SECTION 3

Series and Parallel Circuits: Lighten Up

Section Overview

Students use the kinesthetic Electron-Shuffle model to simulate a parallel circuit. The model is used to observe how varying the current and the voltage in the circuit affects a parallel circuit. When students simulate the Electron-Shuffle model, they investigate how much energy each light bulb receives, as well as the current through each bulb. Students increase the voltage of the battery to determine how much energy and current each bulb receives after the voltage is varied. Students then observe and compare parallel and series circuits, which they construct using a hand generator, wires, and three bulbs. They discuss similarities and differences between them, and also study the basic language of electricity. Students apply what they know to solve problems involving various series and parallel circuits. They consider the advantages of a system of parallel devices for their *Chapter Challenge* and the constraint of the output limit of a hand-cranked generator.

Background Information

Two important physics concepts that describe electric circuits are conservation of energy and conservation of charge. These play a role in the common equations describing simple electric circuits. In simple circuits consisting of K resistors, one can describe the circuit mathematically as follows:

Series Circuits

$V_{total} = V_1 + V_2 + V_3 + \ldots + V_K$

$I_{total} = I_1 = I_2 = I_3 = \ldots = I_K$

$R_{equivalent} = R_1 + R_2 + R_3 + \ldots + R_K$

Parallel Circuits

$V_{total} = V_1 = V_2 = V_3 = \ldots V_K$

$I_{total} = I_1 + I_2 + I_3 + \ldots + I_K$

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_K},$$

where V_n describes the voltage drop across the n^{th} resistor, I_n describes the current through the n^{th} resistor, and R_n describes the resistance of the n^{th} resistor.

The voltage equations describe the total voltage from the battery and how it is related to the drop in voltage across each resistor. These equations arise from the law of conservation of energy. The current equations describe how the total current in the circuit is related to the current across each resistor. These equations arise from conservation of charge. The resistor equations describe what the resistance would be if you replaced all the resistors by one equivalent resistor.

Most circuits are comprised of a combination of resistors in series and parallel, as well as other electronic devices such as capacitors, inductors, diodes, and so on. Usually, Kirchoff's rules are applied to solve more complicated circuits. Kirchoff's rules are based on conservation of charge and conservation of energy. They are the following:

Kirchoff's First Rule: At any junction the sum of currents going into the junction equals the sum of currents going out of the junction.

Kirchoff's Second Rule: The sum of charges in electric potential around any complete loop is zero.

Crucial Physics

- Models are used to study natural phenomena.
- In a parallel circuit the current goes along parallel paths. The voltage dropped across each parallel branch is equal to the total voltage supplied to the circuit (conservation of energy). The sum of the current through each parallel branch is equal to the total current of the circuit (conservation of charge).
- There are two types of charges, positive and negative. A proton has a positive charge of 1.6×10^{-19} C and an electron has a negative charge of -1.6×10^{-19} C. Like charges repel and opposite charges attract. It takes 6.25×10^{18} electrons to make 1 C of electric charge.

Learning Outcomes	Location in the Section	Evidence of Understanding
Compare series and parallel circuits.	***Investigate*** Part B, Step 2 ***Physics Talk*** ***Physics Essential Questions*** ***Physics to Go*** Question 4	Students compare series and parallel circuits by describing the differences they observed while performing the Electron-Shuffle model and while using a hand-cranked generator. Students apply the physics concepts involved to solve for physical quantities in both series and parallel circuits.
Recognize generator output limit.	***Investigate*** ***Physics To Go*** Question 1	Students observe an output limit to the generator and analyze it further in the *Physics to Go*.
Modify the Electron-Shuffle model of electricity.	***Investigate*** Part A, Steps 2-4	Students simulate the current and energy transfers in a parallel circuit using the Electron-Shuffle model.

CHAPTER 6

Section 3 Materials, Preparation, and Safety

Materials and Equipment

PLAN A		
Materials and Equipment	**Group (4 students)**	**Class**
Base (for mini light bulbs)	4 per group	
Generator, hand operated, DC, Genecon	1 per group	
Leads, alligator clip (singles)	4 per group	
Light bulb, mini	4 per group	

*Additional items needed not supplied

Time Requirements

- Allow one and one-half class periods or 65 minutes for the students to complete the *Investigate* portion of this section.

Teacher Preparation

- Open space for the students to form the circuit is required, or the students may circulate around the outside of the desks if done in a classroom.
- Poker chips (or other tokens such as pennies) may be substituted for pretzels if school regulations require this.
- Setting up an actual circuit that duplicates what the students are acting out is desirable. After the students have completed each section of the *Investigate*, showing the electric circuit relates their motion in the *Investigate* to the circuit.

Safety Requirements

- The students should have sufficient space to walk so they are not crowded together, and the area is clear of any obstructions.
- Pretzels should not be eaten after being handled by numerous students.

Materials and Equipment

PLAN B		
Materials and Equipment	**Group (4 students)**	**Class**
Base (for mini light bulbs)	4 per group	
Generator, hand operated, DC, Genecon	1 per group	
Leads, alligator clip (singles)	4 per group	
Light bulb, mini	4 per group	

*Additional items needed not supplied

Time Requirements

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Teacher Preparation

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- Poker chips (or other tokens such as pennies) may be substituted for pretzels if school regulations require this.
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Safety Requirements

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- Pretzels should not be eaten after being handled by numerous students.

NOTES

Meeting the Needs of All Students

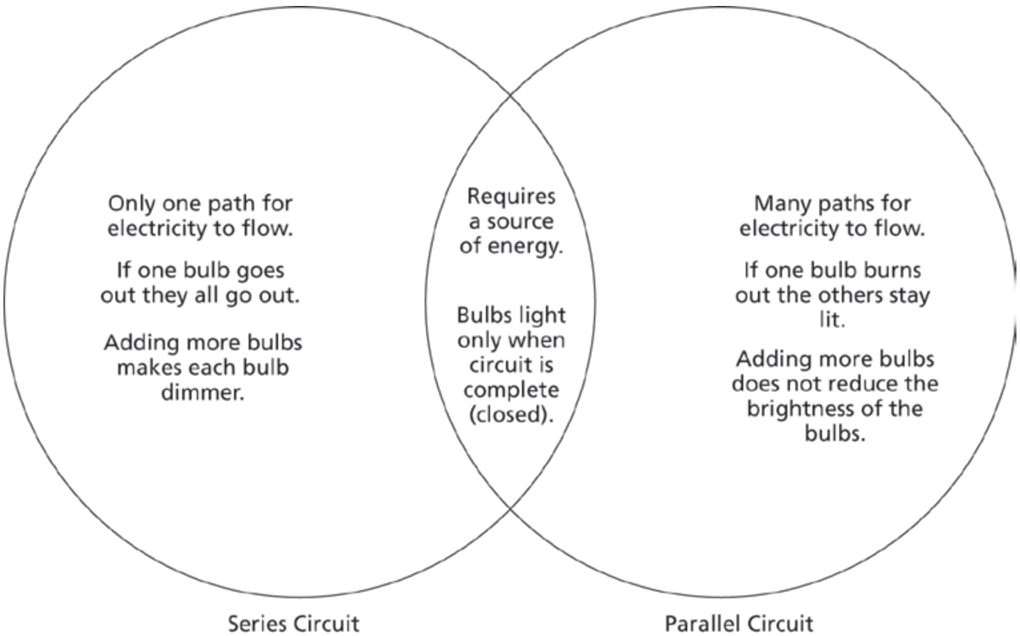
Differentiated Instruction: Augmentation and Accommodations

Learning Issue	Reference	Augmentation and Accommodations
Maintaining appropriate behavior	***Investigate*** Part A	**Augmentation** • During *Investigates* with less structure and lots of movement, some students are unable to maintain appropriate behavior, and they tend to feel out of control. For these students, participating in the investigations as the battery or a light bulb would allow for more control. These two roles have very specific tasks that occur in one location and must be maintained for the "circuit" to function. • During the Electron Shuffle, make the students "freeze" after each trial and ask one question to check for understanding. Sometimes, students perceive *Investigates* as pure fun, so tell them that learning is taking place during this period.
Reading comprehension	***Physics Talk***	**Augmentation** • There is a lot of information packed into this small amount of reading, and students who struggle with reading may skim over important information. • Teach students active reading strategies, such as highlighting, underlining, writing notes and questions in the margins, or using sticky notes to interact with the text. Students will need a copy of the section to use these strategies. • Model two-column notes. In the left column, the teacher provides the questions that focus the students' attention to important details. In the right column, students answer the questions using the text. After students become more comfortable with this strategy, they will be able to write their own questions and answers. **Accommodation** • Provide direct instruction to teach or review the concepts in this section. • Provide guided notes with blank spaces for students to fill in key words.
Synthesizing information	***Physics to Go*** Questions 1 and 2	**Augmentation** • Applying the output limit of the hand generator to understanding and explaining the output limit of the HFE electrical system may be difficult for students who struggle to generalize new information. Lead a group discussion to make sure students understand the output limit of their hand generator, and then ask pairs of students to discuss the implications of output limits for the HFE electrical system. • Model how to write if-then statements to show cause and effect. For example, if too many lights are turned on in series, then they will all be dim. If the refrigerator and the heater are used at the same time, then food might spoil or people might not be warm enough. **Accommodation** • To scaffold cause and effect comparisons, provide the "if" statements, and ask students to write the corresponding "then" statements.

