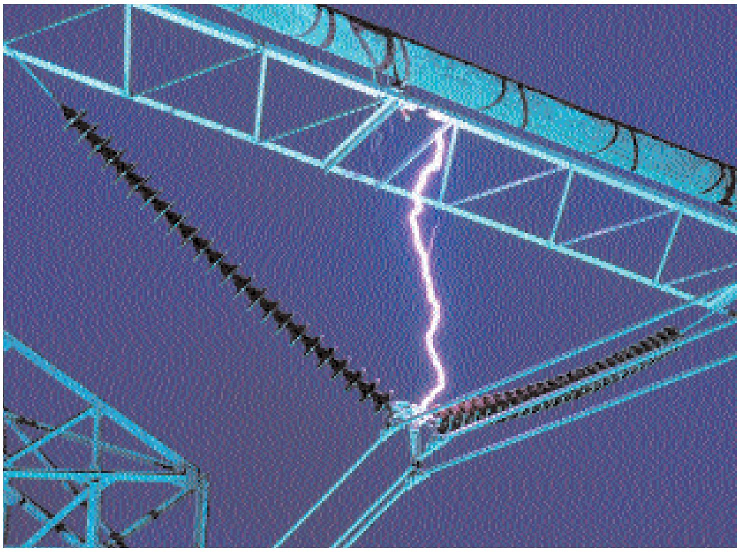
Unit 3

Electricity

Unit 3 Overview

Electricity is an integral part of our lives. It is fundamental to every atom and molecule, and to many of the conveniences we enjoy in our daily lives. What exactly is static electricity, and how does the operation of a photocopier depend on it? Why do we use electrical energy as the main energy source in our homes? How is electricity produced, and what new ways are being developed to produce it more efficiently? What kinds of electric circuits do we use in our homes, and why? How can we promote the safe and sustainable use of electrical energy?

9. Electrostatics



Static electricity affects the behaviour of the particles of matter, presenting both opportunities for practical use and potential hazards.

In this chapter, you will be able to:

- investigate the properties of static electric charges, and their interactions
- explain the behaviour of charged objects in terms of atomic structure
- infer, through observation, the kinds of charges transferred when a charged object contacts an uncharged object
- explain several methods of charging and discharging objects
- identify both positive and negative situations related to static electricity and suggest ways to solve problems that might arise

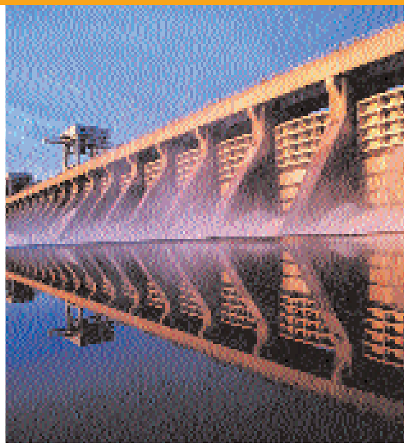
10. The Control of Electricity in Circuits

The electric circuits in our homes and in many electrical appliances consist of combinations of series and parallel circuits.

In this chapter, you will be able to:

- identify and explain the functions of the components of a complete electric circuit
- compare static and current electricity
- use an analogy to describe electric potential
- use Ohm's law to describe the relationship among electrical resistance, potential difference, and current
- recognize safety issues related to the use of electric circuits
- draw, construct, and analyze series and parallel circuits, and measure electric potentials and current related to the circuits

11. Harnessing Electrical Energy



Electrical energy is often called the "in-between" form of energy because we produce it from energy sources such as fossil fuels or moving water, and then convert it into the forms of energy we need.

In this chapter, you will be able to:

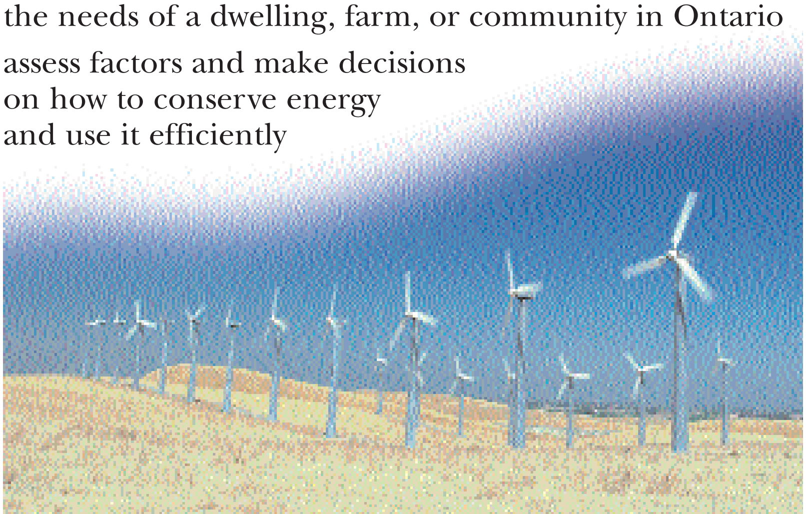
- investigate the relationship among voltage drop, current, and time
- calculate the rate at which electrical energy is used
- identify renewable and nonrenewable sources of energy
- compare methods of producing electrical energy, including their advantages and disadvantages
- assess alternative sources of generating electrical energy

12. Using Electricity Safely and Efficiently

Electricity can be used thoughtfully, with due regard for safety, economy, and the environment.

In this chapter, you will be able to:

- describe and explain the distribution and operation of household electrical wiring systems
- demonstrate understanding of the importance of safety when using electricity and electric devices
- conduct a family energy audit and suggest ways to reduce energy consumption
- describe the relationship among electrical energy, power, and time interval, and calculate electrical energy using these physical properties
- calculate the percent efficiency of electrical transformations
- create a plan to use renewable energy resources to meet the needs of a dwelling, farm, or community in Ontario
- assess factors and make decisions on how to conserve energy and use it efficiently



Challenge

In this unit, you will be able to…

demonstrate your learning by completing a Challenge.

Using Electric Circuit Boards to Promote Energy Conservation

As you learn about electricity and continuing attempts to produce it efficiently and sustainably, think about how you would accomplish these challenges.

1 An Electric Quiz Board

Design and make an electric quiz board that asks questions about the importance of energy conservation.

2 A Display of Renewable and Nonrenewable Resources

Design a display using an electric circuit board to compare the use of resources to meet our needs for electrical energy.

3 A Consumer Awareness Display

Design a display using an electric circuit board to inform the public about how much energy is consumed by household electrical devices.

To start your Challenge, see page 388.

Record your ideas for the Challenge when you see

Challenge

CHAPTER

9

Electrostatics

Getting Started

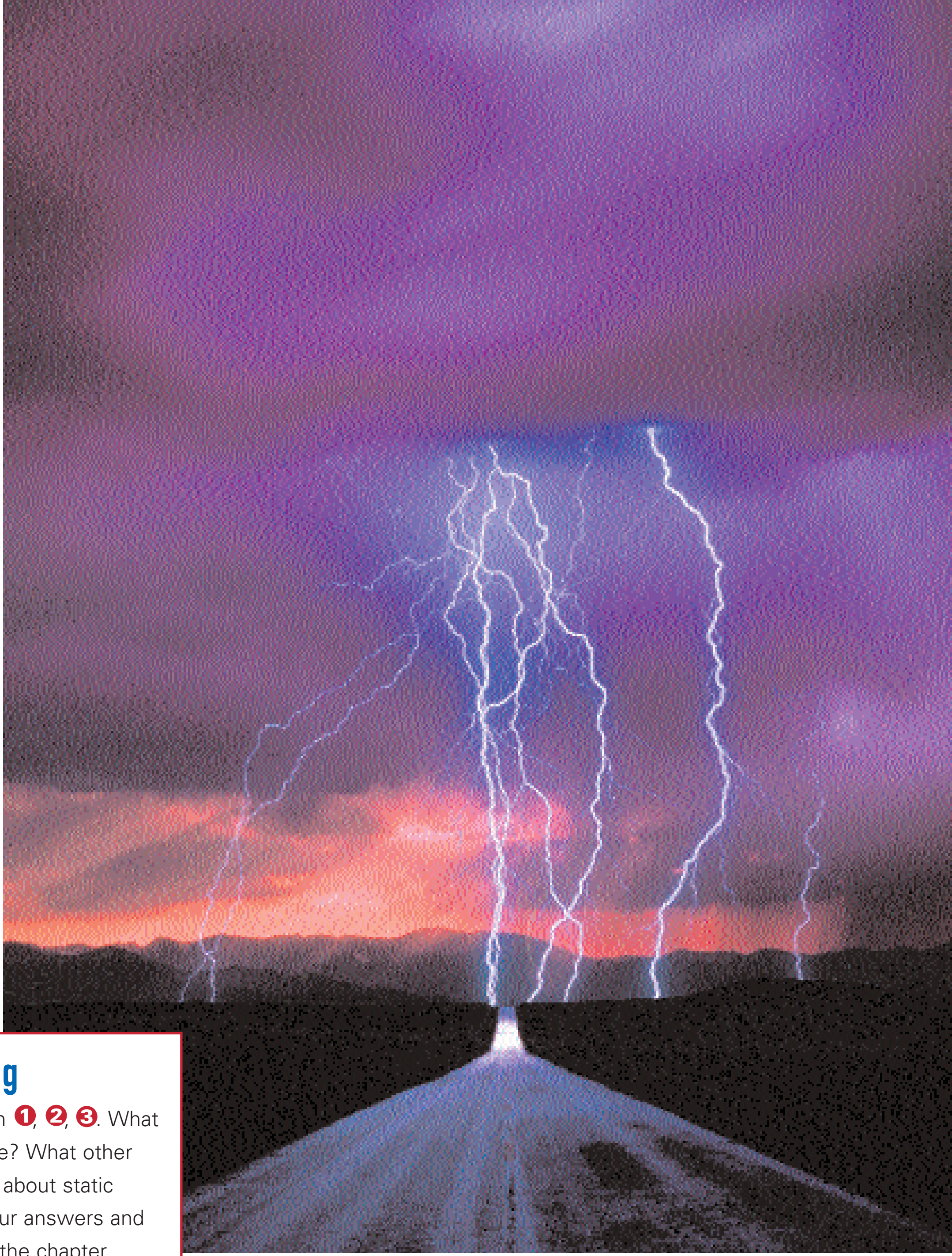
1 Your hair stands on end after you've pulled on a sweater. You get a shock when you touch the doorknob. Your clothes stick together when you take them out of the dryer. In each case, you are experiencing the effects of static electricity. Think about times you have experienced such effects. Write down what happened, what you were doing, where it occurred—even what you were wearing. If you were walking across a room, what type of floor covering were you walking on? Did you notice the effects more often at certain times of the year?

