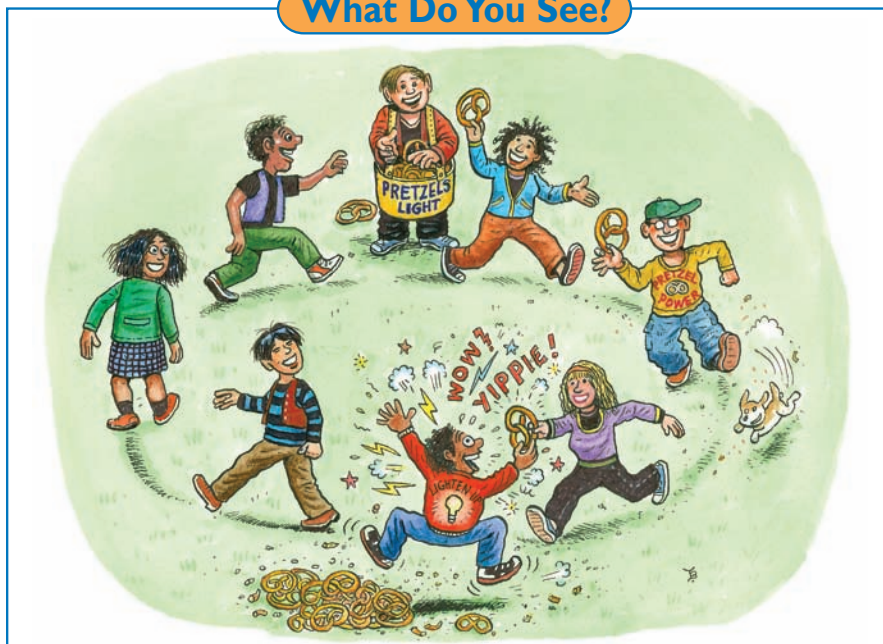




## Section 2

# Modeling Electricity: The Electron Shuffle

### What Do You See?



### Learning Outcomes

In this section, you will

- **Develop** a physical model for electric current and potential energy.
- **Use** this physical model to trace the flow of electric charges in series and parallel circuits.

### What Do You Think?

Electricity is one of the most widely used forms of energy. Every day, you use electricity to perform a multitude of tasks. Yet, like water and air, you probably tend to take electricity for granted.

- **What is electricity and how does it move through a circuit?**

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

### Investigate

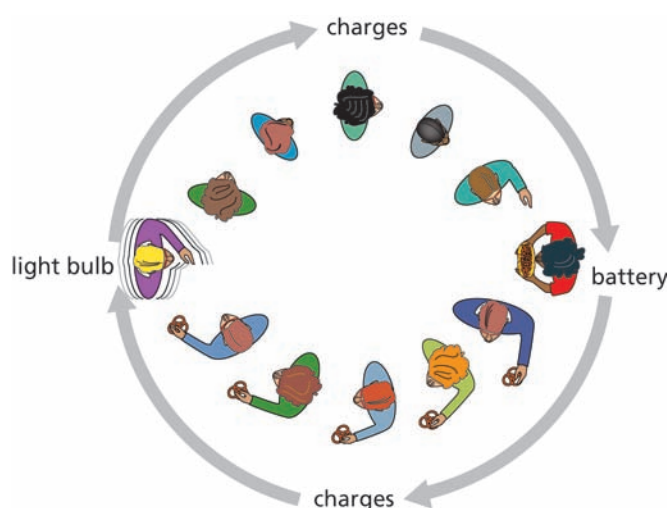
In this investigation, the class will create a model of an electric circuit by students playing the roles of the battery, the electric charge, and the load (light bulb). The model is not a perfect model — few seldom are. However, it will give you a better idea of what is happening in an electric circuit, as energy is passed from the battery to the electric charges to the light bulb.

