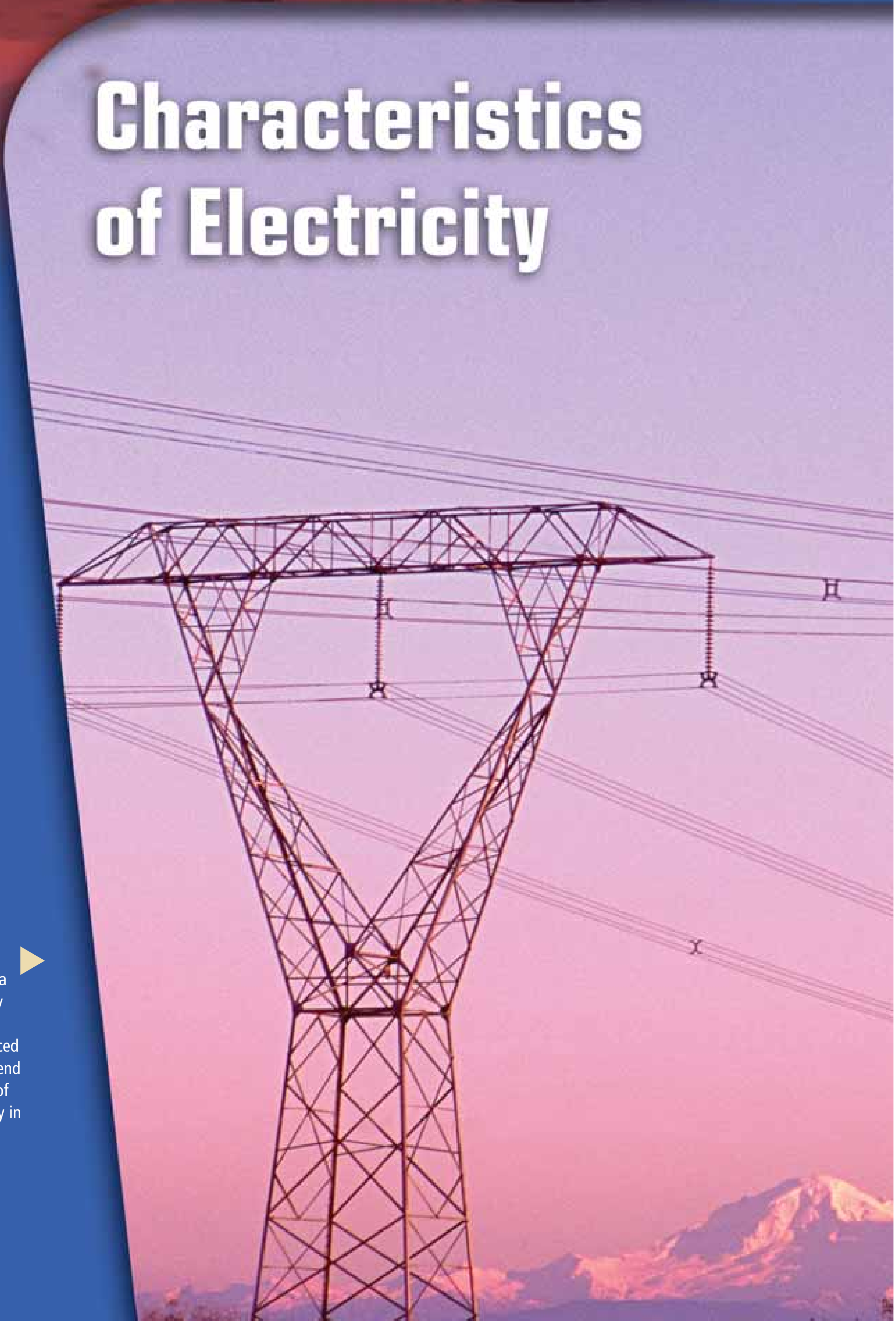
UNIT

3 Characteristics of Electricity



High power transmission lines like these near Vancouver are a familiar sight. Electrical energy has allowed us to develop technologies that have enhanced our way of life. Engineers depend on a scientific understanding of the characteristics of electricity in order to control this valuable resource.

Key Ideas

7 Static charge is produced by electron transfer.

8 Ohm's law describes the relationship of current, voltage, and resistance.

9 Circuits are designed to control the transfer of electrical energy.

Getting Started

Hybrid electric buses are already in use in Victoria and Kelowna. These buses use a quiet electric motor to add to the efficiency of their diesel engine and to reduce fuel consumption and pollution.

