Ohm’s Law and Simple Electrical Connections

Purpose:
To experimentally verify Ohm’s Law and to provide experience in making series and parallel electrical connections.

TO AVOID RUINING FUSES CHECK ALL CIRCUIT CONNECTIONS BEFORE CONNECTING THE CIRCUIT TO THE POWER SUPPLY. DISCONNECT THE CIRCUIT FROM THE POWER SUPPLY BEFORE CHANGING ANY CIRCUIT CONNECTIONS.

Introduction: Ohm’s Law
If we maintain an electric potential difference between two points then there will be an electric field present in that region of space. Charges that are there will feel a force and they will tend to move. Batteries and power supplies maintain electric potential differences between two points in space; that is their function. What happens if we connect those two points with a conductor? The charges that are free to move do so. We get a current flowing. Once it is going there is an interaction between the current and the atoms in the conductor. It amounts to a sort of friction and the resultant balance gives us a steady flow of charge. For some materials there is a simple relationship between the applied electric potential difference and the current; they are proportional. If \( I \) is current (measured in amperes; 1 amp = 1 C/s) and \( \Delta V \) is the applied potential difference then we can write

\[
\Delta V = IR
\]

where \( R \) is the proportionality constant. It is called resistance and is measured in Ohms (because this relationship is called Ohm’s Law!). The symbol for the Ohm is a capital omega, \( \Omega \). Not all substances follow this law, but those that do are called “ohmic”.

Laboratory Procedure:
Part I.I - Taking Direct Measurements: Unknown Resistor

1. Set up circuit 1, shown in Figure 1, with an ammeter in series and a voltmeter in parallel with an unknown resistor (the resistor at your station without a value written on it). The ammeter and voltmeter are both Digital Multimeters (DMM), set to measure current and voltage respectively. Be sure to verify each connection before supplying power to the circuit.

2. Adjust the variable voltage supply until the voltage on your voltmeter is equal to 0.25 V. Record this value \( V \).
3. Determine \( \delta V \) based on the precision of the voltmeter.
4. Determine the fractional uncertainty (\( \frac{\delta V}{V} \)) for this measurement and record this in your data table.
5. Record the current value \( I \) on the current meter.
6. Determine \( \delta I \) based on the precision of the ammeter.
7. Determine the fractional uncertainty (\( \frac{\delta I}{I} \)) for this measurement and record this in your data table.

8. Repeat steps 2–7 for voltage values of 0.5 V, 1.0 V, 2.0 V, 3.0 V, 4.0 V, 5.0 V, 6.0 V, 7.0 V, 8.0 V, 9.0 V, and 10.0 V. Your meters will automatically scale to give the most significant figures.

9. Plot your measured values of V (y-axis) vs. I (x-axis) using a full page graph.

10. Calculate the slope of the line (watch units). Note that if a device follows Ohm’s law the slope of the linear line is the resistance.

11. To find the resistance of the resistor in another way, set your DMM to \( \Omega \) and measure across the resistor, as shown below. Record this value of \( R \) and \( \delta R \) based on the precision of the meter.

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**Part I.II - Taking Direct Measurements: Headlight**

1. Replace the resistor used in the circuit above with the headlight.

2. Adjust the variable voltage supply until the voltage on your voltmeter is equal to 0.25 V. Record this value \( V \).

3. Determine \( \delta V \) based on the precision of the voltmeter.

4. Determine the fractional uncertainty (\( \frac{\delta V}{V} \)) for this measurement and record this in your data table.

5. Record the current value \( I \) on the current meter.

6. Determine \( \delta I \) based on the precision of the ammeter.

7. Determine the fractional uncertainty (\( \frac{\delta I}{I} \)) for this measurement and record this in your data table.

8. Repeat steps 2–7 for voltage values of 0.5 V, 1.0 V, 2.0 V, 3.0 V, 4.0 V, 5.0 V, 6.0 V, 7.0 V, 8.0 V, 9.0 V, 10.0 V, 11.0 V and 12.0 V.