### Part A: Modeling a Simple Circuit

1. Begin with a simple circuit containing a battery and a light bulb. One member of the class will role-play the part of the battery. This student will supply plenty of energy — a bag of pretzels. Food is the source of energy for your body and gets

used up as you play. A second student will play the part of the light bulb. For example, this person will have to shake, jump, dance, or move in some way. Other students will play the parts of the electric charges in the circuit.

2. Form a large circle of the electric charges as if you were all waiting in line for something. You should be facing the back of the charge in front of you.



3. Have the battery stand at one side of the circle ready to give out the energy, the particles sent out by the batteries to carry energy to the light bulb (a pretzel to each charge). Have the light bulb stand at the opposite side of the circle ready to receive and be energized by the charges as they come past (takes the pretzel). Each unit of charge, called a *coulomb*, will pick up one *joule* of energy (represented by one pretzel).
4. The teacher will act as the switch and tell you when to begin and when to stop. On a signal from the teacher (closing and opening the switch), the charges will begin and stop moving in a clockwise circle.

5. When the energized charge passes by the light bulb, it gives its energy to the light bulb by dropping the energy into the hand of the light bulb. The light bulb needs to show that it has become energized by getting “excited” (a little dance will do). The charge now must continue on its path back to the battery to pick up more energy, and repeat the cycle. Notice that only the energy gets used up, not the charges themselves. The charges continue on their path through the circuit.

You have now completed round 1 of the “Electron Shuffle.” In round 1, the battery (source of pretzels) gave each packet of charge (a student) a certain amount of energy (one pretzel). The charge then gave that energy to the light bulb (a student) who converted that electrical energy into light (a dance). The charges continue to the battery to get more energy and repeat the process.

6. In round 2 of the Electron Shuffle, the moves are the same. However, in round 2, there is a vocal part added. 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* (often shortened to amp) of current.” When the light bulb dances, he or she must occasionally say, “I just received one joule of energy from that coulomb of charge.”

- a) What are the variables that could change in the Electron Shuffle?



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

7. 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.
8. 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.
9. In your log, record how the Electron Shuffle would change under the following conditions:
  - a) There is a five-volt battery. (Remember: voltage is the energy for each coulomb of charge.)
  - b) The current is increased to three amps (Remember: current is the number of coulombs that pass through the battery every second.)
  - c) There is a two-volt battery.
  - d) The current is increased to five amps.
  - e) A two-volt battery is replaced with a four-volt battery.
  - f) The current increases from two amps to three amps.

### Part B: Modeling a Series Circuit

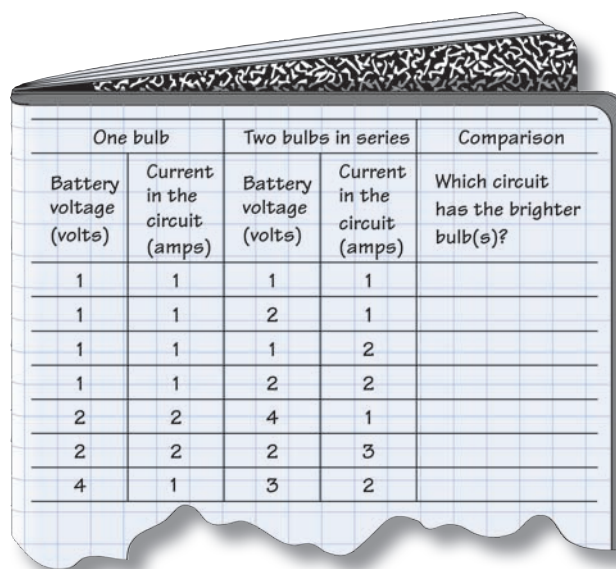
1. You will now investigate what happens when there are two light bulbs in the circuit.
  - a) Describe how the Electron Shuffle could be performed if the circle included two light bulbs, one after the other, and each light bulb must get some energy.
2. Set up the Electron Shuffle circuit as before with a one-volt battery. This time use two light bulbs, one after another, in a series. When an electric charge reaches the first light bulb it will need to drop some of its energy there, but

hold onto some of its energy for the next light bulb. All electrons go through the first light bulb and then through the second light bulb. The exact amount of energy dropped at each light bulb depends on the light bulbs themselves. This property is called their electrical resistance. For now, assume that the light bulbs are identical. They need to share equally the energy of each charge. Each charge will drop half of its energy with each bulb (break the pretzel in half). Once the charge has dropped its remaining energy at the second light bulb, it will continue on its path back to the battery for more energy.

