each of these lines. You may graph all three resistors in a single graph, if you wish.

Series Combination

1. Use the voltage V and current I measurements to determine the experimental value of the resistance for the series combination of the first two resistors. Average these resistance values to obtain the average experimental resistance, $R_{exp,ave}$.

2. Record the values of the resistances of the first and second resistors, $R_{1,ave}$ and $R_{2,ave}$ on your data sheet in the spaces provided. Use these values, and the theoretical expression for the total resistance of a series combination provided in the theoretical background $R_{total,series}$, to calculate the theoretical value for the total resistance of the series combination. Record this theoretical value R_{theo} on your data sheet.

3. Calculate the percent difference between the average experimental value of the total resistance $R_{exp,ave}$ and the theoretical value of the total resistance R_{theo}. Record this value on your data sheet.

$$\%\ difference = 100 \times \frac{Theoretical\ Value\ -\ Experimental\ Value}{Theoretical\ Value} \tag{10}$$

4. Calculate and record the percent variation in the experimental values of the resistance $R_{exp,ave}$.

$$\%\ Variation = 100 \times \frac{Largest\ Value\ -\ Smallest\ Value}{2 \times Average\ Value} \tag{11}$$

5. Use the average experimental value of the individual resistors $R_{1,ave}$ and $R_{2,ave}$ to calculate the current through each resistor during the last trial.

6. Repeat this process for the series combination of the second and third resistor.

Parallel Combination

1. Use the voltage V and current I measurements to determine the experimental value of the resistance for the parallel combination of the first two resistors. Average these resistance values to obtain the average experimental resistance, $R_{exp,ave}$.

2. Record the values of the resistances of the first and second resistors, $R_{1,ave}$ and $R_{2,ave}$ on your data sheet in the spaces provided. Use these values, and the theoretical expression for the total resistance of a parallel combination provided in the theoretical background $R_{total,parallel}$, to calculate the theoretical value for the total resistance of the parallel combination. Record this theoretical value R_{theo} on your data sheet.

3. Calculate the percent difference between the average experimental value of the total resistance $R_{exp,ave}$ and the theoretical value of the total resistance R_{theo}. Record this value on your data sheet.

$$\%\ difference = 100 \times \frac{Theoretical\ Value\ -\ Experimental\ Value}{Theoretical\ Value} \tag{12}$$

4. Calculate and record the percent variation in the experimental values of the resistance $R_{exp,ave}$.

$$\%\ Variation = 100 \times \frac{Largest\ Value\ -\ Smallest\ Value}{2 \times Average\ Value} \tag{13}$$

5. Use the average experimental value of the individual resistors $R_{1,ave}$ and $R_{2,ave}$ to calculate the current through each resistor during the last trial.

6. Repeat this process for the parallel combination of the second and third resistor.

Series and Parallel Combination

1. Use the voltage V and current I measurements to determine the experimental value of the resistance for the series and parallel combination of the resistors. Average these resistance values to obtain the average experimental resistance, $R_{exp,ave}$.

2. Record the values of the resistances of the first, second, and third resistors, $R_{1,ave}$, $R_{2,ave}$, and $R_{3,ave}$ on your data sheet in the spaces provided. Use these values, and the theoretical expressions for the total resistance of a parallel combination and a series combination provided in the theoretical background to calculate the theoretical value for the total resistance of the combination. Record this theoretical value R_{theo} on your data sheet.

3. Calculate the percent difference between the average experimental value of the total resistance $R_{exp,ave}$ and the theoretical value of the total resistance R_{theo}. Record this value on your data sheet.

$$\%\ difference = 100 \times \frac{Experimental\ Value\ -\ Theoretical\ Value}{Theoretical\ Value} \tag{14}$$

4. Calculate and record the percent variation in the experimental values of the resistance $R_{exp,ave}$.

$$\%\, Variation = 100 \times \frac{Largest\ Value\ -\ Smallest\ Value}{2 \times Average\ Value} \tag{15}$$

5. Use the average experimental value of the individual resistors $R_{1,ave}$, $R_{2,ave}$, and $R_{3,ave}$ to calculate the current through each resistor during the last trial.

Selected Questions

1. Review the color code values for each measured resistor. Determine whether or not these values correspond to the calculated average values with respect to the uncertainty factor of each resistor. Do any of the color code resistor values fall well above or below the calculated average value? What reasons can explain this discrepancy?

2. For the Series cases, the voltage and current of each resistor was determined. What should they have been based upon the assumptions made in the Theoretical Background? Does your data support these assumptions?

3. For the Parallel cases, the voltage and current of each resistor was determined. What should they have been based upon the assumptions made in the Theoretical Background? Does your data support these assumptions?

4. For the Combination case, the voltage and current of each resistor was determined. What should they have been based upon the assumptions made in the Theoretical Background? Does your data support these assumptions?