Lab 14:
Ohm's Law

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In this lab you will learn

- the relationship between current, voltage, and resistance in a simple circuit
- how to calculate resistance, current and voltage using Ohm's law, as well as how to measure these variables in an actual circuit using a multimeter
- what factors affect resistance of various materials

Activity 1: Pre-Assessment

1. What is an electric circuit? What is needed for electric charge to flow from one end of a conducting wire to another? Does voltage produce current, or does current produce voltage?
2. What simple experimental demonstration would illustrate the cause-and-effect relationship between resistance and current in an electric circuit? What materials would you use for your demonstration? Draw a circuit diagram to show how you connect your materials. Explain what observations you will be making.
3. **Discuss the answers to questions 1 and 2 with the class.**

Activity 1 Resistance and Current

We can create a simple electric circuit using a source of electrical energy (battery), a conductor of the electrical energy (wire) connected to the energy source, and a device that uses and transforms the electrical energy (lightbulb).

Current can be measured with an **ammeter** and voltage with a **voltmeter.** You may also use a multimeter that combines these functions, and often some others, into a single instrument as illustrated in Figure 14.1. The current is measured in amperes (A). One ampere is the rate of flow of one coulomb (C) of charge per second. To measure the current, the ammeter must be inserted in the circuit so that the current passes directly through it.

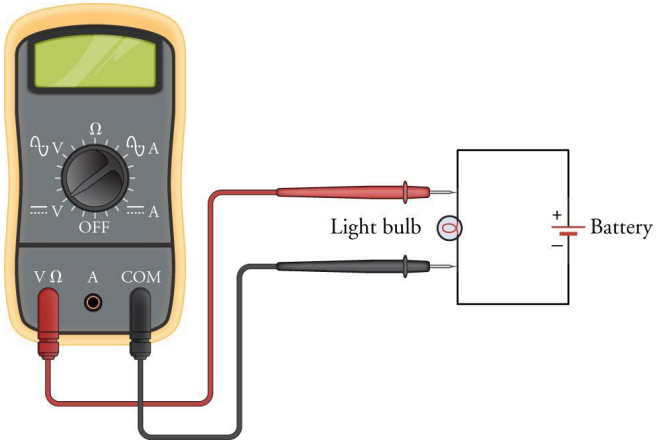


Figure 14.1: A multimeter used as a voltmeter to measure electrical potential through a circuit. This multimeter measures voltage (V) and electrical resistance (Ω) using the same wire port. However, the dial is set to measure voltage.

Described earlier was electrical resistance on a microscopic level, how it results from obstacles to the flow of electrons in the conducting material. We now use a very common analogy that compares the flow of charge through a conductor to the flow of water through pipes. In this analogy, the voltage is represented by the hydrostatic pressure of water, and current is represented by the water flow. Consider a water tank with two pipes, one narrow and one wide, as shown in Figure 14.2. Water flows through the narrow pipe at a slower rate than through the wider pipe under the same pressure. We can regard the narrow pipe to have greater resistance to water flow. Think of this analogy as you explore the relationship between current and resistance in a simple circuit with constant voltage.

The unit of voltage is volt (V). One volt is an energy of one joule per coulomb of electric charge. A voltage of one volt between two points means that electric charge has one joule per coulomb more energy at one point than at the other. A voltmeter measures the voltage (electric potential difference) between two points in a circuit. Therefore, the voltmeter must be connected across the points and is not inserted into the circuit.

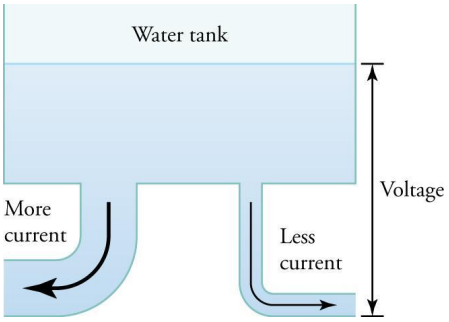


Figure 14.2: The equal water pressure (hydrostatic pressure) at both pipe openings is analogous to the same voltage across two conductors. The pipe width is analogous to the reciprocal of resistance (wider pipes resist less), and the water flow through the pipe is analogous to electric current

Electrical resistance is measured in ohms (Ω). One ohm is the resistance for which a 1 V difference in electric potential produces 1 A of current. You can use an **ohmmeter** or multimeter to measure resistance. Disconnect the resistor from the battery before measuring resistance. Then connect the leads of the ohmmeter across the resistor as shown in Figure 14.3.