- a) Since the brightness of a bulb depends on how much energy is used up in the bulb during a given time, how would the brightness of each of the two bulbs in series compare with the brightness of a single bulb hooked up to the battery?
3. In your log, record how the Electron Shuffle would change under the following conditions:
  - a) Four identical light bulbs are placed in series.
  - b) The series circuit of two light bulbs has the battery replaced with a three-volt battery.
  - c) The circuit of two light bulbs has a larger current.
  - d) The light bulbs are not identical. The first light bulb requires more energy than the second light bulb.
4. In the first rounds of the Electron Shuffle, the bulb received one joule of energy every second. This was modeled by a one-volt battery providing a joule of energy for each coulomb of charge. The charges flowed at the rate of one amp or one coulomb per second. The number of joules per second that a bulb receives determines how bright

the bulb is. This is referred to as the power of the bulb. Power is measured in *watts*. One watt is equal to one joule per second. When you use a 100-W (watt) bulb in your home, it is using 100 J (joules) of energy every second. A 40-W bulb is using 40 J of energy every second. If the bulbs are manufactured the same way and have the same efficiency, the 100-W bulb is much brighter than the 40-W bulb.

- a) Compare a circuit with one bulb and two identical bulbs in series by completing a table similar to the one on the right in your log. The one bulb is not identical to the pair of identical bulbs.



One bulb		Two bulbs in series		Comparison
Battery voltage (volts)	Current in the circuit (amps)	Battery voltage (volts)	Current in the circuit (amps)	Which circuit has the brighter bulb(s)?
1	1	1	1	
1	1	2	1	
1	1	1	2	
1	1	2	2	
2	2	4	1	
2	2	2	3	
4	1	3	2	

## Physics Talk

### A MODEL FOR AN ELECTRICAL CIRCUIT

Have you ever felt really exhausted at the end of a very strenuous period of activity such as a long soccer practice? Your muscles are really tired because you have “burned” a lot of energy in them. When you get this tired feeling, you need to “recharge your batteries,” so to speak, with the energy you get from eating food. Electric circuits are like that in a way. As electric charge moves around in a circuit, it picks up energy at the battery (like you eating food) and loses or “drops” its energy at devices like light bulbs or appliances (like you using that energy to play hard). Just as your blood carries energy to your muscles, electric charge carries energy in a circuit. Notice that in this process, only the energy gets used up, not you or your blood. In an electric circuit, the electric charge does not get used up either, only its energy.

Sometimes, when you are not ready to use the energy right away, your body stores the energy. This gives you the potential to use the energy later. That is why it is called **potential energy**. An electric charge can do that too. **Electric potential energy**, or simply **electric potential** for short, is the energy of an electric charge waiting to be used by some load.

Electrical circuits have **batteries**, **resistors** (for example, light bulbs), and wires. The battery provides the energy for each **coulomb** of electrical charge that will move in the circuit. The rate of flow of this charge is the **current**.



### Physics Words

**potential energy:** the energy of a system due to its positions in a force field.

**electric potential energy:** energy per unit charge.

**battery:** an electronic device serving as a source of electric power.

**resistor:** a conductor whose function is to control the current in a circuit.

**coulomb (C):** the SI unit of charge; one coulomb (1 C) is approximately equal to the charge of a lightning bolt, the charge of  $6.25 \times 10^{18}$  electrons.

**current:** the rate of flow of electric charge; the number of coulombs passing a point in one second.



**Physics Words**

**voltage:** the energy (in joules) for each coulomb of charge.

**volt (V):** the SI units of electric voltage or potential; one volt is equal to one joule per coulomb ( $1 \text{ V} = 1 \text{ J/C}$ ).

