SECTION 5

Electric Power: Load Limit

Section Overview

Students are introduced to load limit and the purpose of circuit breakers and fuses. They build a circuit out of steel wool and observe what happens to the fuse, which is made by taping the steel wool to a balloon, as energy supplied from a hand-cranked generator is gradually increased. Students then record what occurs as the circuit exceeds its load limit for various household appliances plugged into a power strip fitted with a fuse. They calculate the power and current drawn for these appliances. The *Investigate* provides information and experience for designing circuitry and selecting appliances for the *Challenge*. Students discuss electrical power, conductors, and insulators, and consider the power and current drawn by common appliances in a household circuit. They explore what this means for the constraint on the power limit of the wind generator available in the *Chapter Challenge* and apply what they know about power, current, voltage, resistance, and fuses to solve various problems.

Background Information

Most household plugs in newer homes have three holes. The larger rectangular slot is neutral, the shorter rectangular slot is hot, and the bottom hole is ground. The ground slot is physically connected to Earth, which acts as a reservoir of charge. Most ground wires are then connected to the neutral wire at the service panel to make sure that there is a low resistant path to the circuit breaker. The neutral or ground prong of an appliance is attached to the case of an appliance to protect against electric shock. If electric charge builds up it travels to the ground, rather then across the person using the appliance.

In older homes, ground wires were not used. Without measuring the potential across the system, one would not know if the wires were disconnected and this could lead to electric shocks. Some outlets have a circuit breaker on their panel. This type of circuit breaker is called a ground fault interrupter or GFI. The ground fault interrupter is designed so that if there is a leak of even 5 mA through it, it opens the circuit. Ground fault interrupters are required in bathrooms and for some kitchen and outdoor situations. These circuit breakers trip for much lower currents than most other circuit breakers, which trip when 20 A flows through them. This is because it only takes about 100 mA for a person to get electrocuted.

For humans, 1 mA causes a tingling sensation. Between 10 and 20 mA causes muscular contractions in humans and they cannot pull away from the electrical device to break the circuit. Between 100-300 mA causes ventricular fibrillation, which is fatal if sustained. Often, electricians work with one hand in their pocket and insulated shoes to avoid making a closed circuit that includes their bodies. This prevents current flowing through them.

Crucial Physics

- Power is the rate at which energy is delivered to an object or load in a circuit. Power is measured in watts (W). One watt is one joule of energy supplied in one second of time (1 W = 1 J/s). For a circuit, the power can be calculated by multiplying current and voltage ($P = IV$).
- When the flow of electric charge, or current, occurs easily in a material it is called a good electric conductor, or a conductor, for short. When the material does not allow charge to flow easily through it, it is called an insulator.
- Fuses and circuit breakers are used as safeguards to protect the circuit from too much current and prevent electric fires. A fuse consists of a wire that is designed to melt when too much current flows through it, thus opening the circuit. A fuse must be replaced when blown. A circuit breaker is a switch that opens when too much current flows through it. A circuit breaker must be reset when tripped for current to resume flowing.
- The power (and current) drawn by a circuit depends upon the voltage of the circuit and the resistance of the circuit. Decreasing the resistance of a circuit increases the power (and current) for a fixed voltage.

Learning Outcomes	Location in the Section	Evidence of Understanding
Define power, insulator, and conductor.	***Investigate*** Steps 5 and 6 ***Physics Talk***	Students calculate the power for various household appliances. Students describe and discuss power, insulators, and conductors and provide examples of insulators and conductors.
Use the equation for power, $P = IV$.	***Investigate*** Step 5 ***Physics Talk*** ***Physics to Go*** Questions 1, 3, 5-10, 12-14	Students apply the equation for power to determine the power or current needed for a common household appliance to operate, and the power limit to blow a fuse.
Calculate the power limit of a 120-V household circuit.	***Investigate*** Step 6 ***Physics Talk*** ***Physics to Go*** Questions 9-11, and 13 ***Inquiring Further***	Students observe the power limit for a fuse and calculate the power used by various household appliances.
Differentiate between a fuse and a circuit breaker.	***Physics Talk***	Students read about and discuss how circuit breakers and fuses work and how they differ.
Identify the need for the circuit breakers and fuses in a home.	***Physics Talk*** ***Physics Essential Questions***	Students read about and discuss circuit breakers and fuses, and their purpose.

Section 5 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Base (for mini light bulbs)	1 per group	
Generator, hand operated, DC, Genecon	1 per group	
Circuit, 120 V (for demonstrating overload)		1 per class
Leads, alligator clip (singles)	1 per group	
Pad, steel wool, fine	1 per group	
Light bulb, mini	1 per group	
Balloons, 9 in.		50 per class
Fuse, 3 A		5 per class
Fuse, 8 A		5 per class
Access to an electrical outlet*		1 per class
Hair dryer*		1 per class

*Additional items needed not supplied

Plan A

Time Requirements

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

Teacher Preparation

- For the balloon/fuse portion of the *Investigate*, students should only use a single strand of fine steel wool if they are using a hand generator. If fine steel wool is not available, a similar effect can be obtained by replacing the hand generator with a 9-V battery.
- *Step* 2 should only be done by a teacher demonstration when a 120-V source is used. If the equipment available from *It's About Time*® is not used, you may make your own by connecting a fuse holder in series with the power cord to a 15-A power strip. A maximum of 8 A is recommended for the fuse.
- Assemble a sufficient number of appliances to provide a circuit load greater than 8 A. The demonstration is more effective if the appliances start out with smaller current loads, and then increase the total until 8 A is exceeded and the fuse blows. Be aware that an 8-A fuse may require more than 8 A to actually burn out.
- 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, other equipment) to make sure they are working properly and have the correct range or values.

Safety Requirements

- Goggles are required for this *Investigate*.
- If you do not have the equipment available form *It's About Time*® and are not experienced connecting electrical circuits, do not use the 120-V power strip to blow the fuse. In this case, it is recommended that you use a 6-V power source and several mini bulbs with a 1/2-A fuse. At this voltage, the students may also safely do the *Investigate*.
- Disconnect the power strip when changing fuses after the fuse has blown.
- Students should not touch the power strip or any of the equipment if 120 V are used.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Base (for mini light bulbs)	1 per group	
Generator, hand operated, DC, Genecon	1 per group	
Circuit, 120 V (for demonstrating overload)		1 per class
Leads, alligator clip (singles)	1 per group	
Pad, steel wool, fine	1 per group	
Light bulb, mini	1 per group	
Balloons, 9 in.		50 per class
Fuse, 3 A		5 per class
Fuse, 8 A		5 per class
Access to an electrical outlet*		1 per class
Hair dryer*		1 per class

*Additional items needed not supplied

Time Requirements

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

Teacher Preparation

- For the balloon/fuse portion of the *Investigate*, students should only use a single strand of fine steel wool if they are using a hand generator. If fine steel wool is not available, a similar effect can be obtained by replacing the hand generator with a 9-V battery.
- *Step* 2 should only be done by a teacher demonstration when a 120-V source is used. If the equipment available from *It's About Time*® is not used, you may make your own by connecting a fuse holder in series with the power cord to a 15-A power strip. A maximum of 8 A is recommended for the fuse.
- Assemble a sufficient number of appliances to provide a circuit load greater than 8 A. The demonstration is more effective if the appliances start out with smaller current loads, and then increase the total until 8 A is exceeded and the fuse blows. Be aware that an 8-A fuse may require more than 8 A to actually burn out.
- 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, other equipment) to make sure they are working properly and have the correct range or values.

Safety Requirements

- Goggles are required for this *Investigate*.
- If you do not have the equipment available from *It's About Time*® and are not experienced connecting electrical circuits, do not use the 120-V power strip to blow the fuse. In this case, it is recommended that you use a 6-V power source and several mini bulbs with a 1/2-A fuse. At this voltage, the students may also safely do the *Investigate*.
- Disconnect the power strip when changing fuses after the fuse has blown.
- Students should not touch the power strip or any of the equipment if 120 V are used.

