SECTION 4

Ohm's Law: Putting up a Resistance

Section Overview

Students investigate the relationship between current, voltage, and resistance by hooking up three different resistors in a circuit with a battery, voltmeter, and ammeter. Students' measurements and analysis explains the linear relationship between voltage and current as described by Ohm's law. Based on their results and data provided, students determine the resistance of an unknown resistor and are introduced to Ohm's law. They graph the relationship between voltage and current and apply Ohm's law to solve for variables involved in simple series circuits. Students also read about and discuss devices that do not obey Ohm's law.

Background Information

Ohm's law applies to conductors of electricity and the electric current that flows through them. If a material obeys Ohm's law, the current flowing through the material in which the electric current that flows through them is directly proportional to the voltage applied. The ratio of the voltage to the current is called the resistance of the material. When this ratio is constant over a large range of voltages, the material is categorized as an ohmic material. For an alternating current, impedance (a more general opposition to current flow) replaces the resistance in Ohm's law, and the mean square root values of the voltage and current are used. The impedance of AC circuits is not addressed in this text.

Electric current is caused by a push/pull on the charges in a conducting medium due to an electric field created by other nearby charges. As the charges in the conductor begin to move, they can only travel some average distance before they collide with an atom in the conductor. The average speed they acquire because of the external electric field they are in is called the drift velocity. The electrons generally move at a speed known as their Fermi Speed, which is of the order of a million meters per second. The drift velocity that is added to this speed is only of the order of millimeters per second; however, the electric signal is transmitted at the speed of light or 300-million meters per second. The electrons in a wire only achieve a net velocity of the drift velocity and thus travel only very slowly from one end of a wire to the next.

To understand Ohm's law on the microscopic scale one needs to understand the Fermi level. The Fermi level is the energy level that describes the top region of allowed electron energy levels for an atom at absolute zero temperature. This is the lowest possible energy that the electrons can have. The next available energy level allowed is of the order of electron volts away. (An electron-volt is the amount of energy gained by an electron when it passes through a potential difference of 1 V.) Ordinary electrical and thermal processes require small energies (fractions of an electron-volt), so at absolute zero the majority of electrons cannot receive the energy from electrical and thermal processes because the energies do not coincide with the electrons' allowed transitions. At higher temperatures, the number of electrons existing above the Fermi level increases, and these electrons are available to conduct electricity. The Fermi level is so important because it determines the number of free electrons that are available to conduct electricity.

Detailed examples of calculating the resistance and electrical conductivity for different metals, and further discussion are available online. More information can be obtained by doing an Internet search on the key word: Ohm's law.

Crucial Physics

- Voltmeters are used to measure the voltage drop across a branch or load in a circuit. The voltmeter must be hooked up parallel to the branch or load being measured.
- Ammeters are used to measure the current along a path in a circuit. Ammeters must be hooked up in series to the path being measured.
- Many materials are ohmic, meaning their resistance is directly proportional to the voltage dropped across them and inversely proportional to the current through them. These types of materials follow Ohm's law, which states: $V = IR$. As the voltage increases at a fixed rate, the current increases at the same rate.
- The resistance of a circuit element is defined as the ratio of the voltage across that element divided by the current that is flowing through the element.

Learning Outcomes	Location in the Section	Evidence of Understanding
Calculate the resistance of an unknown resistor given the voltage drop and current.	***Investigate*** Steps 5 and 6.a) ***Physics to Go*** Questions 1 and 2	Students make a series of current and voltage drop measurements for various resistors of various strengths to find the relationship among current, voltage and resistance. They use their measurements to develop Ohm's law. Students apply Ohm's law and current and voltage measurements to solve for an unknown resistor in a circuit.
Construct a series circuit.	***Investigate*** Steps 3-4	Students construct series circuits to find the relationship between voltage, current, and resistance.
Use a voltmeter and ammeter in a series circuit accurately.	***Investigate*** Steps 3-4	Students use a voltmeter in a circuit to measure the voltage drop across resistors of different resistances. Students use an ammeter in a circuit to measure the current flowing through these resistors with the known voltages applied.
Express the relationship between voltage and current for a resistor that obeys Ohm's law in a graph.	***Investigate*** Steps 3-4 ***Physics to Go*** Question 5	Students' experiment plans should include graphing their current and voltage data. Students plot the current and voltage from data provided, draw a best fit line for the data, and find that the slope of the line represents the resistance of the circuit.

Section 4 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Leads, alligator clip (singles)	5 per group	
Battery holder, D-cell, stackable	5 per group	
Resistor, ohm, 5W-10W	1 per group	
Resistor, ohm, 10W-10W	1 per group	
Resistor, ohm, 15W-10W	1 per group	
V/I meter	2 per group	
Battery, D-cell, alkaline	5 per group	
Paper, graph, pkg. of 50		1 per class
Power supply (can be used in place of batteries and holders)*	1 per group	

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes for the students to complete the *Investigate* of this section.

Teacher Preparation

- Have students observe and practice connecting voltmeters and ammeter to ensure proper connections during the *Investigate*. Incorrect connections can damage ammeters in particular.
- Test all equipment (voltmeters, ammeters, power sources, resistors) to make sure they are working properly and have the correct range or values.
- If batteries are used as a power source, explain that batteries must be connected in series to increase the voltage. Demonstrate how to make these connections to the students.

Safety Requirements

- Check each group's circuit prior to the students connecting the power source to the external circuit to ensure the correct connections have been made.
- If batteries are used as a power source, make certain the batteries are clean and not leaking any liquid or powder. Alkaline batteries contain potassium hydroxide that can cause burns.
- Caution the students that the resistors may get hot when connected to the power. Students should disconnect the power source immediately upon completing their readings, and before replacing resistors.
- If the resistors are connected to electricity for more than a few seconds while taking readings, the students should allow the resistors to cool down after the circuit is disconnected before changing resistors.
- Although the voltages used are low, the students should always turn off the circuit before changing any connections.
- Safety goggles are recommended.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Leads, alligator clip (singles)		5 per class
Battery holder, D-cell, stackable		5 per class
Resistor, ohm, 5W-10W		1 per class
Resistor, ohm, 10W-10W		1 per class
Resistor, ohm, 15W-10W		1 per class
V/I meter		2 per class
Battery, D-cell, alkaline		5 per class
Paper, graph, pkg. of 50		1 per class
Power supply (can be used in place of batteries and holders)*		1 per class

*Additional items needed not supplied

Time Requirements

- Allow one class period or 45 minutes to complete the *Investigate* for this section as a teacher-led activity, and to complete the other material in the *Pacing Guide*.

Teacher Preparation

- Have the circuit equipment available for quick setup in a location easily visible for all students.
- If large demonstration meters are available, use these in place of student meters to enhance visibility.
- Test all equipment (voltmeters, ammeters, power sources, resistors) to make sure they are working properly and have the correct range or values.
- Make a Blackline Master of the circuit diagram in the *Investigate* of the *Student Edition* to help the students understand the circuit connections being made. Make a Blackline Master of the data table to record the voltage and current data for the resistors used to be copied into the student's notebooks.