**joule (J):** the SI unit of energy.

**ampere:** the SI unit of current; one ampere is the flow of one coulomb/second ( $1 \text{ A} = 1 \text{ C/s}$ ).

**series circuit:** a circuit in which the current flows in a single line, so that all resistance in the circuit (light bulbs, etc.) has the same current flowing through them.

**watt (W):** the SI unit of power; one watt is equal to one joule per second ( $1 \text{ W} = 1 \text{ J/s}$ ).

**Checking Up**

1. How is the unit of current (the ampere) related to the unit of charge (the coulomb)?
2. In an electric circuit, what happens to the energy of each charge?
3. If a circuit has four identical light bulbs, and a battery that provides 24 V, how many volts are lost (dropped) to each light bulb?
4. A light bulb is connected in a circuit. List two things that could be increased to make the bulb glow more brightly.

The Electron Shuffle is a model for electrical circuits that can help you understand what happens in a circuit as the **voltage**, current, or number of resistors is changed.

The Electron Shuffle models the electrical circuit by making the comparisons in the table to the right.

All of the energy of the charges is “dropped” into the resistors of the circuit. Suppose the voltage of the battery

is six **volts** (6 V). That means that the battery provides 6 V, or six **joules** for each coulomb of charge. All 6 V will be provided to the single light bulb in the circuit. This can happen often if there is a large current. The current is measured in **amperes** or **amps** (A). A 2-A current has two coulombs of charge passing a point every second.

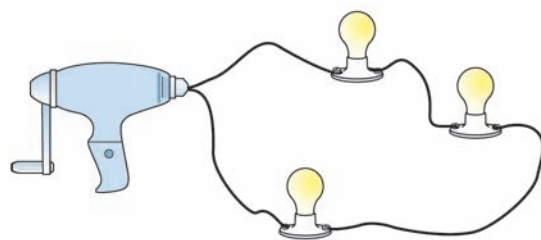
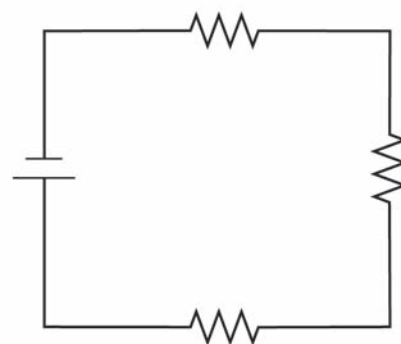
**A Series Circuit**

There is only one way to connect a single light bulb in a circuit. There is more than one way to connect two or more bulbs in a circuit. In this section, you connected the bulbs in a series, to make a **series circuit**. In a series circuit, the electric current has only a single path that it can follow.

If the battery provides 6 V and the circuit contains three identical resistors in series, then each resistor will get 2 V. The total voltage provided to the resistors is equal to the voltage of the battery:  $2 \text{ V} + 2 \text{ V} + 2 \text{ V} = 6 \text{ V}$ . Since each coulomb of charge goes through the first resistor, then the second resistor, and then the third resistor, the current (flow of charge) is the same throughout the circuit.

People are concerned with the brightness of a light bulb. The brightness of a bulb is dependent on the energy per second that the bulb receives. The energy per second is also referred to as the power delivered to the bulb and is measured in **watts** (W). One watt is equivalent to a flow of energy of one joule per second ( $1 \text{ W} = 1 \text{ J/s}$ ). You can increase the brightness of a bulb by increasing either the energy/coulomb (voltage) or the rate the coulombs are delivered (current) or both.