Strategies for Students with Limited English-Language Proficiency

Learning Issue	Reference	Augmentation
Vocabulary comprehension	***Investigate*** Part A, Step 1	Students may need help interpreting the terms "fork" and "junction" in context. You may want to talk about a fork in a road. The term "junction" could be related to a railway junction.
Understanding concepts	***Investigate***	Ask for ELL volunteers to answer the questions aloud. Be sure all students understand how to arrive at the correct answers.
Comprehension	***Investigate***	After students have answered the questions in their *Active Physics* log, pair ELL students with native speakers. Have each pair compare answers and come to a consensus where they disagree. Hold a class discussion to check answers and understanding of both the vocabulary and the concepts. You may wish to role-play any situation with which students have trouble.
Higher-order thinking	***Investigate*** Part B, Steps 3.a), 5.a)	Encourage students to try to explain any changes in the brightness of the bulbs. Do they see the changes with both the series circuit and the parallel circuit? Do they consider the idea of an output limit for the generator?
Vocabulary	***Physics Words***	When you introduce the word "electron," revisit the inferred definitions students wrote in their *Active Physics* log at the end of the last section. Did they understand that an electron is a charged particle? If not, take this opportunity to clear up any misconceptions about the terms "charge" or "electron." Also, give ELL students as much opportunity as possible to use all the vocabulary words in speaking and writing.
Understanding concepts	***Physics Talk***	The series circuit paragraph is largely review from the last section. The parallel circuit paragraphs, however, are quite involved. Hold a class discussion to determine whether students correctly grasp the information. Students may benefit from seeing diagrams representing the situations drawn on the board. You may also wish to role-play the situations.
Understanding concepts	***Active Physics Plus***	Give students adequate time to answer *Questions 1* and *2* in their *Active Physics* log and then check the work for understanding.

Venn diagrams help students compare and contrast. Ask students to make a Venn diagram to show similarities and differences between series circuits and parallel circuits. Have them draw two intersecting circles and give them the labels "series circuit" and "parallel circuit." Have them place similarities between the circuits in the overlap and characteristics that belong to only one category or the other in the appropriate parts of the circles.



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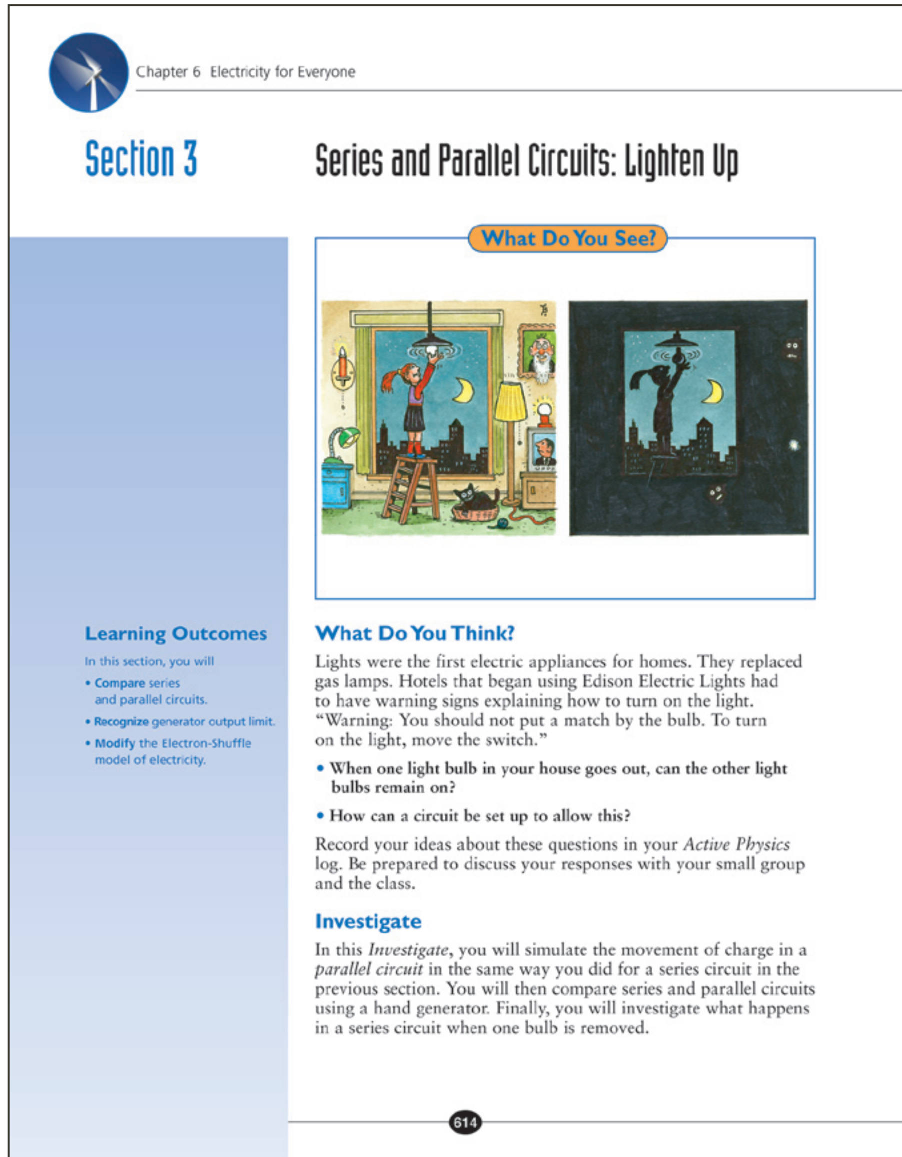
SECTION 3

Teaching Suggestions and Sample Answers

What Do You See?

Have students reflect on the illustration along with the title of the section. Consider using the overhead to discuss what the illustration shows. Ask students what the girl is doing with the bulb, why they think the second image is dark, and what events occurred to cause all the lights to go out. Students who know a bit about parallel and series circuits might suggest that the lights were wired in a series circuit. At this point, it is only important to make students curious about the physics concepts discussed in this section. This illustration is meant to stimulate the students' imagination and shows the artist's effort to create a sharp contrast between the two visuals, linking his art to scientific inquiry.



Chapter 6 Electricity for Everyone

Section 3 Series and Parallel Circuits: Lighten Up

What Do You See?

Learning Outcomes

In this section, you will

• **Compare** series and parallel circuits.

• **Recognize** generator output limit.

• **Modify** the Electron-Shuffle model of electricity.

What Do You Think?

Lights were the first electric appliances for homes. They replaced gas lamps. Hotels that began using Edison Electric Lights had to have warning signs explaining how to turn on the light. "Warning: You should not put a match by the bulb. To turn on the light, move the switch."

• **When one light bulb in your house goes out, can the other light bulbs remain on?**

• **How can a circuit be set up to allow this?**

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

In this *Investigate*, you will simulate the movement of charge in a *parallel circuit* in the same way you did for a series circuit in the previous section. You will then compare series and parallel circuits using a hand generator. Finally, you will investigate what happens in a series circuit when one bulb is removed.

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Students' Prior Conceptions

Students will continue to build mental and physical models for simple electric circuits in this section. Addressing prior conceptions in this section allows students to understand the role of resistance in a circuit and what happens as the number of resistors or bulbs in a circuit increases.

Revisit the first prior conception at the beginning during the *What Do You Think?* section and continue to uncover naïve misconceptions about the change in resistance in a circuit and the change in the number of possible paths for the current to flow.

1. **Bulbs use up current.** This is a false assumption since the rate of flow of charge in a circuit is the same everywhere in a series circuit. Instead, the charge transfers energy to the bulb.

2. **The greater the number of batteries in a circuit, the greater the power of a circuit.** The greater the number of batteries in series in a circuit, the greater the voltage and greater the total push on the mobile electrons in the conductors. Thus, the charge flow or the rate of current increases. Recall that current is the flow of charge across a point in a given unit of time. Power is directly connected to the rate at which work is done on an object.

3. **Electrons move from terminal to terminal in a circuit.** This is one of the most tenaciously held prior conceptions that students hold about charge and electric circuits. It supports student models about the flow of charge and sustains student understanding of resistance and charge. A counter example is a circuit operating with an alternating current.

What Do You Think?

After students have considered the image, discuss how the first electric lights had to have warnings on them to not light them with a match. Consider having a discussion about Thomas Edison. Thomas Edison had very little formal education. He was home-schooled by his mother, and when he was older wished he had a formal education. He was very interested in experimenting and creating new things. When he was a young boy he accidentally started a fire in his house doing an experiment. He was concerned about fires, especially a large fire that occurred in Chicago and burned down hundreds of homes. Part of his desire to build a light bulb came from this concern.

Ask students to consider the questions, record their ideas in their logs, and discuss them with their group. Facilitate a discussion on students' ideas. Students should realize that when one bulb goes out in their house the others do not.

Record students' ideas on how to set up the circuit so that all the other devices remain functioning if a bulb goes out. Then let them know that this is the type of circuit that they will want to use when designing their *Housing for Everyone* package.

What Do You Think?

A Physicist's Response

When one light goes out in a house, the other lights usually do not go out. Sometimes a circuit is overloaded and a circuit breaker or fuse goes out. This will lead to a section of the house not having electricity delivered to it. If the main circuit breaker or fuse goes out, then the entire house will not have electricity flow to its outlets. To allow the other devices in a circuit to remain functioning if a light bulb goes out, one hooks up all the devices directly to the energy source (battery). This is called a parallel circuit. In a house, the electrical outlets are hooked up in parallel to the energy source (electrical cables going into the house). In case of an overload of electricity, the cables going to the house often have a circuit breaker or fuse in series as a special switch.