Based on your previous knowledge of static electricity, answer the following questions:

- What do I already know?
- What do I think I know (but am not sure)?
- What would I like to know?
- Why do I need to know more?

2 The manufacturers of products that reduce the effects of static electricity (or take advantage of it) often get requests from consumers to explain how their product works. Some even print a 1-800 number or a web site on the product package so you can find out more about their products. Do you know how fabric softener sheets work? why plastic wrap clings? how photocopies are made? Make a list of some of your ideas.

3 One of the safest places to be in a lightning storm is inside a car (with the windows up, of course!). Why is this so? Brainstorm explanations of what you think provides you with protection.



Reflecting

Think about the questions in **1**, **2**, **3**. What ideas do you already have? What other questions do you have about static electricity? Think about your answers and questions as you read the chapter.

Try This: Attracting Dust

With your fingernail scrape some small particles from a stick of chalk onto the edge of your hand below your little finger (or tear some paper into pieces as tiny as possible). Use some glass cleaner and a cloth rag to thoroughly polish a glass plate or one of the window panes in the room. Slowly approach the polished glass with the part of your hand covered with chalk dust. Observe what happens to the chalk dust. Now approach an unpolished piece of glass with chalk dust on the edge of your hand. Observe what happens this time. With the knowledge that you currently have about static electricity, explain what you have observed.

9.1 Investigation

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Investigating Electric Charges

One of the most common effects of static electricity occurs when you comb your hair on a day when the air is very dry. Your hair stands on end, and there may be a crackling noise. Static electricity causes clothes to cling together in the dryer. If, on a dry winter day, you take off an acrylic sweater that has been worn over a woollen shirt, you can hear, and sometimes even see, the discharges of built-up static electricity. You can also sense and hear its effects if you move your hand lightly over the surface of a television or computer screen after it has been on for a while.

You have considered some everyday situations in which you have experienced static electricity. Is there some way we can predict what will happen when static charges are produced? In this investigation, you will electrically charge a variety of substances, identify some properties of electric charges, and demonstrate the law of electric charges.

Question

How are uncharged and charged substances affected when they are near one another?

Hypothesis

By charging different substances and bringing them near uncharged and charged substances, it is possible to identify some of the properties of electric charges and to determine interactions that may occur between them.

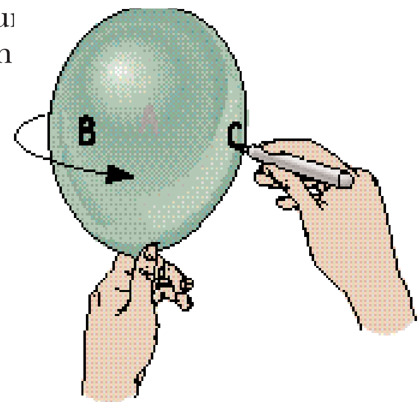
Materials

- inflated balloon (with the letters A, B, and C equally spaced around the middle)
- comb
- water taps
- fur
- paper
- silk
- polyethylene strips (ebonite rods)
- acetate strips (glass rods)
- evaporating dish (and modelling clay) or support stand and stirrup

Procedure

1 Inflate the balloon. Place the part of the balloon labelled A against your hair and rub vigorously. Quickly place the A part of the balloon, and then the unrubbed B and C parts of the balloon, against several vertical surfaces. Repeat, if necessary.

(a) Record your observation



2 Rub a plastic comb on a piece of fur. First bring the comb, then the fur, near some very small pieces of paper.

(a) Record your observations.

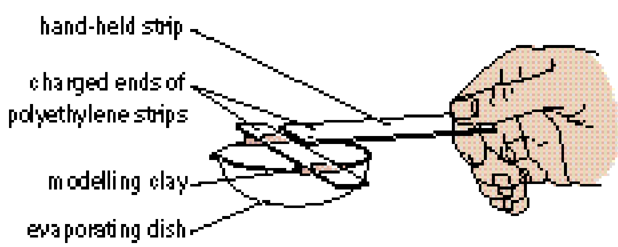
3 Rub a polyethylene strip with fur, then hold the strip near a fine stream of tap water.

(a) Record your observations.

4 Repeat step 3, using the acetate strip and the silk.

(a) Record your observations.

5 Rub one end of the polyethylene strip with fur. Mount the strip on an evaporating dish, or in a stirrup, as shown.



Strip mounted on evaporating dish

Strip mounted in stirrup

6 Rub one end of another polyethylene strip with fur. Bring this charged end of the strip close to, but not touching, the charged end of the strip on the dish.

(a) Record your observations.

7 Bring the uncharged end of the polyethylene strip close to the charged end of the polyethylene strip on the dish.

(a) Record your observations.

8 Repeat steps 5, 6, and 7, but substitute acetate strips that have been rubbed with silk.

(a) Record your observations.

9 Charge a polyethylene strip with fur and mount it on the dish. Charge one end of an acetate strip with silk, and bring it near the charged end of the polyethylene strip on the dish.

(a) Record your observations.

Analysis and Communication

10 Analyze your observations by answering the following questions:

(a) Compare the behaviour of the balloon when parts A, B, and C were placed against the wall. What does this imply about the movement of the electric charges on the surface of the balloon?

(b) What happens to uncharged objects when placed near charged objects?

(c) What happens to the force exerted between charged and uncharged objects as the distance between them decreases? Support your answer with evidence from this investigation.

(d) What evidence suggests that there are two kinds of electric charge?

(e) From your observations, what can you infer about the behaviour of objects brought close to one another if they have like charges, and if they have unlike charges?

(f) Summarize in a paragraph a test that you could perform to determine
  (i) whether an object is charged or uncharged, and
  (ii) the kind of charge present on a charged object.

(g) List the properties of electric charges you have identified in this investigation.

Making Connections

1. The hairs from a cat, dog, or rabbit stick readily to upholstered furniture, draperies, and clothing. Why does this happen? Brainstorm ways that you or others have tried to minimize the effects of "static cling" with pet hair. Invent a device that could be used to remove pet hairs from fabrics.

Exploring

2. Try combing your hair with combs made of different materials. Record what happens and develop an explanation for your observations.

Reflecting

3. Make a chart listing different situations where you have experienced the effects of static electricity. Beside each, indicate what pairs of materials you think might be responsible for producing the static electricity.

9.2

The Electrical Nature of Matter

Rubbing a balloon against your hair doesn't *create* **electric charges**. They were already there. In fact, all the atoms in matter always contain electric charges. But you aren't aware of the charges in the balloon or your hair until you make them move from their normal positions. When they are forced to move, as they are when objects of different materials are rubbed together, we say that the materials have become "charged" with "electricity." Some objects remain charged very briefly, while others, such as satellites in space when they become charged by being hit with cosmic dust particles, can remain charged for months or even longer.

As you know from your own experience, clothing, such as nylon shirts and woollen sweaters, often becomes charged with electricity when the articles rub against one another in a dryer. On many common substances the electric charge remains "static": in other words, the charge stays where the rubbing action occurred on each of the charged objects. Consequently, the phenomenon has come to be known as **static electricity**. The study of static electric charge is called **electrostatics**.

Did You Know

Experiments by the French chemist Charles DuFay (1698–1739) showed that there were two kinds of electric charges. In 1747, Benjamin Franklin named the kind of charge we find on a polyethylene strip the "negative" charge, and that found on wool or fur the "positive" charge. Although Franklin used different materials, the charges were the same kind, and the names have remained the same ever since.

Electric Charge

A plastic comb and a woollen sweater are both electrically uncharged (neutral). Each substance has an equal number of positive and negative charges. Neither object would attract small, uncharged pieces of paper on a desk. When the comb is rubbed with the woollen sweater, however, both the comb and the sweater become electrically charged. As **Figure 1** shows, they both now attract the small uncharged pieces of paper, even though they did not touch the paper.

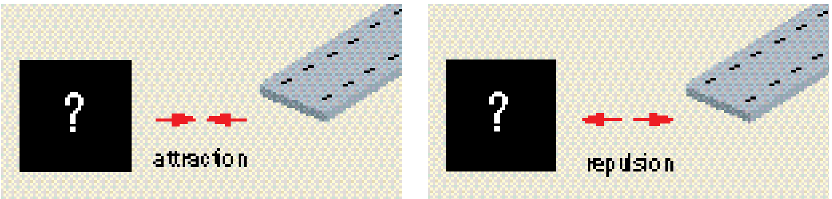
There are two kinds of electric charge: negative and positive. When two different neutral substances are rubbed together, one substance always becomes negatively charged while the other one becomes positively charged. For example, when the comb is rubbed with wool, the comb acquires a **negative charge**, while the wool acquires a **positive charge**. Both positively charged and negatively charged objects attract most neutral objects, including liquids and gases.

Figure 1
The pieces of paper stick only to the part of the comb that was rubbed with wool. The unrubbed part of the comb is still uncharged. Because the electrically charged particles do not move from their original positions on the comb, the electric charge is said to be static (stationary).

The Law of Electric Charges

Two objects with like charges, whether positive or negative, always repel one another. However, when a positively charged object is brought near a negatively charged object, they attract one another. This constancy of behaviour is known as the **law of electric charges**, which states: *like charges repel one another, and unlike charges attract one another*. To determine whether an object is charged and, if it is charged, whether the charge is positive or

Figure 2



a The object being tested could be neutral or positive.

b The object being tested must be negative.

negative, you must observe the object being repelled by an object with a known charge. Charged objects will attract both neutral objects and objects with unlike charges. On the other hand, charged objects will only repel objects with like charges (**Figure 2**).

A Model for the Electrical Nature of Matter

Scientists believe that all matter is made up of atoms containing particles that possess electric charges. Because these atoms are too small to be seen even with the aid of a microscope, a theoretical model, first proposed by Rutherford and later refined by Bohr, was developed that allows us to visualize the particles present in an atom and their relationships to one another (**Figure 3**).

This model provides a basis to explain how matter is structured and how it behaves. It helps explain the effects of electric charge and allows us to predict how charged objects will behave. The main ideas of this model, as they relate to the electrical nature of matter, are summarized in **Table 1**.

