Key Terms
ion
lightning rod
electrostatic precipitator
Van de Graaff generator
radiation dosimeter

10.3 Charges at Work

Do you have an electric dust and pollen filter in your home, or do you know someone who does? This appliance uses electric charges to clean the air. Several office machines, such as the photocopier shown in **Figure 10.15**, also use static charges. Electric charges are used in many applications to control pollution, reduce waste, and monitor workers' safety. On a much larger scale, the first atom smashers (**Figure 10.16**) used large charges to accelerate and separate subatomic particles. In this section, you will learn about some important applications of static charges, many of which involve induced charges. One of the first applications of static charges was a lightning conductor. You will begin this section by studying lightning bolts, which carry large charges that must be discharged safely.

Figure 10.15 Laser printers, scanners, and photocopiers use electric charges to print images.

Lightning

Over 250 years ago, Benjamin Franklin showed that a lightning bolt is a gigantic electrical discharge. A moderate thunderstorm briefly generates electrical energy that is equivalent to the output of a small nuclear generating plant. Every electrical discharge is caused by a transfer of charge.

A storm cloud is a complicated mix of raindrops and ice particles, as shown in **Figure 10.17A**. Strong updrafts in the centre of a storm cloud carry smaller raindrops and ice particles upward. At the same time, gravity causes larger, heavier raindrops and hailstones to fall. The raindrops, ice particles, and hailstones collide. Charge is transferred, and **ions**, which are charged atoms or groups of atoms that have gained or lost one or more electrons, are formed.

ion a charged atom or group of atoms

The negative charge at the bottom of a cloud induces a positive charge in the ground and buildings below it, as shown in **Figure 10.17B**. A charged stream, called a stepped leader, forms, as in **Figure 10.17.C**.When a large enough flow of negative charge is within about 100 m of the ground, a large flow of positive ions, called a return stroke, jumps from the ground, as shown in **Figure 10.17D**. Momentarily, the humid air becomes a superheated conductor. This creates a glow, which you see as lightning, and causes a shock wave of expanding gases, which you hear as thunder. A stepped leader and return stroke may occur many times in what appears to be a single lightning strike. There may also be lightning between or within clouds. See **Figure 10.17E**.

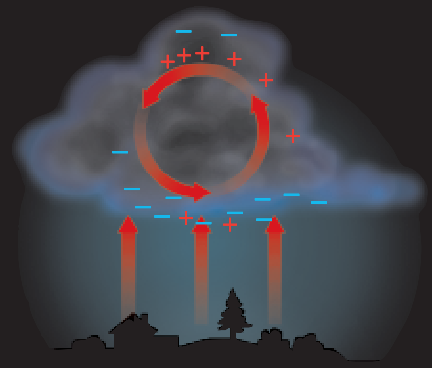
Figure 10.16 This pear-shaped atom smasher was built at the Westinghouse Electric and Manufacturing Company in East Pittsburgh, Pennsylvania, in 1937. It generated enormous static charges, which were used to study subatomic particles.

NATIONAL GEOGRAPHIC

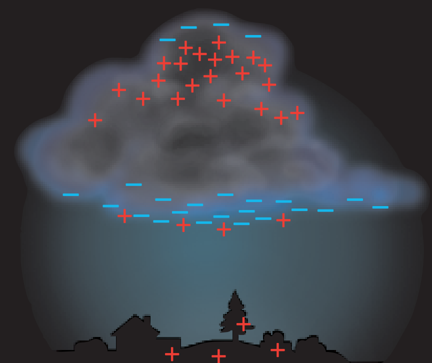
VISUALIZING LIGHTNING

Figure 10.17

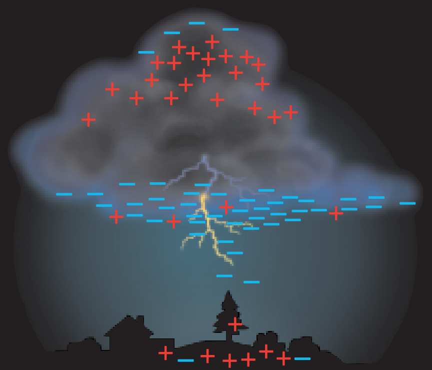
Storm clouds can form when humid, warm air rises to meet a colder air mass. As these air masses churn together, the stage is set for the explosive electrical display we call lightning. Lightning strikes when negative charges at the bottom of a storm cloud are attracted to positive charges on the ground.



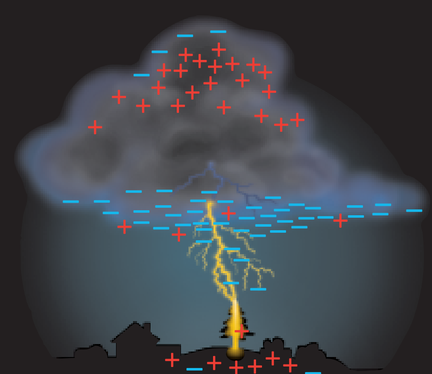
A Air currents in the storm cloud cause charge separation. The top of the cloud becomes positively charged, and the bottom becomes negatively charged.



B Negative charges on the bottom of the cloud induce a positive charge on the ground below the cloud by repelling negative charges in the ground.



C When the bottom of the cloud has accumulated enough negative charges, the attraction of the positive charges below causes electrons in the bottom of the cloud to move toward the ground.



D When the electrons get close to the ground, they attract positive ions that surge upward, completing the connection between the cloud and the ground. This is the spark you see as a lightning flash.