Investigate

Teaching Tip

Prior to starting the Electron Shuffle for this section, set up an electric circuit with a single bulb and one with three bulbs in parallel. After the students complete *Steps 1-4*, light the single bulb circuit, then the three-bulb circuit for the students to compare bulb brightness. This should again confirm what the students have observed from the Electron Shuffle.

4. **Students believe that greater the resistance in a circuit, the greater the rate of flow of charge through the circuit.** Careful observations and measurement enable students to see that the greater the number of bulbs or resistors in a series circuit, the greater the resistance. For ohmic materials, current is voltage divided by resistance. If the voltage is constant, then the current and the resistance are inversely related to each other; the relationship is not direct.
5. **Students must observe and measure the potential difference across parallel currents through parallel circuit elements to recognize that the potential difference (or voltage) across these circuit elements is equal.** Direct experience reinforces students' conceptual understanding of voltage, current, and resistance in parallel circuits.
6. **Students often believe that only the bulb closest to the negative terminal of a battery lights up.** Students may use this misconception to reason how and why bulbs in a parallel circuit light up. A good intervention for the teacher to use is the Cyclic Simultaneous Model to explain what happens with bulbs in parallel to help students focus on the system as a whole entity rather than just on local features. Consider encouraging students to reason what happens to each bulb, or resistor, separately as opposed to what happens to all the bulbs together or to all the resistance together as a system.

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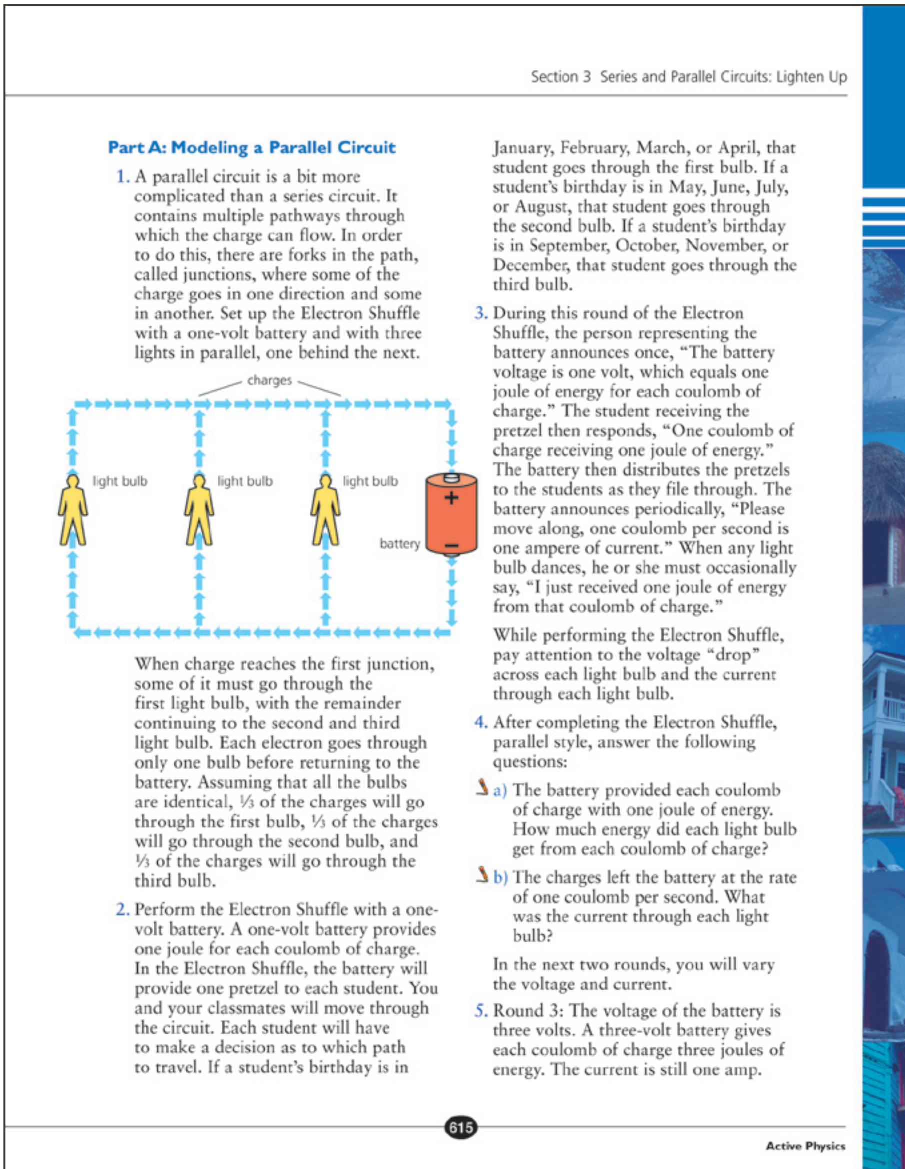

Part A: Modeling a Parallel Circuit

1. A parallel circuit is a bit more complicated than a series circuit. It contains multiple pathways through which the charge can flow. In order to do this, there are forks in the path, called junctions, where some of the charge goes in one direction and some in another. Set up the Electron Shuffle with a one-volt battery and with three lights in parallel, one behind the next.

When charge reaches the first junction, some of it must go through the first light bulb, with the remainder continuing to the second and third light bulb. Each electron goes through only one bulb before returning to the battery. Assuming that all the bulbs are identical, ⅓ of the charges will go through the first bulb, ⅓ of the charges will go through the second bulb, and ⅓ of the charges will go through the third bulb.

2. Perform the Electron Shuffle with a one-volt battery. A one-volt battery provides one joule for each coulomb of charge. In the Electron Shuffle, the battery will provide one pretzel to each student. You and your classmates will move through the circuit. Each student will have to make a decision as to which path to travel. If a student's birthday is in January, February, March, or April, that student goes through the first bulb. If a student's birthday is in May, June, July, or August, that student goes through the second bulb. If a student's birthday is in September, October, November, or December, that student goes through the third bulb.

3. During this round of the Electron Shuffle, the person representing the battery announces once, "The battery voltage is one volt, which equals one joule of energy for each coulomb of charge." The student receiving the pretzel then responds, "One coulomb of charge receiving one joule of energy." The battery then distributes the pretzels to the students as they file through. The battery announces periodically, "Please move along, one coulomb per second is one ampere of current." When any light bulb dances, he or she must occasionally say, "I just received one joule of energy from that coulomb of charge."

While performing the Electron Shuffle, pay attention to the voltage "drop" across each light bulb and the current through each light bulb.

4. After completing the Electron Shuffle, parallel style, answer the following questions:

a) The battery provided each coulomb of charge with one joule of energy. How much energy did each light bulb get from each coulomb of charge?

b) The charges left the battery at the rate of one coulomb per second. What was the current through each light bulb?

In the next two rounds, you will vary the voltage and current.

5. Round 3: The voltage of the battery is three volts. A three-volt battery gives each coulomb of charge three joules of energy. The current is still one amp.

Part A

1.

Students read about the Electron Shuffle in a parallel circuit.

2.

Round 1: Students read about how to divide the current among the "light bulbs" and then perform the Electron Shuffle for the parallel circuit. Because the bulbs are identical, 1/3 of the students (charges) should go through each of the three circuit branches and give their pretzel to the light bulb on that branch. Note that students' birthdays may not be distributed equally. In this case, just split the students acting as electrons into three groups and have them go through the circuit.

3.

Round 2: Students perform the Electron Shuffle for the parallel circuit with vocalizations.

4.a)

Each light bulb receives one joule (one pretzel) for each coulomb of charge (from each student) that passes through that light bulb.

4.b)

Because the current divides equally among the three light bulbs, each light bulb receives one-third of a coulomb of charge per second (one-third ampere), or one student passing by every three seconds.

Teaching Tip

You may choose to verify the student's conclusions similar to *Steps 1-4*.

5.

Round 3: Each light bulb receives three joules (three pretzels) of energy for each coulomb of charge (from each student) that passes through that light bulb. Because the current divides equally among the three light bulbs, each light bulb still receives one-third of a coulomb of charge per second (one-third ampere), or one student passing by every three seconds.

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CHAPTER 6

6. Round 4: The voltage of the battery returns to one volt. The current in the circuit is two amps. A current of two amps has two coulombs of charge moving by every second.

7. In your log, record how the Electron Shuffle, parallel style, would change under the following conditions:

a) Four identical light bulbs were placed in parallel.

b) The circuit of three light bulbs had the battery replaced with a three-volt battery.

c) A circuit of three new light bulbs had a larger current with the original one-volt battery.

d) Four identical light bulbs were placed in parallel with a six-volt battery.

e) Three bulbs that are not identical are placed in parallel.

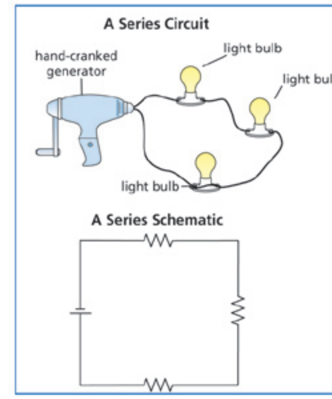
Part B: Comparing Series and Parallel Circuits

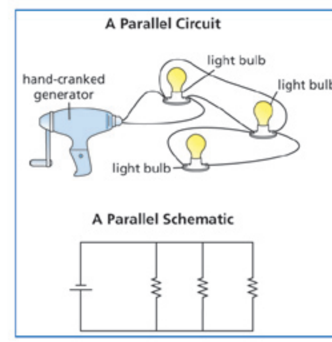
1. Before you begin this investigation, remind yourself about the "feel" of the generator and the brightness of the bulb when the generator was used to energize one bulb in *Section 1*. Connect a single bulb to the generator and crank. Use your observations of a single bulb as a basis for comparison when you use two or more bulbs during this *Investigate*.

