Collaborative Learning

This investigation is Exploros-enabled for tablets. See page xiii for details.

B4 Ohm's Law

Key Question: *How are voltage, current, and resistance related?*

In this investigation, students build circuits and analyze them with a digital multimeter to see how changing resistance and voltage affects electric current. From their data analysis, students determine the mathematical relationship between voltage, current, and resistance in a circuit.

Learning Goals

✔ Describe how current changes when resistance is increased.

✔ Describe how current changes when voltage is increased.

✔ Describe how voltage, current, and resistance are related.

✔ Explain why resistors are used in a circuit.

GETTING STARTED

Time 100 minutes

Setup and Materials

1. Make copies of investigation sheets for students.
2. Watch the equipment video.
3. Review all safety procedures with students.

Materials for each group

- Electric Circuits kit
- 2 D-cell batteries*
- Digital multimeter with leads*

**provided by the teacher*

Online Resources

Available at curiosityplace.com

- Equipment Video: Electric Circuits
- Skill and Practice Sheets
- Whiteboard Resources
- Science Content Video: Resistance
- Student Reading: Resistance and Ohm's Law

Vocabulary

Ohm's law – a law stating that the current in a circuit is directly proportional to voltage and inversely proportional to resistance

potentiometer – a variable resistor that can be adjusted to provide resistance within a certain range

resistor – a component of an electrical circuit that resists the flow of electric current

NGSS Connection

This investigation builds conceptual understanding and skills for the following performance expectation.

HS-PS3-5. *Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.*

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models	PS3.C: Relationship Between Energy and Forces	Cause and Effect

BACKGROUND

The current in a circuit depends on the resistance of the circuit and the voltage of the batteries or other source that is providing energy. Voltage and current are directly proportional; increasing the voltage increases the current a proportional amount. Conversely, resistance and current are inversely proportional. The greater the circuit resistance, the smaller the current. These two relationships form **Ohm's law**. The law relates current, voltage, and resistance with one formula.

OHM'S LAW

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

Current (amps, A) — ***Voltage*** (volts, V) — ***Resistance*** (ohms, Ω)

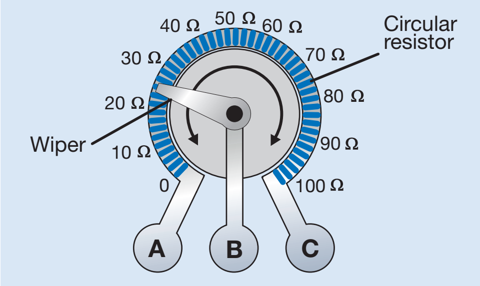
Devices in a circuit that require a large amount of current typically have lower resistances. For example, a small electric motor might have a resistance of only 1 ohm. When connected in a circuit with a 1.5-volt battery, the motor draws 1.5 amps of current. By comparison, a small light bulb with a resistance of 2.5 ohms in the same type of circuit would draw only 0.6 amps.

Resistors are electrical components that are designed to have a specific resistance that remains the same over a wide range of currents. Resistors are used to control the current in circuits. They are found in many common electronic devices such as computers, televisions, telephones, and stereos.

There are two main types of resistors: fixed and variable. **Fixed resistors** have a resistance that cannot be changed. Variable resistors, also called **potentiometers**, can be adjusted to have a resistance within a certain range. If you have ever turned a dimmer switch or volume control, you have used a potentiometer. When the resistance of a dimmer switch increases, the current decreases, and the bulb gets dimmer. Inside a potentiometer is a circular resistor and a little sliding contact called a wiper. If the circuit is connected at A and C, the resistance is always 100 Ω. But if the circuit is connected at A and B, the resistance can vary from 0 Ω to 100 Ω. Turning the dial changes the resistance between A and B and also changes the current in the circuit.

Potentiometer

The inside of a potentiometer



Circuit diagram

5E LESSON PLAN

Engage

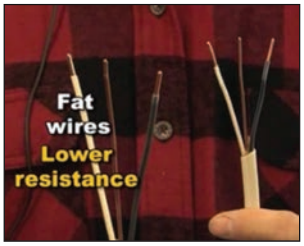
Explain the difference between a direct relationship and an inverse relationship. A direct relationship is one in which an increase in one quantity causes a proportional increase in another quantity. An inverse relationship is one in which an increase in one quantity results in a decrease in another. Ask students to come up with creative examples of each type of relationship. For example, a direct relationship exists between the number of hours worked at a fast food restaurant and the size of the person's paycheck. An inverse relationship exists between the number of hours of homework given and the amount of time a student has available to play video games.