Hybrid vehicles have been transporting people and goods for many years. A vehicle is called a hybrid if it uses more than one source of energy. For example, mopeds are bikes that have a small engine and pedals. Mopeds are hybrid vehicles because you can use the energy in both gasoline and your legs. Diesel-electric hybrid motors have been used in train locomotives and submarines for decades.

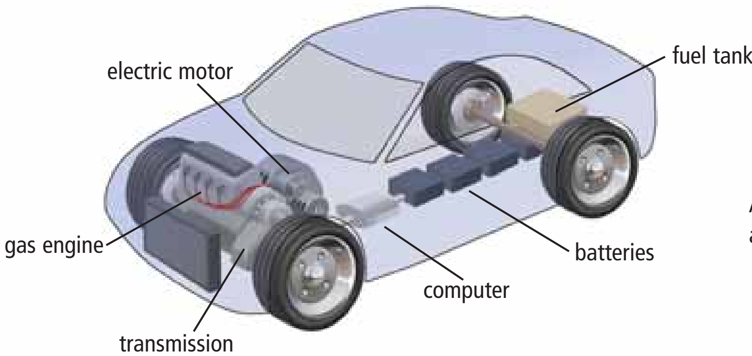
There are several different designs for hybrid cars using a gasoline motor and an electric motor. One design, called a parallel hybrid, uses a small gasoline engine to power the car during most driving. A computer determines when to use the gasoline motor, the electric motor, or both motors. Hybrid cars are very fuel efficient and, more importantly, they reduce air pollution.

At present, electric-only vehicles have a very limited range before they must be recharged. More than 100 kg of batteries are needed to store as much energy as what is provided by 1 L of gasoline. However, as battery and fuel cell technology continues to improve, the reality of a practical electric-only vehicle becomes more certain.

As oil prices continue to rise and environmental concerns are addressed, using electricity for transportation will become even more important. The next generation of vehicles may be hybrid or electric. Either way, electricity and electric motors are going to play a big role in the future of transportation.

internet connect

To find out more about electric and hybrid vehicles, go to **www.bcscience9.ca**.



A hybrid car has a gasoline engine and an electric motor.

A New Spin on Motors

Find Out ACTIVITY

In this activity, you will build a simple electric motor.

Safety

Materials

- small neodymium disk magnet
- C or D cell
- iron nail
- 20 cm length of braided copper wire (stripped on both ends)

What to Do

1. Place the neodymium disk magnet on the head of the nail. Hold the battery vertical with the positive terminal on top. Suspend the nail from the negative terminal of the battery.
2. Hold one end of the copper wire onto the positive terminal of the battery.
3. Gently touch the other end of the copper wire to the side of the suspended nail.

What Did You Find Out?

1. Describe the motion of the nail when it was in contact with the copper wire.
2. Look closely at the location where the wire contacts the nail. What do you observe?
3. What do you think would happen if you used a more powerful battery?
4. Most electric motors do not contain nails. Based on your observations, what components might a commercial electric motor contain?

Chapter 7

Static charge is produced by electron transfer.

At the end of a hot, muggy summer day in Kelowna, dark storm clouds form overhead. Suddenly, a bright fork of light streaks through the sky. A deafening roar of thunder quickly follows. A few seconds later, another lightning bolt illuminates the night.

Lightning looks like a giant spark. The sparks you create when you shuffle across the floor and touch metal are tiny when compared to lightning. By studying sparks, both big and small, scientists have gained an understanding of the properties of electric charge. When the large amount of energy stored in electric charge is controlled, it can be used for many different purposes.

What You Will Learn

In this chapter, you will
- **explain**, with illustrations, the transfer of static charges in various materials
- **describe** the types of static charges
- **state** the three laws of static charge
- **explain** how the amount of charge and distance of separation affect the force between charges

Why It Is Important

Static electricity is the oldest known form of electricity. All of our modern uses of electricity are based on our understanding of the properties of static charges.

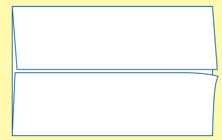
Skills You Will Use

In this chapter, you will
- **explain** how charged objects interact
- **communicate** your knowledge of static charge
- **model** how static charges are distributed on the surface of an object
- **detect** static charge using an electroscope

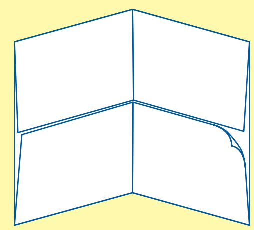
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 7.