2. There are two distinct ways to connect more than one light bulb to the generator. Look at the two pairs of diagrams showing three bulbs connected in series and in parallel. The diagrams show the apparatus you will use. The diagrams also show schematic representations of each circuit.

a) Describe in your log how the two circuits are different.

b) Make predictions about how each circuit operates.





3. Connect two bulbs in series with the generator. Use the diagram showing three bulbs connected in series to help you. Crank the generator, and notice the "feel" of the generator and the brightness of the bulbs. Repeat this for three bulbs, and four bulbs in series.

a) Describe what happens and try to explain why it happens.

6.

Round 4: Each light bulb again receives one joule (one pretzel) for each coulomb of charge (from each student) that passes through that light bulb. Because the current divides equally among the three light bulbs, each light bulb receives two-thirds of a coulomb of charge per second (two-thirds ampere), or one student passing by every one and a half seconds.

7.a)

With a one-volt battery (1 pretzel per student) and a current of one coulomb per second (one student going from the battery per second), each light bulb would still receive one joule for every coulomb of charge that passed through it (one pretzel per student). Each light bulb would receive a current of one-fourth coulomb per second, or one student passing by every four seconds.

7.b)

If the current were still one ampere, this would be the same as *Round 3* above.

7.c)

Each light bulb would still receive one joule of energy for every coulomb of charge that passes through that light bulb (one pretzel per student) and each light bulb would receive one-third of the larger current.

7.d)

Each light bulb would receive six joules of energy for every coulomb of charge that passes through that light bulb (six pretzels per student passing by) and each light bulb would receive one-fourth of the current. If the current were one ampere then one student would pass by every four seconds.

7.e)

Each light bulb would receive the amount of energy per coulomb that the battery provides for each coulomb of charge that passes through the light bulbs (the same number of pretzels per student), but the light bulbs would receive different amounts of charge per second since they are not identical (the number of students passing by per second would vary).

Discuss the equipment with the students. Emphasize to the class that if they crank the hand generator too quickly they can strip the gears, causing the generator to break. Emphasize to students that as they go through the steps they should periodically hook up one bulb to the generator to compare the difference between one bulb and the other circuits they construct.

Part B

Teaching Tip

Students will have difficulty gauging the "feel" of the generator with multiple bulbs in parallel. Ask them to start with lighting the single bulb to a medium brightness. Then have them try to achieve the same level of brightness with two and three bulbs. To give the students a better understanding, have one member of the group "unscrew" one of the bulbs from its socket while another student is cranking the generator. The immediate difference in the feel of the generator should convince the student of the work they are doing.

1.

Students should periodically go back to the one-bulb situation to remind themselves about the "feel" of the one-bulb circuit when the generator is cranked at a certain brightness for the bulb.

2.a)

Students should note that in the series connection there is only a one-current path, and the bulbs are connected "end-to-end," while in the parallel connection there are several paths and the bulbs are connected "side-by-side."

2.b)

Students' predictions will vary. Some students may say that the circuits will act the same, causing equal results in the brightness of the bulbs. If the students have correctly understood the Electron-Shuffle simulations, they should realize that all three bulbs in a given circuit will be equally bright, but the bulbs in the parallel circuit will be brighter than those in the series circuit.

3.a)

Students may notice various things. If the cranking speed is kept the same as with a single bulb, they will find the generator is easier to turn with the multiple bulbs in series than with a single bulb, but the bulbs will not be as bright as a single bulb. This is because the generator is supplying less current at the same voltage. If the students try to maintain the same brightness as they had with a single bulb in the circuit, they will find that they have to turn the generator faster. It will be more difficult because they are supplying the same current as they had for a single bulb and a greater voltage.

6-3b **Blackline Master**

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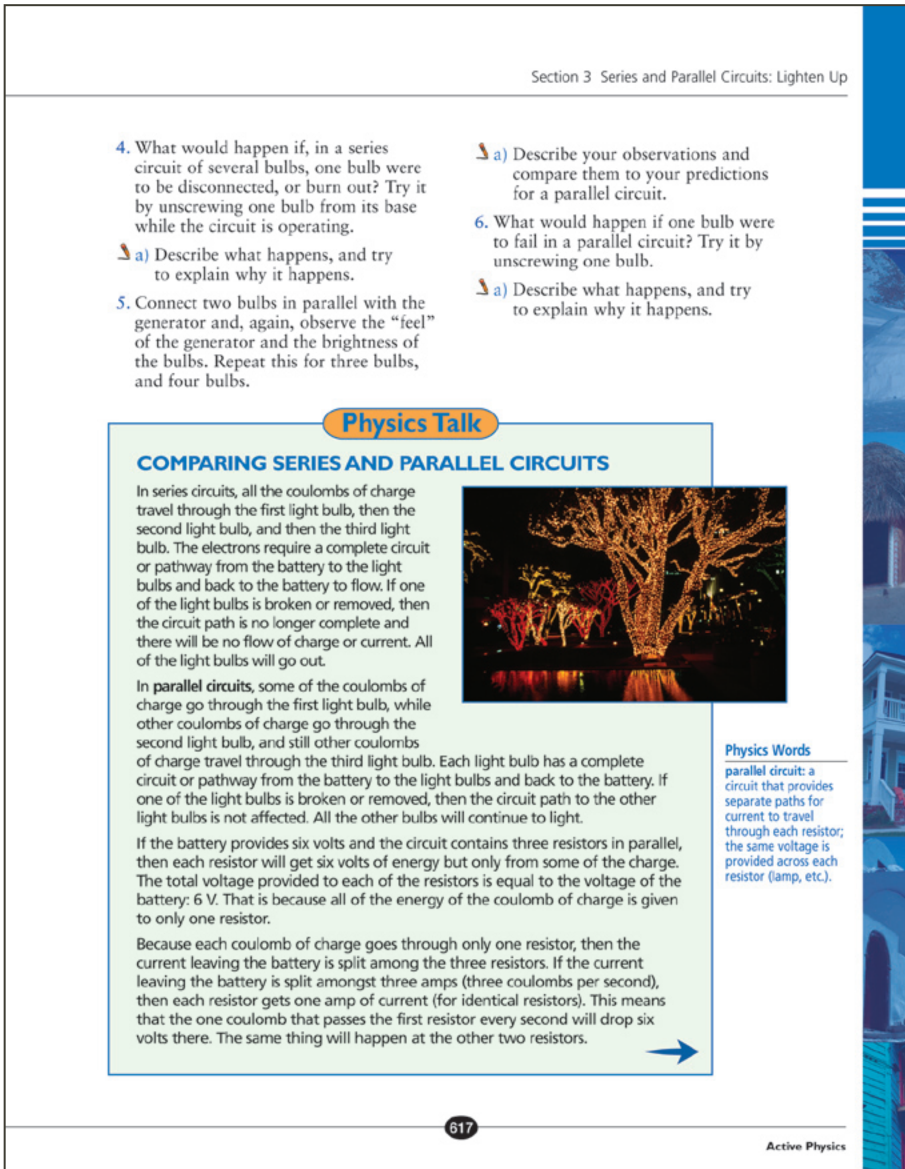

Section 3 Series and Parallel Circuits: Lighten Up

4. What would happen if, in a series circuit of several bulbs, one bulb were to be disconnected, or burn out? Try it by unscrewing one bulb from its base while the circuit is operating.

a) Describe what happens, and try to explain why it happens.

5. Connect two bulbs in parallel with the generator and, again, observe the "feel" of the generator and the brightness of the bulbs. Repeat this for three bulbs, and four bulbs.

a) Describe your observations and compare them to your predictions for a parallel circuit.

6. What would happen if one bulb were to fail in a parallel circuit? Try it by unscrewing one bulb.

a) Describe what happens, and try to explain why it happens.

Physics Talk

COMPARING SERIES AND PARALLEL CIRCUITS

In series circuits, all the coulombs of charge travel through the first light bulb, then the second light bulb, and then the third light bulb. The electrons require a complete circuit or pathway from the battery to the light bulbs and back to the battery to flow. If one of the light bulbs is broken or removed, then the circuit path is no longer complete and there will be no flow of charge or current. All of the light bulbs will go out.

In **parallel circuits**, some of the coulombs of charge go through the first light bulb, while other coulombs of charge go through the second light bulb, and still other coulombs of charge travel through the third light bulb. Each light bulb has a complete circuit or pathway from the battery to the light bulbs and back to the battery. If one of the light bulbs is broken or removed, then the circuit path to the other light bulbs is not affected. All the other bulbs will continue to light.

If the battery provides six volts and the circuit contains three resistors in parallel, then each resistor will get six volts of energy but only from some of the charge. The total voltage provided to each of the resistors is equal to the voltage of the battery: 6 V. That is because all of the energy of the coulomb of charge is given to only one resistor.

Because each coulomb of charge goes through only one resistor, then the current leaving the battery is split among the three resistors. If the current leaving the battery is split amongst three amps (three coulombs per second), then each resistor gets one amp of current (for identical resistors). This means that the one coulomb that passes the first resistor every second will drop six volts there. The same thing will happen at the other two resistors.

Physics Words

parallel circuit: a circuit that provides separate paths for current to travel through each resistor; the same voltage is provided across each resistor (lamp, etc.).