Explore

Have students complete Investigation B4, *Ohm's Law*. In this investigation, students build circuits and analyze them with a digital multimeter to see how resistance and voltage affect the current. From their data analysis, students determine the mathematical relationship between voltage, current, and resistance in a circuit.

Explain

Revisit the Key Question to give students an opportunity to reflect on their learning experience and verbalize understandings about the science concepts explored in the investigation. Curiosityplace.com resources, including student readings, videos, animations, and whiteboard resources, as well as readings from your current science textbook, are other tools to facilitate student communication about new ideas.



Science Content Video
Resistance

Elaborate

Give students a blue (10-ohm) and a red (20-ohm) resistor. Tell them to design a procedure to figure out which is 10 ohms and which is 20 ohms by taking only voltage and current measurements. Then have them carry out their procedures. The easiest way to do this is to make a simple circuit with a battery and resistor. The current and voltage can be measured and used to calculate the resistance. As a challenge, ask students if they can figure out which resistor is which by taking only voltage measurements. This can be accomplished by making a series circuit containing both resistors. The one with the higher resistance will have the higher voltage.

Evaluate

- During the investigation, use the checkpoint ✓ questions as opportunities for ongoing assessment.
- After completing the investigation, have students answer the assessment questions on the *Evaluate* student sheet to check understanding of the concepts presented.

Explore — INVESTIGATION B4

Name ______________________ Date ______________

B4 Ohm's Law

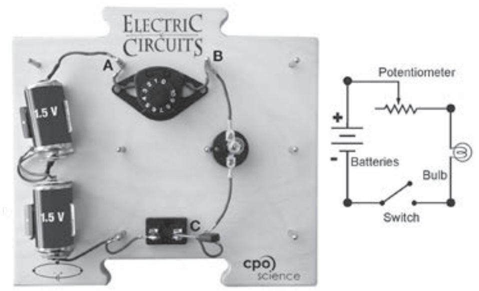
How are voltage, current, and resistance related?

Materials:
- ✔ Electric Circuits kit
- ✔ 2 D-cell batteries
- ✔ Digital multimeter with leads

When working with circuits, you may need to know how much voltage will light a particular light bulb, or how much current will be in a circuit so you can choose the correct size for a wire. German physicist Georg S. Ohm (1787–1854) experimented with circuits to find out how voltage, current, and resistance are related mathematically. The relationship he discovered is called **Ohm's law**.

❶ How does changing resistance affect current?

A **resistor** is used in a circuit to provide resistance to the flow of electric charge. In this part of the investigation you will use a variable resistor. As you turn the dial of the variable resistor, its resistance changes. A variable resistor is also called a **potentiometer**. Many dials you use every day, like dimmer switches, are potentiometers.



1. Build a circuit with two batteries, one bulb, the switch, and your potentiometer. Notice what happens when you turn the dial.
2. Turn the potentiometer until the bulb is very dim.
3. Measure current at the open switch and record in Table 1.

Explore — INVESTIGATION B4

4. Turn the circuit off and measure resistance across the potentiometer (being careful not to touch the dial). Record the value in Table 1.
5. Make the bulb a little bit brighter and repeat steps 4 and 5. Continue until you have completed Table 1 for five settings of the potentiometer.

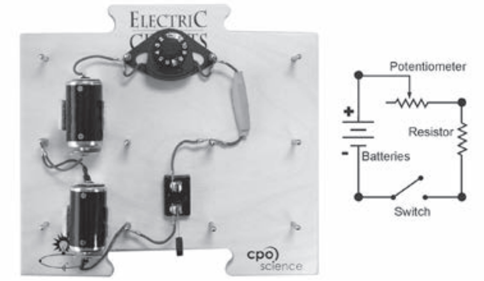
Table 1: Change in current vs. change in resistance for a potentiometer

Potentiometer setting (relative brightness of bulb)	Current (A)	Resistance (Ω)
Very dim bulb	.07	35.3
Dim bulb	.08	28.9
Medium bright bulb	.09	22.4
Bright bulb	.10	14.5
Very bright bulb	.14	0.10

Examine your data. Describe in words what happens to current as resistance is decreased.

