Ohm's Law (Virtual Lab)

Safety and Equipment

- Computer with modern HTML5 web browser
- https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab

Introduction

Georg Ohm discovered that when the voltage (potential difference) across a resistor changes, the current through the resistor changes. He expressed this as

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

where I is current, V is voltage (potential difference), and R is resistance. According to Ohm's Law, current is directly proportional to voltage (if the resistance is constant) and inversely proportional to resistance (if the voltage is constant). In other words, as the voltage increases, so should the current. The proportionality constant is the value of the resistance. Since the current is inversely proportional to the resistance, as the resistance increases, the current decreases

A resistor is 'Ohmic' *if its resistance is constant*. This means that as the voltage across a resistor is increased, the current increases proportionally.

- A graph of voltage vs. current will show the function $V = IR$ as a straight line. The slope of the line is the value of the resistance.
- A graph of current vs. voltage (called an *I-V* graph) will show the function $I = V / R$ as a straight line. The slope of the line is the inverse of the resistance, or the inverse of the slope is the resistance.

A device is 'non-Ohmic' if *I-V* graph is not a straight line. For example, if the resistance changes as voltage changes, the *I-V* graph might show a curve with a changing slope. (Note: the "resistance" is $\frac{V}{I}$, which is the slope of a line from a point on the graph to the origin. If the *I-V* graph is curved, the slope of that curve is not the resistance.)

Virtual circuit simulations are an important part of electronics design. While the PhET simulations used in this lab are developed to help students understand the basics of circuits, more powerful circuit simulators are used by hobbyists and professionals. One free simulator is available at https://www.falstad.com/circuit/. We'll stick with the PhET simulations, though.

Objectives:

- *To verify Ohm's Law.*
- *To determine the internal resistance of a battery using Ohm's Law.*

Part #1 Building an Ohmmeter to Measure Resistance

The device designed to measure a Resistance is called an *ohmmeter*. The Ohmmeter is usually part of a Multimeter, a device designed to measure multiple quantities including a Resistance. Other than the ohmmeter itself, **there should be no voltage across the resistor when its resistance is measured**. Since the PhET Circuit Construction Kit does not have an ohmmeter, we will build one.

A device designed to have a consistent resistance is a *resistor*. A conductive wire is a low-resistance resistor. Insulators like rubber and plastic have high resistance. A variable-resistance resistor is called a rheostat or potentiometer. We will build a simple rheostat.

To measure the resistance, just connect the terminals of the resistor to be measured to the terminals of the ohmmeter or touch the probes of the ohmmeter to the terminals of the resistor.

1. Start the PhET Circuit Construction Kit DC Virtual Lab HTML5 simulation at
   https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc-virtual-lab
2. **Setup**: To reduce confusion, select the Conventional → current option.
   Open the Wire Resistivity panel and drag the slider to "lots".

3. Here are some basics on how to operate the simulation:
   - Build circuits by dragging parts into the workspace. Connection terminals are marked with circles.
   - Wires can be connected directly to terminals, or by dropping the wire out in the open and connecting each end individually.
   - Parts can be edited by selecting them. A properties box should appear at the bottom.
   - Parts can be deleted by selecting them and pressing the delete key or the trashcan icon at the bottom.
   - Connections can be broken by clicking on them and tapping the scissors icon to cut the connection.
4. Build a rheeostat by connecting 8 resistors in series. They don't have to be a straight line, but you want to be able to access any of the connections. It might look like this, but without labels:
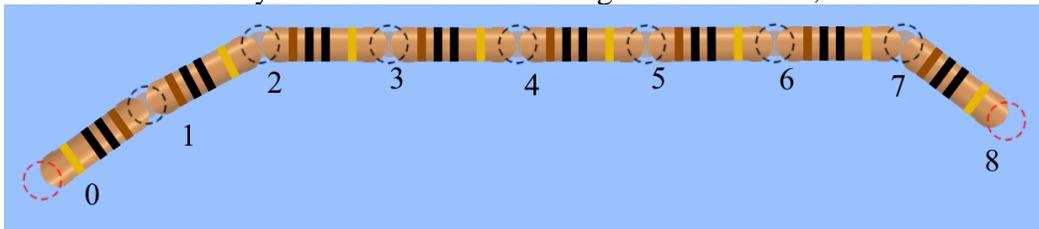
   The circles are the connection points, called terminals. The numbered labels were added so the instructions can refer to them later. Each resistor is 10 Ω, so if we connect between terminals "0" and "2", there are 20 Ω between the terminals. This will be used to select the resistance from 10 to 80 Ω.

5. Build an ohmmeter using a battery, ammeter, and voltmeter.
   - First place the battery out in the open. Click on it and change it to 120 V. A real ohmmeter uses a much lower voltage, such as 0.5 V.
   - Connect an ammeter to one end of the battery.
   - Connect a voltmeter "across" the battery and ammeter.