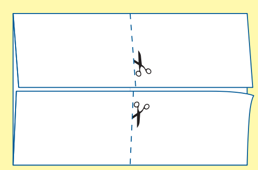
STEP 1 **Make** a shutterfold using one sheet of paper.



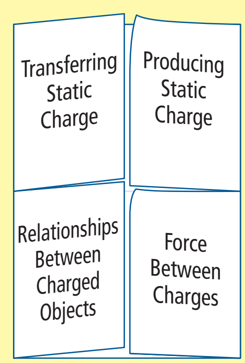
STEP 2 **Fold** the shutterfold in half like a wallet. **Crease** well.



STEP 3 **Open** the Folable and **cut** the small, side tabs in half. These cuts will form four doors on the front.



STEP 4 **Label** the Foldable as shown.



Show You Know As you read the chapter, take notes under the appropriate tabs to demonstrate what you have learned about static electricity.

7.1 Static Charge

Static electricity is electric charge that can be held in one place. Electrons have a negative charge. Protons have a positive charge. An atom or material that has an equal number of electrons and protons is called neutral. When an atom or material becomes charged, it is because electrons transfer in or out of the atom or material. An insulator is a material that does not allow electric charges to move easily. A conductor is a material in which electric charges can move more easily. The unit for measuring charge is the coulomb.

Words to Know

acetate
conductors
coulomb
electrons
grounding
insulators
static charge
Van de Graaff generator

When you think of the word "electricity," you may think of modern devices, such as computers, televisions, and telephones. However, the earliest studies of electricity date back to ancient Greece. Scholars observed that when they rubbed certain materials, such as amber, with wool or fur these materials would attract small bits of lint and dust. When an object becomes "charged" by a rubbing process, it is said to possess a static charge. The word "static" means stationary or not moving. **Static charge**, also known as static electricity, refers to electric charges that can be collected and held in one place.

You have probably experienced the same effect that the early Greeks did, though perhaps not by rubbing amber with fur. When you take clothes out of the dryer, they often cling together. On dry winter days, some clothes will get a static charge and cling to your body. After you comb your hair, it can fly up and separate due to static charges in your hair and your comb. Lightning occurs when static charges that build up during a thunderstorm are released. You may have created your own mini-lightning bolt by shuffling across the carpet and touching something made of metal.

Did You Know?

Lightning contacts the ground at a speed of approximately 220 000 km/h. Earth is struck by lightning an average of 100 times every second.

7-1A Detecting Static Charge

Find Out ACTIVITY

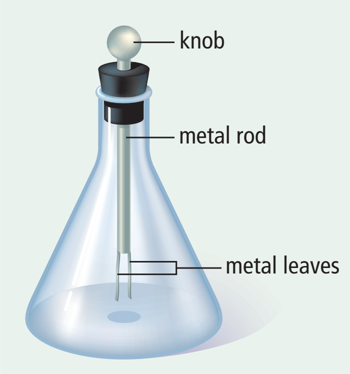
Early scientists had no accurate method of detecting static charge. The most common method was to touch the object and observe the physical sensations the charge caused. The amount of discomfort caused by the shock was proportional to the amount of static charge on the object. Then in 1748, the French physicist and clergyman Jean Nollet invented the electroscope, a device that can be used to detect static charge. In this activity, you will use an electroscope to detect static charge on a balloon.

Materials

- electroscope
- inflated balloon
- wool cloth

What to Do

1. Note the position of the leaves inside the electroscope.
2. Rub an inflated balloon with the wool cloth.



An electroscope

3. Touch the balloon to the knob of the electroscope. Observe the position of the leaves.
4. Remove the balloon from the electroscope. Observe the position of the leaves.
5. Touch the knob of the electroscope with your finger. Observe the position of the leaves.
6. Rub the balloon with the wool cloth again and briefly touch the wool cloth to the knob of the electroscope. Observe the position of the leaves.

What Did You Find Out?

1. Compare the position of the leaves while the balloon was touching the knob of the electroscope with the position of the leaves when the balloon was removed.
2. How did touching a charged electroscope with your finger affect the leaves? Explain what you think might have happened to this charge.
3. Did the balloon and the wool have the same effect on the electroscope?

