# Section 3

## Series and Parallel Circuits: Lighten Up



## 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.

#### Part A: Modeling a Parallel Circuit

 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, <sup>1</sup>/<sub>3</sub> of the charges will go through the first bulb, <sup>1</sup>/<sub>3</sub> of the charges will go through the second bulb, and <sup>1</sup>/<sub>3</sub> 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.



- 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.
- Sc) A circuit of three new light bulbs had a larger current with the original onevolt battery.
- d) Four identical light bulbs were placed in parallel with a six-volt battery.
- Se) 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.

- 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.



## **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



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.

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#### **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.).





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

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

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

**ohm:** the SI unit of electrical resistance; the symbol for ohm is  $\Omega$ .

## **Checking Up**

- 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?

#### 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 x 10<sup>-19</sup> C.
  In order to get a single coulomb of charge, it would take 6.25 x 10<sup>18</sup> 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).

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## **More About Parallel Circuits**

- 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?







#### 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 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.





- 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!)