Meeting the Needs of All Students

Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Understanding vocabulary	***What Do You Think?***	**Augmentation** • Students may not have prior knowledge about what a circuit breaker or fuse looks like. Seeing an example may make it easier for students to make predictions about the purposes of these devices. Show students a real-life circuit breaker or fuse or a picture of a circuit breaker or fuse. • Refer to the picture of a circuit breaker and a fuse in *Physics Talk*.
Fine motor issues	***Investigate*** Step 1	**Augmentation** • Students who struggle with fine motor tasks such as handwriting and/or grasping objects will have a hard time attaching the steel wool to the hand generator and light bulb. • Pair students strategically to include a student with stronger fine motor skills. • Provide longer strands of steel wool for students to manipulate. **Accommodation** • For students with more extensive fine motor struggles, set up the circuit with the fuse for them.
Creating a data table from a model	***Investigate*** Steps 3 and 4	**Augmentation** • Students who struggle with visual tracking or fine motor skills may have a difficult time copying tables from the textbook. Instruct students to fold their page in half once and then in half again to divide the page into four columns. Then students can draw lines down the creases to make the columns and use the horizontal lines on the page for their row dividers. • Many students who struggle with fine motor skills have been penalized on their work because of neatness. Set a time limit, such as 2-3 minutes, to encourage students to make the table quickly. Remind students that it does not have to be perfect. **Accommodation** • Provide students with a blank table to tape into their logs. • Students who are visually impaired will have a difficult time reading the power and current ratings on appliances. Provide these values for students if necessary.
Calculating voltage or current with $P = VI$	***Investigate*** Step 5	**Augmentation** • Instruct students to rearrange the column headings in *Investigate, Step 3*. For problem-solving purposes, it will be easier for students if the column headings are in the same order as the variables in the formula. The new headings would be as follows: Appliance, Power, Voltage, and Current. • Use the helpful algebra circle in the *Physics Talk* from *Section 4* to help students manipulate $P = VI$.
Learning new vocabulary	***Physics Words***	**Augmentation** • In science classes, being able to use new content-specific vocabulary is an imperative skill. By the time students enter high school, teachers often assume that students have learned how to study vocabulary words. However, students with learning disabilities often do not acquire these skills unless they are taught explicitly. • Teach students to make flashcards or two-column study sheets with the word on one side and the definition or a drawing on the other side.

Learning Issue	Reference	Augmentation and Accommodations
Reading comprehension	***Physics Talk*** ***Checking Up***	**Augmentation** • Remind students to read the *Checking Up* questions prior to trying to read the *Physics Talk* section. This will help set a purpose for reading that may increase comprehension. • To help students read actively, students could keep track of who, what, where, when, why, and the how of circuit breakers and fuses as they are reading. The teacher could provide the who and when (_____) before students began reading as background information, and then students could complete the chart. **Accommodation** • For struggling readers, provide students with a guided reading packet that very intentionally requires students to record the key points from each paragraph or section. The packet should include questions or fill-in-the-blank statements and page numbers on which the information could be located. • Provide direct instruction to teach the concepts in *Physics Talk*.
Applying knowledge to conceptual questions	***Active Physics Plus*** Question 3	**Augmentation** • Students may have difficulty with the comparisons for *Question 1* and the calculations for *Question 2* if they struggle with math concepts. However, students could do the Electron Shuffle to answer *Question 3*. Taking the time to do the Electron Shuffle to aid students in understanding the concept of how bulbs in circuits affect each other's brightness will help students with the *Chapter Challenge*.
Performing calculations in table format	***Physics to Go*** Question 1	**Augmentation** • Students who struggle with visual tracking or mathematical calculations will have a difficult time completing this table. • Encourage students to look at one row at a time and cover up the other rows as they are trying to do the calculations. This can be accomplished with a big note card or a piece of oak tag that has a slit the size of a row cut out. • Ask students to number the rows on the table (1-6). Then students can show their work for one row of calculations at a time. This augmentation would also be helpful for students who have difficulty copying tables. **Accommodation** • Provide a copy of the table for students to tape into their logs. • Provide a teacher-made worksheet that separates the rows into six distinctly different problems with two calculations each. • Providing a sheet of the blank problem solving boxes introduced in *Driving the Roads* may help students who struggle to organize information when problem solving.

CHAPTER 6

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Comprehension	***Investigate*** Step 2.c)	Remind students that a scientific model can be a theory or a mathematical relationship; it does not have to be a physical model.
Vocabulary comprehension	***Physics Words***	Use prefixes and roots to help students remember the distinction between "conductor" and "insulator." Tell them that "con-" means "with" or "together" and "duct" means "passageway," so a conductor is something that allows electrons to travel together through a passageway. The term "insulate" is similar to "isolate, which means to put something by itself, so an insulator is a barrier that does *not* allow electrons to travel easily through it.
Comprehension	***Physics to Go*** Question 1	Look carefully at students' completed tables to be sure they are using the correct equations in the correct situations.
Higher order thinking	***Active Physics Plus*** Question 1.a)-b)	In science, it is important to notice relationships between variables. Be sure students can identify the relationships asked in these questions without performing any calculations.

To help students use their vocabulary from the section and demonstrate their knowledge of the equations given in the lesson, have them work through the following dimensional analysis in words:

$P = VI$ [Power equals voltage multiplied by current.]

$W = J/C \times C/s$ [Watts equals joules per coulomb multiplied by coulombs per second.]

$W = J/s$ [Watts equals joules per second.]

$W = W$ [Watts equals watts.]

Consider finishing this section with a cloze activity. Cloze activities are useful tools for summarizing material and for giving English-language learners an opportunity to practice using their science vocabulary words in context. Write the following paragraphs on the board, replacing the underlined words with a write-on-line. Encourage volunteers to fill in the blanks.

6-5a Blackline Master

<u>Insulators</u>, such as glass and wood, do not allow <u>current</u> to flow easily. <u>Conductors</u> have low <u>resistance</u>, so current flows easily through them. A hair dryer is more likely than a radio to trip a <u>circuit breaker</u> because devices that create a lot of <u>heat</u> also use a lot of <u>energy</u>. A <u>fuse</u> must always be connected in <u>series</u> to protect a <u>circuit</u> from overloading. The <u>load</u> <u>limit</u> of a 15 A fuse in a 120 V house is <u>1800</u> <u>W</u>. <u>Power</u> is not the same as energy. Power is the <u>rate</u> at which energy is supplied. It determines the <u>brightness</u> of a bulb. Compact fluorescent bulbs are more energy efficient. They generate much less <u>heat</u> than incandescent bulbs, so they use much <u>less</u> power.

NOTES

SECTION 5

Teaching Suggestions and Sample Answers

What Do You See?

Consider using an overhead of the illustration to provide a focus for discussion. Ask students what they think the visual depicts and record their responses. Query them about the box on the wall above the stereo system. Most students should recognize this as a fuse box. Find out if they know what the box does and why it is there. Have them relate the illustration to the title of the section. Draw students' attention to the images of too many electrical appliances plugged to a single power strip. This visual should make students curious about the physics content they are about to study.

What Do You Think?

Students should have some idea of the function of circuit breakers from their everyday experiences. Encourage students to make connections with the *Investigate* they did with steel wool in which they observed the steel wool getting hot and burning. Ask students to record their responses in their *Active Physics* logs then have them discuss it with their group members to come up with their best response. Have a class discussion to record their initial ideas. Refer to these ideas as students progress through the section and learn more about fuses and circuit breakers.

What Do You Think?

A Physicist's Response

Fuses and circuit breakers open a circuit when too much current flows through them. A fuse opens the circuit due to the melting of a thin piece of metal inside it. A circuit breaker has a bimetallic strip that bends when too much current flows through it, causing a spring-loaded switch to move and open the circuit. Fuses must be replaced once they are blown; circuit breakers only need the switch pushed back to the closed position.

What triggers the fuse or circuit breaker from opening is a limiting amount of current. When the current reaches a certain level it melts the wire in a fuse, or causes the bimetallic metal strip to bend and flip a switch that is connected to a spring to open the circuit. These devices are used as safeguards to keep people and equipment safe.

Students' Prior Conceptions

This section helps students to sort their ideas on current and power. Current is the flow of charge past a specific point in a given period of time and power is the work done on an object in a given period of time. Both concepts are rate variables and common language usage may lead to naïve preconceptions on how they involve simple DC circuits. Semantics certainly muddles this concept.

1. **Students believe that power is a constant source of current and the electricity that travels around the circuit is provided by the power supply.** Categorizing current, voltage, and resistance as variables of the circuit and relating them to power in a mathematical construct may assist students to recognize that electric energy is useful energy because it can be transformed into other forms of energy. There are many collisions between the vibrating/moving electrons and atoms in electrical elements. The increase in kinetic energy of the atoms as a result of the collisions increases the internal temperature and thermal energy, and it is this energy which can do work in blowing a fuse or lighting a bulb in the *Investigate*. Power is energy transformed per unit time expressed as voltage times current or QV/t, where electric current is the flow of charge (Q) per second (t), or $I = Q/t$. Using mathematical substitution for charge, I for Q/t gives IV, which is the mathematical construct for power. Encouraging students to define power as $P = IV$ will command their attention to the work done by the moving charges as they travel around the circuit losing their energy per charge, rather than to power as a source of current.

Section 5 Electric Power: Load Limit

What Do You See?

Learning Outcomes

In this section, you will

- **Define** power, insulator, and conductor.
- **Use** the equation for power, $P = IV$.
- **Calculate** the power limit of a 120-V household circuit.
- **Differentiate** between a fuse and a circuit breaker.
- **Identify** the need for circuit breakers and fuses in a home.