9. Plot your results as a separate graph from part I.I. Note that not all substances have constant resistance so \( V/I \) is not always constant. Your graph should clearly show whether the headlight could be considered an ohmic circuit element or not.
Introduction: Series and Parallel Circuits

Now, we will explore different ways that resistors can be connected in a circuit. Most complicated circuits can be reduced to sub-units where the resistors are connected in one of two basic ways. These are called series and parallel. One is end to end to end so that all of the current flows through each in turn. We call this connection scheme a series combination. The kinked lines represent resistors. The straight lines are wires. In a series connection, the current must flow first through one resistor, and then through the next as there is no alternate path (see figure 2). In a parallel connection, the current can split into two or more paths and may be different for the different paths. The current then recombines on the other side.

Laboratory Procedure:

Part II.I - Taking Direct Measurements: Series Circuit

Make sure you dial the voltage supply to zero before starting Part II.

1. Three important facts can be learned from the following exercise with resistors in series:
   (a) In a series connection, the current is the same in all parts of the circuit (to within the uncertainty of the meter).
   (b) The voltages across two resistors in series are not necessarily equal.
   (c) Resistors in series act like one resistor with $R_{\text{total}} = R_1 + R_2 + \ldots$

2. Place two 100 Ω resistors in series with each other (see figure 3). Connect two ammeters in series with, and on either side of, the resistors, then plug the circuit into the variable voltage supply.

3. Dial the voltage up to 5 volts (DO NOT EXCEED 5 V).

4. Record the current value $I_1$ on the first current meter next to resistor $R_1$.

5. Determine $\delta I_1$ based on the precision of the ammeter.

6. Determine the fractional uncertainty ($\frac{\delta I_1}{I_1}$) for this measurement and record this in your data table.

7. Record the current value $I_2$ on the second current meter next to resistor $R_2$.

8. Determine $\delta I_2$ based on the precision of the ammeter.
9. Determine the fractional uncertainty ($\frac{\delta I}{I}$) for this measurement and record this in your data table.

10. Connect the voltmeter across resistor $R_1$ and record this voltage, $V_1$.

11. Determine $\delta V_1$ based on the precision of the voltmeter.

12. Determine the fractional uncertainty ($\frac{\delta V_1}{V_1}$) for this measurement and record this in your data table.

13. Connect the voltmeter across resistor $R_2$ and record this voltage, $V_2$.

14. Determine $\delta V_2$ based on the precision of the voltmeter.

15. Determine the fractional uncertainty ($\frac{\delta V_2}{V_2}$) for this measurement and record this in your data table.

16. Connect the voltmeter across both resistors and record the total voltage $V_t$.

17. Determine $\delta V_t$ based on the precision of the voltmeter.

18. Determine the fractional uncertainty ($\frac{\delta V_t}{V_t}$) for this measurement and record this in your data table.

19. Calculate $R_1$ from your measurements of $V_1$ and $I_1$ using Ohm’s Law.

$$R = \frac{V}{I}$$

20. Calculate $R_2$ from your measurements of $V_2$ and $I_2$.

21. Calculate $R_{total}$ from your measurement of $V_{total}$ and what you infer from the facts known about resistors in series for $I_{total}$.

22. Measure and record $R$ and $\delta R$ for each resistor using the ohmmeter setting of your meter.

23. Replace one of the 100 $\Omega$ resistors with the 25 $\Omega$ resistor and repeat steps 3–21.
Part II.II - Taking Direct Measurements: Parallel Circuit

1. Three important facts can be learned from the following exercise with resistors in parallel:
   
   (a) In a parallel connection, the voltage across all resistors are equal (to within the uncertainty of the meter.)
   (b) The currents through resistors in parallel are not necessarily equal.
   (c) Resistors in parallel act like one resistor with \[ \frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots \]

2. Connect the two 100 Ω resistors in parallel with each other (see figure 4). Note that each resistor must be connected in series with its own ammeter in order to measure the amount of current flowing through each resistor individually.