Safety Requirements

- Note the safety requirements for the students in Part A, and repeat these requirements to the students to emphasize the safety aspects of working with electric circuits.
- No circuit should be worked on while energized.

NOTES

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Planning an experiment	***Investigate*** Step 2.a)	**Augmentation** • Students who struggle with organization or who do not feel confident about their prior knowledge may struggle to plan their own experiment. • Provide students with guided opportunities to practice using the ammeters and voltmeters before they begin the lab. Many students have difficulty reading the scales on these pieces of equipment. • Provide a list of pre-lab questions for students to consider before they begin to make a plan. How can the voltage be changed? How will the change be measured? How can the current be changed? How will the change in current be measured? • Instruct students to write their plan as a list of directions to complete. Then when the plan is presented to the teacher, it will be easier to modify steps if necessary. **Accommodation** • Provide a checklist of steps for students to complete the experiment.
Making a data table	***Investigate*** Step 2.b)	**Augmentation** • Use the pre-lab questions to help students decide what information should be recorded in a data table. • Check the data table that students create before they begin to make sure that they have selected useful data to measure and record. **Accommodation** • Provide a blank data table for students to record their measurements.
Applying mathematical relationships conceptually	***Physics Essential Questions***	**Augmentation** • Students may be able to use the formula to solve problems but struggle to conceptually understand Ohm's law. Explicitly ask students to explain the relationship between current and voltage. Ask them to visually represent the relationship with a picture, symbols, or words.
Solving word problems	***Physics to Go*** Questions 2-4, 6, 8, and 9	**Augmentation** • Extracting information is the challenging part of solving word problems. Most students can do the computation once the needed values have been identified. • Remind students to use their electricity variable and units chart that they created in *Section 2* to help them to identify "wants and givens." Then ask students to use the problem-solving box introduced in *Driving the Roads* or another problem-solving graphic organizer to organize the information needed to solve the problem. **Accommodation** • Provide a sheet of blank problem-solving boxes. • Highlight the "want" with one color and the "givens" with another color to help students identify the key information and diminish this accommodation as students gain mastery.

Learning Issue	Reference	Augmentation and Accommodations
Constructing a graph	**Physics to Go** Question 5	**Augmentation** • Students who struggle with number concepts and graphomotor skills have a difficult time creating graphs. • Model how to set up an appropriate axis scale based on the data provided. Remind students to use an evenly spaced scale that has a pattern. Refer to the scale on thermometers or meter sticks if students are stuck. • Model how to plot one point. Ask students to tell the teacher how to plot the second point, and then let them plot the other points independently. • Ask students what best-fit line means. Provide a few sample graphs with plotted points and ask students to draw a best-fit line for each graph. • Review the mathematical formula for slope and provide further instruction if students are confused. **Accommodation** • Provide a blank graph with the axes and scales already labeled. Then ask students to plot their data points. Using a note card or ruler will help students track the locations of the data points.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Making inferences Vocabulary	***Investigate*** Step 1	Have ELL students infer the meanings of "voltmeter" and "ammeter." As students read the instructions for setting up the circuit, you may need to help them with some terms, including "positive terminal" and "leads."
Comprehension	***Investigate*** Step 2.b)	Examine students' tables to make sure they have figured out that they will be using different voltages to find the current in a circuit with a resistor of a known size. Their tables must show both the voltage they start with and the current they measure.
Vocabulary comprehension	***Active Physics Plus***	Presenting and interpreting data in graph form are important science skills. Some students may be learning the vocabulary of graphing, which can distract from learning about the physics content. It may help to review with the whole class terms such as "axis," "vertical axis," "horizontal axis," and "slope." Reinforce vocabulary by referring to more familiar terms, such as Earth's axis or the horizon. Tell students that "slope" tells you the steepness of the line formed by connecting data points on a graph. To show "steepness," demonstrate "steep," "steeper," and "steepest" with your hand or with lines drawn on the board.
Understanding concepts	***Physics Talk***	Review "dimensional analysis" from *Safety*, *Section 3*: "Dimensional analysis is a big term for a simple concept: comparing a measure in one unit to a measure in another unit." Explain that dimensional analysis is also used to show that two units are equivalent (in this case, amperes and volts/ohm).
Vocabulary comprehension Making inferences	***Physics to Go*** Step 6.c)	Encourage students to infer the meaning of "circuit breaker" and then look up the term in the dictionary to check their inference. You may need to offer further explanation.
Comprehension	***Inquiring Further***	ELL students may have trouble with the play on words presented here. Perhaps there is no playing with words that sound alike in their native language. Many proverbs and other English sayings will be unfamiliar. Therefore, pairing ELL students with native speakers may be beneficial.

SECTION 4

Teaching Suggestions and Sample Answers

What Do You See?

The image of the box placed in front of a curious audience is meant to prompt students to comment on its significance. Have students reflect on the images in relation to the title of the section. Ask students what they think the Ohm Show's table of values represents. Emphasize how the artist is trying to reveal the purpose of this illustration through a play on numbers and words. Use an overhead of the illustration and record students' initial ideas to provide a focus for the science content. Engaging students in a discussion of this visual will help you understand what misconceptions they might have. As a result, you will be able to guide them toward a better grasp of the physics of electricity at various stages of their investigations and analysis.

What Do You Think?

Ask students to think of the new physics terms they have learned in the previous sections of this chapter. Suggest that making a small map of ideas will assist them in making connections between related concepts. The *What Do You Think?* section provides students the opportunity to recall prior knowledge and form new ideas. As they progress further in the chapter, students test their prior conceptions against an evolving set of scientific data that helps them form logical conclusions. At this stage of inquiry, ask students not to worry about the correctness of their response. Reiterate that you expect them to record all responses, so that they can revisit them at a later point.

What Do You Think?

A Physicist's Response

The brightness of a bulb is determined by two things—how much electrical energy the bulb can withstand before breaking, and how fast the energy can be delivered to the bulb, or the power. The power can be determined mathematically by multiplying the current flowing through the bulb with the voltage drop across the bulb ($P = IV$).