What Do You Think?

Everybody has at one time blown a fuse, or tripped a circuit breaker causing the lights to go off in a circuit in the house.

- **What is the function of a fuse or circuit breaker?**
- **Exactly what conditions do you think make a fuse blow or a circuit breaker trip?**

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

1. Create your own *fuse* by taping a very thin strand of steel wool to an inflated balloon. Connect the hand generator to one end of the steel wool. Connect the other end of the steel wool to a light bulb. Complete the circuit by connecting the other end of the light bulb to the generator. (You can use additional wires.)

   Begin cranking the generator, slowly at first, and observe the steel wool. Gradually increase the speed of the generator and watch what happens to your fuse.

Investigate

Teaching Tip

Warn the students that the balloon will burst when the wire starts to glow. This works best with small balloons that are inflated to the point where the rubber is stretched thin and tight.

For safest operation, use of the equipment available from *It's About Time*® is recommended. If that is not an option, use of a good power strip with a circuit breaker is an alternative, although it will not show that a fuse has blown.

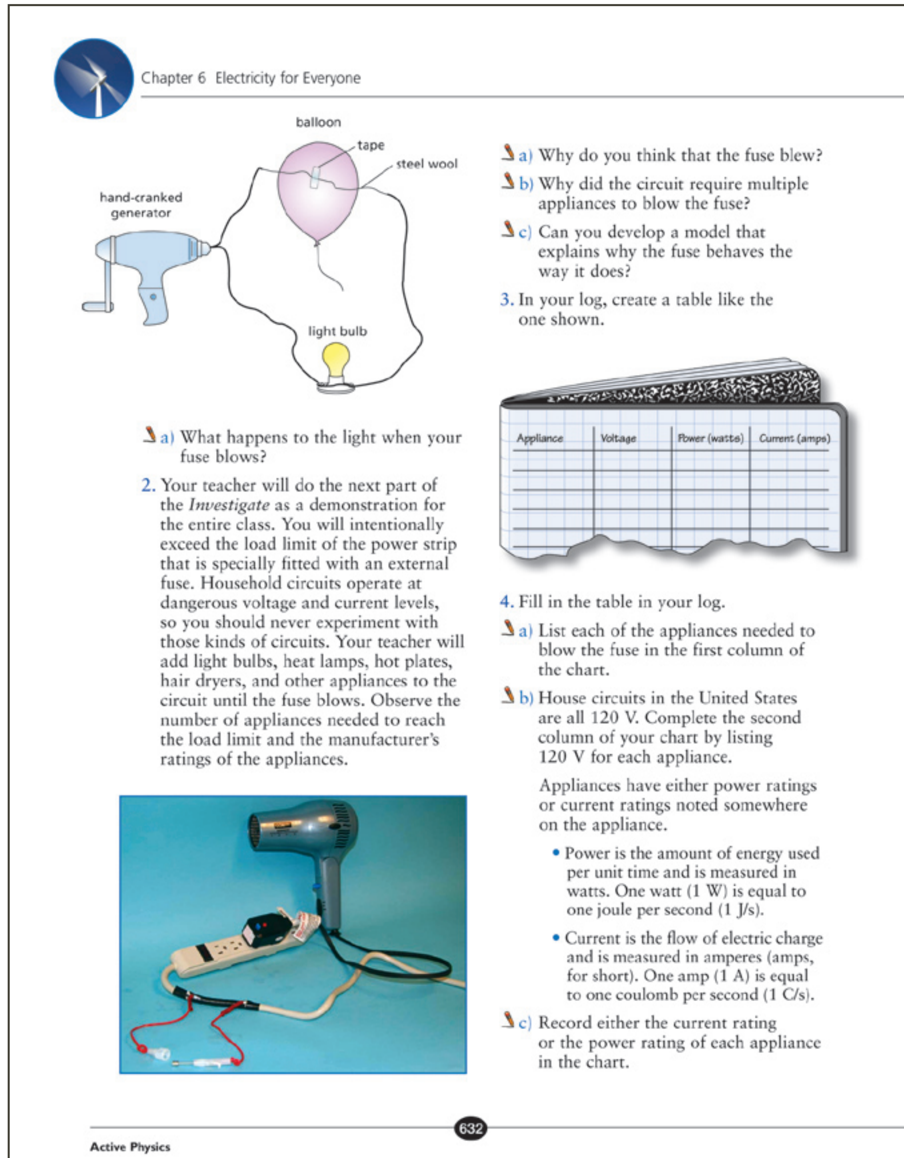
Using one high power device such as a hair dryer or a hot plate will reduce the number of appliances that need to be plugged in if using a power strip with a 15-A circuit breaker. If you are using the equipment from *It's About Time*®, fuses of various capacities are available and the load limit can be reached with fewer devices.

1.a)

This section requires one thin strand of medium or fine steel wool, and the balloon should be inflated so that it is tightly stretched with the steel wool in contact. As the generator is cranked slowly, the light bulb should barely light. As the generator is cranked faster, the steel wool should start to glow causing the balloon to burst. This will break the steel wool and the light will go out. This is similar to what a fuse does in a circuit, without the bursting balloon for effect.

CHAPTER 6

6-5a Blackline Master



a) What happens to the light when your fuse blows?

2. Your teacher will do the next part of the *Investigate* as a demonstration for the entire class. You will intentionally exceed the load limit of the power strip that is specially fitted with an external fuse. Household circuits operate at dangerous voltage and current levels, so you should never experiment with those kinds of circuits. Your teacher will add light bulbs, heat lamps, hot plates, hair dryers, and other appliances to the circuit until the fuse blows. Observe the number of appliances needed to reach the load limit and the manufacturer's ratings of the appliances.

a) Why do you think that the fuse blew?

b) Why did the circuit require multiple appliances to blow the fuse?

c) Can you develop a model that explains why the fuse behaves the way it does?

3. In your log, create a table like the one shown.

Appliance	Voltage	Power (watts)	Current (amps)

4. Fill in the table in your log.

a) List each of the appliances needed to blow the fuse in the first column of the chart.

b) House circuits in the United States are all 120 V. Complete the second column of your chart by listing 120 V for each appliance.

Appliances have either power ratings or current ratings noted somewhere on the appliance.

- Power is the amount of energy used per unit time and is measured in watts. One watt (1 W) is equal to one joule per second (1 J/s).
- Current is the flow of electric charge and is measured in amperes (amps, for short). One amp (1 A) is equal to one coulomb per second (1 C/s).

c) Record either the current rating or the power rating of each appliance in the chart.

2.

For this section, it is strongly suggested that you use the power strip and fuse assembly available from *It's About Time*®. If this is not an option, a good power strip with a known circuit breaker of appropriate size or surge suppressor is an option. Various appliances should be plugged into the power strip that is connected to the wall outlet until the rated power of the fuse or circuit breaker is exceeded, at which point the fuse will blow. Do not use a power strip with a circuit breaker load limit that exceeds the limit of the school's circuit breaker. If you do, the circuit breaker will fail first causing additional problems with restoring electricity to the classroom.

2.a)

Students may think that the power strip outlets were "full" or some may realize that too much current is being drawn from the circuit.

2.b)

Students may suspect that it is only when too many appliances are plugged in that the circuit blows the fuse.

2.c)

Student models will vary. Some will look at a fuse as a switch.

3.