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Active Physics

4.a)

Unscrewing one bulb in a series circuit opens the circuit so no current flows. All the light bulbs will go out. The generator will become much easier to turn since no current is being supplied (and thus no energy) to the circuit.

5.a)

Again, the students may observe various things. For the same cranking speed, the multiple bulbs in parallel will make the generator harder to turn as more current is supplied at the same voltage. For the same difficulty turning the generator, the students will see that the bulbs are dimmer as less energy is supplied.

6.a)

When one light bulb in parallel is unscrewed, only that light bulb goes out while the rest remain lit. The generator will become somewhat easier to turn at the same cranking speed because it will be supplying less energy and current to the circuit.

Physics Talk

This *Physics Talk* compares parallel and series circuits based on student observations and it introduces physics words and facts used to describe electricity. Have a class discussion on series and parallel circuits. Ask students what similarities and differences they observed between these two circuits. Then discuss the information in the student text. Emphasize that in a series circuit there is only one path for the electricity to flow and if that path is broken, the electricity can no longer flow. In a parallel circuit there is a closed path for each device and the energy source (battery), so if one device breaks the electricity still flows in the other branches. Describe how this affects the current and voltage. Have a class discussion summarizing the physics involved in circuits. Emphasize that for an electric circuit to work, electric charge must flow (electric current), and this is caused by a push and/or pull between charges. Like charges push each other away; opposite charges attract each other. Also, let students know that in common circuits metals are used which have electrons that move freely. Although their protons are charged, they are bound in the center of the metal atom. It is only the outermost electron that travels from one metal atom to another when a current flows through a metal wire.

Discuss what a coulomb of charge is and what is meant by resistance. Emphasize that some of the energy carried by the charge goes into heating of the wires and battery. Ask students how their model described this

CHAPTER 6

previously (with crumbs of pretzels). Describe how heating devices (like toasters, ovens, and hair dryers) work by using different metals and introduce the unit of electrical resistance.

Checking Up

1.

There is only one path for the electric current in a series circuit. If one bulb goes out the circuit is no longer closed and electricity cannot flow. This causes all the bulbs to go out.

2.

In a parallel circuit, each bulb is hooked up to the battery. If a bulb goes out, the electricity continues to flow through the other bulbs.

3.

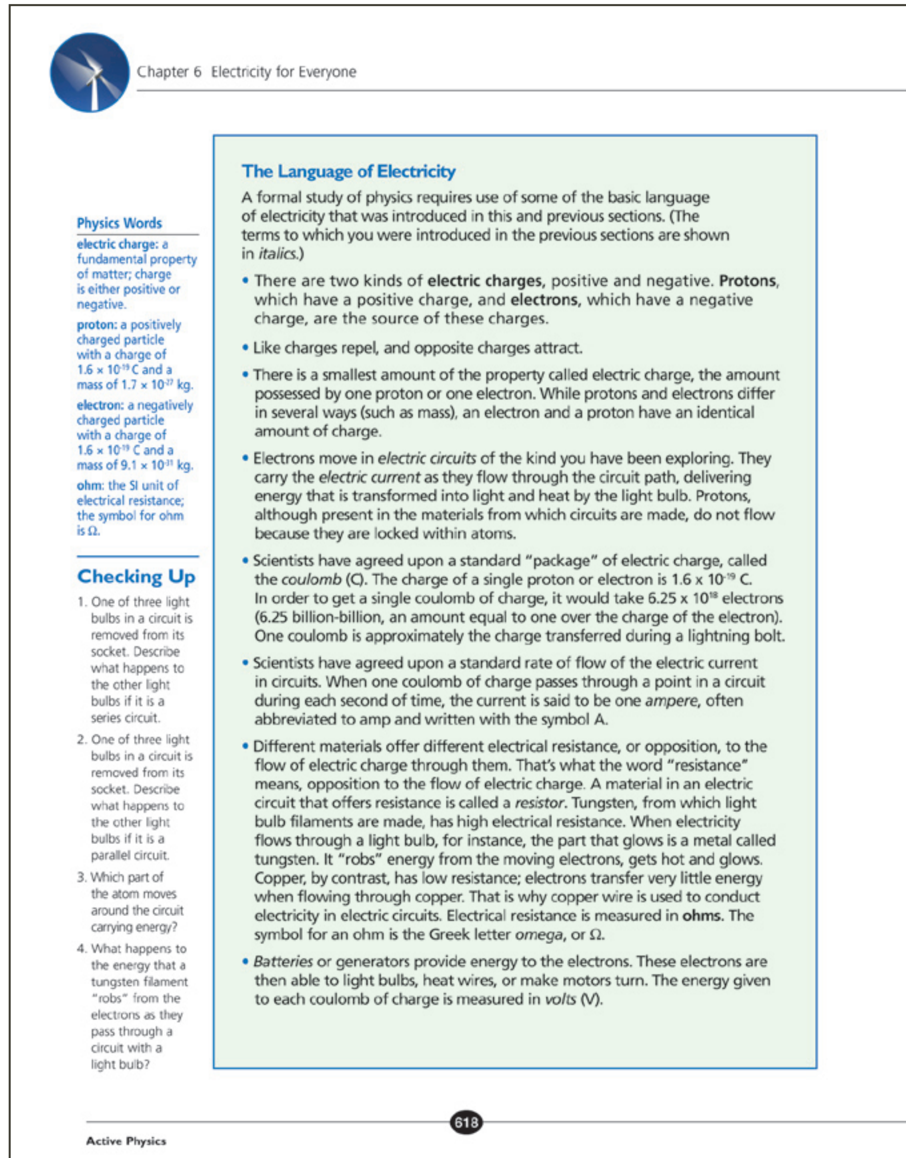
The outermost electrons of an atom, which can easily move from one atom to the other carry energy around a circuit.

4.

Tungsten has much more resistance than copper. When the electrons carrying energy flow from copper to tungsten, the energy carried by the electrons is transferred into motion energy of the tungsten atoms. The tungsten atoms move around enough to glow, transferring light and heat energy to the surroundings.

Active Physics Plus

This *Active Physics Plus* questions are designed to increase students' understanding of parallel circuits. They compare the voltage drop, current, and brightness between parallel and series circuits.



Chapter 6 Electricity for Everyone

Physics Words

electric charge: a fundamental property of matter; charge is either positive or negative.

proton: a positively charged particle with a charge of 1.6×10^{-19} C and a mass of 1.7×10^{-27} kg.

electron: a negatively charged particle with a charge of 1.6×10^{-19} C and a mass of 9.1×10^{-31} kg.

ohm: the SI unit of electrical resistance; the symbol for ohm is Ω.

The Language of Electricity

A formal study of physics requires use of some of the basic language of electricity that was introduced in this and previous sections. (The terms to which you were introduced in the previous sections are shown in *italics*.)

- There are two kinds of **electric charges**, positive and negative. **Protons**, which have a positive charge, and **electrons**, which have a negative charge, are the source of these charges.
- Like charges repel, and opposite charges attract.
- There is a smallest amount of the property called electric charge, the amount possessed by one proton or one electron. While protons and electrons differ in several ways (such as mass), an electron and a proton have an identical amount of charge.
- Electrons move in *electric circuits* of the kind you have been exploring. They carry the *electric current* as they flow through the circuit path, delivering energy that is transformed into light and heat by the light bulb. Protons, although present in the materials from which circuits are made, do not flow because they are locked within atoms.
- Scientists have agreed upon a standard "package" of electric charge, called the *coulomb* (C). The charge of a single proton or electron is 1.6×10^{-19} C. In order to get a single coulomb of charge, it would take 6.25×10^{18} electrons (6.25 billion-billion, an amount equal to one over the charge of the electron). One coulomb is approximately the charge transferred during a lightning bolt.
- Scientists have agreed upon a standard rate of flow of the electric current in circuits. When one coulomb of charge passes through a point in a circuit during each second of time, the current is said to be one *ampere*, often abbreviated to amp and written with the symbol A.
- Different materials offer different electrical resistance, or opposition, to the flow of electric charge through them. That's what the word "resistance" means, opposition to the flow of electric charge. A material in an electric circuit that offers resistance is called a *resistor*. Tungsten, from which light bulb filaments are made, has high electrical resistance. When electricity flows through a light bulb, for instance, the part that glows is a metal called tungsten. It "robs" energy from the moving electrons, gets hot and glows. Copper, by contrast, has low resistance; electrons transfer very little energy when flowing through copper. That is why copper wire is used to conduct electricity in electric circuits. Electrical resistance is measured in **ohms**. The symbol for an ohm is the Greek letter *omega*, or Ω.
- *Batteries* or generators provide energy to the electrons. These electrons are then able to light bulbs, heat wires, or make motors turn. The energy given to each coulomb of charge is measured in *volts* (V).

Checking Up

1. One of three light bulbs in a circuit is removed from its socket. Describe what happens to the other light bulbs if it is a series circuit.
2. One of three light bulbs in a circuit is removed from its socket. Describe what happens to the other light bulbs if it is a parallel circuit.
3. Which part of the atom moves around the circuit carrying energy?
4. What happens to the energy that a tungsten filament "robs" from the electrons as they pass through a circuit with a light bulb?

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Active Physics

1.a)

The voltage drop across each bulb in the parallel circuit is 6 V, the same as the voltage drop across the battery. The voltage drop across each bulb in the series circuit is 2 V; each bulb shares the total voltage supplied (6 V) equally.