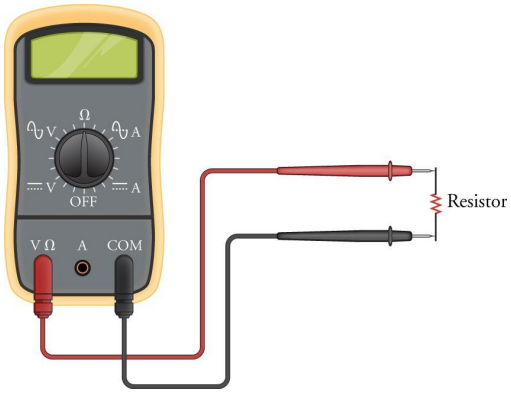


Figure 14.3: Measuring resistance with an ohmmeter

Safety Precautions

- If you choose to use a power supply rather than a battery pack, set the voltage to a fixed maximum around 5 V.
- Emphasize proper meter usage.

For this activity you will need the following:

- Battery holder(s) that can hold up to four batteries
- Four batteries
- Wire leads with alligator clip
- One miniature light bulb with corresponding bulb holder (check maximum voltage for light bulb to avoid burnout)
- Four to six different resistors
- Basic multimeters or single-value meters (ammeter and ohmmeter)

For this activity you will work *in pairs*.

Structured Inquiry

Step 1: Hypothesize/Predict: Put together a simple circuit to light the light bulb using batteries. Suppose you inserted different resistors into the circuit without changing the lightbulb or batteries? How do you predict this would affect the current and the brightness of the light bulb? How do you predict changing the voltage by changing the number of batteries in series would affect the current through the lightbulb? Write your predictions in your notebook.

Step 2: Measure resistance of all resistors, and record these values in your notebook. Construct the simple circuit shown in Figure 14.4 with one resistor.

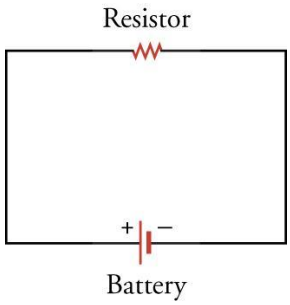


Figure 14.4: A simple circuit consisting of a resistor and a battery

Step 3: Student-Led Planning: Add a lightbulb into the circuit. Then, change the number of batteries in series. Observe the effect on the light bulb, and record your observations. Discuss with your partner how best to measure the current. Create a data table for the measurements of current and resistance in your notebook. Include correct units in all measured values. Test the predictions you made in Step 1.

Step 4: Critical Analysis: Does your data support the predictions you made in Step 1? Does it support your statement with calculations? Why or why not? Describe the relationship you found between the voltages across the resistor, and express it mathematically. Discuss your answers with your partner, and then write them in your notebook. Discuss the results of the experiment with your partner, and then write your conclusion in your notebook. Formulate the relationship you found between the current through the resistor and the resistance both descriptively and mathematically.

Guided Inquiry

Step 1: Hypothesize/Predict: What is the mathematical relationship between voltage, current, and resistance? Write your prediction in your notebook.

Step 2: Student-Led Planning: Decide with your partner how you can confirm your prediction experimentally. Think of conducting several experiments. For each experiment, identify which variable(s) you will control and which variable(s) you will vary. Design the data table for each experiment, and complete the experiments.

Step 3: Critical Analysis: What mathematical relationship between the current, voltage, and resistance do your findings in Activities 1 and 2 suggest? How can you use your experimental data in this part of the investigation to confirm this relationship? Discuss your answers with your partner, and write them in your notebook.

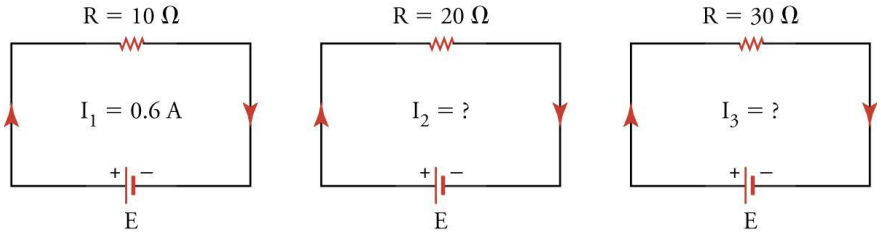
Assessments

1. From their recent trip to Russia, your parents/guardians brought home an electrical samovar for making tea, as done in traditional Russian tea ceremonies (Figure 14.5). The samovar is designed for a 220 V electric outlet. Your family invited guests to a ceremony and plugged the samovar into the wall outlet (110 V), but water did not boil. Why?



Figure 14.5: Traditional Russian samovar for boiling water

2. Each of the three simple circuits have the same battery. The voltages of batteries for each circuit and the current through the first circuit are shown in Figure 14.6.



   a. What is the current in the second circuit?
   b. What is the current in the third circuit?
   c. Explain your reasoning.

3. A light bulb filament has a resistance of 580 Ω. A voltage of 120 V is connected across the filament. How much current is in the filament?
4. A variable resistor is connected to a battery. Each value of the resistance and the corresponding current is listed in Table 14.1: Question 3. Use the data to determine the voltage of the battery. Explain your reasoning and calculations.