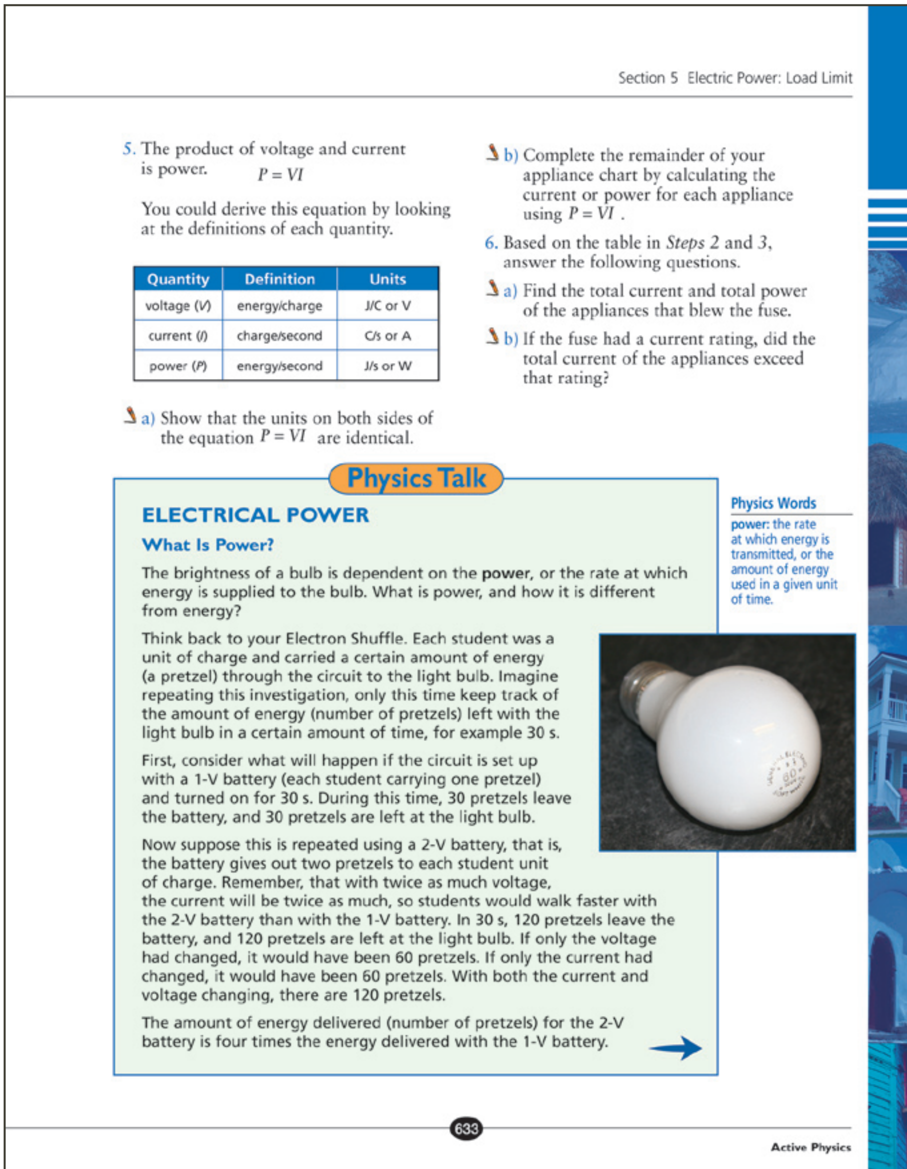
Some sample values of appliance rating readily available in many labs are shown to the right:

Appliance	Voltage	Power (watts)	Current (amps)
Hot plate	120	800	6.7
Lamp with 100-W bulb	120	100	0.9
Water-immersion heater	120	300	2.5

4.a)-c)

Many combinations of appliances with associated power and current values are possible to blow the fuse or circuit breaker.

The appliances needed and the total power to cause the fuse to blow will depend upon the size of the circuit breaker or fuse, and the order the appliances are plugged into the circuit. For the table on the next page, it is assumed that there is a 15-A circuit breaker, and the appliances are energized in order from top to bottom. A total power of 1800 watts ($P = VI = (120\text{ V})(15\text{ A}) = 1800\text{ W}$), is assumed to be needed for the circuit breaker to pop.



5. The product of voltage and current is power. $P = VI$

You could derive this equation by looking at the definitions of each quantity.

Quantity	Definition	Units
voltage (V)	energy/charge	J/C or V
current (I)	charge/second	C/s or A
power (P)	energy/second	J/s or W

a) Show that the units on both sides of the equation $P = VI$ are identical.

b) Complete the remainder of your appliance chart by calculating the current or power for each appliance using $P = VI$.

6. Based on the table in *Steps 2* and *3*, answer the following questions.

a) Find the total current and total power of the appliances that blew the fuse.

b) If the fuse had a current rating, did the total current of the appliances exceed that rating?

Physics Talk

ELECTRICAL POWER

What Is Power?

The brightness of a bulb is dependent on the **power**, or the rate at which energy is supplied to the bulb. What is power, and how it is different from energy?

Think back to your Electron Shuffle. Each student was a unit of charge and carried a certain amount of energy (a pretzel) through the circuit to the light bulb. Imagine repeating this investigation, only this time keep track of the amount of energy (number of pretzels) left with the light bulb in a certain amount of time, for example 30 s.

First, consider what will happen if the circuit is set up with a 1-V battery (each student carrying one pretzel) and turned on for 30 s. During this time, 30 pretzels leave the battery, and 30 pretzels are left at the light bulb.

Now suppose this is repeated using a 2-V battery, that is, the battery gives out two pretzels to each student unit of charge. Remember, that with twice as much voltage, the current will be twice as much, so students would walk faster with the 2-V battery than with the 1-V battery. In 30 s, 120 pretzels leave the battery, and 120 pretzels are left at the light bulb. If only the voltage had changed, it would have been 60 pretzels. If only the current had changed, it would have been 60 pretzels. With both the current and voltage changing, there are 120 pretzels.

The amount of energy delivered (number of pretzels) for the 2-V battery is four times the energy delivered with the 1-V battery.

Physics Words

power: the rate at which energy is transmitted, or the amount of energy used in a given unit of time.

5.a)

Power is expressed in watts, which equals joules/second. Voltage is expressed in joules/coulomb, and current is expressed in coulombs/second. The students should perform the manipulation shown to prove that the two sides of the equation have the same units.

P = J/s = IV = (coulomb/second)(joule/coulomb)

5.b)

Students finish completing the chart they started in *Step 3*.

6.

When the appliances are plugged in successively, everything will operate until the load limit is exceeded, at which point the circuit breaker or fuse will fail. It is suggested that you start with larger wattage appliances, and go to smaller ones as the load limit is approached so the students may see the cumulative effect.

6.a)

The total wattage necessary to blow the fuse or circuit breaker will depend upon the fuse or circuit breaker value that is chosen.

6.b)

The current required by the massed appliances should exceed the fuses' rated current. Some fuses may take a while to heat up sufficiently to blow, so the current rating may actually be exceeded by 10% or more.

If an *It's About Time*® setup is used, the power will be less, since an 8-A fuse is included, leading to a total power of 960 W. Using this equipment would preclude using the hot plate (1200 W). It would need to be replaced by smaller wattage appliances.

Appliance	Voltage	Power (watts)	Current (amps)
Hot plate	120	1200	
Heat lamp	120	250	
Curling iron	120		0.33
Coffee maker	120		5

CHAPTER 6

Physics Talk

Have a class discussion on power, reminding students that power is equal to the energy per second delivered to a device and that the brightness at which a given bulb burns is directly related to the power. The brighter the bulb the more power it uses. Emphasize that this is for the same bulb and doesn't hold true if one is comparing compact fluorescent bulbs versus incandescent bulbs.

Refer students back to the Electron-Shuffle model and what made the bulb brighter as described in the student text. Point out that an increase in voltage and/or an increase in current increases the brightness of the bulb and the power. Discuss the mathematical relationship between power, voltage and current, as well as the dimensional analysis of each term. Ask students why metals are used in circuits rather than other materials. Let students know that conductors allow electric current to flow easily and that most metals are conductors. Ask them why metals are good conductors and then briefly discuss how electrons in most metal atoms can easily move from one metal atom to the next, being bound to a set of metal atoms rather than just one atom.

Ask students what they know about an insulator. Describe how insulators do not conduct electricity well because their electrons are tightly bound to their atoms. Explain that insulators are considered to be important for electrical devices because they can provide protection from dangerous amounts of current. Let students know that in general devices that create a lot of heat use a lot of energy. Remind them that the load limit for the challenge is 2400 W. Then discuss the power ratings for different appliances. Inform students that in the United States the common voltage supplied for circuitry is 120 V. Show students how they can use this information to calculate the current drawn, if they are given the power rating for a device. Have students calculate some of the examples provided in the student text for light bulbs. Then revise the sample problems with the class. Check student understanding by asking questions concerning the dimensions of the variable being calculated and what that means in terms of the Electron-Shuffle model.

If more electric charges were delivering their energy (voltage) at a higher rate of flow (current), it makes sense that you get more power as the current and/or the voltage increase. Increasing the voltage increases the current as well as the amount of energy delivered. This, in turn, increases the power to the light bulb. More power is more energy every second and that will make the bulb brighter.

Is There an Equation?

Power equals voltage multiplied by current.

Power (P) is the energy per time. The units are joules per second (J/s), or watts (W).

Voltage (V) is energy per charge. The units are joules per coulomb (J/C) or volts (V).

Current (I) is the flow of charge per unit time. The units are coulombs per second (C/s) or amps (A).