   The completed ohmmeter should look like this, without labels:
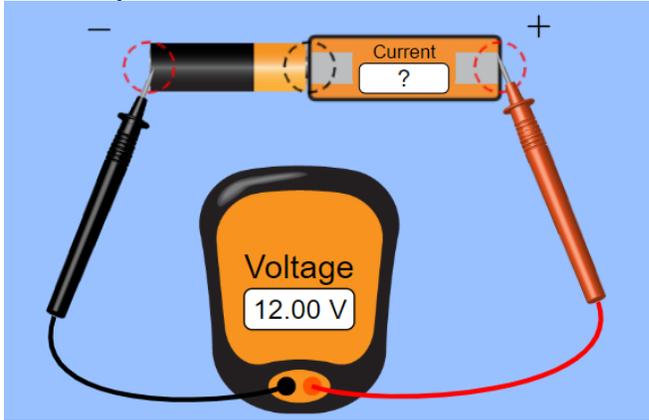
   The dashed circles at either end are the terminals. The negative terminal ("−") is at the left and positive terminal ("+") is at the right.
6. To use the ohmmeter, connect the ohmmeter terminals to the resistance terminals using two wires.
   - One wire connects the "−" terminal to the rheostat's "0" terminal, at the left ends.
   - The other wire connects will go from the "+" terminal of the ohmmeter to one of the other terminals on the rheostat. For now, select 10 Ω by connecting to the "1" terminal. Once the connection is made, you'll see red arrows representing the conventional current flowing around the circuit.
7. To take a reading on our makeshift ohmmeter, we have to do a quick calculation with ohm's law: $R = V/I$. For example, if the displayed voltage is 120 V and the displayed current is 1.72 A, the resistance is calculated to be $R = (120 \text{ V})/(1.72 \text{ A}) = 70.6 \text{ } \Omega$. (Your values will be different.)
8. Set up Table 1 and record the current and calculate the resistance, ohmmeter terminal is connected to various selected resistors, from 10 Ω to 80 Ω. The easiest way to change where the ohmmeter terminal is connected is by removing the wire and connecting a new wire to a different rheostat terminal.

Selected Resistance (ohms)	Measured Current (A)	Calculated Resistance (ohms)	Extra Resistance (ohms)
10			
20			
30			
40			
50			
60			
70			
80			

Table 1: Current measurements and resistance calculations for rheostat. The makeshift ohmmeter has its − terminal connected to terminal 0, while the + ohmmeter terminal is connected to different rheostat terminals to select the resistance. The ohmmeter has a 120 V voltage source.

9. Calculate the extra resistance as the difference between the measured and selected resistance values. The extra resistance is caused by the wires.
10. As an observation in your Discussion, comment on how the current, measured resistance, and extra resistance change. Is the extra resistance roughly constant? Does it vary at all? Why?
11. Make a graph of Calculated Resistance vs. Current. The trendline shouldn't be linear. If we solve Ohm's Law for Resistance, we get $R = V/I = V\,I^{-1}$. That is a power function. Make the trendline take that form, and display the equation. Change the equation to physics variables and compare it to what you expect from Ohm's Law.

Part #2 Using an Ammeter

The device designed to measure an Electric Current (I) is called an *ammeter*. The Ammeter can be a part of a Multimeter, a device designed to measure multiple quantities including an Electric Current. To ensure that the same current passes through both the resistor and the ammeter, the ammeter is always inserted into the circuit next to the resistor by *disconnecting and reconnecting wires* as shown on Figure 3. The current flows from "+" terminal (higher potential) of the battery into the Ammeter, then it flows out of the Ammeter to enter the resistor. Therefore, the red terminal of the ammeter should be connected to a higher potential ("+" end of the battery) and black terminal of the ammeter should be connected to the resistor.
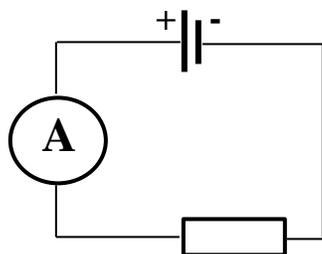

Figure 3. Schematic set up of the circuit with an ammeter, a battery (with + and − labeled), and a resistor (the box).

1. Keep the 120 V battery and 80 Ohm resistor chain. Remove the voltmeter by dragging it back to its home.
2. Break the circuit in the middle of the resistor chain. Insert a second ammeter into the break.

3. Note how the two current readings relate to each other, as part of the discussion.
4. Move the second ammeter to different locations within the resistor chain and at each end. Make sure the current readings maintain the same relationship. (The value may change when you move things around, because the wires change length and hence resistance.)

Part #3 Measuring Voltage and an I-V Curve.

The device designed to measure a Potential Difference or Voltage is called a *voltmeter*. The Voltmeter can be a part of a Multimeter, a device designed to measure multiple quantities including a potential difference. A Voltmeter is often built in to a DC Power Supply. To measure a potential difference between any two points in a circuit, the red terminal of the voltmeter is connected to a point at a higher potential and the black terminal to a point at a lower potential. On the Figure 4, point ① has higher potential than point ② (current **always** flows from higher potential to lower potential). Notice that the potential difference or voltage is measured **across** a battery or resistance.
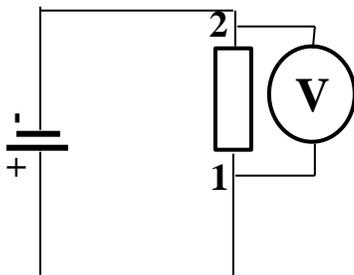
Figure 4. Schematic set up of the circuit with a voltmeter

During this part, *the rheostat resistance doesn't change*. Instead, the battery's voltage will vary. The response of the current to the variations of the voltage is the "*I-V* Curve" for the rheostat.