Electron Shuffle	Electrical circuit
bag of pretzels	battery
students delivering pretzels	charges
student receiving pretzels	light bulb
number of pretzels	voltage ( $1 \text{ V} = 1 \text{ J/C}$ )
number of students passing a point every second	current ( $1 \text{ A} = 1 \text{ C/s}$ )
number of pretzels per second received by the student	power—brightness of bulb ( $1 \text{ W} = 1 \text{ J/s}$ )

**Diagram of a Series Circuit****Schematic Diagram of a Series Circuit**

## Active Physics

+Math	+Depth	+Concepts	+Exploration
	♦	♦	

*Plus*

### Improving the Electron-Shuffle Model

In describing a series circuit consisting of a battery and three light bulbs, it was assumed that all the energy of the charges was “dropped” into the light bulbs. If a 6-V battery was used, then each coulomb provided has two joules to each of the three light bulbs. In this model, the wires were assumed to have no resistance and none of the energy was required to move the charges through the wires. That is not true. The wires are made of materials that do not use much of the energy, but they do use some of the energy. In your Electron-Shuffle model, it is as if a few crumbs of the pretzel must be provided to

each wire in the circuit. A few additional crumbs are required to move the electrons through the battery as well.

1. Write a description of how to perform the Electron Shuffle that includes the voltage drops through each wire and the battery.
2. In a series circuit, all the light bulbs do not have to be identical. Calculate the voltage drops in each of three light bulbs if one of the bulbs requires twice the voltage of the other two. The voltage of the battery is 12 V.
3. How does the solution to *Question 2* change, if each of the wires requires 0.1 V?

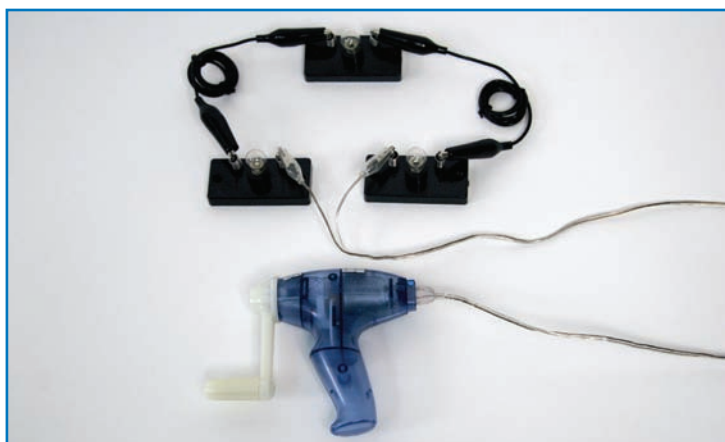
### What Do You Think Now?

At the beginning of this section, you were asked:

- What is electricity and how does it move through a circuit?

Now that you have completed this section, how would you answer the question now?

What else do you think you need to know to answer the question more completely?





## Physics

## Essential Questions

**What does it mean?**

How do voltage and current relate to the brightness of a bulb?

**How do you know?**

How would you know if the Electron-Shuffle model is a useful model of current flow in circuits?

**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 describe and better understand many phenomena. A description of how electricity works is called a “model.” The Electron Shuffle is a model that helps support the description of how electricity works. Is a scientific model the same thing as reality, or is it just a convenient (and sometimes limited) description of reality?

**Why should you care?**

Part of your challenge is to create an outline for a training manual that will help people become acquainted with electrical use. Explain voltage and current using the Electron-Shuffle model and without using the Electron-Shuffle model.

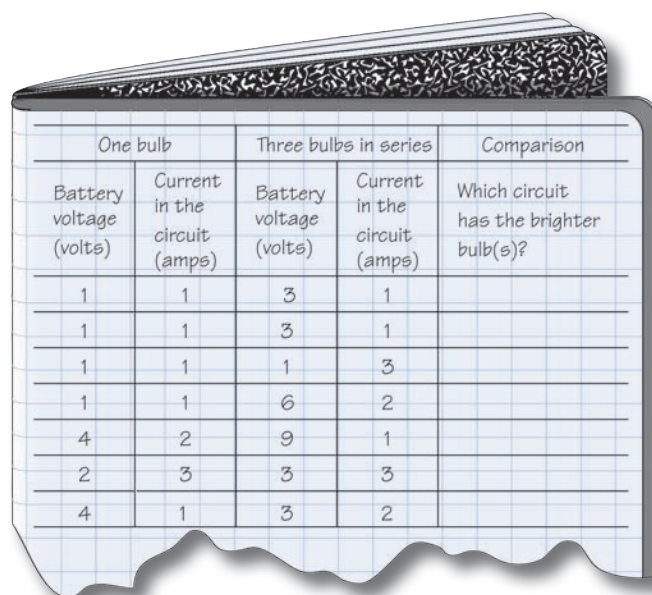
**Reflecting on the Section and the Challenge**