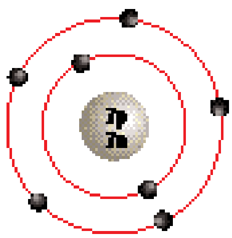


Figure 3
The Bohr-Rutherford model of a nitrogen atom

Understanding Concepts

1. (a) Why is the term "static" electricity used?
   (b) Describe a situation involving static electricity to explain your answer.
2. (a) State the law of electric charges.
   (b) Explain in detail how you could demonstrate this law.
   (c) Why does the attraction test not prove that two objects have opposite charges?
3. List the properties of electric charges identified so far.
4. Draw a labelled diagram showing the structure of the atom. Indicate the kind of charge on each of the particles that make up the atom. (6C)

Making Connections

5. A photocopier or computer printer sometimes takes in several sheets of paper at once.
   (a) Why does this happen?
   (b) What can be done to correct this problem?

Reflecting

6. (a) Describe what happens when charged objects are brought near uncharged objects.
   (b) Illustrate your answer with a real-life example from your list in 1 and 2 on page 269.

Table 1 A Model for the Electrical Nature of Matter

1. All matter is made up of submicroscopic particles called atoms.
2. At the centre of each atom is a **nucleus**, with two kinds of particles: the positively charged **proton** and the uncharged **neutron**. Protons do not move from the nucleus when an atom becomes charged (**Figure 3**).
3. A cloud of negatively charged particles called **electrons** surrounds the nucleus. An electron has the same amount of charge as a proton, but the kind of charge is opposite. When atoms become charged, only the electrons move from atom to atom.
4. Like charges repel each other; unlike charges attract each other.
5. In some elements, such as copper, the nucleus has a weaker attraction for its electrons than in others, and electrons are able to move freely from atom to atom. In other elements, such as sulfur, the electrons are strongly bound to each atom.
6. In each atom, the number of electrons surrounding the nucleus equals the number of protons in the nucleus. A single atom is always electrically neutral.
7. If an atom gains an extra electron, the net charge on the atom is negative, and it is called a **negative ion**. If an atom loses an electron, the net charge on the atom is positive, and it is called a **positive ion**.

SKILLS HANDBOOK: (6C) Scientific Drawing

9.3

Charging by Friction

Which rooms at school or in your home produce the worst shocks from static electricity in winter? How can you minimize or eliminate the problem? The effects of static electricity occur only when electric charges shift from their normal position on a neutral object or are transferred from one object to another. Remember, when an atom (or molecule) is electrically neutral, the positive and negative charges are equal in number and are positioned to make the atom appear uncharged. There are three ways in which objects become electrically charged: by friction, by contact, and by induction.

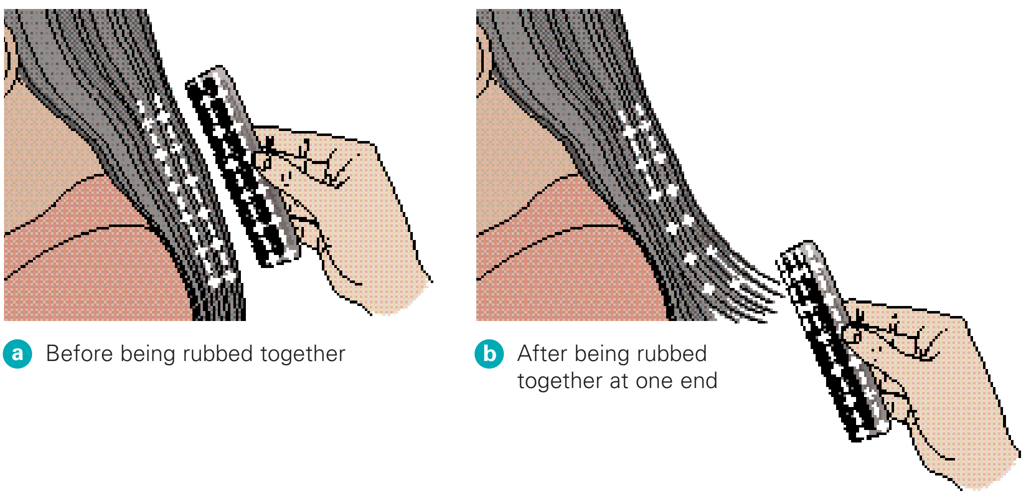
Charging by Friction

When plastic food wrap is smoothed and shaped to the sides of a bowl, static charges are produced that cause it to stick to the bowl. This is because electric charges can be transferred by a rubbing action or friction. **Charging by friction** causes many of the effects produced by static electricity. Large amounts of electric charge build up on clothes in a dryer because the tumbling motion is a kind of rubbing action. When someone walks across a carpet, the friction between the carpet and the person's shoes produces a charge on both the person and the carpet.

Sometimes substances rub against one another in a less obvious way. For example, when gasoline rushes out of a hose at a gas station, or when dry air rushes over the surface of a car or an airplane travelling at high speeds, large amounts of electric charge can be transferred. You can receive an electric shock when you touch the surface of a car charged this way, especially in winter. Even wearing clothes made of different materials can cause a buildup of electric charge. As the different materials rub together, each piece of clothing develops its own electric charge.

The model for the electrical nature of matter can be used to explain charging by friction (**Figure 1**). When a comb is rubbed against your hair, the comb becomes negatively charged, and the hair becomes positively

Figure 1
When a comb is rubbed through hair, the comb becomes negatively charged, and the hair becomes positively charged. Only electrons move during the transfer of electric charge on an atom. The protons remain in their original locations, at the centre of the atom.



(a) Before being rubbed together

(b) After being rubbed together at one end

Did You Know

A Greek philosopher named Thales is reputed to have studied static electricity around 600 B.C. He found that when amber was rubbed with fur it attracted a small piece of cloth or leaves. The Greeks called this attraction the "amber effect."

Around A.D. 1600, William Gilbert (1540–1603), personal physician to Queen Elizabeth I, found that many other materials, including glass, also showed the amber effect. Because the Greek word for amber is "elektron," Gilbert called this effect "electric."

charged. In terms of the model, this occurs because the positively charged nuclei of the molecules in the comb attract electrons, including the electrons on the hair molecules, much more strongly than the nuclei of the hair molecules.

Just touching the hair with the comb allows only small numbers of both kinds of molecules to come close enough to transfer electrons from the hair to the comb. The rubbing brings many more molecules of hair into contact with molecules of the comb, allowing the transfer of significantly more electrons. The large number of electrons transferred causes an excess negative charge to build up on the comb. Because the hair loses some electrons, it becomes positively charged.

The Electrostatic Series

You can use a list called the **electrostatic series** (**Table 1**) to determine the kind of electric charge produced on each substance when any two substances on the list are rubbed together. When charging by friction occurs, the substance higher in the list (for example, acetate) always loses electrons and becomes positively charged, while the substance lower in the list (for example, silk) gains those same electrons and becomes negatively charged.

Table 1 The Electrostatic Series

acetate	Weak hold on electrons
glass	
wool	
cat's fur, human hair	
calcium, magnesium, lead	
silk	
aluminum, zinc	
cotton	Increasing tendency to gain electrons
paraffin wax	
ebonite	
polyethylene (plastic)	
carbon, copper, nickel	
rubber	
sulfur	
platinum, gold	Strong hold on electrons

Understanding Concepts

1. (a) Draw a series of diagrams and explain, in terms of the electrical model for matter, how objects become charged by friction. 6C
   (b) What two factors affect the amount of static charge produced when you rub two different substances together? Explain why.
2. How can you use the electrostatic series to determine how two different substances will become charged when rubbed against one another?
3. (a) Predict what will happen when (i) acetate is rubbed with fur, and (ii) rubber is rubbed with cotton.
   (b) Explain your answer in terms of the electrical model for matter.

Making Connections

4. A silk blouse and a pair of wool socks are put into a clothes dryer. What charge will appear on the blouse when it rubs against the socks? Explain why. How would an antistatic product help?
5. Which kinds of combs are best to use in winter, plastic combs or combs made of aluminum? Explain why (in terms of the electrostatic series).

Reflecting

6. Sometimes at night if you move your feet around quickly against the sheets you can observe an interesting effect. Explain what is happening.

Challenge

When deciding where to place (set up) your electric circuit boards, what should you do to minimize the effect of static electricity on the users?

SKILLS HANDBOOK: 6C Scientific Drawing

SKILLS MENU
- ○ Questioning
- ○ Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Charging Different Substances by Contact

Sometimes just shaking hands with a friend or touching your pet can have an unexpected effect: an electric shock. These little irritations are caused when electric charge is transferred from one substance to another because the substances touch each other. This is called **charging by contact**. However, charging by contact does have its uses. Part of the photocopying process is dependent on the transfer of electric charges from one substance to another.

By investigating what happens, we can develop ways to minimize or control the effects caused by charging by contact. In this investigation you will electrically charge objects by contact and determine the kind of charge transferred. A pith-ball **electroscope** (**Figure 1**) will be used to help detect and identify the kind of charge being transferred. It consists of a small, light ball suspended by a thin cotton thread. The ball moves in response to the electric forces on charged objects held near it. (Note: If a charged object touches the pith ball, it may become charged. To remove the charge, simply hold the pith ball gently in your fingers—do not squeeze.)

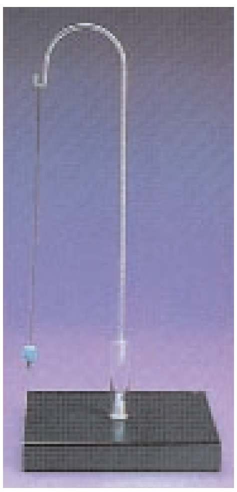


Figure 1

Question

How can we determine what kind of charge is transferred when a charged object contacts an uncharged one?

Hypothesis

If we know that an object possesses either a positive or negative charge, then the charge transferred by contact to an uncharged object can be determined using the law of electric charges.

Materials

- pith-ball electroscope
- polyethylene strip
- fur
- acetate strip
- silk
- evaporating dish (and modelling clay) or support stand and stirrup
- iron rod
- glass rod

Procedure

1. Without allowing the pith ball to touch the strip, bring a negatively charged polyethylene strip close to the uncharged pith ball, and then remove it.

   (a) Record your observations.

2. Repeat step 1 using a positively charged acetate strip.

   (a) Record your observations.