Early Theories of Electricity

In early studies of static electricity, scientists hypothesized that there are two "electricities." They observed that rubbing materials such as amber produces one kind of electricity and rubbing materials such as glass produces a different kind. The American scientist, statesman, and inventor Benjamin Franklin (Figure 7.1) hypothesized that there is only one kind of "electrical fluid," as he called it. He explained some different experimental situations that resulted in a build-up, or excess, of this electrical fluid. He called the build-up of electrical fluid "positive" or "+," and he called the shortage of electrical fluid "negative" or "−."

Scientists still use plus and minus to refer to the electrical charge on an object, but the meaning is not the same as Franklin's, as you will see on the next page. Over the last two centuries, scientists have developed theories about electricity based on particles.

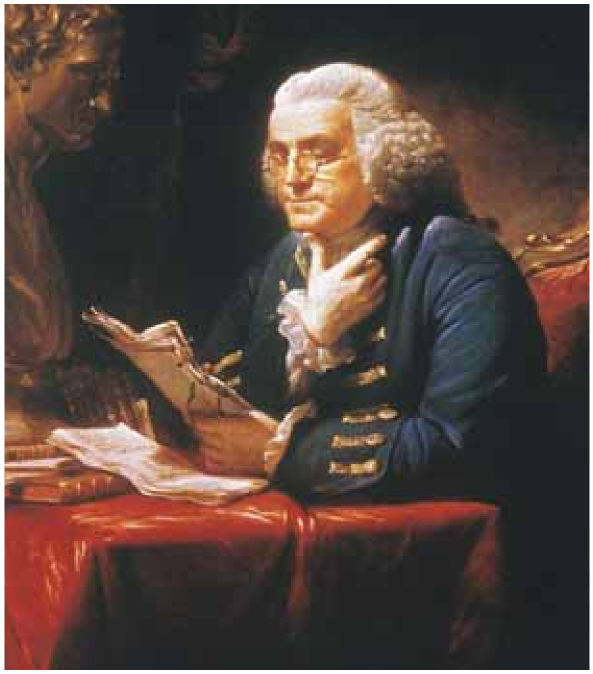


Figure 7.1 Benjamin Franklin (1706–1790)

Connection

Section 1.3 has more information on atoms, electrons, protons, and neutrons.

Positive and Negative Charge in the Atom

You may remember from earlier science studies that all matter is made of tiny particles called **atoms**. Figure 7.2 shows a simplified model of an atom. At the centre of the atom is the nucleus, which contains particles called neutrons and protons. Neutrons do not have a charge. **Protons** have a positive charge, so the nucleus is positively charged. Around the positive nucleus are much lighter particles called **electrons** that have a negative charge. If the number of positive charges equals the number of negative charges, the atom is uncharged or **neutral**.

In a solid material, the positive nucleus vibrates but remains in the same position at the centre of the atom. The negative electrons are outside the nucleus and can move quite easily. Only the electrons can move in the solid material, so *all solid materials are charged by the transfer of electrons.*

- If an electron is *removed* from a neutral atom, a negative charge has been taken away. The atom then has more positive charge than negative charge. An atom or object that has more protons than electrons has an overall positive charge.
- If an electron is *added* to a neutral atom, then the negative charge increases. The atom then has more negative charge than positive charge. An atom or object that has more electrons than protons has a negative charge.

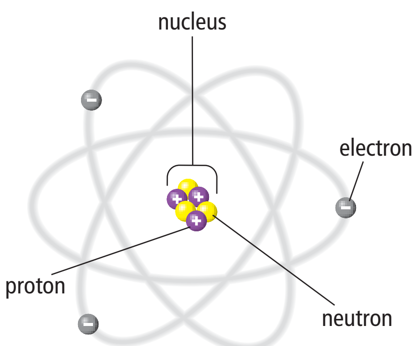


Figure 7.2 An atom

The movement, or transfer, of electrons from one atom to another changes the charge on the atom. When an atom loses electrons, the atom becomes more positive. When an atom gains electrons, the atom becomes more negative.

Friction and Electron Transfer

Friction occurs when objects rub against each other. The friction between two objects can result in one object losing electrons and the other object gaining electrons. Figure 7.3A shows a neutral acetate strip and a neutral paper towel. **Acetate** is a type of plastic used in photographic film and overhead transparencies. If the acetate strip is rubbed with the paper towel, electrons will move from the paper towel onto the acetate strip. The acetate strip will now have more negative charges than positive charges. The paper towel, which lost the electrons, will have more positive charges than negative charges. The result is that the acetate strip is charged negatively and the paper towel is charged positively. (Figure 7.3B).