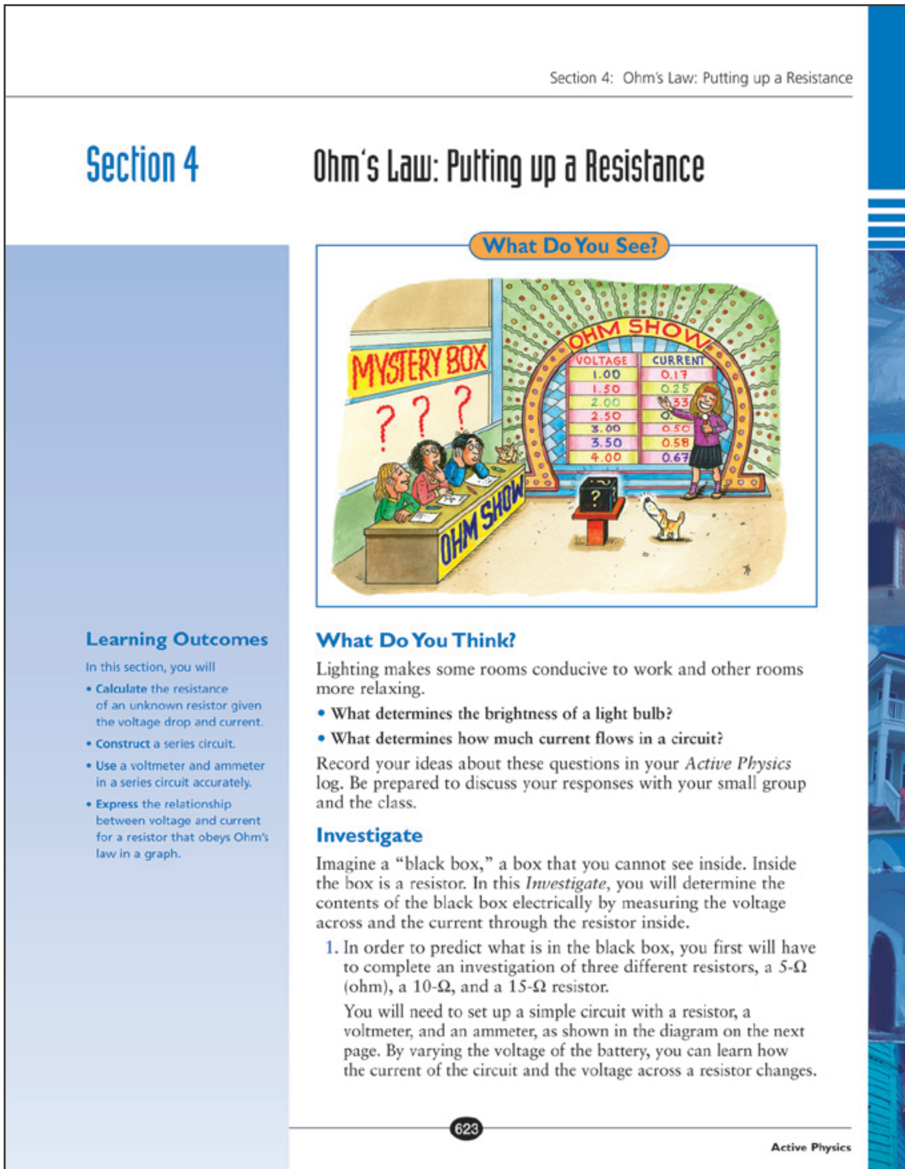
The brightness of the bulb increases with increasing power. One can increase the power by increasing the current flowing through the bulb and/or increasing the voltage drop across the bulb.

One way to increase the voltage is to put batteries in series in a circuit. To increase the current the amount of charge has to increase or the charge has to move faster. The charge can move more quickly through a circuit if the resistance is decreased. The amount of current that flows through a circuit is determined by the resistance in the circuit.

Students' Prior Conceptions

Ohm's law details the relationship between voltage, current, and resistance. Typically, students try to memorize the equation and then to "plug and chug" the numbers into it in order to derive an answer. A suggested strategy is to emphasize constraint-based reasoning.

1. Even after working through the first three sections, students may continue to profess that current can be manipulated directly within the circuit; that is, the current may be changed and thus affect the voltage or the resistance. Students tend to understand the mathematical model of voltage, current, and resistance, expressed through Ohm's law, as a causal relationship between resistance and voltage. Emphasize the constraints of voltage, resistance, and current while doing calculations. State Ohm's law as $I = V/R$, rather than the more usual $V = IR$ to point out that the current flow is the dependent variable and is determined by the voltage and resistance, rather than the other way around. At the same time, students should understand how the variables of voltage, resistance, and current relate to each other. Students need to revisit their conceptual models and to understand that the amount of current in a circuit is determined by the amount of voltage applied to the circuit and resistance in the circuit.



Section 4 Ohm's Law: Putting up a Resistance

What Do You See?

Learning Outcomes

In this section, you will

- **Calculate** the resistance of an unknown resistor given the voltage drop and current.
- **Construct** a series circuit.
- **Use** a voltmeter and ammeter in a series circuit accurately.
- **Express** the relationship between voltage and current for a resistor that obeys Ohm's law in a graph.

What Do You Think?

Lighting makes some rooms conducive to work and other rooms more relaxing.

- **What determines the brightness of a light bulb?**
- **What determines how much current flows in a circuit?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.

Investigate

Imagine a "black box," a box that you cannot see inside. Inside the box is a resistor. In this *Investigate*, you will determine the contents of the black box electrically by measuring the voltage across and the current through the resistor inside.

1. In order to predict what is in the black box, you first will have to complete an investigation of three different resistors, a 5-Ω (ohm), a 10-Ω, and a 15-Ω resistor.

   You will need to set up a simple circuit with a resistor, a voltmeter, and an ammeter, as shown in the diagram on the next page. By varying the voltage of the battery, you can learn how the current of the circuit and the voltage across a resistor changes.

Investigate

Teaching Tip

Analog meters (those with a scale and a pointer) are often delicate, and may be subject to being damaged by students who misconnect wires. Analog meters once damaged in this manner are difficult to repair. Digital meters are generally more reliable and less likely to be damaged. Many have fuses that will blow to protect the meter if misconnected and are simple to replace.

With all meters with multiple scales, time should be spent acquainting the students with how to read and record the correct voltage and current values from the meter readings.

Consider constructing one (or several) "black boxes" for the students to make measurements on (*Step 6*). Different value resistors in the boxes for different groups make for a more interesting problem.

1.

Have the students practice connecting the circuits as shown in the diagrams, but without connecting the power source (battery or power supply) until the circuit has been checked. Although this is time consuming, it will prevent the equipment from being damaged. If the meters that are being used by the students have multiple scales, make certain that the meters are all set on the highest setting when connecting the battery. Meters set at a reading level that is too low may be damaged when the circuit is connected. After the battery is connected, have the students decrease the setting level until they have a reading in the middle of the scale of the meter.

6-4a Blackline Master

6-4b Blackline Master

2.

Explain that the “ohm” is the unit for electrical resistance, which is a measure of how much an object resists electric current. Consider comparing the electric current to the flow in a water pipe, and the resistance to changing the rate of flow. If this comparison is used, point out that in an electric circuit the electrons start to flow at every point in the circuit when the power source is connected and the circuit is closed. It is similar to a situation of the water pipes being filled with water before the water was turned on.

2.a)

Students should plan to see how the current through the resistor varies when the applied voltage is increased in successive steps. Successful plans include a proposed graph of current vs. voltage for the resistor.

2.b)

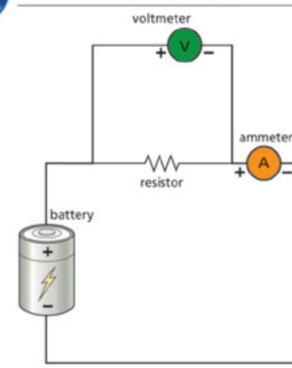
Data tables should be similar to the one shown in *Step 5*.

3.