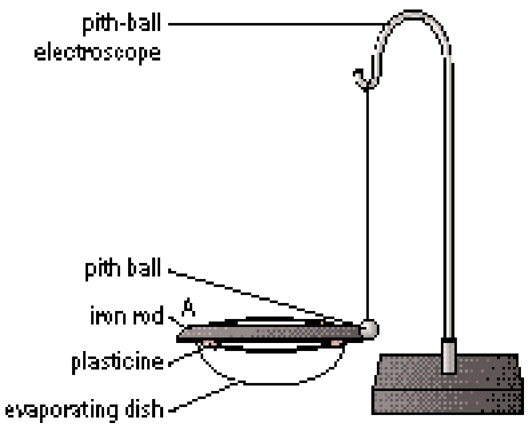
3. Touch the uncharged pith ball with a negatively charged polyethylene strip, remove the strip, and then approach the pith ball with the charged strip again. Then approach, but do not touch, the pith ball with a positively charged acetate strip. Remove the charge from the pith ball by touching it with your hand.

   (a) Record your observations.

4 Touch the uncharged pith ball with a positively charged acetate strip, remove the strip, and then approach the pith ball with the charged strip again. Then approach, but do not touch, the pith ball with a negatively charged polyethylene strip.

(a) Record your observations.

5 Set up the equipment as shown below.



6 Touch a negatively charged polyethylene strip against end A of the iron rod, then remove it.

(a) Record your observations.

7 Recharge the polyethylene strip and bring it close to the pith ball. Discharge the pith ball by touching it with your hand.

(a) Record your observations.

8 Repeat steps 5 to 7, replacing the iron rod with a glass rod.

Analysis and Communication

9 Analyze your observations by answering the following questions:

(a) What can you infer about the transfer of electric charge when a charged object is placed near, but does not touch, the pith-ball electroscope? Explain your answer.

(b) What can you infer about the transfer of electric charge when the pith ball is touched by
(i) a negatively charged object
(ii) a positively charged object
Explain your answer.

(c) Write summary statements that explain your observations in steps 3 and 4. Use diagrams to illustrate the transfer of charges.

(d) What kind of charge is on the pith ball in step 6?

(e) Explain what happened when the polyethylene strip touched the end of the iron rod in step 6?

(f) What kind of charge is on the pith ball in step 8?

(g) Explain what happened when the polyethylene strip touched the end of the glass rod in step 8.

(h) Summarize your observations in a statement by comparing the movement of electric charge in the iron rod with that in the glass rod.

Understanding Concepts

1. If you walked over a wool carpet in cotton socks, in what direction would the negative charges move when you touched a neutral doorknob? Explain your answer.

Exploring

2. Use two pith-ball electroscopes and predict, observe, and explain what happens when they are brought close together if

(a) they are charged alike;

(b) they are charged oppositely;

(c) one is charged and the other is not.

Use simple diagrams to analyze your observations.

9.5

Transferring Charge by Contact

A single spark produced by a charge transferred by contact can cause dangerous fires and explosions. Safety precautions, such as wearing boots and shoes that do not produce sparks and the use of special clothing, are required in grain elevators, flour mills, coal mines, hospital operating theatres (**Figure 1**), and some parts of oil refineries. Planes and vehicles transporting flammable materials need to have special equipment installed to prevent or control sparks produced by static electricity.

Transferring a charge by friction is difficult to avoid. Even if you are initially uncharged and walk carefully over a carpet, many electric charges are gradually transferred by the rubbing action of your shoes on the carpet fibres. But when charging by contact occurs, one object is already electrically charged. The other object may or may not be charged as well. The important factor is that there must be a difference in the amount of charge already on the two objects.

Before you touch the doorknob, you may be charged negatively, due to friction with the carpet. The doorknob is usually uncharged. When you touch it, some of the extra electrons on your body transfer

Did You Know ?

The rubbing produced by sliding across a car seat may charge you to an electric potential of 15 000 V. When you step out onto the ground, the charge is transferred by contact, but the high voltage produces only a small electric shock because the amount of electric charge is too small to be dangerous.

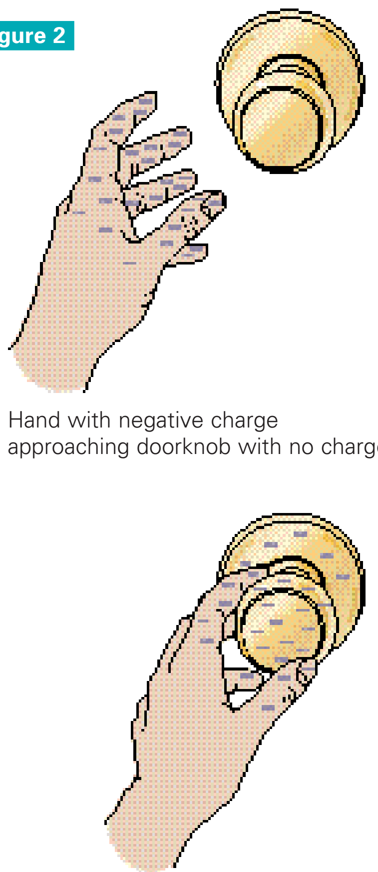
Figure 1

The clothing worn by doctors and nurses in operating theatres is woven with special fibres designed to eliminate sparks caused by static electricity.

to it. Thus, as shown in **Figure 2**, the total electric charge on your body is shared between you and the doorknob, and the charge transferred to the doorknob is also negative.

The shock produced by this kind of charge transfer can be surprising and even painful. This is because the electric charges on your body are shared with the doorknob very rapidly. In fact, usually your hand doesn't even touch the doorknob before the charges begin to transfer in the form of a spark. The electrons actually jump across the air gap between your hand and the knob just before you touch it, like a miniature lightning stroke. What could you do to prevent yourself from getting a shock? If you can't think of an answer, try again after reading more about electrostatics.

Figure 2



a Hand with negative charge approaching doorknob with no charge

b Hand touching doorknob, now both charged negatively

Understanding Concepts

1. What happens when a negatively charged object touches an uncharged pith ball on an electroscope? Use a diagram to explain your answer.
2. When an object is charged by contact, what kind of charge does the object have compared with that on the object giving the charge? Explain in terms of the model for the electrical nature of matter.
3. Why does a spark occur when a person who is charged touches an uncharged object? Would moving the hand to the doorknob very fast prevent the spark from occurring?
4. If a cat was combed with an ebonite comb, and someone else touched the cat, what charge would that person receive from the cat's fur? (See **Table 1** on page 275.) Explain your answer.

Making Connections

5. List three situations in which charging by contact can be dangerous. Explain why in each case and suggest safety precautions.
6. What makes grain elevators and flour mills among the most dangerous places to work? What precautions are taken?

Exploring

7. Talk to your friends and relatives to see if they have found ways to reduce or eliminate shocks produced by charging by contact. List some solutions.
8. What special precautions must astronauts take to guard against static electric shocks
   (a) while inside the spacecraft?
   (b) on returning to the spacecraft after a walk in space?
9. 3A Carry out some research in your school or local library, on the Internet, or talk to people you know to identify some actual cases where explosions or fires have been caused by static electricity. Write a report or present what you find to your class.

9.6

Insulators and Conductors

Insulators

We often wear several different substances, such as wool and nylon, at the same time. The fabrics rub against each other and continually become charged with static electricity. The result can be very irritating, especially during winter, because the different pieces of clothing tend to stick to each other. The static charge remains in the places where the wool and nylon rub together because they are **electrical insulators**.

An electrical insulator is a substance in which electrons cannot move freely from atom to atom. If some atoms of an insulator become negatively charged with extra electrons, these electrons remain on the same atoms until removed by a substance that exerts a stronger force on the electrons. An insulator that has positively charged atoms on its surface behaves in a similar manner. This explains the continuous buildup of static charge on furniture and glass during cleaning. Wooden furniture and glass are both electrical insulators. When you polish furniture, the electric charges remain on the surfaces and attract uncharged dust particles.

Very large amounts of charge can still build up on the surface of an insulator. Review the electrostatic series on page 275. The amount of charge that builds up depends on the relative ability of the two substances to hold on to their electrons, and how much rubbing action occurs. Paint and wax are both insulators. The surface of a car can often build up very large amounts of charge due to the air rushing over it. Most people have experienced a static shock from a car when stepping out of it after a journey.

However, even though some insulators do cause static electricity problems, they can also be very useful (**Figure 1**). Because electrons cannot be conducted *through* electrical insulators, these materials can protect us from electric shocks. The two wires carrying the electric

Figure 1
The long ceramic insulators isolate the high voltage transmission line from the metal support towers.

Table 1 Common Conductors and Insulators

Good Conductors	Fair Conductors	Good Insulators (Nonconductors)
silver	carbon	oil
copper	nichrome	fur
gold	human body	silk
aluminum	moist human skin	wool
magnesium	acid solutions	rubber
tungsten	salt water	porcelain, glass
nickel	Earth	plastic
mercury	water vapour (in air)	wood
platinum		paper
iron		wax
selenium (in the light)		ebonite
		selenium (in the dark)

current to an electric kettle would be very dangerous if they were not covered with a plastic or rubber insulating substance. Insulators cover many household tools and appliances. Electrical cords, plugs, wall sockets, and switches are actually metal conductors covered by an insulating substance.

Conductors

It doesn't matter how hard you polish a metal tap in the kitchen or bathroom, it never builds up a static charge because metals are **electrical conductors**. A conductor is a substance in which electrons can move freely from one atom to another. If a conductor becomes negatively charged with extra electrons, they move freely (are conducted) along the conductor. When taps are charged negatively by friction, the extra electrons repel one another and are conducted away from the taps along metal water pipes to the main water supply pipe, where they transfer into the ground. Because the electric charge is conducted away as soon as it is produced, the taps remain uncharged.

Table 1 lists common conductors and insulators.

Static Electricity and Winter

The reason that problems with static electricity are much worse in winter than during other times of the year is that the cold air is so much drier and contains fewer water molecules than it does in other seasons. Dry air is an insulator and does not easily pick up charges from our body as the air molecules constantly collide against us. So, in the winter, any static charge that builds up on our clothes or on painted or polished surfaces tends to stay there. At other times of the year, the air is warmer and contains huge numbers of water molecules. Water molecules tend to pick up and transfer electric charges easily. When the air is moist, the molecules of water vapour in the air are constantly striking us all over our bodies, and these water molecules redistribute the static charges produced by friction as soon as they occur.

Challenge

What materials would you consider using when building the case for your electric circuit board to minimize the effect of static electricity for the user?