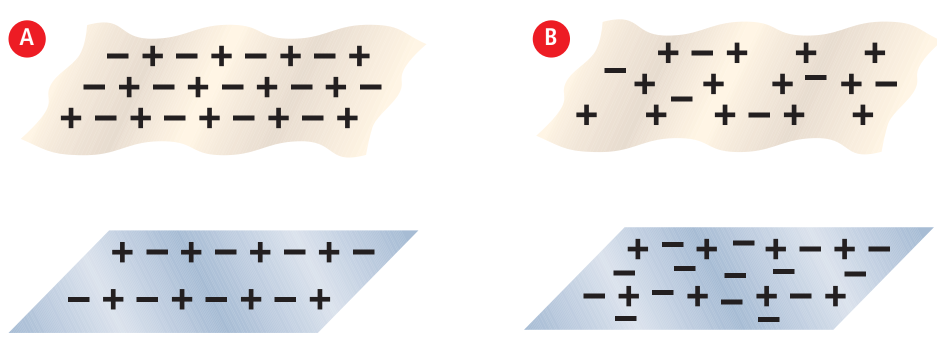


Figure 7.3 (A) The acetate strip and paper towel are both neutral. As you rub the acetate strip with the paper towel, electrons transfer from the paper towel to the acetate strip. (B) The acetate strip becomes negatively charged overall. The paper towel becomes positively charged overall.

Visualizing Charge Transfer

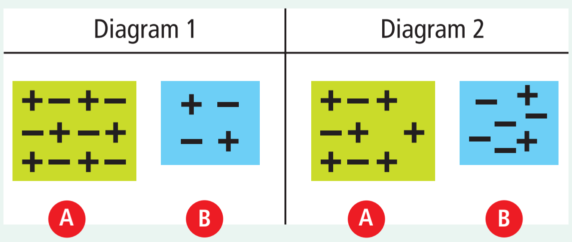
Think About It

In Part 1 of this activity, you will use diagrams to answer questions about the movement, or transfer, of charge. In Part 2 of this activity, you will draw diagrams that demonstrate positive, negative, and neutral objects.

What to Do

Part 1

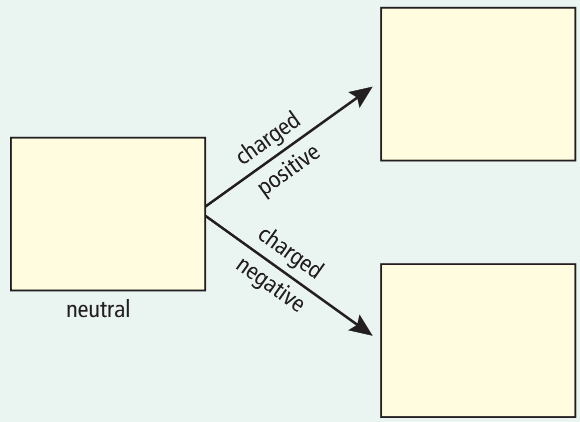
Use the following diagrams to answer the questions that follow. Diagram 1 shows two objects, A and B, that are initially neutral. Diagram 2 shows the same objects after they have been rubbed together.



1. How does Diagram 1 show that A and B are both neutral?
2. Diagram 2 shows A and B after they have been rubbed together.
   (a) Are they still neutral? How do you know?
   (b) What is the charge on A?
   (c) What is the charge on B?
3. Which charge, positive or negative, was transferred?
4. How does the location of the positive charges in Diagram 2 compare with their location in Diagram 1?
5. Count the total number of negative charges (electrons) in Diagram 1. Compare that number to the total number of negative charges in Diagram 2. Were any electrons lost or gained in this charging process?

Part 2

6. Copy the following diagram into your notebook.



7. In your notebook, draw positive (+) and negative (−) signs in each object to demonstrate:
   (a) a neutral object being charged positive
   (b) a neutral object being charged negative
8. If you compared your correct diagrams with a classmate's correct diagrams, would they have to look identical? Explain.

Reading Check

1. The atom consists of three smaller particles.
   (a) Give the name and charge of each of these particles.
   (b) State where in the atom each of the three particles is found.
2. When is an atom uncharged or neutral?
3. How are solid materials charged?
4. What is the overall charge when an atom has more protons than electrons?
5. What happens to the charge on an atom when it gains electrons?
6. What can happen to electrons during friction?