Ask questions to so that students can refine their plan rewrite it to meet the criteria of a successful investigation. Review students’ plans before allowing them to begin the experiment.

3.a)

Students should place their data in a table similar to the one shown in *Step 5*.



Before beginning your study, please note the following circuit rules:

- The ammeter is always placed in series in the circuit.
- The positive terminal of the ammeter is always closest to the positive terminal of the battery.
- The voltmeter is always placed in parallel in the circuit. The simplest way to measure the voltage drop across the resistor is to take the two leads from the voltmeter and touch the two ends of the resistor simultaneously.
- The positive terminal of the voltmeter is always closest to the positive terminal of the battery.
- Keep the connection in the circuit on for as long as it takes to read the ammeter and voltmeter, and no longer.
- You can vary the voltage with a variable voltage supply or by adding additional batteries into the circuit.

2. Begin with the 5-Ω resistor. Plan your experiment to find out how the voltage and current vary for a 5-Ω resistor.

a) Record your plan.

b) Make a table that will summarize the data you intend to collect.

3. After your teacher has approved your plan, conduct your experiment.

a) Record your data for the voltage and current of the 5-Ω resistor.

4. Repeat your investigation for the 10-Ω and 15-Ω resistors.

a) Record your data for the 10-Ω resistor.

b) Record your data for the 15-Ω resistor.

c) Given a voltage and current, how would you determine if the circuit had a 5-Ω, 10-Ω, or 15-Ω resistor?

5. A black box for a resistor yielded the following data:

Voltage (volts)	Current (amps)
1.00	0.17
1.50	0.25
2.00	0.33
2.50	0.42
3.00	0.50
3.50	0.58
4.00	0.67

a) Did the student’s circuit have a 5-Ω, 10-Ω, 15-Ω, or some other resistor?

6. Your teacher will supply you with a resistor inside a black box.

a) Record data to determine which resistor is inside the black box. Explain how you know.

b) How confident are you about the contents of the black box? (1 = I have no idea; 10 = I am completely sure; nothing else is possible.)

4.a) and b)

Students repeat the investigation steps for a 10-Ω and a 15-Ω resistor. If resistors with these values are not available, other resistors with similar values may be used. The choice of resistors will depend upon the meters available.

4.c)

Students should graph and analyze their data and determine a reasonable relationship between voltage and current for their data. With only three data points, uncertainty of measurements, and experimental error, students may not feel confident enough to come up with the relationship $R = V/I$, however their data should indicate a linear relationship.

5.

Students may realize the relation of Ohm’s law: $V = IR$ by this point, and substitute into the equation to obtain the answer.

Physics Talk

OHM'S LAW RELATES RESISTANCE TO VOLTAGE AND CURRENT

Scientists study "black boxes" all the time. A black box is an object or a phenomenon that you cannot see directly. Scientists will often define something to be a black box and describe it in terms of how it interacts with the world around it. In this section, you investigated a black box electrically to discover the resistor that was inside.

You first measured the voltage and current of three known resistors. The measurements of voltage and current showed that increasing the voltage increased the current in the circuit. This was true for all three resistors.

The ratio of the voltage to current was constant for any single resistor. For example, data of the voltage and current for the 3-Ω may have looked like the first two columns of the chart. The third column is the ratio of voltage to current.

Voltage (V)	Current (A)	Voltage / Current $\frac{V}{I}$
1.00	0.33	3
1.50	0.50	3
2.00	0.67	3
2.50	0.83	3
3.00	1.00	3
3.50	1.17	3
4.00	1.33	3

Georg Simon Ohm, a German physicist.

The ratio of the voltage to current is equal to the **electrical resistance**. This relationship is referred to as **Ohm's law**. Many resistors obey Ohm's law, which states that as the voltage increases at a fixed rate, the current increases at the same rate. This is expressed mathematically:

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

where R is the resistance in ohms (Ω),
V is the voltage in volts (V), and
I is the current in amperes (A).

Physics Words

electrical resistance: the ratio of the voltage across a conductor divided by the current.

Ohm's law: voltage increases at a fixed rate as the current increases at the same rate.

Alternatively, they may choose to graph the data and get the slope to obtain the value of the resistance. Graphing the data should further support the linear relationship between voltage and current for ohmic materials. The resistance of the resistor described in the table is 6 Ω.

6.a)

Students should use their voltage and current measurements to determine the resistance inside the black box as they did in *Step 5*. The calculated value they determine for the resistance should match the resistance inside the box. Acceptable answers for how they know which resistor is inside the black box should be supported by their data and analysis in previous steps. If students are aware of Ohm's law their explanation should relate back to it.

6.b)

Responses will vary.

Physics Talk

Students are introduced to Ohm's law relating voltage to current and resistance. They also learn that many resistors follow Ohm's law, but not all. To understand Ohm's law, sample problems are provided with a dimensional analysis.

Ask students what a black box is and discuss it. Describe how scientists are always investigating black boxes or objects that cannot be seen directly. Ask students to describe how they investigated the black box they studied in the *Investigate*. Discuss their results and Ohm's law, which describes the linear relationship between the voltage and current.

Emphasize to students that not all resistors have a constant resistance with voltage, but many do over a wide range of voltages. The materials that obey Ohm's law are called Ohmic materials. Discuss the sample problems with the class, pointing out the linear relationship between voltage and current, and the units involved. Have a discussion on dimensional analysis involved with Ohm's law, using the information in the student text.

Checking Up

1.

Resistance is the name for the ratio of applied voltage and current.

2.