Understanding Concepts

1. Explain the difference between a conductor and an insulator, in terms of the transfer of electrons. Use diagrams to illustrate your explanation.
2. **(a)** Why does the amount of static charge continue to increase on a glass surface as you rub it?
   (b) What would eventually happen if you continued rubbing it?
3. If you charged the end of a plastic comb and then put the same kind of charge on one place on the surface of a round metal ball on an insulating stand, what would happen to the charge in each case? Explain why with the help of a diagram.
4. Why are problems with static electricity more common in winter than at other times of the year? How could any of these problems be reduced?

Making Connections

5. Look around your home, or in the family car, and identify examples where insulators and conductors are used on electrical equipment. Give reasons for their use.
6. List at least two reasons why you think plastic materials are used to cover the copper wires in electrical equipment.

Exploring

7. When people began using electricity in homes, copper wire was used. Then in the 1970s aluminum wire largely replaced copper. After a few years, aluminum was replaced by copper again. Why did each change occur? List the advantages and disadvantages of using each metal.

9.7

Discharging Electrically Charged Objects

Every time you pump gasoline into the gas tank of a car, the flow of gas through the nozzle generates large amounts of static electricity. Think what would happen if a static spark jumped from the nozzle to the car. As aircraft travel through the air, they continuously build up huge amounts of static charge on the outside surface of the plane. In both cases, if there were not a way of continuously removing the charge as soon as it was produced, there could be serious consequences. The plane's communications systems would not operate properly, and the gasoline would ignite.

If a charged object has all the excess electric charges removed, it is said to be **discharged** or **neutralized**. Several methods are used to discharge charged objects.

Grounding

The simplest way to discharge an object is to connect it to Earth itself by means of a conductor, such as a wire connected to a metal rod buried in the ground. When a charged object is connected, or **grounded**, to Earth, it shares its charge with the entire Earth. The damp soil is a fairly good conductor, and Earth is so large that it effectively removes all the excess charge from the object. All the parts of the gas pump, and everything attached to it, are very carefully grounded. As soon as the charge is generated at the nozzle, it is immediately conducted safely to ground. People who assemble sensitive electronic equipment, such as microchips to computer circuit boards, usually wear metal straps on one of their wrists (**Figure 1**). The strap is attached by a wire to a grounding system on all the benches, and they in turn are grounded to Earth. Astronauts sometimes wear similar straps, using their spacecraft as the ground.

Figure 1

Discharge at a Point

Clearly, the grounding wire is not a very practical idea for aircraft or cars. Another method, which is based on the way electric charges behave on the surface of conductors, is used to discharge airplanes. The surface shape of a charged conductor affects the rate at which it becomes discharged. Smooth, spherical shapes retain charges indefinitely, because the charges spread themselves evenly over the surface. However, conductors pointed at the ends lose charges rapidly

Did You Know ?

The discharge of charged particles from a point is sometimes called corona discharge. Corona discharge also occurs from the wires on high-voltage transmission lines.

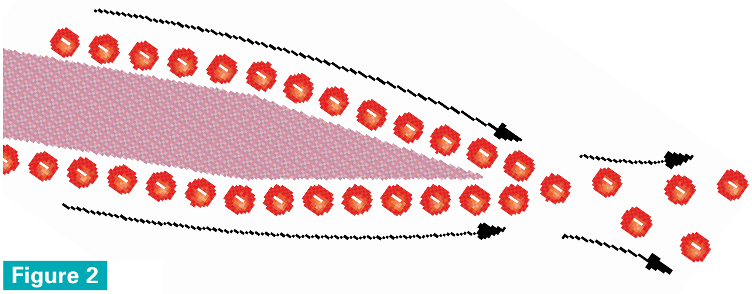


Figure 2
The electrons at the tip of the pointed rod are repelled into the air by the electrons just behind the point.

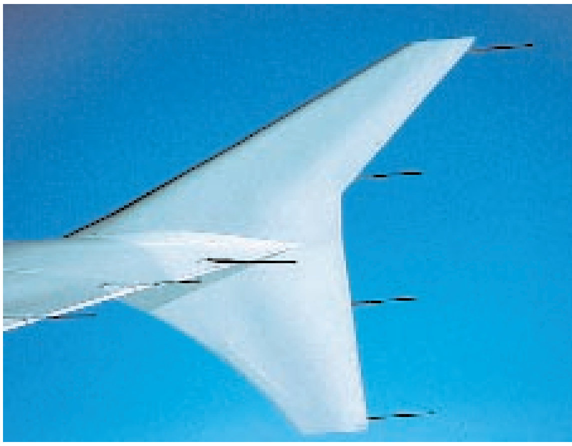


Figure 3
Static wicks on airplane wings and tail

(**Figure 2**). At the sharply curved point of a negatively charged rod, electrons repel one another so strongly that those right at the tip are actually pushed off the point in a continuous stream. This method of discharging charged objects is called **discharge at a point**.

Several different point discharge methods are used to continuously discharge airplanes. Planes, ranging in size from small executive jets to Boeing 747s, use "static wicks" (**Figure 3**), which are pointed metal rods that stick out from the movable control surfaces in the wings and tail. They allow a continuous discharge of static electricity. To prevent the discharge from travelling through the hinges on the control surfaces, flexible wires connect the movable and fixed parts of the aircraft. Aircraft maintenance workers must monitor the condition of the static wicks and test them on a regular basis. Medium-sized aircraft also use an inflatable rubber covering on the leading edge of the wings. The rubber surface is covered with a conductive cement that overlaps the metal parts and allows the electricity to leak away. These protective measures are also useful when airplanes are flying in stormy weather. The smallest aircraft lack static electric reduction devices and, therefore, are prohibited from flying when storms are in the area.

Other Ways to Discharge Objects

Over a period of time, charged objects can be discharged by simple exposure to the air. On a humid summer day, because of the number of water molecules in the air, the charge leaks away so rapidly that many of the problems caused by static electricity are not noticeable. However, on a cold, dry winter day, when the humidity is low, the charge leaks away so slowly that just combing your hair can be difficult. Other ways to discharge an object are to shine a light on it or to expose it to radioactivity.

Understanding Concepts

1. What is the meaning of the term "discharge"?
2. Why does Earth not become charged when so many electrons are constantly flowing into it as various devices are "grounded"?
3. **(a)** Why does the flow of gasoline through the hose and nozzle of a gas pump produce a static charge?
   (b) Why is there no static discharge at a gas station when the nozzle of the pump is brought up to the car's fuel tank opening?

Making Connections

4. Why do people working on electronic equipment have metal wires clipped to their bodies as they work?
5. Why would it not be acceptable to allow the discharge from a wing flap of an airplane to travel through the hinges attaching it to the wing?
6. On a cold, dry winter day, how would a woollen toque or the hood of a parka affect your hair? Explain.
7. How is a gasoline tank truck protected from static discharge?
8. Would an airplane made of wood be subject to a buildup of static electricity? Explain.
9. How can you avoid getting a shock from static electricity when you touch a doorknob?

Career Profile

Aircraft Mechanic

Gary Masse is an aircraft mechanic, pilot, and owner of an aircraft maintenance company called WCS Aviation. His interest in airplanes dates back to his early teens when he became a member of the local Air Cadet Squadron. His desire to work with planes was inspired when he talked with a mechanic for the Snowbirds.

> It is clean work with no cutting of corners and with a great deal of attention to detail.

Masse took machine shop and welding in addition to mathematics, science, and the other required areas of study in high school. He emphasizes the importance of English since aircraft mechanics must communicate accurately with others and must write clear records and reports.

After graduation, he enrolled in a two-year Aircraft Maintenance program at Canadore College. The areas of study included airframes, avionics (communications systems), power plants, federal regulations, mathematics, science, and English. Approximately 20% of the time at school was spent studying electricity.

Aircraft must be serviced frequently and thoroughly. Safety is everything. The mechanics must pay particular attention to the static electricity discharge equipment because communications systems and instruments will not work properly when static charges build up. Masse enjoys the precision and accuracy of these procedures. "Everything must be done according to the maintenance manuals." Records must be kept of all parts that are used so that every one can be traced back to its original manufacturer. In addition, all parts must be destroyed when their rated life span has passed.

Masse recommends that high school students who think that they might be interested in a career in aircraft mechanics should try to obtain summer jobs working around aircraft. And ask lots of questions.

Exploring

1. Research courses in aircraft mechanics. Where are they available, how long do they take, and what entrance requirements are there?
2. Why is electricity such a major part of an aircraft mechanic's training?
3. Servicing aircraft takes great precision and attention to detail. List 10 other careers in which these characteristics are valuable.

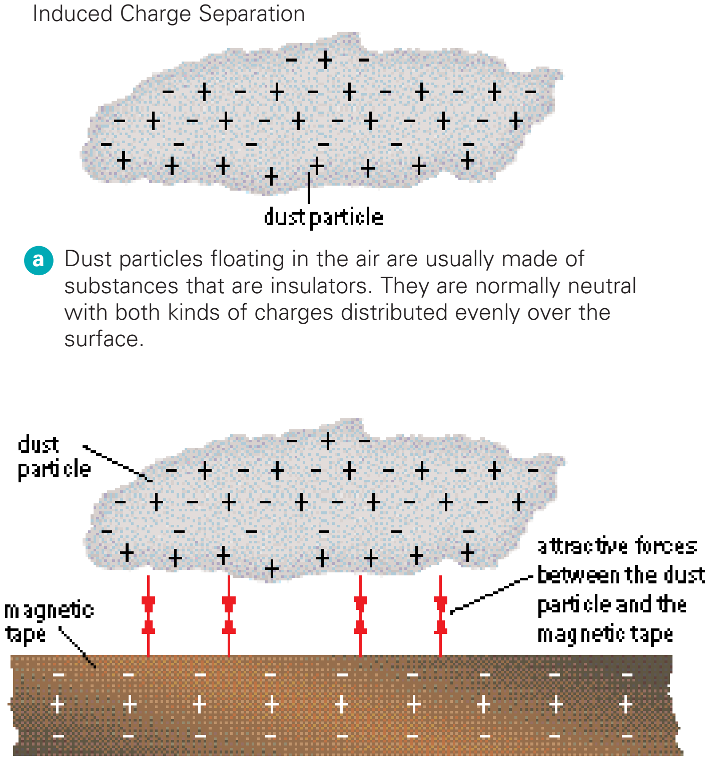
Induction

What do lint and dust sticking to your clothes and the operation of a pager have in common? They are both examples of the third way of charging an object, **charging by induction**. In physics, the term "induction" suggests that something is made to happen without direct contact. With the other two methods of transferring charge, charging by friction and charging by contact, the buildup or transfer of charge occurs only when the objects rub against or touch one another.