Did You Know?

Liquids can also be influenced by static charges, such as by holding a charged object near a gentle stream of water from a tap.

Insulators and Conductors

If you held a neutral plastic rod in the middle and rubbed just one end of the rod with a paper towel, the end you rubbed would become charged. The other end of the plastic rod would remain neutral. The electrons you added to the neutral plastic by friction will stay in one place.

Materials that do not allow charges to move easily are called electrical **insulators** (Figure 7.4A). Electrons removed from one location on an insulator are not replaced by electrons from another location. Glass, plastics, ceramics, and dry wood are good examples of insulators.

Materials that allow electrons to travel freely are called electrical **conductors** (Figure 7.4B). If a charged acetate strip is touched to one end of a metal rod, the excess electrons on the acetate will spread evenly over the entire length of the rod. Metals are good conductors because the atoms in metals have at least one electron that is easily transferred. These electrons are sometimes called "free electrons" because they are free to move throughout the conductor.

Since static electricity is charge that is held very nearly fixed in one place, only insulators can retain a static charge. Conductors such as copper and aluminum allow charge to flow.

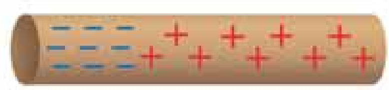


Fig 7.4A Charges on insulator

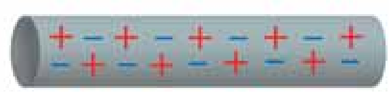


Fig 7.4B Charges on conductor

Measuring Charge

Suppose we start with a neutral object. That means the object has exactly the same number of electrons and protons. The smallest negative charge this neutral object could have is if it gained one electron. The smallest positive charge a neutral object could have is if it lost one electron.

The unit of electric charge is called the **coulomb** (C), named after the French physicist Charles Augustin de Coulomb (1736–1806). It takes the addition or removal of 6.25×10^{18} electrons to produce 1 C of charge. A typical lightning bolt can carry 5 C to 25 C of charge. That penny in your pocket has about 1 million coulombs of negative charge. Why then does that penny not give you a huge static shock? Luckily, the penny also has about 1 million coulombs of positive charge. Since the amount of negative charge is equal to the amount of positive charge, the penny is neutral.

Suggested Activity

Find Out Activity 7-1C on page 255

Generating Static Charge

Charging an object by using friction occurs naturally in many situations in nature. For example, the static charge in the clouds that produce lightning is due to friction as hot air rises rapidly in cloud banks. Scientists are studying how friction between ice crystals in storm clouds produces a large static charge. In order to study static charge in lightning and in other phenomena, scientists needed a device that could produce large amounts of static charge in the laboratory.

The first successful "lightning" machine was invented in 1929 by American physicist Robert Van de Graaff. The **Van de Graaff generator** uses friction to produce a large static charge on a metal dome as shown in Figure 7.5. A moving belt produces a static charge at the base of the generator. The belt carries this charge to the top where it collects on the dome (Figure 7.6).

internet connect

Beyond the study of static electricity, the Van de Graaff generator has applications with X-ray tubes, food sterilization, and nuclear physics experiments. Go to **www.bcscience9.ca** to learn more about these applications.

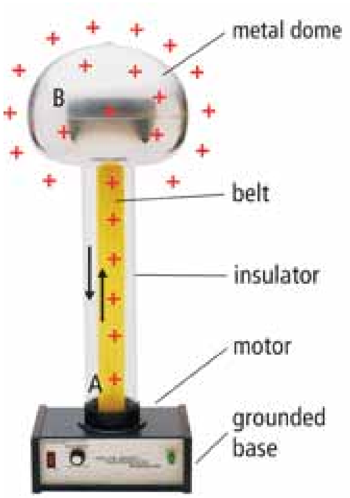


Figure 7.5 Charge is transferred onto a moving belt at the base of the generator, position A, and is transferred off the belt onto the metal dome, position B.

Figure 7.6 A Van de Graaff generator produces enough static charge to give a student a "hair raising" experience.