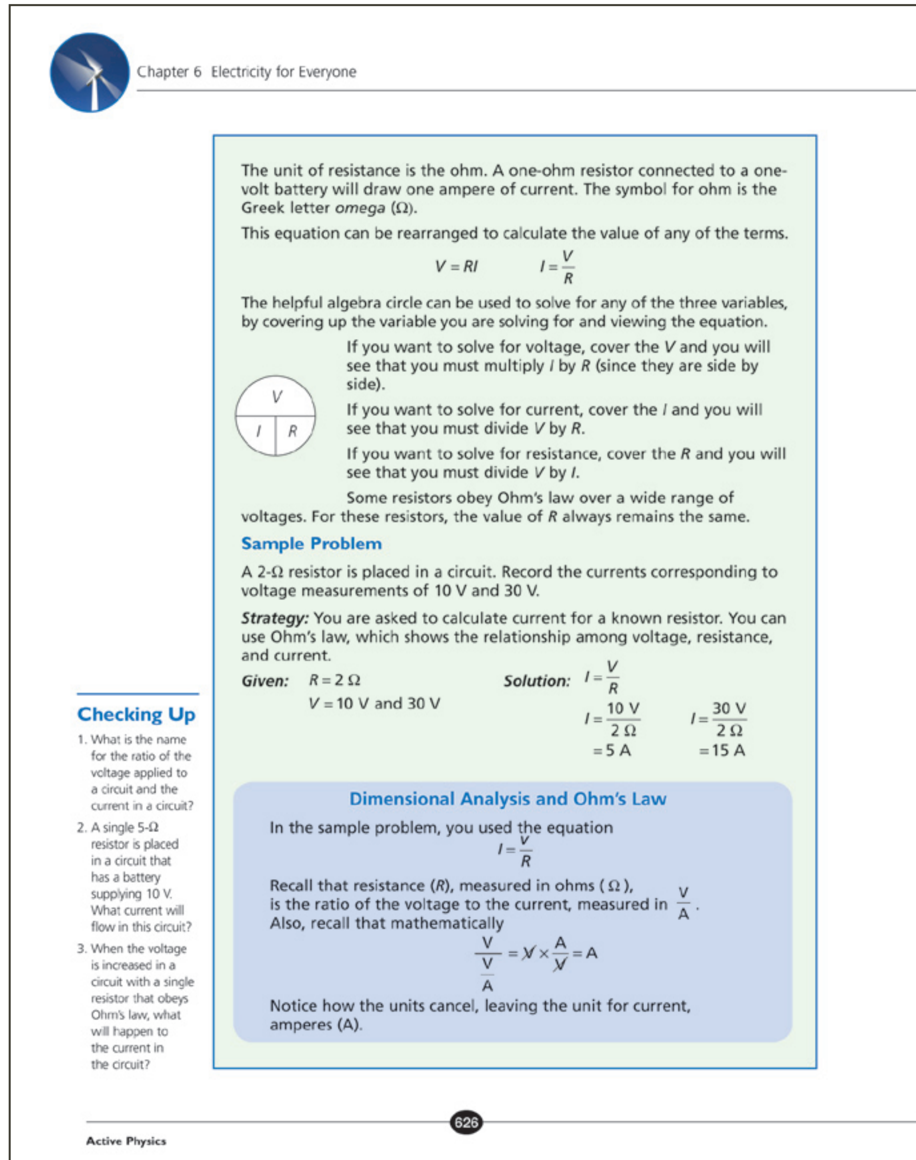
Students should apply Ohm's law to solve for current.

$$V = IR$$

$$I = \frac{V}{R} = \frac{10\ \text{V}}{5\ \Omega} = 2\ \text{A}$$

3.

If the voltage is increased in a circuit with a resistor that obeys Ohm's law, the current will increase. The graphs constructed in the *Investigate* illustrate this relationship.



The unit of resistance is the ohm. A one-ohm resistor connected to a one-volt battery will draw one ampere of current. The symbol for ohm is the Greek letter *omega* (Ω).

This equation can be rearranged to calculate the value of any of the terms.

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

The helpful algebra circle can be used to solve for any of the three variables, by covering up the variable you are solving for and viewing the equation.

If you want to solve for voltage, cover the *V* and you will see that you must multiply *I* by *R* (since they are side by side).

If you want to solve for current, cover the *I* and you will see that you must divide *V* by *R*.

If you want to solve for resistance, cover the *R* and you will see that you must divide *V* by *I*.

Some resistors obey Ohm's law over a wide range of voltages. For these resistors, the value of *R* always remains the same.

Sample Problem

A 2-Ω resistor is placed in a circuit. Record the currents corresponding to voltage measurements of 10 V and 30 V.

Strategy: You are asked to calculate current for a known resistor. You can use Ohm's law, which shows the relationship among voltage, resistance, and current.

Given: $R = 2\ \Omega$, $V = 10$ V and 30 V

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

$$I = \frac{10\ \text{V}}{2\ \Omega} = 5\ \text{A} \qquad I = \frac{30\ \text{V}}{2\ \Omega} = 15\ \text{A}$$

Dimensional Analysis and Ohm's Law

In the sample problem, you used the equation

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

Recall that resistance (*R*), measured in ohms (Ω), is the ratio of the voltage to the current, measured in $\frac{\text{V}}{\text{A}}$. Also, recall that mathematically

$$\frac{\text{V}}{\frac{\text{V}}{\text{A}}} = \cancel{\text{V}} \times \frac{\text{A}}{\cancel{\text{V}}} = \text{A}$$

Notice how the units cancel, leaving the unit for current, amperes (A).

Checking Up

1. What is the name for the ratio of the voltage applied to a circuit and the current in a circuit?
2. A single 5-Ω resistor is placed in a circuit that has a battery supplying 10 V. What current will flow in this circuit?
3. When the voltage is increased in a circuit with a single resistor that obeys Ohm's law, what will happen to the current in the circuit?

Section 4 Ohm's Law: Putting up a Resistance

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
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Graphing Ohm's Law

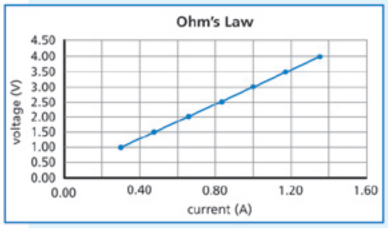
Ohm's law expresses the relationship between the voltage and current

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

For most resistors, the ratio of the voltage and current is a constant.

Recording the varying voltage and the corresponding current would allow you to make a graph. If the resistor obeys Ohm's law, the ratio of the voltage and current remains the same and the graph would be a straight line. If the current is on the *x*-axis and the voltage on the *y*-axis, the slope of the line is equal to *R*.

For the data given in the *Physics Talk* for a 3-Ω resistor, the graph would look like the one shown.



1. Calculate the slope of the line and determine if, in fact, it is equal to 3 Ω.

   It makes sense to calculate the slope. The equation for a straight line is $y = mx + b$, where m is the slope of the line, and b is the *y*-intercept. The *y*-axis has the value of voltage (V) and the *x*-axis has the values of current (I). The *y*-intercept is zero. Lining up the equations for a straight line and Ohm's law, you can see that the slope m is equal to the resistance (R).

   $$y = m x + b$$
   $$V = R I$$

   Recognize that this graph is a bit unusual. Usually, the independent variable (the one you vary) goes on the *x*-axis and the dependent variable goes on the *y*-axis. If your data were plotted like that, the slope of the line would be equal to $^{I}/_{V}$ which is equal to $^{1}/_{R}$.

2. Plot the data as current versus voltage. Calculate the slope and determine if, in fact, it is equal to 1/(3-Ω).

3. Using either the *V-I* format or the *I-V* format, graph the data from the three resistors, 3 Ω, 10 Ω, and 15 Ω on a single graph.

What Do You Think Now?

Lighting makes some rooms conducive to work and other rooms more relaxing.

- What determines the brightness of a light bulb?
- What determines how much current flows in a circuit?

How would you answer these questions now? What else would you think you need to know to answer the questions more completely?

Active Physics Plus

Students further explore Ohm's law and deepen their understanding by solving problems and studying the linear relationship between voltage and current on a graph.

1.

Discuss the linear relationship between current and resistance for Ohmic materials and what this means mathematically. Students should calculate the slope of the line using two points on the line and determine that it is equal to 3 Ω.

2.

Students should graph current vs. voltage and determine that the slope is $1/3\ \Omega$. Discuss why one would graph current vs. voltage rather than voltage vs. current.

3.