   ![Figure 4: Circuit #3.](image)

3. Dial the voltage up to 5 volts (DO NOT EXCEED 5V).
4. Record the current value \( I_1 \) on the first current meter next to resistor \( R_1 \).
5. Determine \( \delta I_1 \) based on the precision of the ammeter.
6. Determine the fractional uncertainty \( \left( \frac{\delta I_1}{I_1} \right) \) for this measurement and record this in your data table.
7. Record the current value \( I_2 \) on the second current meter next to resistor \( R_2 \).
8. Determine \( \delta I_2 \) based on the precision of the ammeter.
9. Determine the fractional uncertainty \( \left( \frac{\delta I_2}{I_2} \right) \) for this measurement and record this in your data table.
10. Connect the voltmeter across resistor \( R_1 \) and record this voltage, \( V_1 \).
11. Determine \( \delta V_1 \) based on the precision of the voltmeter.
12. Determine the fractional uncertainty \( \left( \frac{\delta V_1}{V_1} \right) \) for this measurement and record this in your data table.
13. Connect the voltmeter across resistor \( R_2 \) and record this voltage, \( V_2 \).
14. Determine \( \delta V_2 \) based on the precision of the voltmeter.
15. Determine the fractional uncertainty \( \left( \frac{\delta V_2}{V_2} \right) \) for this measurement and record this in your data table.
16. Connect the voltmeter across both resistors and record the total voltage \( V_t \).
17. Determine \( \delta V_t \) based on the precision of the voltmeter.
18. Determine the fractional uncertainty \( \left( \frac{\delta V_t}{V_t} \right) \) for this measurement and record this in your data table.
19. Calculate $R_1$ from your measurements of $V_1$ and $I_1$ using Ohm’s Law.

$$ R = \frac{V}{I} $$

20. Calculate $R_2$ from your measurements of $V_2$ and $I_2$.

21. Calculate $R_{total}$ from your measurement of $V_{total}$ and what you infer from the facts known about resistors in series for $I_{total}$.

22. Measure and record $R$ and $\delta R$ for each resistor using the ohmmeter setting of your meter.

**Part III - Determining Uncertainties in Your Final Values**

In the results section of your notebook, state the results of part I.I of your experiment in the form $R \pm \delta R$. Note, $\delta R$ should be equal to the largest fractional uncertainty from your values of voltage $V$ and current $I$.

$$ \delta R = R \times \max\left(\frac{\delta V}{V}, \frac{\delta I}{I}\right) $$

In the results section of your notebook, state the results of part II of your experiment for each resistor in each circuit in the form $R \pm \delta R$. Note, $\delta R$ should be equal to the largest fractional uncertainty from your values of voltage $V$ and current $I$.

$$ \delta R = R \times \max\left(\frac{\delta V}{V}, \frac{\delta I}{I}\right) $$

You should also address the following questions:

1. Does your result for $R$ in part I.I agree within the uncertainties to the value you measured using the ohmmeter reading of your DMM? Be sure to clearly state the quantitative values you are comparing. If there are any large discrepancies, **quantitatively** comment on their possible origin. (Hint: Is there resistance in the meter and how might this affect your results? Feel free to use the internet to help you with this)

2. Which device in Part I is non-ohmic?

3. Do your results for $R_1$ and $R_2$ in part II.I agree within the uncertainties to the resistance values you determined using the ohmmeter reading of your DMM? Be sure to clearly state the quantitative values you are comparing. If there are any large discrepancies, **quantitatively** comment on their possible origin.

4. Does your result for $R_{total}$ in part II.I agree within the uncertainties to the calculated value using the following formula (use the values you measured with the ohmmeter for $R_1$ and $R_2$ in the formula).

$$ R_{total} = R_1 + R_2 $$

5. Do your results for $R_1$ and $R_2$ in part II.II agree within the uncertainties to the value you measured using the ohmmeter reading of your DMM? Be sure to clearly state the quantitative values you are comparing. If there are any large discrepancies, **quantitatively** comment on their possible origin.

6. Does your result for $R_{total}$ in part II.II agree within the uncertainties to the calculated value using the following formula (use the values you measured with the ohmmeter for $R_1$ and $R_2$ in the formula).

$$ R_{total} = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1} $$