1.b)

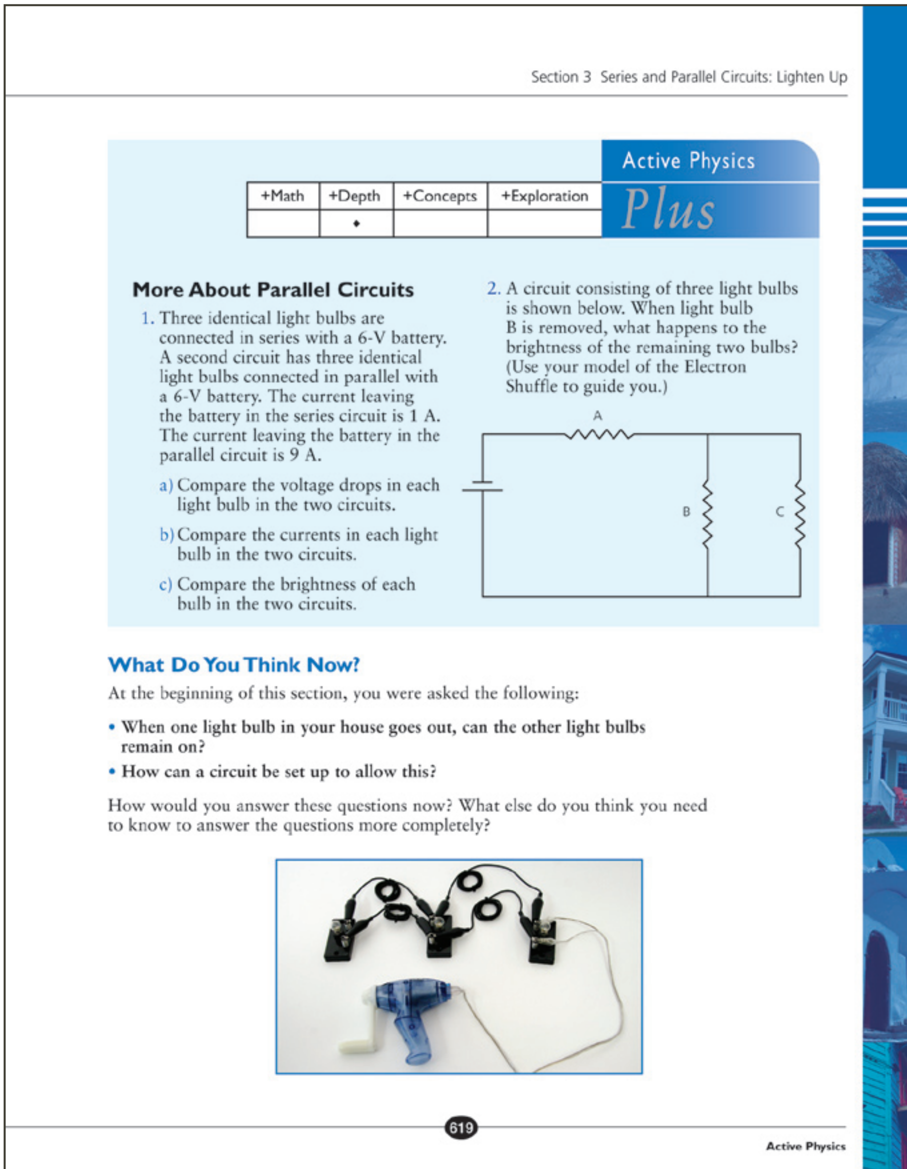
In the parallel circuit, each bulb has 3 A going through it; each bulb shares the total current supplied (9 A) equally. For the series, circuit each bulb has 1 A going through it; each bulb has the same number of charges passing by per second.

1.c)

The bulbs in the parallel circuit are brighter.

2.

Have students consider the Electron Shuffle. Each coulomb of charge carries their pretzel from the battery. They supply 2/3 of



Active Physics *Plus*

+Math	+Depth	+Concepts	+Exploration
	•		

More About Parallel Circuits

1. Three identical light bulbs are connected in series with a 6-V battery. A second circuit has three identical light bulbs connected in parallel with a 6-V battery. The current leaving the battery in the series circuit is 1 A. The current leaving the battery in the parallel circuit is 9 A.
   a) Compare the voltage drops in each light bulb in the two circuits.
   b) Compare the currents in each light bulb in the two circuits.
   c) Compare the brightness of each bulb in the two circuits.
2. 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.)

What Do You Think Now?

At the beginning of this section, you were asked the following:

- **When one light bulb in your house goes out, can the other light bulbs remain on?**
- **How can a circuit be set up to allow this?**

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

their pretzel to bulb A. Then 1/2 the charges move through bulb B and half through bulb C, giving each 1/3 pretzel. Twice as many coulombs of charge go through bulb A than bulb B and bulb C. Bulb A has the total current flowing through it, while bulbs B and C each have 1/2 of the current flowing through them because they are in parallel. Bulb A has a voltage drop across it of 2/3 the batteries voltage while bulbs B and C each have a voltage drop of 1/3 the output of the battery.

When bulb B is removed, the circuit changes—bulb A and bulb C are now in series. The current in bulbs A and C is now the same, but less than it was when bulb B was connected (it is 3/4 times greater than it was when all three bulbs were connected). Half the energy supplied from the energy source is now supplied to bulb A and half to bulb C, since these are in series. In terms of the Electron-Shuffle model, each bulb gets half a pretzel. Bulb A decreases in brightness because it has a lower voltage drop across it (less pretzels), and less charge per second going through it. Bulb C increases in brightness because the current passing through it increases (more charges per second pass through C), as does the voltage drop across it (C gets more pretzels than it did when B was in place.)

What Do You Think Now?

Students should reflect on their earlier answers to the *What Do You Think?* question and revise them based on their current understanding of parallel circuits. Have them discuss their responses in small groups and encourage them to share their answers with each other. Each time they address their doubts and concerns, they will have a better grasp of concepts. You might want to provide students with *A Physicist's Response* to give them more insights into how parallel circuits work. Consider asking them to draw diagrams while explaining their answers. Students should by now be able to connect their responses to their observations in the *Investigate* and subsequent analysis in the *Physics Talk*.

Reflecting on the Section and the Challenge

Discuss the information in the student text with the class. Ask students to reflect on the new physics terms they have learned in this section. Have them write a brief summary of parallel and series circuits that also includes diagrams. Point out the difference in electrical circuits between older and newer homes. Emphasize that students now have the opportunity to plan their design for parallel circuits in the *Chapter Challenge*.

Physics

Essential Questions

What does it mean?

Why is a house wired using parallel circuits rather than series circuits?

How do you know?

What evidence do you have from the activities you performed that series and parallel circuits behave differently?

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

* Electricity can seem like magic. Why do you believe that electricity is based on sound physics principles and not magic?

Why should you care?

Why should your understanding of the differences between series and parallel circuits matter in the electrical design and wiring of your appliance package in the *Chapter Challenge*?

Reflecting on the Section and the Challenge

In this section, you were introduced to parallel and series circuits and to electrical terms that you will need to know and be able to use for planning electric circuits to be used in the wind-powered home.

It is a fact that homes are wired using parallel circuits. Individual houses, apartments, mobile homes, or any other dwellings that receive electricity from a power company, have parallel circuits. Some older homes have as few as four circuits, and newer homes usually have many more. Each circuit in a home may have several light bulbs and other electrical appliances "plugged in," all in parallel. When electrical appliances are hooked up in parallel, if one is off or disconnected, the others can still be on. In a series circuit, if any appliance is disconnected, the other appliances cannot work. In your training manual, you will need to explain why the circuits in the home are wired in parallel.

Physics Essential Questions

What does it mean?

When a house is wired in parallel to the voltage source (120 V), all appliances receive the same 120 V but different amounts of current, depending upon their individual resistances. In addition, if one appliance is turned off, all other appliances do not go off. If the house was wired in series, each appliance would receive the same current, and turning off one appliance would interrupt the current flow to all the other appliances and none of them would work.

How do you know?