Induced Charge Separation

When an uncharged object, such as a dust particle, is charged by induction, the nearby charged object doesn't actually touch the dust particle at all. As you know, the surface of a television screen or computer monitor becomes charged after it has been operating for a while. When a dust particle is near a charged television screen, the charges on the screen cause, or induce, the electrons on the dust particle to change position slightly. This slight shift of the electrons has the effect of making the side of the dust particle facing the screen have the opposite charge to that on the screen, and the dust is attracted toward the charged television screen. This charging effect is known as **induced charge separation**. **Figure 1** shows what happens to a dust particle near a negatively charged object. Whether an object is charged positively or negatively, the dust particle is still attracted to it. A neutral object always has an opposite charge induced on the surface closest to the charged object. This is why there is an attractive force between charged objects and neutral objects.

Figure 1
Induced Charge Separation



a Dust particles floating in the air are usually made of substances that are insulators. They are normally neutral with both kinds of charges distributed evenly over the surface.

b As the uncharged dust particle comes close to the negatively charged object, the negative charges on the dust particle closest to the object are repelled and shift position slightly. The side of the dust particle closest to the object now has a positive charge induced on its surface, and it is attracted to the negatively charged object. However, it is important to realize that the dust particle is actually still neutral.

Charging Conductors by Induction

What would your life be like if you were no longer able to watch television, listen to the radio, or talk on a cell phone? All these modern conveniences use charging by induction to operate. Previously, you learned about the induced charge separation that occurred on uncharged insulating materials, such as dust. When induced charge separation occurs in conductors, it is possible to make the electrons move from atom to atom along the uncharged conductor, rather than just shift position slightly. In fact, it is possible to induce a permanent charge on a conductor.

If a negatively charged strip is brought near one end of an uncharged metal rod, the electrons at that end of the metal rod are repelled toward the other end. This movement of electrons induces a negative charge on the other end of the metal rod (**Figure 2a**). When the negatively charged strip is removed, the electrons redistribute themselves evenly along the rod again (**Figure 2b**).

However, if a conducting wire is connected from the metal rod to a "ground" such as a water tap, the rod will lose electrons, as explained in **Figure 3**. The induced charge is always opposite to that of the charged object producing the charge. For example, a negative charge can be induced on a metal rod by placing a positively charged strip near the metal rod when the conducting wire is connected to it.

In this explanation of charging by induction, the conducting wire was connected and disconnected to show that a charge can be induced on the conductor. However, in practical applications of charging by induction, the wire is usually connected permanently. The induced charge can then move onto and off the object freely whenever electric forces act on the object. Devices such as electrostatic microphones, television and car radio aerials, cell phones, and lightning rods all work on the principle of induced charges.

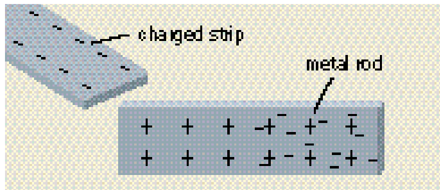
Using Static Electricity to Advantage

Although static electricity can be annoying and even dangerous, it also has many practical uses. Charging by induction is the principle used in the design of many devices that remove pollutants and dust from the air. It is also used as a way of coating surfaces with a variety of coverings. As you will learn (in section 9.11), the photocopier uses two of the three ways of transferring charge as it makes copies.

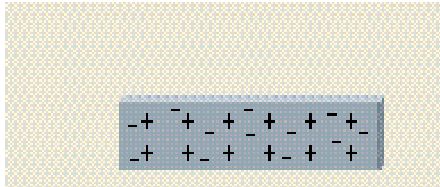
Pollution and Dust Control

The electrostatic air cleaners installed in homes and hospitals use static electricity. Dust and other particles are removed from the air by using the attraction between unlike charges. The dirty air is usually sprayed with positively charged ions as it passes into the air cleaner. The positive ions are attracted to the dust particles by induction. This produces positively charged dust particles that are then forced between negatively charged flat plates. These plates attract the oppositely charged dust particles, and the cleaned air passes on through. A similar method removes many kinds of smoke particles and harmful pollutants as they travel up industrial chimney stacks (**Figure 4**).

Figure 2

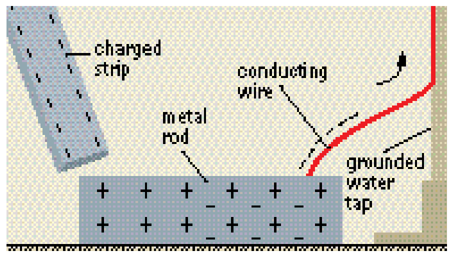


a Electrons in the metal rod are repelled by the negatively charged strip.

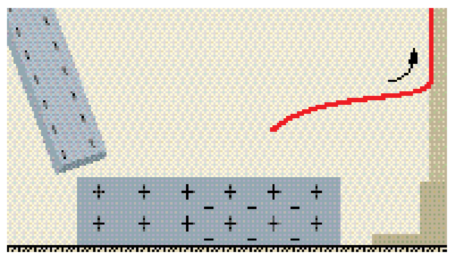


b When the negatively charged strip is removed, the electrons redistribute themselves evenly throughout the metal rod.

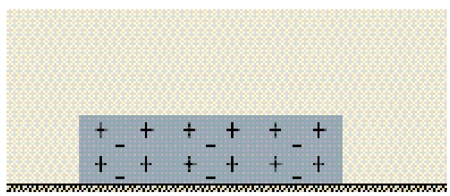
Figure 3



a When the negatively charged strip is brought close to the metal rod, some of the electrons repelled along the metal rod are conducted into the wire.



b If the wire is now removed from the metal rod, the metal rod will have lost some electrons and will be positively charged.



c When the negatively charged strip is removed, the remaining electrons spread evenly along the metal rod again, but the rod has a permanent positive charge.

Figure 4
Many smokestacks are equipped with electrostatic air cleaners, which remove air pollutants before they enter the atmosphere.

Coating Surfaces with Particles

An electrostatic process is also used in machines that paint objects (**Figure 5**). The tiny paint particles from the spray gun are electrically charged as they pass an electrode attached to the gun. The object to be painted is given a charge opposite to that on the paint. If the object is made of an insulating material, it is first coated or dipped in a conducting substance. The charged paint particles are attracted toward the oppositely charged object. Paint droplets that would normally have missed the object are pulled toward it by the attraction of opposite charges.

Did You Know

A completely emission-free automobile spray-painting system is now being tested. It uses dry-powder paint instead of water-based paint. Even the small amount of electrically charged paint powder that misses its target can be collected and reused, leaving no waste whatsoever.

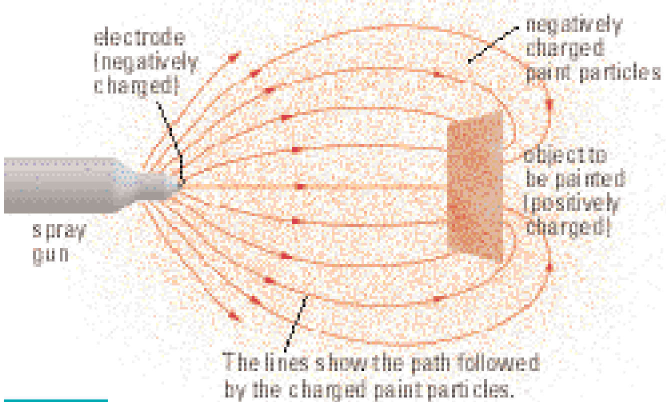


Figure 5
An electrostatic spray-painting machine

Understanding Concepts

1. Why is a neutral dust particle attracted to a charged object?
2. Explain the difference between induced charge separation and charging by induction.
3. When an object is charged by induction, what kind of charge does the object have compared with that on the object inducing the charge? Explain.
4. It is possible to spray the back of an object, even though the spray gun is pointed at the sides. Explain why.

Making Connections

5. (a) The same ducts are used to distribute hot air from the furnace in winter and cold air from central air conditioning in the summer. Would dust build up on the return air flow grates more quickly in winter or summer? Explain your answer.
   (b) Would you recommend the air ducts in your house be cleaned in summer or winter?
6. Why is charging by induction important in helping to protect our environment? Describe some of the ways it is used to do so.

Exploring 3A

7. How does an electronic air cleaner in an automobile work?
8. When was the "electrostatic precipitator" first developed? Who did it? Why is it so important to our everyday lives?

9.9 Investigation

SKILLS MENU
- ○ Questioning
- ● Hypothesizing
- ○ Planning
- ● Conducting
- ● Recording
- ● Analyzing
- ● Communicating

Charging by Induction

The next time you are eating nuts or cooking with different kinds of seeds, think about how they are cleaned and processed. The sorting of many kinds of seeds and the separation of nuts from their shells is done using charging by induction. Over 30 different kinds of minerals can be separated by electrostatic processes. In this investigation, you will study the two different methods of charging objects by induction. You will also develop your understanding by making predictions and testing them.

A metal-leaf electroscope consists of a small metal ball or plate connected to a metal rod (**Figure 1**). Hanging from the rod are two thin metal strips, or leaves, which are protected from air currents by being enclosed inside an insulated glass container. Because the parts of the electroscope inside the container are made of a conducting metal, electrons are able to move freely. When charged objects are brought near the ball, electrons move onto or out of the metal leaves through the rod. The resulting charge on the leaves causes them to repel each other.

Question

How can we determine the kind of charge induced on a neutral object when it is approached by a charged object (step 5)?

Hypothesis

1 Read the procedure and write a hypothesis (4A) that will answer the question.

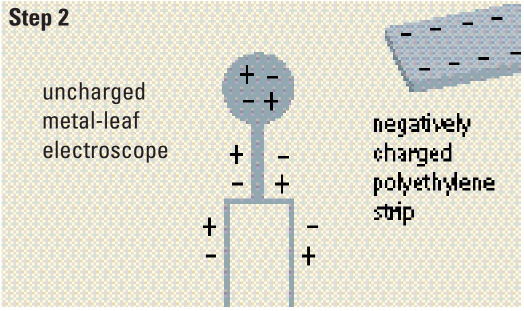
Materials

- metal-leaf electroscope
- polyethylene strip
- fur
- acetate strip
- silk
- water taps
- insulated wire conductor (with alligator clips)

Figure 1

Procedure

2 Without touching the uncharged metal-leaf electroscope, approach it with a negatively charged polyethylene strip. Move the strip toward and away from the ball several times.