Think of this in terms of dimensional analysis. Voltage is the amount of energy per unit of charge, and current is the amount of charge per unit of time.

$$\begin{aligned} \text{Power} &= \text{voltage} \times \text{current} \\ &= (\text{energy per charge}) \times (\text{charge per second}) \\ &= \frac{\text{energy}}{\text{charge}} \times \frac{\text{charge}}{\text{second}} \\ &= \text{energy/second} \end{aligned}$$

Using symbols:

$$\begin{aligned} P &= VI \\ &= \frac{\text{J}}{\cancel{\text{C}}} \times \frac{\cancel{\text{C}}}{\text{s}} \\ &= \text{J/s} \end{aligned}$$

Blowing a Fuse or Tripping a Circuit Breaker

A **fuse** and a **circuit breaker** are devices that are placed in an electrical circuit to protect it from damage due to too much current. A fuse is designed to melt when too much current flows through, thereby breaking the circuit. A circuit breaker operates like an automatic switch to open the circuit when there is too much current flowing. Unlike a fuse that must be replaced once it has been blown, a circuit breaker can be reset to close the circuit again and return to normal operation. When the wire in a fuse melts and the circuit is opened, the expression used is "blow a fuse." When a circuit breaker opens a circuit when too much charge is flowing through, the expression used is "trip a circuit breaker."

Physics Words

fuse (electrical): a device placed in an electrical circuit that melts when too much current flows through it, thereby breaking the circuit; it protects the other parts of the circuit from damage due to too much current.

circuit breaker: a device placed in an electrical circuit that operates like an automatic switch to open the circuit when too much current flows through.

Section 5 Electric Power: Load Limit

Some materials are considered to be good **conductors** of electricity. In a conductor, electric charge can flow easily. Metals, such as copper, are good conductors of electricity. That is why copper is commonly used for electrical wires. In a conductor, the outer electrons of each atom are loosely bonded and can be easily shared among atoms. Therefore, the electrons can move freely through the material. Conductors have a very low resistance to electric current. (You will learn more about electrons and bonds when you study the atom.)

Insulators do not allow electric charge to flow easily. The outer electrons of the atoms of insulators are tightly bonded. The electrons cannot be easily shared between neighboring atoms. Examples of insulators include air, glass, plastic, rubber, and wood. Insulators are used to provide protection from potentially dangerous amounts of current flowing through a conductor. The rubber coating on electrical wires protects you from the current flowing through the wire. Insulators have a very high resistance to electrical current. You unfortunately do not!

Did you ever wonder why some appliances cause a fuse to blow or a circuit breaker to trip? Why might turning on a hair dryer blow a fuse but turning on a radio would not? Devices that generate lots of heat also use lots of energy. In the appliance package that you will be creating for the wind generator, there is a load limit of 2400 W. In your own home, you are not restricted to a load limit. If you have the money, the electric company will set up more circuits, allowing you to use more electricity. The company can then collect more money from you.

Many people have plugged in a hair dryer and blown a fuse. If you think back, it always seems to be that a blown fuse or a tripped circuit breaker is due to someone plugging in a hair dryer, a toaster oven, or a hot plate (all heat-generating devices). It never seems to happen when someone plugs in a radio or a clock. The table below shows the power ratings of some appliances.

Appliance	Power rating (W)
hair dryer	1200
toaster oven	1500
radio	70
clock	3

The appliances with high power ratings are responsible for blowing a fuse or tripping the circuit breaker.

In the *Investigate*, you were able to burn a wire and explode a balloon by increasing the current. During the demonstration, something similar happened. As you added appliances, you kept increasing the current until a small wire in the fuse burned (or a circuit breaker tripped) and an open, incomplete circuit resulted. For this reason, a fuse must always be connected in series, so that when it burns out, the circuit will be open and current flow will stop.

Physics Words

conductor: a material through which electric current can move easily; metals are good conductors.

insulator: a material through which electric current cannot move easily; air, glass, plastic, rubber, and wood are examples of insulators.

CHAPTER 6

Why have a fuse? It seems like a nuisance. If the power company will supply the electricity, why do you need fuses to limit the current and power you use? The fuse is a safety device. The fuse or circuit breaker is there to limit the total current in a typical circuit to 15 A or 20 A, depending upon the wires. All electrical currents generate heat. This is because the movement of electric charge in the resistors of the circuit involves transforming energy into heat. Even wires that typically have very low resistance can get hot. Since the job of the wires is to deliver energy to the circuit loads, you do not want the wires to get too hot, or they might cause a fire. Electrical fires within the walls are exceedingly dangerous because they often go undetected while building up deadly fumes. Limits must be set on how much current a wire may carry safely. That is the job of a fuse or circuit breaker.

If the fuse is rated at 15 A, you can use as many appliances as you like in that circuit as long as the total current is less than 15 A. Once you exceed 15 A, the fuse will blow, opening the circuit and reminding you to unplug some appliances.

Thinking About Your Appliance Package

Home circuits in the United States provide 120 V. Knowing this, you can calculate the current of each appliance.

Appliance	Power rating (W)	Voltage (V)	Current (A)
hair dryer	1200	120	10
toaster oven	1500	120	12.5
radio	70	120	0.6
clock	3	120	0.03

Brightness of a bulb is related to the rate of light energy emitted, which is related to the energy per second or power used. If bulbs are manufactured the same way, a 100-W bulb will be brighter than a 60-W bulb.

However, there are now 20-W compact fluorescent bulbs that can produce the same amount of light as 100-W conventional bulbs. Much of the 100 W of power used in the conventional bulb generates heat and not light. Replacing a conventional bulb with a compact fluorescent bulb saves quite a lot of power. When you are limited to 2400 W of peak power from the wind generator, the compact fluorescent bulbs may be just what you want to recommend.

Since the appliances you will use are all designed to operate at 120 V, the voltage of the circuits in your home needs to be 120 V. If the fuse or circuit breaker can handle a maximum of 15 A, then the power limit is 120 V × 15 A or 1800 W. If a toaster is 1200 W and a hair dryer is 1000 W, they cannot both be operating simultaneously on any one line in your house since they total 2200 W, which is more than the 1800-W limit. If you want to run both appliances at the same time, you must use different circuits, each with its own 1800-W limit.

A second way of viewing the circuit is to look at the current requirements of each appliance. Since the appliances are in parallel, the total current will be the sum of all of the individual currents. In the example above, the current of the 1200-W toaster can be found using the power equation. The current is 1200 W ÷ 120 V or 10 A. Similarly, the hair dryer requires about 8 A. The total current is about 18 A. This is more than the 15-A fuse can tolerate.

Sample Problem I

A 12-V starter battery in a car supplies 48 A of current to the starter. What is the power output of the battery?

Strategy: You are asked to find the power, so you use the power equation that is specific to electrical circuits.

Given: $V = 12\ \text{V}$

$I = 48\ \text{A}$

Solution:

$$P = VI$$
$$= (12\ \text{V})(48\ \text{A})$$
$$= \left(12\ \frac{\text{J}}{\cancel{\text{C}}}\right)\left(48\ \frac{\cancel{\text{C}}}{\text{s}}\right)$$
$$= 576\ \text{J/s or about } 580\ \text{W}$$

CHAPTER 6

Checking Up

1.

A fuse and circuit breaker are safety devices that help to prevent damage if too much current flows through a circuit.

2.

The fuse needs to be in series with the circuit, otherwise it will not open the circuit when too much current flows through it.

3.

Using the limiting current specified by the fuse,

$P_{max} = I_{max}V = (15\text{ A})(120\text{ V}) = 1800\text{ W}$

4.

The 100-W bulb will draw a larger current.

$$I = \frac{P}{V} = \frac{60\text{ W}}{120\text{ V}} = 0.5\text{ A}$$

$$I = \frac{P}{V} = \frac{100\text{ W}}{120\text{ V}} = 0.8\text{ A}$$

Sample Problem 2

A 75-W study lamp is plugged into the 120-V household outlet in your room. What current does the outlet supply to the light bulb?

Strategy: Again, use the power equation but rearrange the equation to solve for current.

Given:

$P = 75\text{ W}$

$V = 120\text{ V}$

Solution:

$$I = \frac{P}{V} = \frac{75\text{ W}}{120\text{ V}} = \frac{75\text{ (J/s)}}{120\text{ (J/C)}}$$

$$\frac{75}{120}\left(\frac{J}{s}\right)\times\left(\frac{C}{J}\right)$$

$$= 0.63\text{ C/s or }0.63\text{ A}$$

Light bulbs do not draw a lot of current.

Sample Problem 3

A light bulb operating at 120 V draws 0.50 A. Determine the bulb's

a) resistance

b) power

Strategy: Ohm's law can be used to determine the resistance of the light bulb. The power can be determined using $P = VI$.