Have students graph current vs. voltage or voltage vs. current for a 3-Ω, 10-Ω, and 15-Ω resistor. Discuss with students how to interpret the graph. For students who graph voltage vs. current, they should see an increasing or steeper slope as the resistance increases (slope = $R = V/I$). For students who graphed current vs. voltage, they should observe a decreasing slope or a slope that is less steep for increasing resistance (slope = $1/R = I/V$).

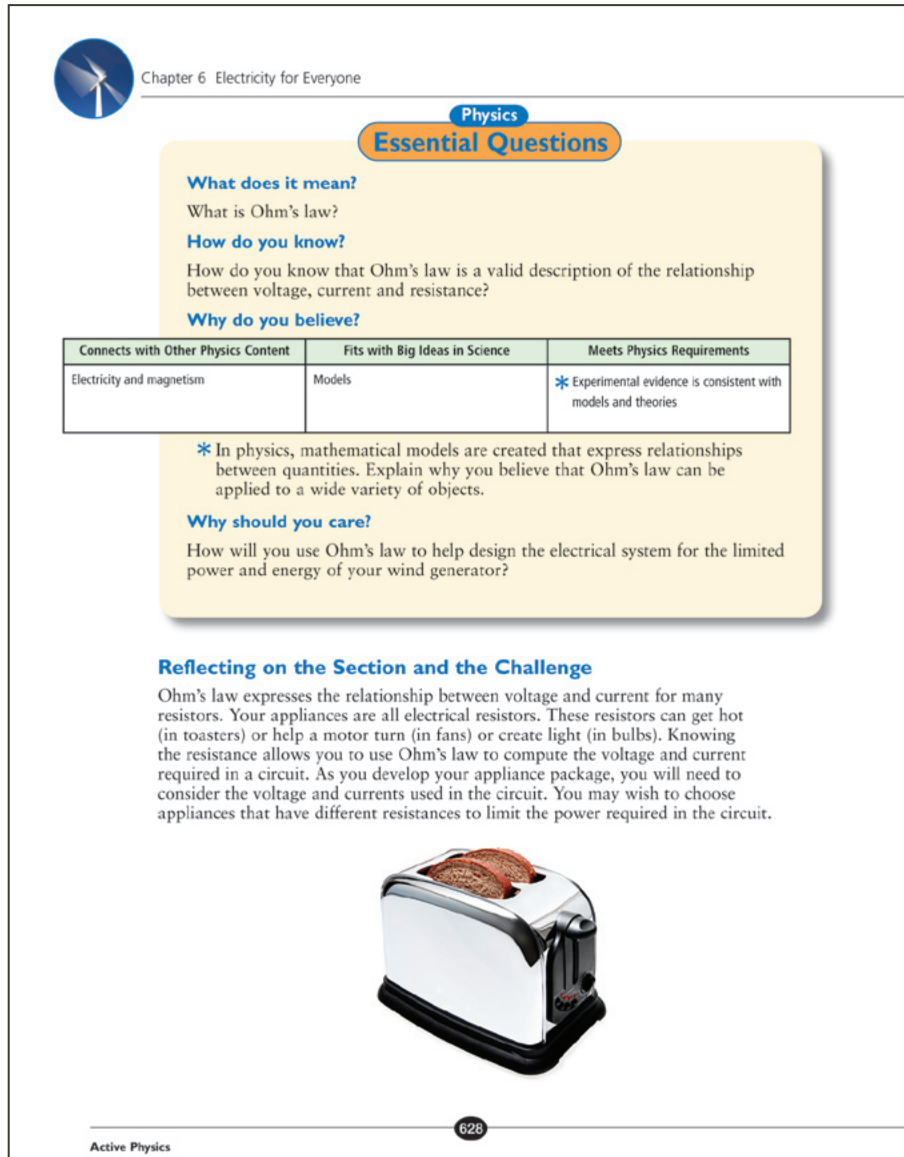
What Do You Think Now?

Revisit the *What Do You Think?* questions, and review students' initial ideas. Based on their observations and what they now know about Ohm's law, ask students how they would answer these questions. Discussing *A Physicist's Response* will give them a better understanding of Ohm's law and resistance. Students should be able to relate the brightness of a bulb to the amount of current flowing through it, and the voltage it receives. Encourage students to share their answers with each other and ask questions when they are not sure about a concept. This is also a good time for students to return to the illustration and see how their perception of the visuals has evolved.

CHAPTER 6

Reflecting on the Section and the Challenge

Have students reflect on the importance of Ohm's law. Reiterate that all appliances people use at home are electrical resistors. Ask students how knowing the resistance will help them develop an appliance package for their *Chapter Challenge*. Discuss how using Ohm's law can help students figure out which appliances to select in order to regulate the power used. Students should consider the different resistances they intend to use because they will have to limit the amount of power required for the circuit. This is the time for students to reflect on their investigations and highlights of the *Physics Talk*.



Physics
Essential Questions

What does it mean?

What is Ohm's law?

How do you know?

How do you know that Ohm's law is a valid description of the relationship between voltage, current and resistance?

Why do you believe?

Connects with Other Physics Content	Fits with Big Ideas in Science	Meets Physics Requirements
Electricity and magnetism	Models	* Experimental evidence is consistent with models and theories

* In physics, mathematical models are created that express relationships between quantities. Explain why you believe that Ohm's law can be applied to a wide variety of objects.

Why should you care?

How will you use Ohm's law to help design the electrical system for the limited power and energy of your wind generator?

Reflecting on the Section and the Challenge

Ohm's law expresses the relationship between voltage and current for many resistors. Your appliances are all electrical resistors. These resistors can get hot (in toasters) or help a motor turn (in fans) or create light (in bulbs). Knowing the resistance allows you to use Ohm's law to compute the voltage and current required in a circuit. As you develop your appliance package, you will need to consider the voltage and currents used in the circuit. You may wish to choose appliances that have different resistances to limit the power required in the circuit.

Physics Essential Questions

What does it mean?

Ohm's law is the relationship between the current and voltage in a resistor. Ohm's law states that the ratio of voltage to current is a constant called the resistance, $R = V/I$.

How do you know?