Table 14.1: Question 3

Resistance (kΩ)	Current (mA)
0.01	300
0.10	30
0.33	9.1
0.56	5.4
1.0	3.0
10.0	0.3

Activity 2: Pre-Assessment

1. What is the resistance of an electric skillet that draws 12 A of current when connected to 120 V circuit? Metals are electrical conductors, so why do they have resistance to the electric current?
2. What do we mean by an "intrinsic property of a material"? Give an example of an intrinsic property. Give an example of a property of a material that is not intrinsic. Can you make two wires from the same material that have different resistance? Can you make two wires from different materials that have the same resistance?
3. **Discuss the answers to questions 1 and 2 with the class.**

Activity 2 Resistance and Resistivity

Based on Ohm's law, the electrical resistance of a conducting object (e.g., a wire) is defined as the ratio of the voltage across the object to the electric current through it. Recall the analogy between the flow of charge through a conductor and the flow of water through a pipe. The narrow pipe resists water flow more than the wide pipe. By analogy, a thin wire has more resistance to electric current than a thick wire. The longer pipe resists water flow more than a short pipe. By analogy, a longer wire has more resistance than a short wire. Recall that electrical resistance results from obstacles to the flow of electrons in the conducting material. Therefore, the electrical resistance also depends on the material composing the conductor. Electrical resistivity is an intrinsic property that quantitatively describes how strongly a given material will oppose electric current.

In this activity you will compare resistance of wires made from different materials that have different length and/or cross-sectional areas, and you will determine a mathematical relationship between resistance, resistivity, length, and cross-sectional area of a resistor. We will assume that all wires have cylindrical shape. The cross-sectional area of a cylinder is the area of a circle formed at its base. If the radius of the cylinder is r, then cross-sectional area is πr^2. The length of the cylinder is also the height of the cylinder defined as the perpendicular distance between the bases.

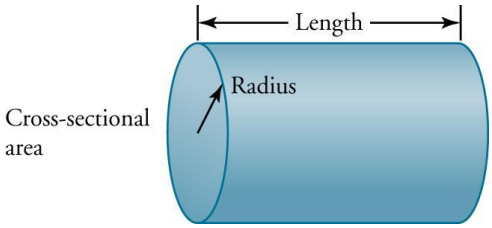


Figure 14.6: The cylinder shown represents the shape of a typical wire.

Safety Precautions

- Emphasize proper meter usage.
- Note that the wire may become hot when connected to the voltage source for long periods of time.

For this activity you will need the following:

- Wires of different diameter and length (at least three different diameters per length per material, three different lengths per diameter per material, and three different materials per length per diameter)
- An ohmmeter or multimeter
- Ruler for length measurements
- Caliper for diameter measurements
- Table of values of electrical resistivity for common metals that includes metals used in this activity

For this activity you will work *in pairs*.

Structured Inquiry

Step 1: Hypothesize/Predict: What is the relationship between the resistance of a wire and its length? What is the relationship between the resistance of a wire and its cross-sectional area?

Step 2: Student-Led Planning: Discuss with your partner how best to take the measurements to find each relationship you predicted in Step 1. Think of conducting one experiment for each relationship. For each experiment, identify which variable(s) you will control and which variable(s) you will vary. For example, to find relationship between the resistance of a wire and its length, you should use wires of the same diameter made from the same material but in different lengths. Design the data table for each experiment and complete the experiments.

Step 3: Critical Analysis: Discuss the results of each experiment with your partner. For each experiment, describe how the resistance of a wire depends on the specific properties of the wire, and express this relationship mathematically. Explain how you arrived at the mathematical formula describing each relationship.

Guided Inquiry

Step 1: Hypothesize/Predict: Which material has higher resistivity? How does the resistance of a wire depend on the resistivity of the material from which it is made? What is the mathematical relationship between resistance and resistivity?

Step 2: Student-Led Planning: Discuss with your partner which variable(s) you will control and which variable(s) you will vary to test relationship between resistance and resistivity. For resistivity values, use the reference table provided by your teacher. How will you organize your data? Display your data in the best way to test your predictions. Carry out necessary measurements of controlled and varied variables.

Step 3: Critical Analysis: Were the predictions you made in Step 1 supported by your data? Discuss the results of the experiment with your partner, and then write your conclusions in your notebook. Using your data, develop a mathematical relationship between resistance and resistivity of a wire. What role does length and cross-sectional area of a wire play in this relationship? Use your findings from previous activities to develop a formula that can be used to calculate resistance of a wire based on resistivity of the material, length, and cross-sectional area of the wire. Confirm your formula for wires that you have available to you.

Assessments

1. Does the resistance of a copper wire increase or decrease when both the length and the diameter of the wire are doubled? Justify your answers.
2. Two wires have the same length and the same resistance; one is made from aluminum, and the other one is made from copper.
    a. Explain how that is possible.
    b. Provide calculations to support your explanation.
3. The resistance of a particular wire is 21 Ω. It is melted down, and a new wire is made from all of the melted material. The new wire is twice as long as the original wire. What is the resistance of the new wire?