Given:

$V = 120\text{ V}$

$I = 0.50\text{ A}$

Solution:

a) $V = IR$

Solving for R,

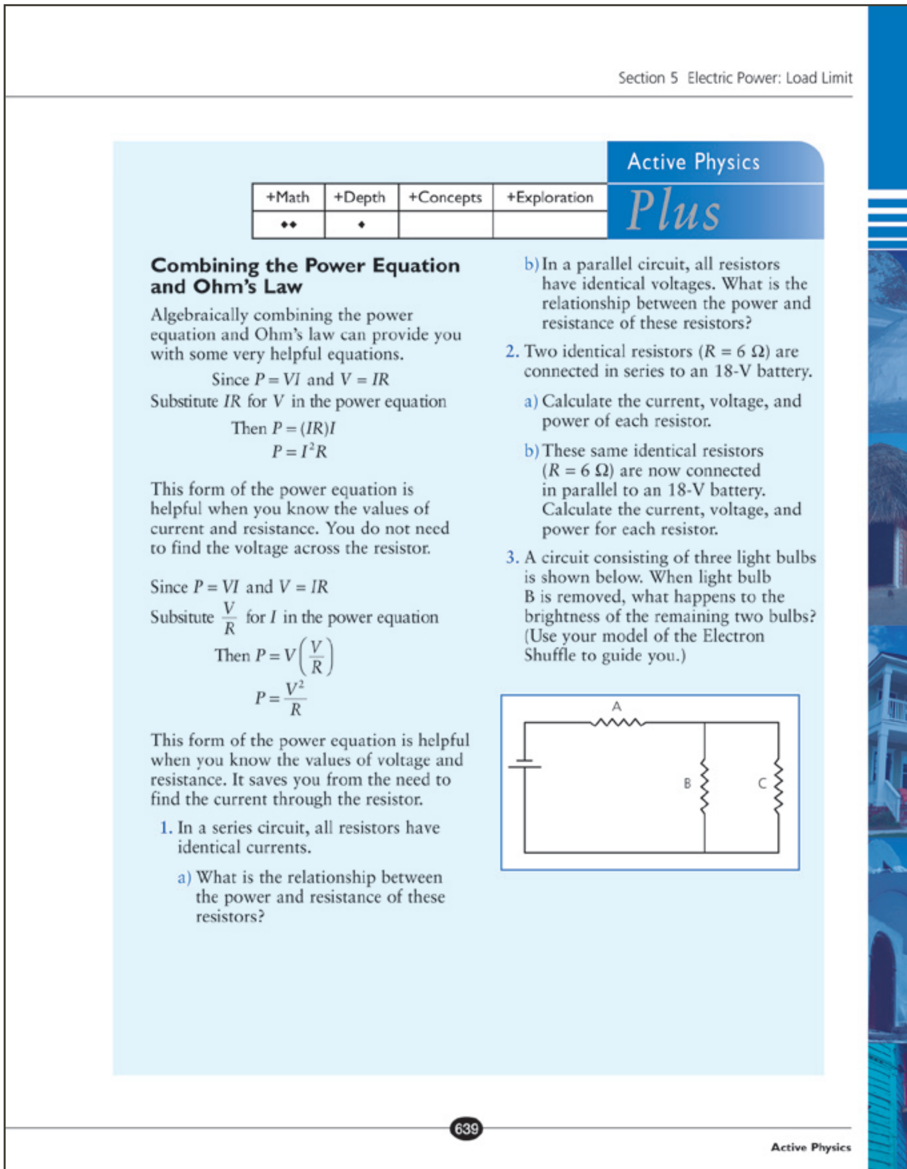
$$R = \frac{V}{I} = \frac{120\text{ V}}{0.50\text{ A}} = 240\ \Omega$$

b) $P = VI$

$$= (120\text{ V})(0.50\text{ A}) = 120\frac{J}{C}\times 0.50\frac{C}{s} = 60\text{ J/s or }60\text{ W}$$

Checking Up

1. What is the purpose of a fuse in a circuit?
2. How must a fuse be connected in a circuit to prevent current from flowing when the circuit becomes "overloaded"?
3. A household circuit that uses 120 V has a 15-A fuse in the circuit. How many total watts from different appliances can the circuit supply before the fuse is in danger of burning out?
4. A 60-W and a 100-W bulb are each plugged into a 120-V circuit. Which light bulb will have the larger current?



Section 5 Electric Power: Load Limit

Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
••	•		

Combining the Power Equation and Ohm's Law

Algebraically combining the power equation and Ohm's law can provide you with some very helpful equations.

Since $P = VI$ and $V = IR$

Substitute IR for V in the power equation

Then $P = (IR)I$

$P = I^2R$

This form of the power equation is helpful when you know the values of current and resistance. You do not need to find the voltage across the resistor.

Since $P = VI$ and $V = IR$

Substitute $\frac{V}{R}$ for I in the power equation

Then $P = V\left(\frac{V}{R}\right)$

$P = \frac{V^2}{R}$

This form of the power equation is helpful when you know the values of voltage and resistance. It saves you from the need to find the current through the resistor.

1. In a series circuit, all resistors have identical currents.
   a) What is the relationship between the power and resistance of these resistors?
   b) In a parallel circuit, all resistors have identical voltages. What is the relationship between the power and resistance of these resistors?
2. Two identical resistors ($R = 6\ \Omega$) are connected in series to an 18-V battery.
   a) Calculate the current, voltage, and power of each resistor.
   b) These same identical resistors ($R = 6\ \Omega$) are now connected in parallel to an 18-V battery. Calculate the current, voltage, and power for each resistor.
3. A circuit consisting of three light bulbs is shown below. When light bulb B is removed, what happens to the brightness of the remaining two bulbs? (Use your model of the Electron Shuffle to guide you.)

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Active Physics Plus

The *Active Physics Plus* is geared toward increasing students' ability to apply the concept of power and to solve problems algebraically.

Review the example of combining the algebraic relationship for power and Ohm's law.

1.a)

According to the relationship $P = I^2R$, the power increases with increasing resistance. Because the current remains constant in a series circuit, there is a linear relationship between power and resistance in the series circuit.

1.b)

According to the relationship $P = \frac{V^2}{R}$, the power decreases as the resistance increases. Since the voltage is the same across devices in a parallel circuit, there is an inverse relationship between power and resistance in the parallel circuit.

2.a)

The current across each resistor, and the current leaving the battery in a series is

$$I_1 = \frac{V_1}{R_1} = \frac{9\text{ V}}{6\ \Omega} = 1.5\text{ A}.$$

The power rating for each resistor is

$$P = I^2R = (1.5\text{ A})^2(6\ \Omega) = 13.5\text{ W}.$$

2.b)

In a parallel circuit, the voltage across each resistor is the same or 18 V. The current across each resistor is

$$I_1 = \frac{V_1}{R_1} = \frac{18\text{ V}}{6\ \Omega} = 3\text{ A}$$

The power rating for each resistor is

$$P = I^2R = (3\text{ A})^2(6\ \Omega) = 54\text{ W}.$$

3.

This is the same circuit that was considered in *Section 3, Active Physics Plus* with the Electron Shuffle. One way to figure out which bulb will burn more brightly is to consider the voltage drops and current. The current going through A will decrease as will the voltage drop across it. The current going through C will increase and so will the voltage across C. Therefore, when B is removed C will burn more brightly, and A will be a bit dimmer.

What Do You Think Now?

Revisit the *What Do You Think?* questions with your class and review students' initial ideas. Then ask them how they would answer these questions now, using what they know about fuses and circuit breakers. You might want to share *A Physicist's Response* to give them a better understanding of fuses and circuit breakers. When students are revising their answers, point out the relationship between power, voltage, and current. Discuss why appliances with high power ratings are responsible for tripping circuits. Point out that when electrical devices are connected in parallel, the circuit draws more current and power than a series circuit comprised of the same elements. Encourage students to share their answers with their group members.

Reflecting on the Section and the Challenge

Read or have a student read this section aloud. Ask students to reflect on the experiments in the *Investigate*. Remind them of the constraint of total power capacity for the wind generator of 2400 W. Point out that the voltage provided to the circuits will be 120 V because most appliances are designed to operate on this voltage. Since the generator has a clearly defined power output limit, students should think carefully about choosing appliances that do not exceed the load limit. Ask students to ponder the requirements of their *Chapter Challenge* and determine how they can best design an effective appliance package that runs on a single generator with a specific capacity.

Chapter 6 Electricity for Everyone

What Do You Think Now?

At the beginning of this section, you were asked:

- **What is the function of a fuse or circuit breaker?**
- **Exactly what conditions do you think make a fuse blow or a circuit breaker trip?**

Now that you have completed this section, how would you now answer these questions? What else would you think you need to know to answer the questions more completely?

Physics

Essential Questions

What does it mean?

What does it mean to blow a fuse or trip a circuit breaker?

How do you know?

In a typical household circuit, what evidence do you have that a 15-A fuse will blow when more than 1800 W are plugged in?

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

* Physicists use models to help understand and make sense of a wide variety of phenomena. How does the Electron-Shuffle model help you to understand the relationship among power, voltage, and current?

Why should you care?