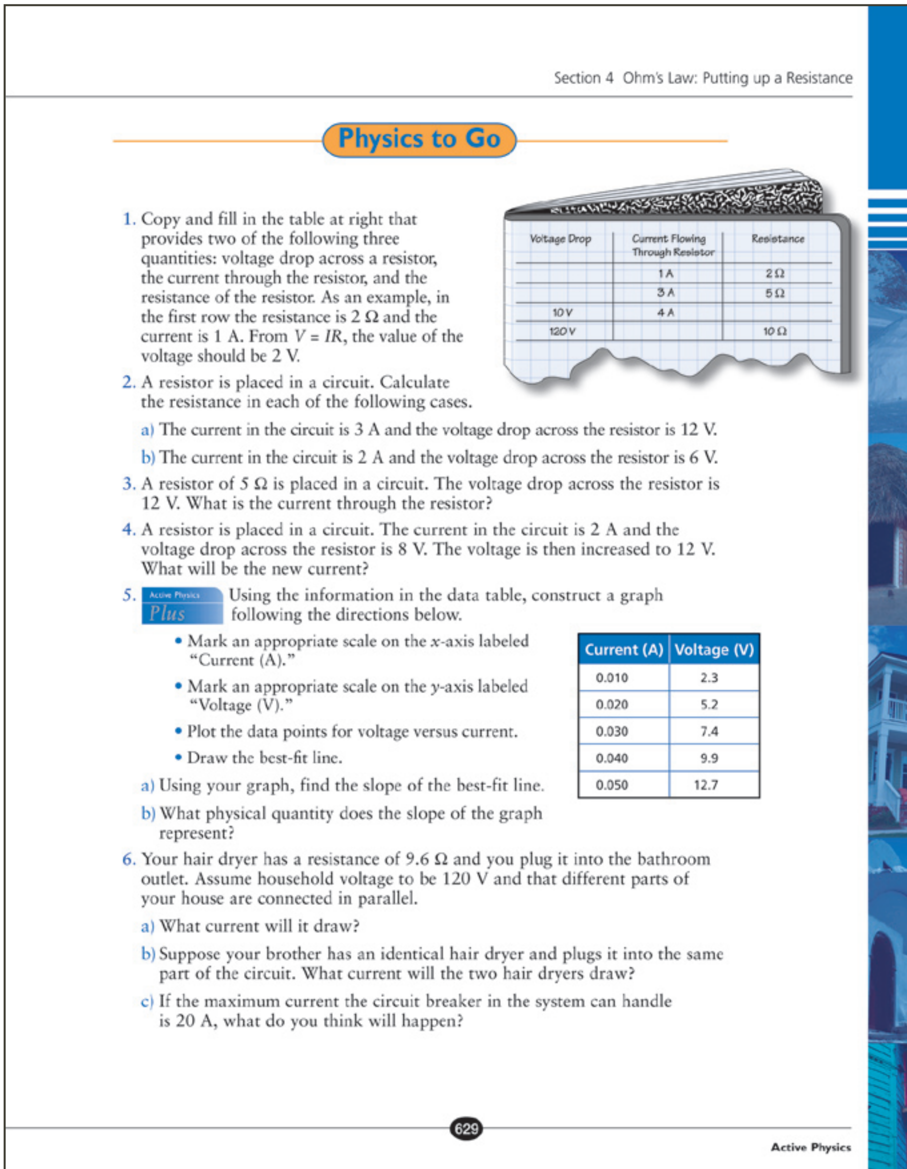
Data collected by varying the voltage and current for multiple resistors all exhibited Ohm's law.

Why do you believe?

Ohm's law was experimentally verified for the resistor used in this section. It should also be tested for other materials.

Why should you care?

The equation for power ($P = VI$) can be combined with Ohm's law ($V = IR$) in order to find the power and energy, if the resistance is known.


Section 4 Ohm's Law: Putting up a Resistance

Physics to Go

1. Copy and fill in the table at right that provides two of the following three quantities: voltage drop across a resistor, the current through the resistor, and the resistance of the resistor. As an example, in the first row the resistance is 2 Ω and the current is 1 A. From $V = IR$, the value of the voltage should be 2 V.

Voltage Drop	Current Flowing Through Resistor	Resistance
	1 A	2 Ω
	3 A	5 Ω
10 V	4 A	
120 V		10 Ω

2. A resistor is placed in a circuit. Calculate the resistance in each of the following cases.
   a) The current in the circuit is 3 A and the voltage drop across the resistor is 12 V.
   b) The current in the circuit is 2 A and the voltage drop across the resistor is 6 V.
3. A resistor of 5 Ω is placed in a circuit. The voltage drop across the resistor is 12 V. What is the current through the resistor?
4. A resistor is placed in a circuit. The current in the circuit is 2 A and the voltage drop across the resistor is 8 V. The voltage is then increased to 12 V. What will be the new current?
5. Active Physics Plus Using the information in the data table, construct a graph following the directions below.
   - Mark an appropriate scale on the x-axis labeled "Current (A)."
   - Mark an appropriate scale on the y-axis labeled "Voltage (V)."
   - Plot the data points for voltage versus current.
   - Draw the best-fit line.

Current (A)	Voltage (V)
0.010	2.3
0.020	5.2
0.030	7.4
0.040	9.9
0.050	12.7

   a) Using your graph, find the slope of the best-fit line.
   b) What physical quantity does the slope of the graph represent?
6. Your hair dryer has a resistance of 9.6 Ω and you plug it into the bathroom outlet. Assume household voltage to be 120 V and that different parts of your house are connected in parallel.
   a) What current will it draw?
   b) Suppose your brother has an identical hair dryer and plugs it into the same part of the circuit. What current will the two hair dryers draw?
   c) If the maximum current the circuit breaker in the system can handle is 20 A, what do you think will happen?

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Active Physics

2.a)

Using Ohm's law,

$$R = \frac{V}{I} = \frac{(12\ \text{V})}{(3\ \text{A})} = 4\ \Omega$$

2.b)

Using Ohm's law,

$$R = \frac{V}{I} = \frac{(6\ \text{V})}{(2\ \text{A})} = 3\ \Omega$$

3.

Using Ohm's law,

$$I = \frac{V}{R} = \frac{(12\ \text{V})}{(5\ \Omega)} = 2.4\ \text{A}$$

4.

Students should first calculate the resistance. Using this resistance they should calculate the current with the new voltage using Ohm's law.

$$R = \frac{V}{I} = \frac{(8\ \text{V})}{(2\ \text{A})} = 4\ \Omega.$$

After the voltage is increased,

$$I = \frac{V}{R} = \frac{(12\ \text{V})}{(4\ \Omega)} = 3\ \text{A}.$$

Physics to Go

1.

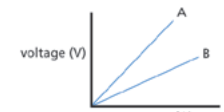
Ohm's law should be applied to solve for the unknowns and complete the table as shown to the right. Students should show their calculations.

Voltage drop	Current flowing through resistor	Resistance
$V = IR = (1\ \text{A})(2\ \Omega) = 2\ \text{V}$	1 A	2 Ω
$V = IR = (3\ \text{A})(5\ \Omega) = 15\ \text{V}$	3 A	5Ω
10 V	4 A	$R = \frac{V}{I} = \frac{(10\ \text{V})}{(4\ \text{A})} = 2.5\ \Omega$
120 V	$I = \frac{V}{R} = \frac{(120\ \text{V})}{(10\ \Omega)} = 12\ \text{A}$	10 Ω

CHAPTER 6

Chapter 6 Electricity for Everyone

7. Active Physics *Plus* Two wires are tested in a lab setting. Current was measured as the voltage across the wire was varied. The results of the experiment are shown in the graph to the right. Both wire A and B obey Ohm's law. Which wire has the greatest resistance?