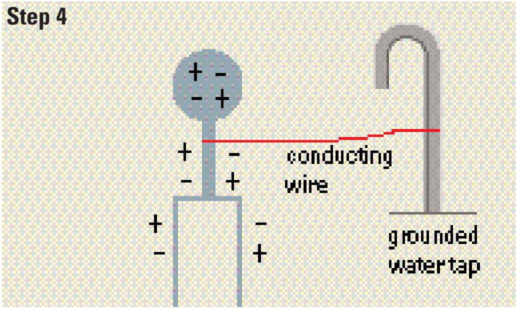


(a) Draw the above diagram. Draw a (6C) second diagram to record what happens when the strip is very close to the ball.

3 Repeat step 2, using a positively charged acetate strip.

(a) Record your observations using diagrams.

4 Attach an insulated wire conductor from the rod of the metal-leaf electroscope to the water tap, as shown below.



5 Bring a negatively charged polyethylene strip near (but don't touch) the ball on the metal-leaf electroscope. While the charged strip is near the metal ball, remove the wire conductor from the rod. Remove the charged strip.

(a) Draw the diagram in step 4, then draw diagrams to show what happens to the metal leaves (i) when the strip is brought near the ball before the conductor is removed, and (ii) after the conductor is removed and the charged strip is moved away from the ball.

6 Predict the kind of charge that has been induced on the electroscope, and state how you will test your prediction. Test your prediction, using the appropriate charged strip. Discharge the electroscope by touching the ball.

(a) Record your observations using labelled diagrams.

7 Predict what will happen if steps 4 and 5 are repeated using a positively charged acetate strip. Then test your prediction.

(a) Record your observations using labelled diagrams.

Analysis and Communication

8 Analyze your observations by answering the following questions and making the necessary explanations:

(a) In terms of the law of electric charges, what can you infer about the kind of charge that appears to be induced on the leaves of electroscope in step 2, and in step 3? Explain your answers.

(b) In terms of the movement of electrons, explain what happened to the electroscope in step 2, and in step 3.

(c) Why is it possible for an uncharged object to appear charged if no charge has been transferred to it?

(d) What kind of charge was induced on the metal-leaf electroscope in step 5? Comment on the validity of your predictions and testing procedure in step 6.

(e) Explain what happened in step 5, in terms of the movement of electrons.

(f) What kind of charge was induced on the metal-leaf electroscope in step 7? Comment on the validity of your predictions and testing procedure.

(g) Explain what happened in step 7, in terms of the movement of electrons.

9 Write a summary of your observations based on the following:

(a) Identify the kind of charge that is temporarily induced on the side of a neutral object closest to the charged object and explain this charge, using supporting diagrams.

(b) Identify the kind of charge on an uncharged object after it has had a charge induced on it and explain this charge, using supporting diagrams.

Understanding Concepts

1. Why are dust particles attracted to a newly polished car?

2. Explain why lint and hairs from pets stick to your clothes more readily in winter than in other seasons of the year, in terms of induced charge separation. Would you alter the device you invented in question 1 in section 9.1, based on new knowledge you have gained?

3. (a) If a dust particle in the air floated near some free electrons that had been released by an electrostatic device, what would happen? Explain why.

(b) If a charged dust particle floated near a wall or a piece of furniture, what would happen? Explain why.

4. How is charging by induction involved in the operation of cell phones, radios, and televisions? In this investigation, the wire was disconnected to show charging by induction. What is the difference with the devices mentioned above?

Exploring

5. Look back at Table 1 on page 275. In a group, brainstorm eight common materials not included in the electrostatic series list in the table. Make your own simple electroscope and, by using only three materials selected from the electrostatic series list, produce a revised electrostatic series that includes the eight items you thought of.

9.10

Lightning

Figure 1

Just about everyone has at least one vivid memory of a particularly violent lightning storm. Although lightning and thunderstorms seem to occur infrequently, about 2000 thunderstorms are occurring throughout the world at any given time, generating about 100 lightning strikes every second, or about 8 million strikes daily.

Actually, lightning is part of a natural process of exchanging electric charges between the atmosphere and Earth itself. Electric charges, mostly negatively charged electrons, are continuously being removed from Earth's surface by a variety of processes. Some are natural processes, such as the evaporation of water molecules, and others are related to the production of exhaust gases by vehicles and industrial activities. When thunderclouds form, huge numbers of these negative charges tend to concentrate near the bottom of the cloud. When the negative charge at the base of the cloud moves over tall objects, such as the buildings in **Figure 1**, it is sometimes close enough to return to the ground in a huge spark we call lightning.

Lightning appears to be a jagged path of white light moving toward the ground. The jagged path is caused by the electric charges moving along the path of least resistance in the air. This path is sometimes created by traces of moisture in the air, or by a concentration of positive ions. The electric charge flows in a series of steps as it finds the easiest path to the ground. The charges are more likely to move toward the tallest objects, because it shortens the path to the ground, especially if they are made of metal conductors.

Try This: Lightning and Safety

Think about the last major thunderstorm you experienced.

1. During the thunderstorm, what activities did you continue to engage in that you now realize were placing you in danger?
2. When is the appropriate time to stop playing golf, baseball, soccer, or tennis, or to get out of a pool or lake when a thunderstorm is approaching?
3. What safety precautions should you take when indoors during a lightning storm?
4. Make a list of the actions that you will take in the future if you are engaged in an activity or are in a location that could place you in danger during a thunderstorm.

Research and review the Canada Safety Council recommendations on actions to take if you are caught in a thunderstorm. 3A

SKILLS HANDBOOK: 3A Research Skills

Lightning Rods

The diagram in **Figure 2** shows how a lightning rod can protect a house from a lightning strike. A pointed metal rod is attached to the highest part of the building. A thick conductor, usually copper, is connected from the pointed rod to a metal plate buried in the ground. The plate is used to conduct the electric charges between the rod to the ground.

Lightning rods provide two kinds of protection: they help prevent lightning from striking and, if lightning does strike, they direct the charge through the conductor to the ground. To understand the first case, look at the charges indicated in **Figure 2**. The negative charge at the base of the thundercloud induces a positive charge on the things below it, including the building, the lightning rod, and the ground. The lower atmosphere always contains 1000 to 2000 positively and negatively charged ions in every cubic centimetre of "normal" air. The positive ions are repelled by the highly charged (positive) lightning rod toward the thundercloud, thereby neutralizing some of the negative charge. This can prevent a lightning strike. If, however, a lightning strike does occur, the copper conductor carries the negative charges safely to the plate in the ground.

A car is a safe place to be in a lightning storm because most of the car body is made of a metal conductor. Also, because it is usually raining, the outside of the car is wet. When lightning strikes the car, the electric charge travels over the entire body of the car and then easily crosses the short distance from the base of the car to the ground.

Did You Know?

On May 6, 1937, the huge 240-t airship *Hindenburg* burned as it came in to the landing area during a storm at Lakehurst, New Jersey. Research has revealed that the fire was caused by an electrical discharge that ignited the highly flammable coating painted on the cotton-fibre skin.

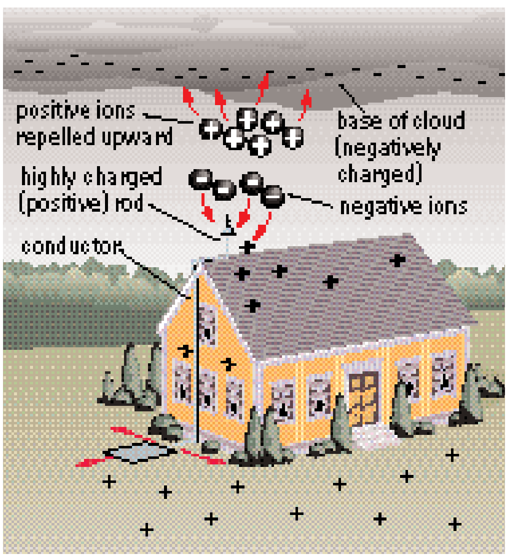


Figure 2
The protection of a building by a lightning rod

Understanding Concepts

1. Why does lightning occur?
2. Why does lightning seem to strike the tallest objects?
3. Draw and label the typical path of (6C) a lightning strike. Explain why it looks as it does.
4. **(a)** What are the two main ways a lightning rod protects a building?
   (b) Explain how each protection method works.

Making Connections

5. What kinds of buildings are most at risk from lightning strikes? What buildings are at the least risk? Explain why.
6. Why are golf courses, parks, and open boats particularly dangerous places to be during a thunderstorm? How would you minimize the safety risks in these public places?

Exploring

7. Use the Internet or a library to (3A) investigate the effects of lightning on the human body. Choose two of the following questions and prepare an artistic or electronic visual presentation for the class:
   - What are the physical signs you might experience to warn that lightning might be about to strike?
   - What parts of the body are most vulnerable to lightning damage?
   - How does lightning cause death?
   - How many people are injured or killed annually by lightning in Canada?
8. What positive results occur because of lightning strikes? Investigate any chemical reactions that might occur as the result of a lightning strike.

9.11 Case Study

Interesting Insulators and Conductors

Fabric Softener Sheets

A clothes dryer is a perfect static electricity generator. When clothes made of different materials rub against one another as they tumble in the dryer, some of the molecules making up the materials lose electrons and some gain electrons. As the clothes become drier, the humidity in the dryer is lowered and the fabrics act as insulators preventing the charges from easily returning to their original locations. This favours the additional buildup of charge, and the clothes snap and crackle with static charge when we take them out of the dryer.

As sheets of fabric softener tumble around with the clothes, they act as conductors allowing the electrons to migrate among the clothes easily, lessening the buildup of charges. The molecules of the softener transfer to the fabrics and make the different materials appear more like one another. This allows the electrons to distribute themselves more evenly throughout the entire load in the dryer, and clothes can be separated without clinging to each other.

(a) If you take the clothes out of the dryer when they are only partially dry, is there any static cling? Explain your answer.

(b) Why do the clothes become charged? How could you predict which clothes would be charged (i) positively, and (ii) negatively?

(c) What two things does the fabric softener do to reduce static cling?