The wind generator available for Homes For Everyone is limited to a maximum power of 2400 W at any one time. How will you use this information when you develop your appliance package? How can a fuse help to limit people's power consumption?

Reflecting on the Section and the Challenge

The total power capacity of the wind generator is 2400 W, so the load limit of the electrical system for the HFE dwelling is 2400 W, as outlined in the *Scenario* of the *Chapter Challenge*. Since most electrical appliances are designed around an industry standard of 120 V, the power plant of the wind generator will provide 120 V to circuits within the dwelling. In this *Investigate*, you learned what load limit means, and how to relate it to current and voltage. If the people in the dwelling try to run appliances that require more than 2400 W, the fuse will blow. If this were to happen in your own home, you could always choose a different line to run the extra appliances. With only one generator, this is not an option in the HFE dwelling. This will have direct application soon when you begin selecting appliances to be used in the dwelling.

Active Physics 640

Physics Essential Questions

What does it mean?

When the current in a circuit is beyond the maximum allowed by the fuse or circuit breaker, the safety devices will stop the flow of current. Blowing a fuse or tripping a circuit breaker means that the maximum current was reached.

How do you know?

More and more appliances were added to the circuit until the limit of the fuse was exceeded. The power of the appliances was then recorded and it was over 1800 W. This corresponds to a current of 15 A in a 120-V circuit.

Why do you believe?

The Electron Shuffle uses pretzels to represent energy. The energy is carried by charges. Voltage is the energy per charge. The current is the rate at which the charge goes by the bulb. The power is the rate at which energy is supplied to the bulb. The Electron Shuffle makes abstract concepts more concrete. It also helps prevent misconceptions, such as the charges getting used up. Just as the people carrying the pretzels don't disappear, the charges in a circuit do not disappear, and the bulb only lights up when energy is transferred to the bulb.

Why should you care?

The 2400-W limit places a major constraint on the total number of appliances that can be used at a given time. The fuse can ensure that this limit is never exceeded.

NOTES

Physics to Go

1.

Students should show their work.

Power	Voltage	Current	Resistance
$P = I^2R = (1\text{ A})^2(2\ \Omega) = 2\text{ W}$	$V = IR = (1\text{ A})(2\ \Omega) = 2\text{ V}$	1 A	2 Ω
$P = I^2R = (3\text{ A})^2(4\ \Omega) = 36\text{ W}$	$V = IR = (3\text{ A})(4\ \Omega) = 12\text{ V}$	3 A	4 Ω
$P = IV = (10\text{ V})(4\text{ A}) = 40\text{ W}$	10 V	4 A	$R = \frac{V}{I} = \frac{10\text{ V}}{4\text{ A}} = 2.5\,\Omega$
$P = \frac{V^2}{R} = \frac{(120\text{ V})^2}{10\ \Omega} = 1440\text{ W}$	120 V	$I = \frac{V}{R} = \frac{120\text{ V}}{10\ \Omega} = 12\text{ A}$	10 Ω
2400 W	120 V	$I = \frac{P}{V} = \frac{2400\text{ W}}{120\text{ V}} = 20\text{ A}$	$R = \frac{V}{I} = \frac{120\text{ V}}{20\text{ A}} = 6\,\Omega$
1800 W	$V = \frac{P}{I} = \frac{1800\text{ W}}{10\text{ A}} = 180\text{ V}$	10 A	$R = \frac{V}{I} = \frac{180\text{ V}}{10\text{ A}} = 18\,\Omega$

2.

Explanations should include the following information:

Load limit means the maximum power that can be drawn for a circuit. Most appliances use 120 V therefore the load limit can also be expressed in terms of maximum electric current drawn as measured in amperes (coulombs/second). If the load limit is exceeded the fuse will blow or the circuit breaker will be tripped.

3.

$$I = \frac{P}{V} = \frac{1200\text{ W}}{120\text{ V}} = 10\text{ A}$$

4.

Because the devices are hooked up in parallel, the sum of the current going through each device must be less than or equal to 20 A, the maximum allowed current. Calculating for the current for each device students should get the following values:

Current for Household Devices	
1000-W toaster	$I = \frac{P}{V} = \frac{1000\text{ W}}{120\text{ V}} = 8.3\text{ A}$
1200-W frying pan	$I = \frac{P}{V} = \frac{1200\text{ W}}{120\text{ V}} = 10\text{ A}$
300-W blender	$I = \frac{P}{V} = \frac{300\text{ W}}{120\text{ V}} = 2.5\text{ A}$
600-W coffee maker	$I = \frac{P}{V} = \frac{600\text{ W}}{120\text{ V}} = 5\text{ A}$

Possible combinations are those in which the sum of the currents drawn by each individual appliance does not exceed the limit. Some examples are frying pan, blender, and coffee maker (total current of 17.5 A); toaster, blender, and coffee maker (total current of 15.8 A); or toaster and frying pan (total current 18.3 A).

5.

The total current drawn is the sum of currents through each bulb. To solve for the current through each bulb apply the power equation.

Each 60-W incandescent bulb draws a current of

$$I = \frac{P}{V} = \frac{60\text{ W}}{120\text{ V}} = 0.5\text{ A}.$$

If the load limit is 15 A, then no more than 30 bulbs can be operated at the same time.

Each 22-W energy efficient bulb draws a current of

$$I = \frac{P}{V} = \frac{22\text{ W}}{120\text{ V}} = 0.18\text{ A}.$$

If the load limit is 15 A, no more than 83 bulbs can be operated at the same time.

6.

Convert horsepower to watts and then solve for the current.

$$0.8\text{ HP}\left(\frac{746\text{ W}}{1\text{ HP}}\right) = 596.8\text{ W}$$

$$I = \frac{P}{V} = \frac{596.8\text{ W}}{120\text{ V}} = 5\text{ A}$$

Physics to Go

1. In your *Active Physics* log, complete the table below. The table provides two of the following four quantities in a circuit: voltage, current, power, and resistance. If you know two of these, you can find the others.

   Example: In the first row the resistance is 2 Ω and the current is 1 A. Using Ohm's law, $V = IR$, you can find the value of the voltage (V). The value of the voltage is 2 V. The power is given by $P = IV$. The power is 2 W.

Power	Voltage	Current	Resistance
		1 A	2 Ω
		3 A	4 Ω
	10 V	4 A	
	120 V		10 Ω
2400 W	120		
1800 W		10 A	

2. Explain in detail what load limit means, and include maximum current, in amperes, as part of your explanation.
3. An electric hair dryer has a power rating of 1200 W and is designed to be used on a 120-V household circuit. How much current flows in the hair dryer when it is in use?
4. A 120-V circuit for the kitchen of a home is protected by a 20-A circuit breaker. What combinations of the appliances listed below can be used on the circuit at the same time without the circuit breaker shutting off the circuit?
   - 1000-W toaster
   - 1200-W frying pan
   - 300-W blender
   - 600-W coffee maker
5. How many 60-W incandescent light bulbs can be operated at the same time on a 120-V, 15-A circuit in a home? How many energy-efficient 22-W bulbs can operate on a similar circuit?
6. Some electrical appliances are rated in horsepower (HP). 1 HP = 746 W. What amount of current flows in a 0.8 HP vacuum cleaner operating on a 120-V circuit?

CHAPTER 6

7. Some electrical appliances are rated in amps. What is the power in watts of a 6-A appliance designed to operate on a 120-V circuit?

8. A 1500-W hair dryer is plugged into the outlet in your bathroom. How much current does this hair dryer draw?

9. When you turn on the toaster in the kitchen, it draws 8.0 A of current from the line.

a) Find the power output of the toaster.

b) You plug another toaster in the same outlet and the circuit breaker trips. What is the maximum current for the type of breaker you are using?

10. A 3-W clock operates at 120 V.

a) How much current does the clock draw?

b) Determine the clock's resistance.

c) If the maximum current that can be drawn from the outlet is 15 A, how many clocks would it take to blow the fuse? (Assume all clocks could be plugged into the outlet.)

11. An iron has a resistance of 13.1 Ω. Could two identical clothing irons operate on the same fuse? (Assume $V = 120$ V and $I_{max} = 15$ A.)

12. The load limit for a household circuit operating at 120 V is 2400 W. Exceeding that limit will result in a blown fuse. Which combination of the following devices would blow the fuse: mini-refrigerator ($P = 300$ W), microwave oven ($R = 19$ Ω), hair dryer ($I = 12$ A), coffee maker ($R = 9.2$ Ω).

13. How much current, in amps, must exist in the filament of

a) A 60-W light bulb when it is operating in a 120-V household circuit?

b) A 100-W light bulb?

c) Fuses and circuit breakers are rated in amperes, usually 15 or 20 A for most household circuits. Use the equation $P = VI$ to show how you can calculate the load limit, in watts, of a 120-V household circuit protected by a 15-A circuit breaker.