8. A 12-V battery is hooked up to a 3-Ω resistor. The current through the resistor is

   a) 36 A b) 12 A c) 4 A d) ¼ A

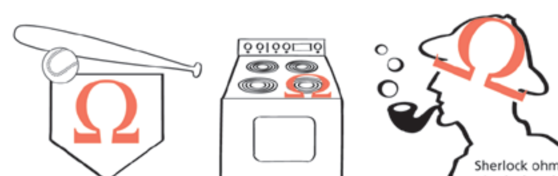
9. A 2-Ω resistor has 4 A of current running through it. The voltage drop (or potential drop) across the resistor is

   a) ½ V b) 2 V c) 4 V d) 8 V

Inquiring Further

Write ohm (home) about it

The ohm is a unit of electrical resistance and is given the symbol **Ω**, the Greek letter *omega*. You can have some fun with the ohm by creating an "ohm-expression." A few examples are given below. Try to develop one of your own "Ω-expressions."



ohm plate or home plate

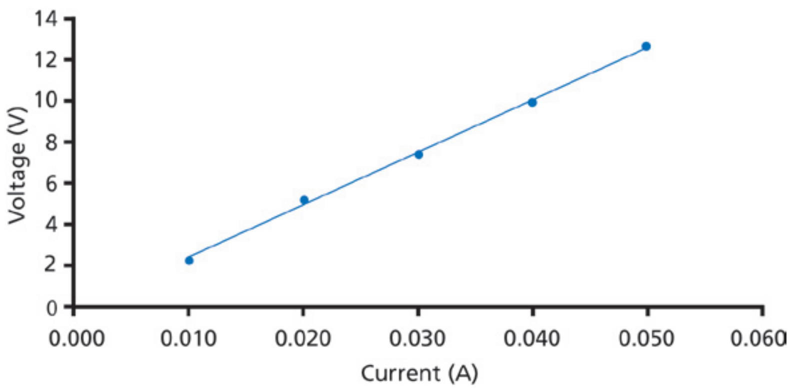
ohm on the range, or home on the range

Sherlock ohms or Sherlock Holmes

Active Physics Plus

5.

Students' graphs of the data and best-fit lines should look similar to the following:



5.a)

Students should calculate the slope of the best-fit line. Their calculations should be similar to $V = (255 \text{ volts/amp})I$. A graphing program may give a small intercept value.

5.b)

Students should realize that the slope is the voltage divided by the current, or the resistance. The graph shown above indicates that in this circuit the total resistance is 255 Ω.

6.a)

$$I = \frac{V}{R} = \frac{(120\ V)}{(9.6\ \Omega)} = 12.5\ \text{A}$$

6.b)

The circuits are parallel so they both have the same voltage drop across them and therefore draw the same current of 12.5 A, or a total current of 25 A.

6.c)

If the maximum current that the circuit breaker can handle is 20 A, then the circuit breaker will "break" the circuit due to exceeding the limits of the current.

7.

Students should recognize that the graphs show voltage versus current so the slopes represent the resistance. As the slope increases (becomes steeper), the resistance increases. *A* has a steeper slope than *B* so it has the greater resistance.

8.c)

$$I = \frac{V}{R} = \frac{(12\ \text{V})}{(3\ \Omega)} = 4\ \text{A}$$

9.d)

$$V = IR = (4\ \text{A})(2\ \Omega) = 8\ \text{V}$$

Inquiring Further

Write ohm (home) about it

Students should come up with expressions that replace "home" with "ohm" similar to those suggested. Drawings going with the expression should be encouraged.

NOTES

CHAPTER 6

SECTION 4 QUIZ

6-4c **Blackline Master**

1. A lamp has a current of 2.0 A when the voltage is 6.0 V. The resistance of the lamp must be

   a) 1.5 Ω. b) 6.0 Ω.

   c) 3.0 Ω. d) 12 Ω.

2. The ratio of the voltage across a light bulb to the current in the light bulb is known as the light bulb's

   a) potential difference. b) resistance.

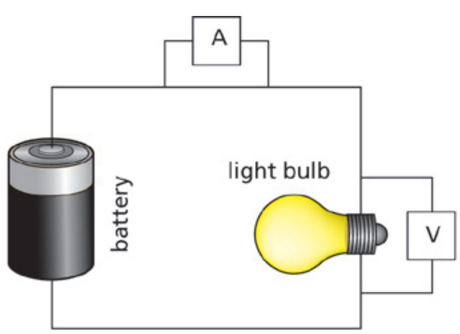
   c) insulation value. d) charge.

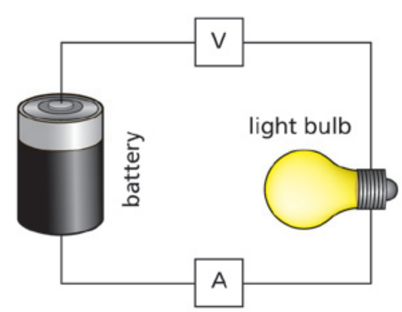
3. What is the voltage across a 2.0-Ω resistor that draws two coulombs of charge per second?

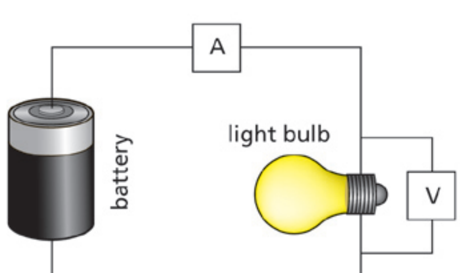
   a) 1.0 V b) 2.0 V

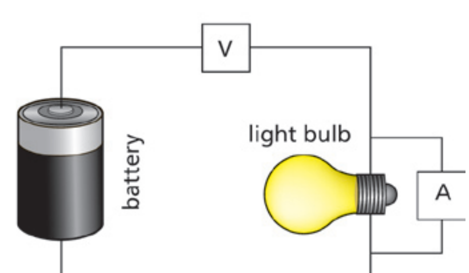
   c) 3.0 V d) 4.0 V

4. In which diagram below are the ammeter and voltmeter correctly connected to measure the resistance of the light bulb?

a)


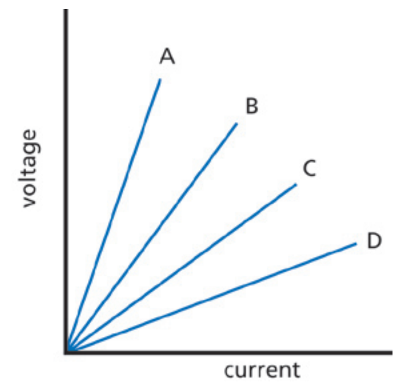
b)


c)


d)


5. The graph shows how the current varies with changing resistance for four different resistors, A through D. Which resistor has the largest resistance?

a) A
b) B
c) C
d) D



SECTION 4 QUIZ ANSWERS

1 c) 3.0 Ω. To find the resistance students should use Ohm's law:

$$R = \frac{V}{I} = \frac{6.0\ \text{V}}{2.0\ \text{A}} = 3.0\ \Omega.$$

2 b) Using Ohm's law, $R = \frac{V}{I}$.

3 d) Using Ohm's law. $V = IR = (2.0\ \text{A})(2.0\ \Omega) = 4.0\ \text{V}$.

4 c) The ammeter must be in series with the light bulb and the voltmeter parallel to it.

5 a) The slope of the line represents the resistance. Because A has the steepest slope, it has the highest resistance.

CHAPTER 6