Applications of Static Electricity

Although static electricity may sometimes be unwanted, it has many valuable uses in technology. For example, plastic sandwich wrap clings because of static charge. Static electricity is also used to decrease air pollution. Devices in chimneys use static charge to remove small particles of smoke and dust that would normally flow out into the air. Air ionizers that freshen the air inside homes work in a similar way. The ionizers remove electrons from particles in the air, and the charged particles are then attracted to a plate on the device. Static electricity is even useful in painting automobiles. The paint is given an electrical charge and then sprayed onto the body of the automobile. The charged paint particles stick to the metal, just as a charged balloon sticks to the wall.

Dangers of Static Electricity

Static charge can be more than just a nuisance. Sometimes static charge can be dangerous to both people and equipment. Trucks that deliver fuel to your local gas station or that refuel airplanes must get rid of all static charge before they begin pumping the fuel (Figure 7.7). A spark caused by a build-up of static charge could cause an explosion. To prevent this, a cable is attached to the objects before any fuel is pumped. The cable is a conductor, and it transfers any excess static charge to the ground. Allowing charge to flow into Earth's surface is called **grounding**. Earth is so large it can accept charges without becoming charged itself.

To protect a building from lightning, a lightning rod is placed on top of the building (Figure 7.8). If lightning occurs near the building, the large amount of charge will pass through the lightning rod to the ground rather than onto the building.

Figure 7.7 As a fuel truck drives down the highway or an airplane lands on a runway, it can become charged. The excess charge has no way of escaping because it cannot move through the rubber tires. A small spark near the fuel could cause a huge explosion. Therefore, the fuel hose includes a grounding cable to prevent sparking.

Figure 7.8 A lightning rod carries the electric charge from a lightning bolt safely to the ground.

Explore More

Air is normally an insulator. Under certain conditions, it will become a conductor. This type of conductor is called plasma. To learn more about plasma, go to **www.bcscience9.ca**.

Reading Check

1. In terms of the motion of electrons, what is the difference between an insulator and a conductor?
2. Explain how an object that is made up of millions of electrons and protons can still be neutral.
3. What is the purpose of the Van de Graaff generator?
4. What are four uses of static electricity?
5. What is grounding?
6. Why do fuel trucks and airplanes need to be grounded before pumping fuel?

7-1C Charging Insulators and Conductors

Find Out ACTIVITY

If a static charge is created on an insulator, that charge tends to remain held very nearly in one place and cannot move very far. When there are extra electrons in one location on a conductor, the charge travels throughout the conductor. In this activity, you will investigate how to produce static charge using various materials.

Safety

- Never eat anything in the science room.

Materials

- puffed rice cereal
- various solid materials such as plastic straw, comb, plastic ruler, acetate strip, vinyl strip, glass rod, aluminum strip, iron strip, brass strip
- various soft materials such as wool, paper towel, plastic wrap, fur

What to Do

1. Create a table like the sample table below to record your observations. Substitute the names of the materials your teacher has supplied for the examples shown here.

Solid Material	Soft Material	Number of Puffed Rice Grains Attracted
Plastic straw	Paper towel Wool Nylon cloth	
Glass rod	Paper towel Wool Nylon cloth	
Aluminum strip	Paper towel Wool Nylon cloth	

2. Place a handful of puffed rice cereal in a pile on your desk.
3. Select one of your solid materials. Use one of your soft materials to rub one end of the solid object 10 times. Bring the end that you rubbed in contact with the puffed rice cereal. Slowly lift the object and count how many pieces of cereal stuck to the object. Record this value in your data table.
4. Remove the cereal from the object and return this cereal to your original pile of cereal.
5. Before rubbing this same object with the next soft material, wipe the surface of the object with your bare hand.
6. Repeat steps 3 to 5 until you have completed your data table. Be sure to rub each material in a similar way.
7. Clean up and put away the equipment you have used.

What Did You Find Out?

1. Which combination of objects attracted the most puffed rice?
2. Why do you think it is important to rub each material in a similar way?
3. What was the purpose of wiping the object with your bare hand before performing the next test?
4. List the solid materials that you think are conductors. What observations did you use in your decision?
5. List the solid materials that you think are insulators. What observations did you use in your decision?

Science Watch

Franklin's Kite

It was the middle of the 18th century. For the average person, the natural world was mostly explained by superstition and stories passed on through generations. Most people would not have thought it possible to study lightning. But Benjamin Franklin was not an average person. For several years, Franklin and two of his friends had studied static electricity. Franklin believed that lightning was a dramatically larger display of the same spark he had produced by rubbing certain materials together. But how could he capture the electricity from the clouds? He devised his famous kite and key experiment to do exactly that.