The data show that as resistance decreases, the amount of current increases.

❷ How does changing voltage affect current?



In this part of the investigation, your teacher will give you a **fixed resistor**. This component adds an unchanging resistance to the circuit. Replace the light bulb in the circuit from Part 1 with the fixed resistor as shown above.

Guiding the INVESTIGATION

❶ How does changing resistance affect current?

When collecting data, students should not be concerned with the number on the potentiometer dial. They should simply turn the knob until the bulb is at the brightness level for which they are collecting data. The exact amount of light produced at each setting is not important; what one group calls "bright" will differ from that of another group. The aim is to collect data for a range of current values.

TEACHING TIP

Have each student write his or her own "cheat sheet" showing how to set up the meter to measure current, voltage, and resistance. Students should also include how to connect the meter leads to the circuit or device. For example, when measuring resistance, the device should not be part of a circuit. You might allow them to use the cheat sheet on a test or quiz, especially if there is a lab component to the evaluation.

Explore — INVESTIGATION B4

1. Use the digital meter to measure the resistance of your resistor. Record the value in the second column, all five rows, of Table 2.
2. Measure the current across the open switch, then the voltage across the fixed resistor. Record the values in the first row of Table 2.
3. Change the setting of the potentiometer and measure current and voltage again. Make sure that the new potentiometer setting results in a change in the value for current. If not, adjust it until the value for current is different.
4. Repeat for a total of at least five settings of the potentiometer. Record all values of current and voltage in the table.

Table 2: Change in voltage vs. change in current for a resistor

Potentiometer setting	Fixed resistor (Ω)	Current at open switch (A)	Voltage across fixed resistor (V)
First setting	5.0	.07	.353
Second setting	5.0	.08	.392
Third setting	5.0	.09	.443
Fourth setting	5.0	.11	.540
Fifth setting	5.0	.13	.640

Examine the data in your table. Describe in words what happens to the voltage across the resistor as the current increases.

As the current increases, the voltage across the resistor increases.

Explore — INVESTIGATION B4

❸ **Finding the relationship between voltage, current, and resistance**

a. Graph the data from Part 2. Put voltage across the fixed resistor on the *y*-axis and current at the open switch on the *x*-axis. Label your *x*- and *y*-axes and title your graph.

Title: ____________

y-label: ____________

x-label: ____________

See 3a sample graph.

✓ **b.** The slope of a line is rise over run. For the graph of voltage vs. current, slope is change in voltage (rise) over change in current (run). Calculate the slope of the graph. What other electrical quantity in the circuit does the slope approximately equal?

From the graph, the slope of the line is 0.10 volts/0.02 amps = 5.0.
This is the resistance value of the resistor I used.

c. Using your answer to question 3b, write the mathematical equation for Ohm's law (keep in mind that slope is equal to rise over run). Remember: V stands for voltage, I stands for current, and R stands for resistance.

$R = V/I$ is the equation for Ohm's law.

✓ **d.** Most circuits use fixed voltage sources. Different values of current are needed to run different devices and appliances. With this information, explain the importance of resistors in a circuit.

The resistors can be used to control and set the current in a circuit since the voltage cannot be changed.

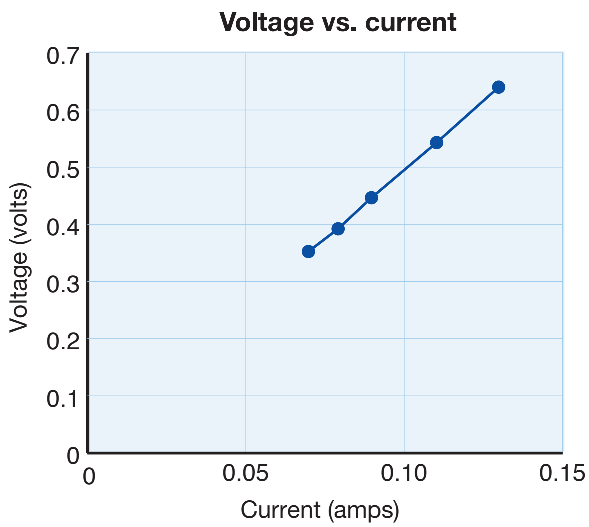
Guiding the INVESTIGATION

❷ How does changing voltage affect current?