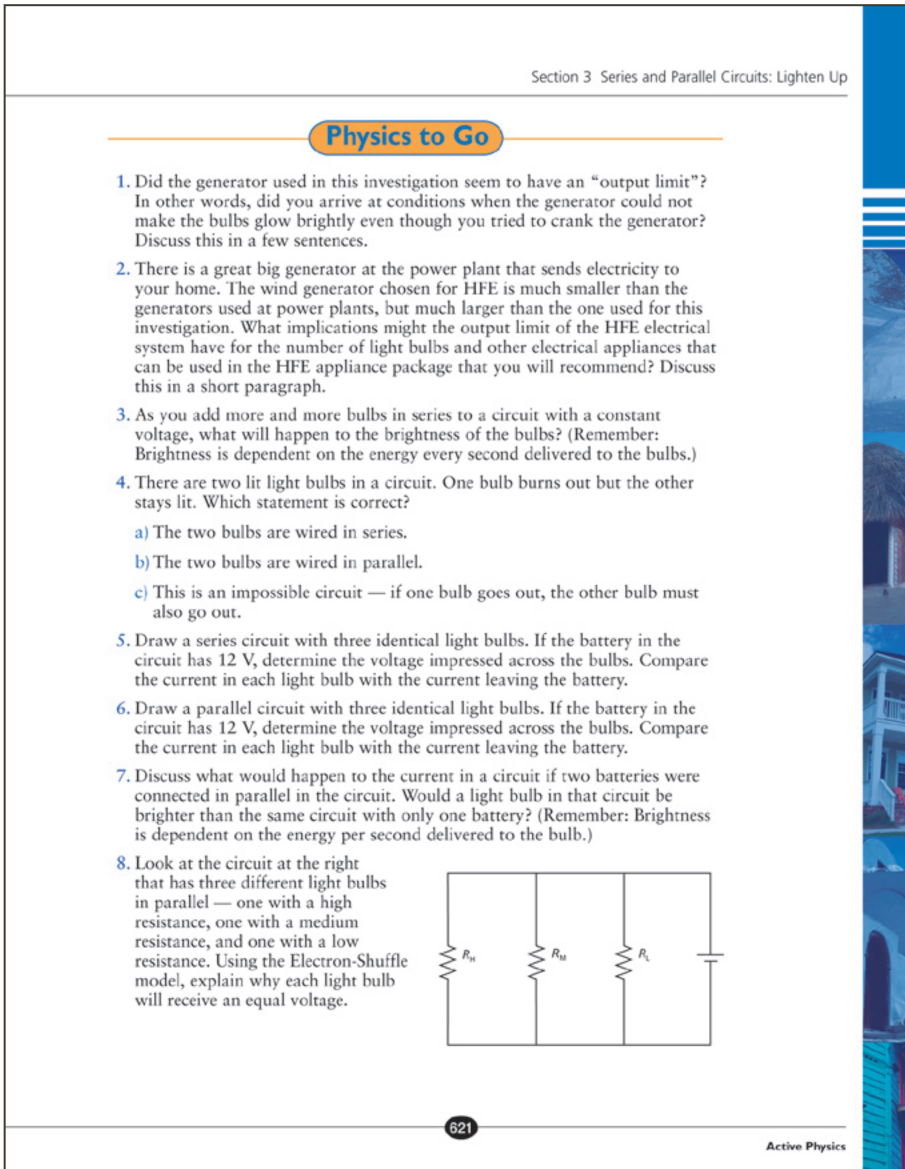
The voltages and currents in each resistor were different in parallel and series circuits.

Why do you believe?

You can accurately predict the voltages, currents, and characteristics of all components of an electrical circuit.

Why should you care?

It will affect decisions on how to place appliances and switches into the circuit.


Section 3 Series and Parallel Circuits: Lighten Up

Physics to Go

1. Did the generator used in this investigation seem to have an "output limit"? In other words, did you arrive at conditions when the generator could not make the bulbs glow brightly even though you tried to crank the generator? Discuss this in a few sentences.
2. There is a great big generator at the power plant that sends electricity to your home. The wind generator chosen for HFE is much smaller than the generators used at power plants, but much larger than the one used for this investigation. What implications might the output limit of the HFE electrical system have for the number of light bulbs and other electrical appliances that can be used in the HFE appliance package that you will recommend? Discuss this in a short paragraph.
3. As you add more and more bulbs in series to a circuit with a constant voltage, what will happen to the brightness of the bulbs? (Remember: Brightness is dependent on the energy every second delivered to the bulbs.)
4. There are two lit light bulbs in a circuit. One bulb burns out but the other stays lit. Which statement is correct?
   a) The two bulbs are wired in series.
   b) The two bulbs are wired in parallel.
   c) This is an impossible circuit — if one bulb goes out, the other bulb must also go out.
5. Draw a series circuit with three identical light bulbs. If the battery in the circuit has 12 V, determine the voltage impressed across the bulbs. Compare the current in each light bulb with the current leaving the battery.
6. Draw a parallel circuit with three identical light bulbs. If the battery in the circuit has 12 V, determine the voltage impressed across the bulbs. Compare the current in each light bulb with the current leaving the battery.
7. Discuss what would happen to the current in a circuit if two batteries were connected in parallel in the circuit. Would a light bulb in that circuit be brighter than the same circuit with only one battery? (Remember: Brightness is dependent on the energy per second delivered to the bulb.)
8. Look at the circuit at the right that has three different light bulbs in parallel — one with a high resistance, one with a medium resistance, and one with a low resistance. Using the Electron-Shuffle model, explain why each light bulb will receive an equal voltage.

R_H R_M R_L

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Active Physics

Physics to Go

1.

As the number of bulbs connected in parallel increases, it becomes more difficult to turn the generator fast enough to keep all the bulbs brightly lit. The output limit of the generator seems to be reached after 3 or 4 bulbs are connected in parallel. After this, the generator can't be hand-cranked fast enough to keep all the bulbs glowing with same intensity.

2.

Students should list possible implications to power output limits. Some possible implications of the output limit of the HFE electrical system could limit the number of light bulbs and how bright the light bulbs are, as well as how many devices might be used at the same time. It might be possible to allow dwellers to have a few items running at a time, limiting the amount of power they use. Students may also consider what time of day the items might run, depending on the location of the dwelling and the needs of the inhabitants.

3.

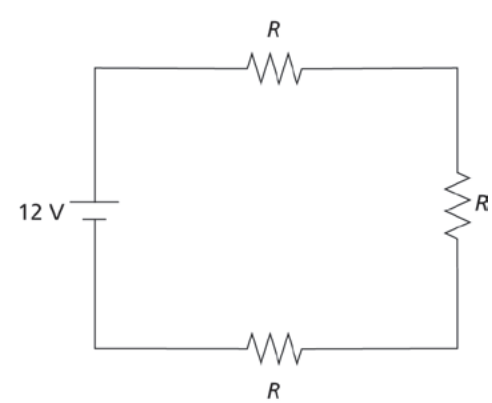
As more bulbs are added in series, the brightness of all the bulbs decreases because all these bulbs have to share the energy delivered from the battery to the charges. The current is the same through each bulb and the energy is shared equally by the bulbs if they are all identical.

4.b)

The two bulbs are wired in parallel because one burns out and the other stays lit, so the bulbs must be in parallel.

5.

An example of a circuit drawing is shown below. The bulbs share the energy from the battery equally, so each bulb will receive 4 V. The current going through each bulb is the same as the current leaving the battery. The current does not split off into different branches as it does for a parallel circuit.

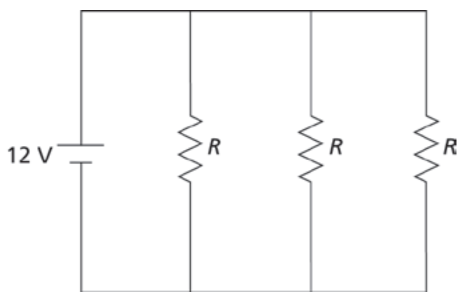


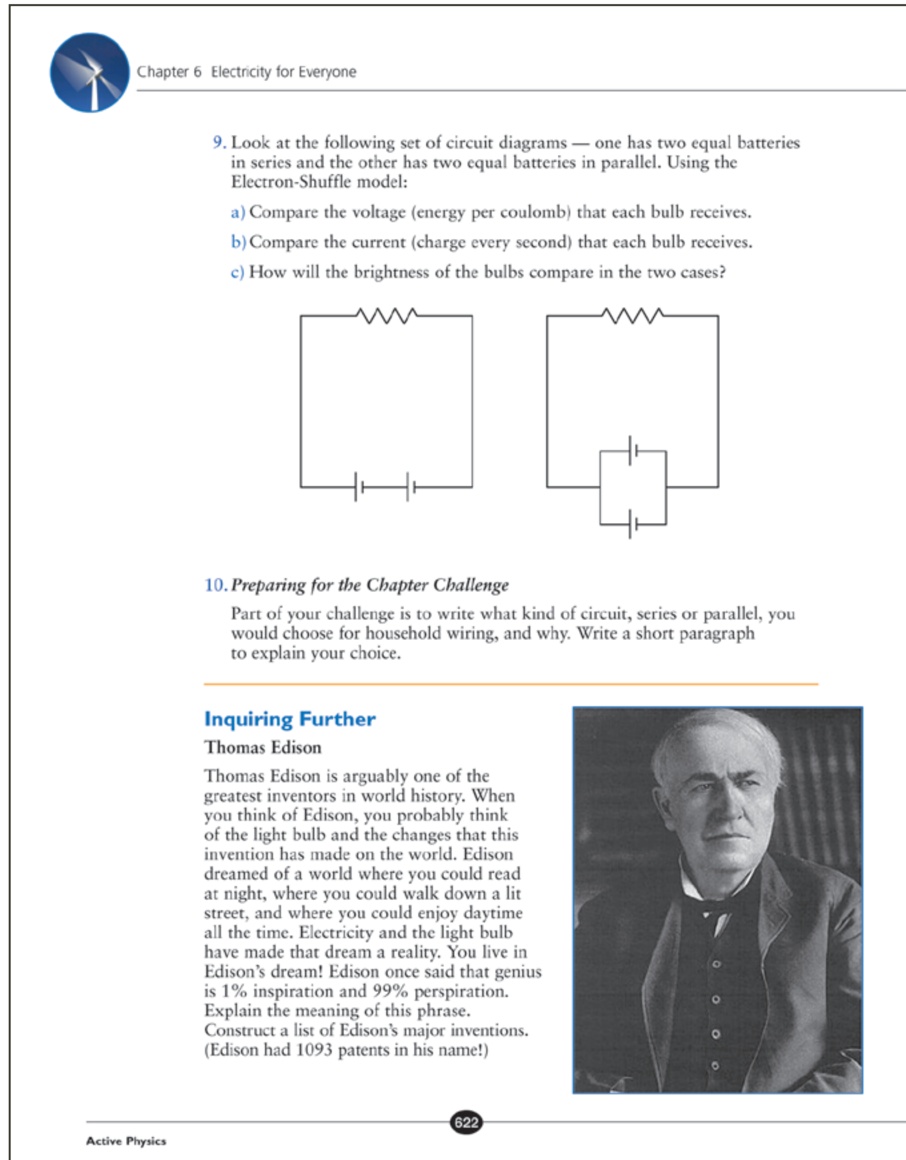
6.