14. *Preparing for the Chapter Challenge*

a) Find out about the power rating, in watts, of at least six electrical appliances. You can do this at home, at a store that sells appliances, by studying a catalog, or on the Internet. Some appliances have the watt rating stamped somewhere on the device itself, but for others you may have to check the instruction book for the appliance or find the power rating on the original package. Also, your local power company probably will provide a free list of appliances and their power ratings on request. If the appliance lists the current in amperes, you can assume a voltage of 120 V and calculate the power (in watts) by using the equation $P = VI$.

7.

$$P = IV = (6\ \text{A})(120\ \text{V}) = 720\ \text{W}$$

8.

$$I = \frac{P}{V} = \frac{1500\ \text{W}}{120\ \text{V}} = 12.5\ \text{A}$$

9.a)

$$P = IV = (8\ \text{A})(120\ \text{V}) = 960\ \text{W}$$

9.b)

The total current drawn is just the sum of currents for each individual device. Two toasters would draw twice as much current, or 16 A. The maximum current for the type of breaker being used is probably 15 A.

10.a)

$$I = \frac{P}{V} = \frac{3\ \text{W}}{120\ \text{V}} = 0.025\ \text{A}$$

10.b)

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.025\ \text{A}} = 4800\ \Omega$$

10.c)

The total current drawn is just the sum of currents for each individual device. Because the devices are all the same, each draws 0.025 A, so the total number of radios that could be plugged in is

$$\frac{15\ \text{A}}{0.025\ \text{A}} = 600.$$

11.

Students first need to find the current drawn by an iron and then see if two irons exceed the limit.

$$I = \frac{V}{R} = \frac{120\ \text{V}}{13.1\ \Omega} = 9.2\ \text{A}$$

Because this is more than half of the maximum current allowed, two irons would blow the fuse.

12.

Because the devices are hooked up in parallel, the addition of the power going through each device must be less than or equal to 2400 W, the maximum allowed power.

Calculating for the current for each device, students should get the following values:

Power in Household Devices	
1000-W toaster	$P = 300$ W
microwave $R = 19\ \Omega$	$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{19\ \Omega} = 758$ W
hair dryer $I = 12$ A	$P = IV = (12\ \text{A})(120\ \text{V}) = 1440$ W
coffee maker $R = 9.2\ \Omega$	$P = \frac{V^2}{R} = \frac{(120\ \text{V})^2}{9.2\ \Omega} = 1565$ W

Section 5 Electric Power: Load Limit

b) List three appliances you would include in the HFE appliance package that will be part of the *Chapter Challenge*. For each appliance, list the power demand. For each appliance, describe how it will contribute to the well-being of the people living in the dwelling.

Inquiring Further

Electrical system of a house

Find out about the electrical system of your home or the home of a friend or acquaintance. With the approval of the owner or manager, and with adult supervision, locate the load center, also called the main distribution panel, for the electrical system. Open the panel door and observe whether the system uses circuit breakers or fuses. How many are there, and what is the ampere rating shown on each fuse or circuit breaker?

You may find some larger fuses or breakers that control large, 240-V appliances such as a kitchen range (electric stove); if so, how many are there and what are their ampere ratings? If you can, determine what they control.

In some load centers there is a list of what rooms or electrical devices are controlled by each fuse or breaker, but often the list is missing or incomplete.

With the approval of the owner or manager, and with adult supervision, you can develop a list that indicates what each fuse or breaker controls. To do so, shut off one circuit and go through the entire house to find the lights and outlets that are "dead" (check outlets with a lamp that you can carry around easily). Those items that are "off" are controlled by that fuse or breaker. List them. Then turn that circuit back on and repeat the same process with another circuit.

Report your findings to your teacher in the form of a list or diagram of the house showing what is controlled by each fuse or circuit breaker.

Possible combinations in which the sum of the individual powers drawn does not exceed the power limit of 2400 W are mini-refrigerator and microwave (total power of 1058 W); mini-refrigerator and hair dryer (total power of 1740 W); mini-refrigerator and coffee maker (total power 1865 W); microwave and hair dryer (total power 2198 W); or microwave and coffee maker (total power 2323 W).

13.a)

Students should solve for current using the power equation.

$$I = \frac{P}{V} = \frac{60\text{ W}}{120\text{ V}} = 0.5\text{ A}$$

13.b)

$$I = \frac{P}{V} = \frac{100\text{ W}}{120\text{ V}} = 0.83\text{ A}$$

13.c)

The load limit for a household circuit protected by a 15-A circuit breaker is

$$P = I_{max}V = (15\text{ A})(120\text{ V}) = 1800\text{ W}$$

Preparing for the Chapter Challenge

14.a)

Students should create a table of six common household appliances and list the power rating, current, voltage (120 V), and resistance.

14.b)

Students should list three appliances that they plan to include in the HFE appliance package, and how each appliance could contribute to the well-being of the people in the dwelling. Students should describe where the dwelling is located to support the needs. They should also list the power demand for each appliance.

Inquiring Further

Electrical system of a house

Students should locate and describe a load center or main distribution panel for a dwelling. They should record their observations of the circuit breakers and the ampere rating for each. If possible, they should describe what outlets each circuit breaker controls and construct a diagram showing this.

SECTION 5 QUIZ

6-5c **Blackline Master**

1. To protect a circuit, how should a fuse always be connected?

   a) In series in both series and parallel circuits.

   b) In parallel in both series and parallel circuits.

   c) In parallel in a series and in series in a parallel circuit.

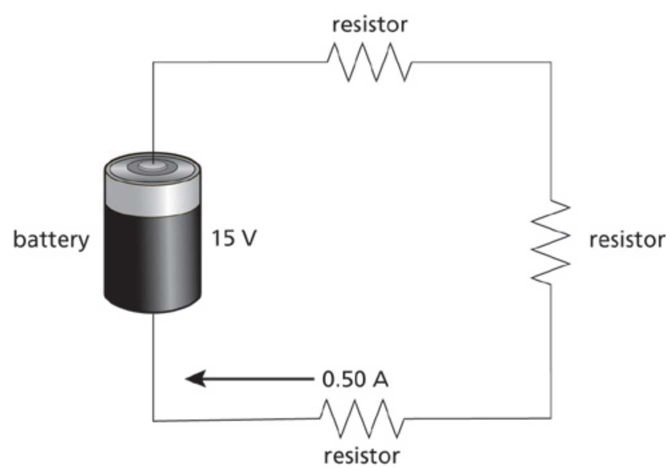
   d) In parallel in a parallel circuit and in series in a series circuit.

2. A 120-V toaster uses 600 W of power. What current flows in the toaster?

   a) 0.20 A   b) 5.0 A

   c) 10 A   d) 25 A

3. The diagram shows three resistors connected to a voltage source. What is the power being delivered to the circuit?



   a) 2.5 W   b) 5.0 W

   c) 7.5 W   d) 15 W

4. To increase the brightness of a desk lamp, a student replaces a 60-W light bulb with a 100-W light bulb. Both light bulbs work on a circuit that has 120 V. Compared to the 60-W light bulb, the 100-W light bulb must have

   a) higher resistance and draws higher current.

   b) higher resistance and draws lower current.

   c) lower resistance and draws lower current.

   d) lower resistance and draws higher current.

5. An air conditioner is rated at 2400 W and designed to operate on 110 V. Can the air conditioner be used on a 110-V circuit that has a 15-A circuit breaker?

   a) Yes, because the current needed is less than 15 A.

   b) No, because the current needed is greater than 15 A.

   c) No, because the voltage is too high.

   d) Yes, 2400 is larger than 110 and 15 added together.

SECTION 5 QUIZ ANSWERS

1 a) If the fuse is in series with the entire circuit, then it will open the circuit if the load limit is exceeded and protect the circuit. If the fuse is placed in parallel, even if the fuse blows the circuit it will still receive the damaging levels of current.

2 b) The current is found using the relationship between current, power, and voltage.

$$I = \frac{P}{V} = \frac{600\text{ W}}{120\text{ V}} = 5.0\text{ A.}$$

3 c) This is found using the relationship between current, power, and voltage. $P = IV = (0.50\text{ A})(15\text{ V}) = 7.5\text{ W}$.

4 d) Students can reason this by using the equation for power and Ohm's law. $P = IV$. For a fixed value of V, if P increases then I must increase. Ohm's law states $V = IR$. For a fixed value of V, if I increases, R must decrease.

5 b) The current required to operate the air conditioner is

$$I = \frac{P}{V} = \frac{2400\text{ W}}{110\text{ V}} = 22\text{ A.}$$

If the air conditioner were connected to the circuit, the 15-A circuit breaker would be tripped, opening the circuit.

CHAPTER 6