The green 5-ohm resistor works well for this investigation. Students should not leave the circuit running for a long time with the potentiometer set to a low resistance. Doing so will cause the resistor to heat up.

Students can use a computer graphing program to make their graphs of voltage vs. current. The program can be used to generate a line of best fit and to display its equation in $y = mx + b$ form. The value of the slope in the equation should equal the resistance of the resistor. Inaccuracies are often due to the lack of precision in the ammeter. If your meters have a milliampere (mA) setting, you may wish to have students use this setting, then divide their values by 1,000 to record data in amperes.

3a sample graph

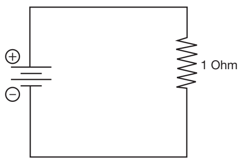


Evaluate

INVESTIGATION **B4**

Name ____________________ Date ____________

1. Explain what happens to the value of current in a circuit if the voltage is increased.
   As voltage increases, the value of current increases. This is a direct relationship.
2. Explain what happens to the value of current in a circuit if the resistance is increased.
   As resistance increases, current decreases. This is an inverse relationship.
3. A hair dryer draws a current of 10 amps. If it is plugged into a 120 volt circuit, what is the resistance of the hair dryer? Show your calculation.
   The resistance of the hair dryer is: $R = V/I$, R = 120 volts/10 amps, R = 12 ohms.
4. A flashlight bulb has a resistance of approximately 6 ohms. If it works in a flashlight containing two D-cells (you have been using D-cells throughout the investigations), how much current does the bulb draw? Show your calculation.
   The current drawn by the bulb is: $I = V/R$, I = 3.0 volts/6 ohms, I = 0.5 amps
5. Household circuits in the United States commonly run on 120 volts of electricity. A 15 amp circuit breaker is designed to break a circuit if it is drawing more than 15 amps of current. What is the minimum amount of resistance that must be present in the circuit to prevent the circuit breaker from activating?
   The minimum resistance that must be present in the circuit is: $R = V/I$, R = 120 volts/15 amps, R = 8 ohms.
6. Study the circuit shown at right. If the circuit uses two brand new D-cells, what will the value for the current in the circuit be? Show your work.
   The current in the circuit will be: $I = V/R$, I = 3.0 volts/1 ohm, I = 3.0 amps.



B4 Ohm's Law
Program Title

WRAPPING UP

Have your students reflect on what they learned from the investigation by answering the following questions:

1. Explain how current, voltage, and resistance are related.
2. The slope of a graph equals resistance if ________ is graphed on the *x*-axis, and ________ is graphed on the *y*-axis.
3. A circuit contains a 9-volt battery and a resistor. The current in the circuit is 0.5 A. What is the resistance of the resistor?

STEM CONNECTION

Photo courtesy of Queens Library

Lewis Latimer Lewis Latimer was born in Chelsea, Massachusetts, in 1848, six years after his parents escaped from slavery in Virginia. As a child, Lewis loved reading and drawing. When he was sixteen, Lewis joined the U.S. Navy, fighting for the Union in the Civil War. Afterward, he worked in a law office in Boston that specialized in assisting people who wanted to patent their inventions. There he taught himself how to use draftsman's tools to make scale drawings of machines.

Latimer met Alexander Graham Bell at that office. Working late, Latimer made blueprints and helped Bell file the papers for his telephone patent—just hours before a rival. A new job as a mechanical draftsman for the U.S. Electric Lighting company helped Latimer learn about incandescent bulbs. Four years later, Thomas Edison hired Latimer as an electrical engineer and patent advisor. Latimer was later invited to join the prestigious research team known as the Edison Pioneers. Latimer improved incandescent bulb design by replacing a paper filament with a carbon one. He also wrote the first engineer's handbook on electric lighting.

TEACHING TIP

Many new units and abbreviations are introduced when students start studying circuits. It is common for there to be confusion between the abbreviation for a quantity (such as I for current) and the abbreviation for the unit in which the quantity is measured (A for ampere). You will notice this when you see a current measurement written as 0.20 I. Provide plenty of opportunities for students to work with the abbreviations, both in writing and when discussing measurements out loud.