Benjamin Franklin was born January 17, 1706, the 15th child out of 17 children. Even though Franklin was eventually recognized for his inventions and contributions to science and politics, he was a printer by trade. He was an avid reader and used the knowledge he gained from books to develop his experiments and inventions. Had Franklin not gained an understanding of the dangers of electricity, the kite experiment could have been his last.

Benjamin Franklin was aware of the power of electricity. How could he safely prove if lightning was in fact caused by static electricity? Despite the stories that have been passed down, Franklin did not fly his kite in a lightning storm. Other people who have flown kites in storms have been electrocuted.

On June 15, 1752, Franklin launched his kite into the dark clouds of a *developing* storm. He correctly assumed that the thunderclouds would have a static charge before there was a lightning strike. His goal was to collect the electricity from these storm clouds. Had lightning actually struck his kite, the precautions that Franklin had put in place would not have been enough to prevent his being electrocuted.

Franklin's apparatus consisted of a kite attached to a long hemp string tied to an iron key. This string was damp from the storm and therefore would conduct the electricity. Franklin held onto the kite by a dry silk string that was attached to the key. Franklin and the silk string were under cover so that they stayed dry. Franklin understood that electricity would not easily travel along the dry silk string. A further safety precaution was a metal wire also attached to the key that led to a Leyden jar. A Leyden jar is a device that can store static electricity.

After flying the kite for a few minutes, Franklin brought his knuckles close to the iron key and a spark jumped from the key to his knuckles. This static electricity spark was identical to those produced by friction. Benjamin Franklin had proved that lightning was caused by a build-up of static electricity in the storm clouds.

Questions

1. What observations do you think led Benjamin Franklin to believe that lightning was electricity?
2. List two safety precautions in Benjamin Franklin's experiment. Explain how each was intended to prevent Franklin from getting a deadly shock.
3. A Leyden jar was attached to the iron key by a metal wire. Research how the Leyden jar stores static electricity. Begin your search at **www.bcscience9.ca.**

Check Your Understanding

Checking Concepts

1. The word "static" in static electricity describes what property of the charge?
2. When an acetate strip is charged by rubbing, does it acquire a positive charge or a negative charge?
3. Draw a diagram of an atom that has three protons, four neutrons, and three electrons.
   (a) Label the protons, neutrons, and electrons.
   (b) State which particles are neutral, negative, or positive.
4. Which particles in an atom are transferred when you charge an object?
5. Using + and – signs, make a sketch of:
   (a) a neutral object
   (b) a negative object
   (c) a positive object
6. What is the term for a solid object that holds charges very nearly in one place?
7. What is the term for a solid object that allows free electrons to move easily through it?
8. What unit is used for measuring static charge?
9. What does it mean to say that a conductor is grounded?
10. What is the purpose of the electroscope?

Understanding Key Ideas

11. (a) What are the similarities between a proton and an electron?
    (b) What are the differences?
12. What is the difference between a positively charged object and a negatively charged object?
13. How is it possible for an object to be neutral if it contains millions of electrons?

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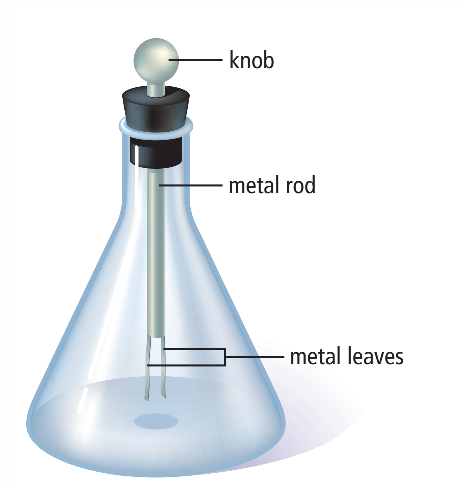
14. Explain why a person can get a shock by walking across a carpet and then touching a metal object such as a doorknob.
15. When you touch a charged object with your hand, the object becomes neutral. Explain what has happened to the charge in this process.
16. Compare and contrast charged conductors and insulators.
17. Suppose two *identical* neutral objects were rubbed together. Is it possible for these objects to gain a static charge? Explain.

Pause and Reflect

At the beginning of this section, you saw how an electroscope is used to detect static charge. Explain why the knob, rod, and leaves are made of metal. How would replacing the metal knob with a plastic knob affect the electroscope? Use vocabulary words from this section in your explanations.



An electroscope