In this section, you developed a concrete model for the flow of current in a series circuit. You modeled how the voltage of the battery provides energy to each light bulb in the circuit. You have also introduced new vocabulary words in this section. You will get an opportunity to practice this vocabulary in this chapter. You may want to use the Electron Shuffle in your training manual to help others learn about electric circuits. Your wind generator will provide 120 V of electricity, which is identical to the 120 V in your home. This allows all home appliances to work properly with your wind generator.

**Physics to Go**

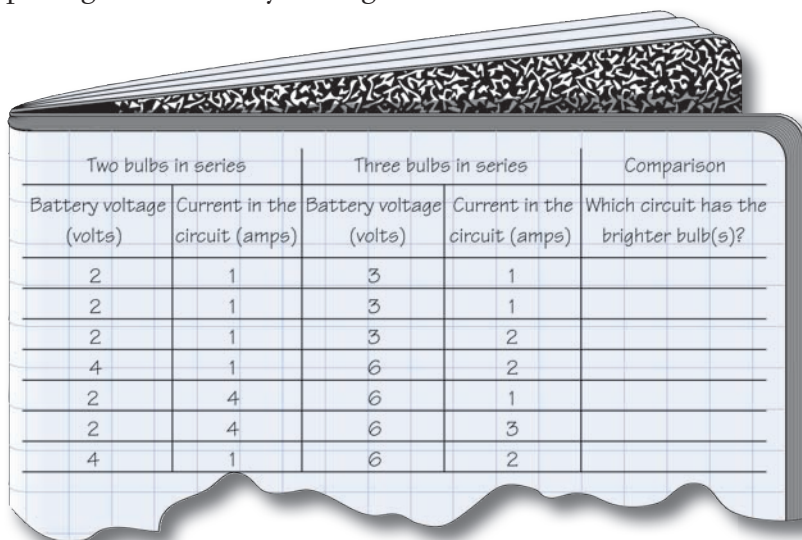
1. Make a chart with two columns, the first one labeled “Word” and the other labeled “Meaning.”
  - a) In the first column make a list of “electricity words.” These are words that you have heard used in connection with electrical units of measurement, parts of electrical systems, or how electricity behaves.
  - b) In the second column write what you think each word means or describes.

2. Suppose you had two one-volt batteries in series.
- How many pretzels would a “charge” pick up passing through both batteries in the Electron Shuffle?
  - Predict what would happen if a light bulb were to be connected with two batteries in series and explain using your physical model of current and voltage.
  - Would the light bulb be brighter? (Remember: Brightness is dependent on the energy per second delivered to the bulb.)
3. Compare a circuit with one bulb and three identical bulbs in series by completing the table in your log:



One bulb		Three bulbs in series		Comparison
Battery voltage (volts)	Current in the circuit (amps)	Battery voltage (volts)	Current in the circuit (amps)	
1	1	3	1	
1	1	3	1	
1	1	1	3	
1	1	6	2	
4	2	9	1	
2	3	3	3	
4	1	3	2	

4. Compare a circuit with two bulbs and three identical bulbs in series by completing the table in your log:



Two bulbs in series		Three bulbs in series		Comparison
Battery voltage (volts)	Current in the circuit (amps)	Battery voltage (volts)	Current in the circuit (amps)	
2	1	3	1	
2	1	3	1	
2	1	3	2	
4	1	6	2	
2	4	6	1	
2	4	6	3	
4	1	6	2	