The Photocopier

The photocopying machine provides an interesting example of how one substance, selenium, has the unusual property of being able to function both as an insulator and a conductor, depending on how much light is shining on it. Selenium is **photoconductive**—it acts as an insulator in darkness and as a conductor when light shines on it.

A copying machine uses the scientific principle that electric charges can be removed from a surface by light (**Figure 1**). First, a special selenium-coated, flat metal plate is positively charged (step 1). Light shone through a lens then projects an image of the

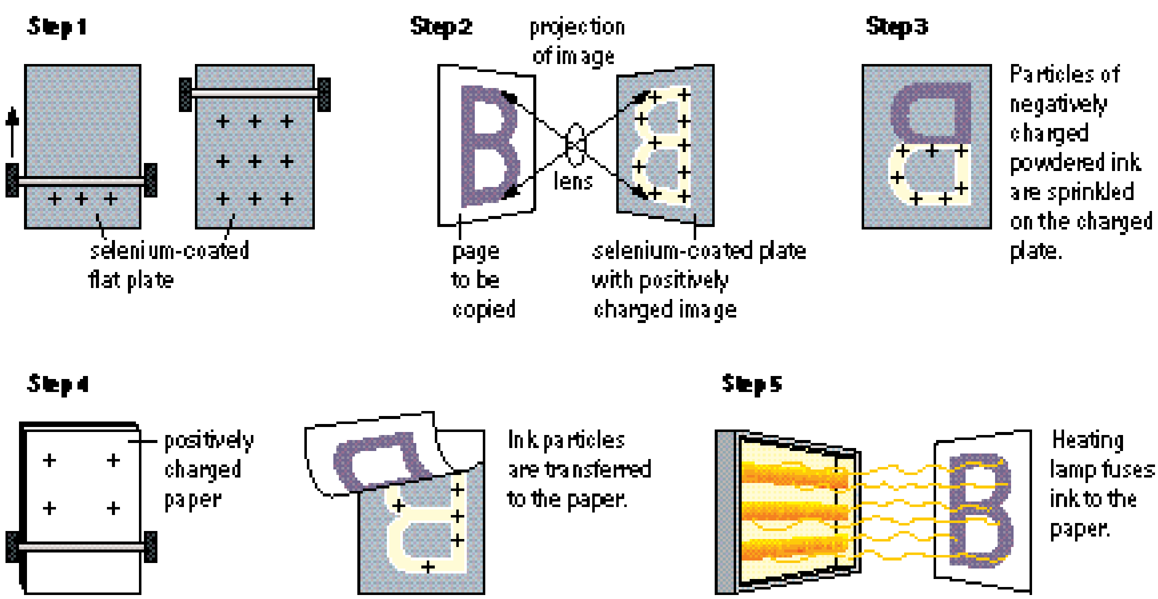


Figure 1
The operation of a photocopying machine

page to be copied onto the charged plate. Wherever the light falls on the selenium plate, the plate becomes a conductor and the positive charge is conducted away from the selenium by the metal plate (step 2). Only the areas coloured yellow, representing the printed material on the page, remain charged (the selenium remains an insulator). Particles of negatively charged powdered ink are then sprinkled over the plate, and these particles are attracted to the positively charged areas (step 3). Next, a positively charged piece of paper is brought in contact with the plate, and the negatively charged ink particles transfer to the paper (step 4). A lamp rapidly heats the paper, causing the ink to fuse or melt onto it, making a permanent copy of the original page (step 5).

(d) What kinds of charge transfer occur during the photocopying process? Describe each one and explain why it is used.

(e) Why is the metal plate coated with selenium?

(f) Use the Internet or a library to research (3A) who invented the photocopy process. Outline the difficulties that were faced in marketing the idea to a manufacturer.

Cell Phones and Car Radios

Every time you get a signal on a pager, talk to someone on a cell phone, or listen to the radio in the car, charging by induction is occurring on some rather unusually shaped conductors. Attached to each of these devices is a conductor called an aerial. Sometimes the aerial is so small it can be placed inside the device itself. In many cars it is attached to the back window.

Whenever a cell phone receives a signal, there is no actual wire connecting it to the source of the signal (**Figure 2**). The signals are waves of electromagnetic energy that travel from the person calling you through the air to the aerial on the cell phone. When the electromagnetic wave interacts with the conducting aerial in the cell phone, the electric charges in the conductor move by induction in exactly the same patterns as the electromagnetic wave. This movement of electric charges is passed on to the circuits in the phone, and you can hear the voice of the person calling.

(g) Sometimes you cannot receive the signals very well. Think back to your own experiences and list the places where this problem has occurred. Suggest reasons why this happened in each case.

(h) Why are portable telephones called "cellular" phones? How do they work?

Figure 2

Making Connections

1. Could a fabric softener sheet be reused (4A) indefinitely? Make a hypothesis, then design and carry out an investigation. Share your results and conclusions.
2. What is the purpose of the bright light that flashes every time a photocopier makes a copy? Use a diagram in your explanation.

Exploring

3. Recent research on the use of cell phones suggests that there may be health risks associated with their use. Research information about those risks. What are the implications for the future?

Reflecting

4. Reexamine the list you made in Getting Started (1). How has your understanding changed?

Chapter 9 Review

Key Expectations

Throughout the chapter, you have had opportunities to do the following things:

- Describe the properties of static electric charges, and explain electrostatic attraction and repulsion. (9.1, 9.2, 9.3)
- Describe and explain several methods of charging and discharging objects. (9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 9.10)
- Use safety procedures when conducting investigations. (9.1, 9.4, 9.9)
- Investigate static electricity, and organize, record, analyze, and communicate results. (9.1, 9.4, 9.9)
- Formulate and research questions related to electrostatics and communicate results. (9.5, 9.6, 9.8, 9.9, 9.10, 9.11)
- Charge objects using several methods. (9.1, 9.4, 9.9)
- Explain practical applications of electrostatics. (9.3, 9.8, 9.11)
- Describe common electrostatic phenomena, and suggest and assess solutions to problems related to static electricity. (9.3, 9.5, 9.6, 9.7, 9.10)
- Explore careers requiring an understanding of electricity. (Career Profile)

KEY TERMS

charging by contact
charging by friction
charging by induction
discharge
discharge at a point
electric charge
electrical conductor
electrical insulator
electron
electroscope
electrostatic series
electrostatics
ground
induced charge separation
law of electric charges
negative charge
negative ion
neutralize
neutron
nucleus
photoconductive
positive charge
positive ion
proton
static electricity

Reflecting

- "Studying static electricity helps us to understand the behaviour of particles of matter, to explain common effects produced by static charges, and to become aware of both its potential hazards and its many practical uses." Reflect on this idea. How does it connect with what you've done in this chapter? (To review, check the sections indicated above.)
- Revise your answers to the questions raised in Getting Started. How has your thinking changed?
- What new questions do you have? How will you answer them?

Understanding Concepts

1. Make a concept map to summarize the material you have studied in this chapter. Start with the word "electrostatics."
2. What is
   (a) a negatively charged ion?
   (b) a positively charged ion?
3. List six materials that are electrical conductors and six that are electrical insulators.
4. Describe three methods of discharging a charged object.
5. (a) List three methods of charging a neutral object.
   (b) List two examples of situations where neutral objects are charged by each of the methods in part (a).
6. Which particles in the atom move when electric charge is transferred from one atom to another? Explain why.
7. Explain the purpose of the electrostatic series. Describe a practical example to illustrate your answer.
8. (a) What is the function of an electroscope?

(b) Name the kind of electroscope that can be recognized as being charged, just by observation. Explain why.

(c) Explain how to identify the kind of charge present on (i) a charged pith-ball electroscope and (ii) a charged metal-leaf electroscope.

9. Describe and explain, with the aid of diagrams, what happens when (a) a negatively charged and (b) a positively charged object is brought up to an uncharged pith-ball electroscope.

10. Explain how to identify the unknown charge on an object, using a pith-ball electroscope.

11. If you rub a comb in your hair and bring it close to some small pieces of paper, some of the pieces jump toward the comb, and then quickly jump off it again. Explain why.

12. Explain why an electric charge quickly builds up on the surface of furniture when it is being polished, but not on water taps.

13. What does it mean to "ground" an object?

14. When static electricity is discharged rapidly, what forms of energy can be produced? List examples to support your answer.

15. If you were given only a negatively charged strip, how could you charge a metal-leaf electroscope (a) positively and (b) negatively?

Applying Skills

16. Explain how you could determine the charge on your comb after you comb your hair. Design a test and carry it out. What is the kind of charge on the comb?

17. Consider the following interactions between various combinations of four charged pith balls, A, B, C, and D. B repels A. D attracts C and A. If D is attracted to an acetate strip that has been rubbed with silk, what are the charges on A, B, and C?

18. (a) Describe what happens when a negatively charged object is touched to a metal-leaf electroscope, and then removed.

(b) Draw a series of diagrams to show what happens to the movement of electric charges on the electroscope in part (a).

19. (a) Suppose you have a positively charged acetate strip, and two uncharged metal spheres mounted on insulating stands. Describe how to use the charged strip to charge one sphere positively and one sphere negatively by electrostatic induction.

(b) Explain what happened to the charges on the two spheres. Draw a series of diagrams to illustrate your answer.

(c) Describe how you can check the kind of charge on each sphere.

20. The Bohr-Rutherford model for the structure of the atom was developed after much careful experimentation and thought by many brilliant scientists. An interesting problem arises if you think about the structure of the nucleus itself. Based on the Law of Electric Charges, what should happen to the protons in the nucleus? What does happen? Try to develop a theory to explain why the protons behave as they do.

Making Connections

21. Why do some cars and trucks have wires and chains hanging underneath them?

22. (a) How does a lightning rod protect a house during a thunderstorm?

(b) List three safety precautions that you should take inside a house during a lightning storm.

(c) List three safety precautions to follow if you are outside during a lightning storm.

23. You want to buy a new comb to reduce the problem of flyaway hair on dry winter days. What should the comb be made of? Explain why. (Hint: Review Table 1 in 9.3 and Table 1 in 9.6.)

24. When you polish a metal ornament in the kitchen, dust particles are attracted to it. However, when you polish a nearby metal water tap, it does not attract dust particles. Explain these two situations.

25. Are all makes of cars equally safe during a lightning storm? Explain your answer.

26. Which has more need of lightning protection, a wooden barn or a steel skyscraper? Explain.

27. (a) List two major areas of application in which electrostatic devices are used.

(b) For each area, state the properties of electric charges that are used to advantage.