1. Use the original battery, ammeter and 80 Ω rheostat, but connect the voltmeter across the rheostat, to terminals "0" and "8".
2. Click on the battery, so that its voltage can be adjusted.
3. Set up Table 2, and take measurements for voltages selected between 20 and 120 V.

Selected Voltage (V)	Measured Voltage (V)	Measured Current (A)
20		
40		
60		
80		
100		
120		

Table 2. Voltage across and Current through an 80 Ω rheostat, measured at different battery voltages.

4. Make an *I-V* graph, which is scatterplot Current vs. Voltage (measured *V*, not Selected). Remember, we name graphs by the y-axis first, so current should be on the vertical axis. Add a linear trendline and display the equation. Change the trendline equation to physics variables instead of *x* and *y*.
5. The inverse of the slope of the *I-V* graph should be equal to the resistance of the rheostat. Verify whether they are equal. Calculate % difference between the slope and the resistance of the rheostat.

Inverse Slope of *I-V* graph (V/A)	
Selected Resistance of rheostat (Ω)	
% Difference	

Table 3. Comparison of the *I-V* graph of the rheostat to its resistance.

6. Comment on how the experimental data supports the Ohm's Law. Include this statement in the abstract.

Part #4. Determining the Internal Resistance of a Battery.

Every power supply has an ***internal resistance (r)***. In a circuit, the current flows in closed loop. This means that it flows through power supply as well as through the rest of the circuit. The power supply itself adds some extra resistance to the circuit. The voltage measured across the terminals of the power supply before connecting anything is different from the voltage measured across the terminals after the circuit is complete. The maximum possible potential difference across the terminal of the power supply is called emf (ε). The voltage across the terminals of the power supply or ***terminal voltage*** equals emf of the battery when circuit is open and there is no current in the battery.

In the closed circuit, where there is current passing through the battery, the value of the terminal voltage is lower than the value of emf. The difference between ***terminal voltage*** of an open circuit and ***terminal voltage*** of a closed circuit comes from the internal resistance of the power supply that drops voltage as any resistance. The effect of the internal resistance on the circuit could be described by the Ohm's Law for a complete circuit

$$emf = V_{terminal} + Ir$$

The greater the current in the circuit the greater the difference between emf and terminal voltage of a closed circuit.

1. Clear the simulation.
2. Setup: select the Conventional → current option. Open the Wire Resistivity panel and drag the slider to "lots". Set the Battery Resistance to 3.0 ohms. (Do not use this value in your calculations.)
3. Build the makeshift ohmmeter again. Set the battery for 9.0 V (the default). The voltmeter reading should match. This is the EMF (ε) of the battery, and should match what the battery is set for.
4. Build a circuit with a single 10 Ω resistor and the ohmmeter. You should see a current measurement, and a new voltage measurement. Since the voltmeter is connected to the battery terminals, this is called the terminal voltage ($V_{terminal}$) of the battery. (The ammeter has no effect on the voltage, but the wires do.)
5. Determine the internal resistance of the battery from the Ohm's Law for a complete circuit.
6. Design and label Table 4 to record the results. Include the numerical results in the abstract.

Requirements for the Report:

The report must contain a **Header** at the top (Title of Lab, Authors, and Date)

Abstract Section must contain the following in paragraph form:

- Brief Introduction that includes objectives and basic theory of the lab. Include:
    - The definition of Voltage, Current, and Resistance.
    - According to Ohm's Law, what is the relationship between the three quantities above?
- Methodology describing broadly what was done, using what tools, and what was measured/recorded.
- Data Summary including quantities worked into sentences.
    - Explain how and why the connection to the rheostat is used to select a resistance.
    - Explain how and why *current* changes as the rheostat resistance changes. Analyze the graph and interpret its trendline (include equations using physics variables). How does the trend relate to Ohm's Law?
    - Comment on the relationship between voltage and current. Use the *I-V* graph to support your discussion. Does the inverse slope of the graph match the resistance of the rheostat? Does the data support Ohm's Law?
    - Explain how you calculated the internal resistance of the battery. Include your measured values in your explanation. What is the difference between emf and terminal voltage?
- The lab manual contains questions and/or imperatives throughout that will guide you with the conclusions. **Always incorporate the questions and/or imperatives from the lab manual**.
- Sources of Error and a ballpark estimate of their contribution. DO NOT use "human error". That term is too vague to be meaningful.

Data Section must contain the following:
[Each table and graph should be labeled and descriptively captioned]
- 4 Tables
- 2 Graphs (each graph will use a different type of trendline)