Students should draw a circuit similar to the diagram on the next page. Because each bulb is directly connected to the battery, each bulb has the same voltage across

CHAPTER 6

it as the battery voltage, 12 V. The current leaving the battery must split up into three branches. Since the resistance is the same in each branch, each resistor has 1/3 the total amount of current leaving the battery.




Chapter 6 Electricity for Everyone

9. Look at the following set of circuit diagrams — one has two equal batteries in series and the other has two equal batteries in parallel. Using the Electron-Shuffle model:

a) Compare the voltage (energy per coulomb) that each bulb receives.

b) Compare the current (charge every second) that each bulb receives.

c) How will the brightness of the bulbs compare in the two cases?

10. *Preparing for the Chapter Challenge*

Part of your challenge is to write what kind of circuit, series or parallel, you would choose for household wiring, and why. Write a short paragraph to explain your choice.

Inquiring Further

Thomas Edison

Thomas Edison is arguably one of the greatest inventors in world history. When you think of Edison, you probably think of the light bulb and the changes that this invention has made on the world. Edison dreamed of a world where you could read at night, where you could walk down a lit street, and where you could enjoy daytime all the time. Electricity and the light bulb have made that dream a reality. You live in Edison's dream! Edison once said that genius is 1% inspiration and 99% perspiration. Explain the meaning of this phrase. Construct a list of Edison's major inventions. (Edison had 1093 patents in his name!)

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Active Physics

7.

If two identical batteries were placed in parallel in a circuit, and in the same direction, each would supply half the charges and the same amount of energy. These energy-carrying charges would then join together into a single branch where they would flow at the same rate through the bulb. Therefore the bulb would burn with the same brightness, as if there were one battery. Each battery is supplying the same amount of energy to the charges per second, and the rate at which the charge moves per second does not change.

8.

Each bulb will have the same voltage drop across them because each coulomb of charge leaving the battery heads to one of the bulbs and transfers its energy to it. In terms of the Electron Shuffle, the pretzel is not split up into pieces along the way to be shared. Rather the entire pretzel is dropped off at the light, regardless of its resistance. Because each bulb has a different resistance, each will require a different amount of current or charges going by per second. The lower the resistance the greater the current, or more charges per second will pass through that branch of the circuit.

9.a)

For the first circuit with the batteries in series, each coulomb of charge receives energy (a pretzel) from the first battery, receives more energy (another pretzel) from the second battery before, and then heads to the light bulb. When the coulomb of charge reaches the light bulb, it has two pretzels to give to the light bulb.

For the second circuit, each coulomb of charge must go through either the first battery or the second one. Only half the charge can go to the first battery and the other half of the charge can go to the second battery. The charges then join together on the same branch and head to the light bulb where they transfer their energy (a single pretzel) to the light bulb.

The series batteries supply each coulomb of charge with twice the energy that the parallel batteries supply.

9.b)

The current in each circuit flowing past the bulb is the same. The power (energy per second) being delivered is different. It is twice as much for the circuit with the batteries in series. In the circuit with the batteries in series, each coulomb of charges receives twice the amount of energy than the other circuit and then transfers this energy to the bulb.

9.c)

The bulb in the circuit with the batteries in series will be brighter since it is receiving twice the amount of energy in the same amount of time.

10.

Preparing for the Chapter Challenge

Students should select parallel circuits for household wiring and support this with the fact that if one device stops functioning all the other devices in the house will continue to function. Also, students should realize that this provides a consistent voltage drop across the device.

Inquiring Further

Thomas Edison

Students should explain the phrase *Genius is 1% inspiration and 99% perspiration.* They should show understanding that great ideas are only the beginning of a great feat.

Students should also construct a list of Edison's major inventions. Some of these are listed below. Doing an Internet search of his patents should provide a complete list.

Patents dealing with the telegraph: writing telegraphs, speaking telegraphs, printing telegraphs, parts of the telegraph machine.

Patents involving lighting: electric lights, electric lamps, and apparatus for these.

Other patents:

telephones

phonographs, recording phonographs, other sound devices

stencils and printing devices

motors and engines

preserving fruit

circuit devices (batteries, meters, etc.)

electric locomotive and electric railways

mechanisms for electric and gas-run cars

electric cars, cars

flying machine

kilns

kinetographic camera

moving picture apparatus

magnetic devices

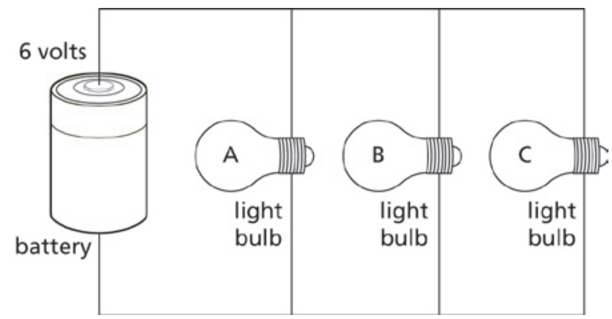
crushing and grinding devices

apparatus for reheating compressed air

NOTES

SECTION 3 QUIZ

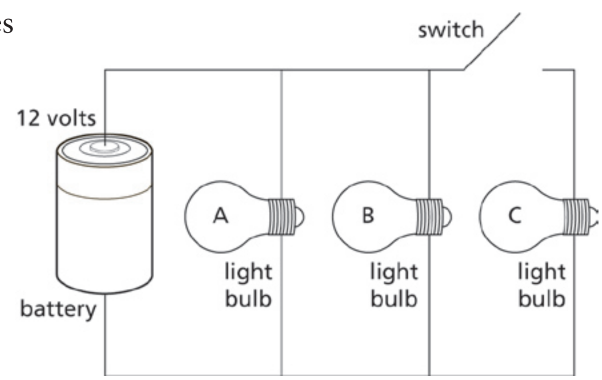
6-3c Blackline Master



1. The diagram to the right shows three light bulbs connected in parallel to a 6-V battery. What is the voltage across light bulb B?

   a) 1 V   b) 2 V

   c) 6 V   d) 12 V



2. In the diagram to the right, the battery provides 12 V to the circuit made up of three identical light bulbs. When the switch is closed the voltage across bulb A will be

   a) 12 V.

   b) 2 V.

   c) 6 V.

   d) 4 V.

3. In the diagram for *Question 2*, what would happen to the brightness of bulbs A and B when the switch is closed?

   a) Bulb A gets dimmer, and bulb B remains the same.

   b) Bulb B gets dimmer, and bulb A remains the same.

   c) Both bulb A and bulb B become dimmer.

   d) Bulbs A and B retain the same brightness.

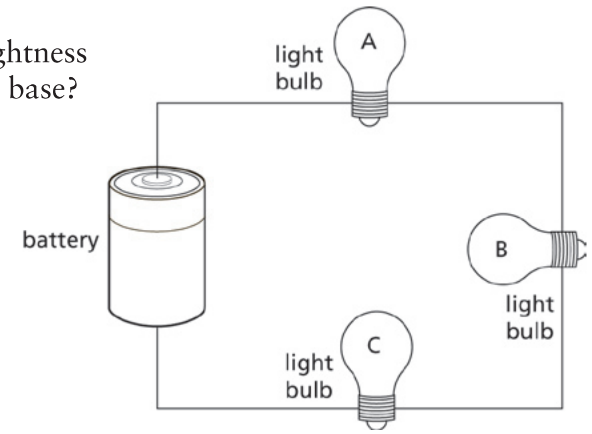
4. In the diagram to the right, what happens to the brightness of bulbs A and C when bulb B is unscrewed from its base?

    a) Bulb A goes out, and bulb C remains the same.

    b) Bulb C goes out, and bulb A remains the same.

    c) Both bulb A and bulb C go out.

    d) Bulbs A and C retain the same brightness.



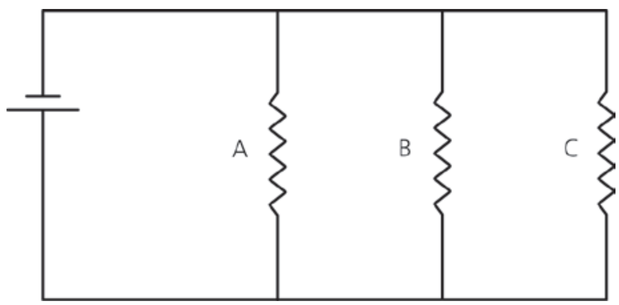
5. In the circuit shown to the right, each light bulb receives 3 A of current. How much current is supplied by the battery?

    a) 1 A

    b) 9 A

    c) 3 A

    d) 4.5 A



SECTION 3 QUIZ ANSWERS

1 c) The bulbs are in parallel and all are directly connected to the battery, so each bulb has a voltage drop equal to the voltage of the battery, or 6 V.

2 a) The bulbs are in parallel and all are directly connected to the battery, therefore each bulb has a voltage drop across it equal to the voltage of the battery, or 12 V.

3 d) This is because each bulb has the same voltage across it, and each has the same current since all the bulbs are identical.

4 c) If one bulb is not connected (either by burning out or by being unscrewed), then the circuit is no longer closed because the bulbs are in series.

5 b) The three bulbs are identical and in parallel; therefore, they equally share the current supplied from the battery. If 3 A is going through one bulb, then 3 A is going through each bulb, and the total current supplied by the battery is 9 A.

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