LIGHTNING BETWEEN OR WITHIN CLOUDS never strikes Earth and can occur much more often in a storm than cloud-to-ground lightning.

How Does a Lightning Rod Work?

Lightning takes the path of least resistance between a cloud and the ground, usually striking the highest object in an area. This explains why a tall building, a tree, or a person who is standing in an open field or sitting in a boat on a lake is the most likely to be hit by lightning.

A lightning strike carries a very large electric current, which will damage any unprotected building, tree, or person it hits. In Canada, lightning strikes cause about one third of all forest fires and about 10 deaths each year. They occur most frequently in June, July, and August, when warm, humid air masses collide with cooler air masses. Buildings can catch fire if they are hit by a lightning bolt.

Since lightning cannot be prevented, many buildings have a lightning rod on top. A **lightning rod** is a metal sphere or point that is attached to the highest part of a building and connected to the ground. A thick, insulated copper wire connects the lightning rod to a metal plate or bare metal cable in the ground. A lightning rod is especially important in rural areas, where a house or barn may be the tallest building, as shown in **Figure 10.18**.

lightning rod a metal sphere or point, attached to the highest part of a building and connected to the ground

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Study Toolkit

Interpreting Diagrams

How do the + and – symbols help you understand the function of a lightning rod?

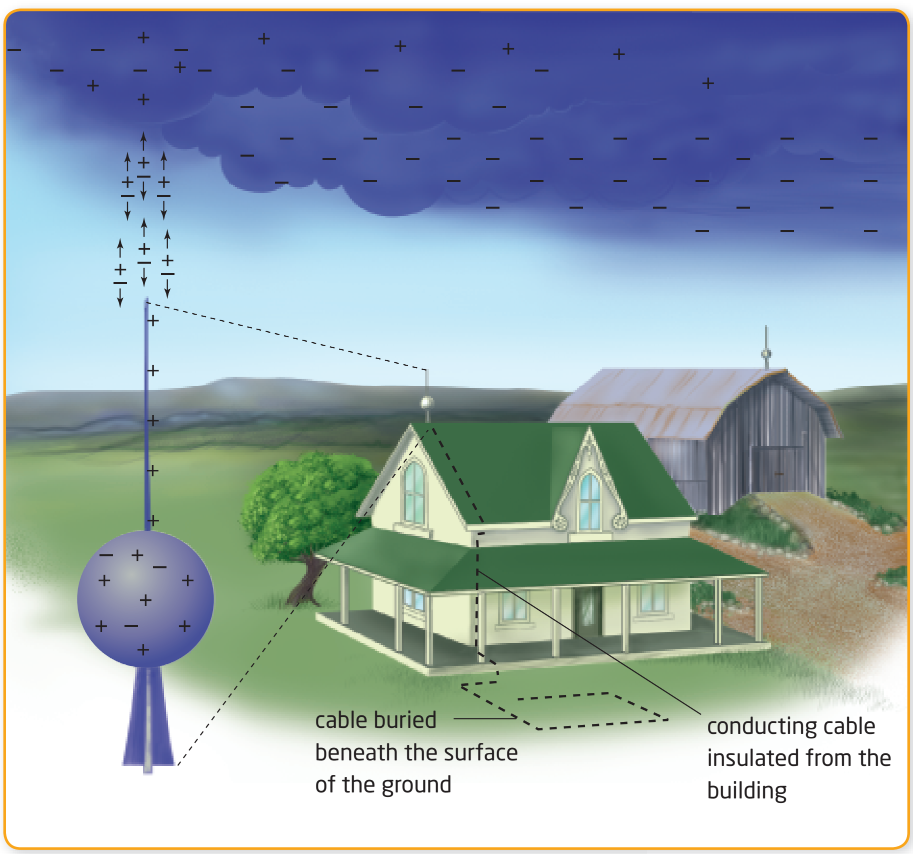


Figure 10.18 A lightning rod becomes positively charged by induction. To protect the building, the cable that is attached to the lightning rod is insulated. Below the surface of the ground, the cable is bare, allowing the charge to be conducted into the ground.

Lightning Rods and Safety

A lightning rod has two functions: to reduce the likelihood of a lightning strike and, if a strike occurs, to conduct the charge safely to the ground. Ideally, a lightning rod reduces the likelihood of a lightning strike. The charges streaming between the cloud and the lightning rod tend to neutralize each other, and this may be enough to prevent lightning from striking. If lightning does strike, however, it will likely hit the lightning rod rather than the building to which the lightning rod is attached. Charge from the lightning bolt will then be safely conducted to the ground.

Lightning produces visible light and an expanding shock wave of air that you hear as thunder. The light and sound wave are formed at the same instant, but they travel at very different speeds. This explains why you hear the thunder after you see the flash of light. Environment Canada suggests that you take shelter in a building or a metal vehicle when you can count 30 s or less between the flash of light and the thunder.

Sense of *time*

The speed of light is about 300 000 km per second, so the flash of light reaches you almost immediately. The speed of sound is much less–about one third of a kilometre per second. So, when you can count 30 seconds between seeing a lightning bolt and hearing thunder, the storm is about 10 km away.

Learning Check

1. Refer to **Figure 10.18**. Why does lightning tend to strike the tallest building nearby?
2. Briefly describe the two functions of a lightning rod.
3. What is an ion? How can positive ions move through the air?
4. What are some of the hazards of a lightning strike?

Using an Electric Charge to Reduce Pollution and Waste

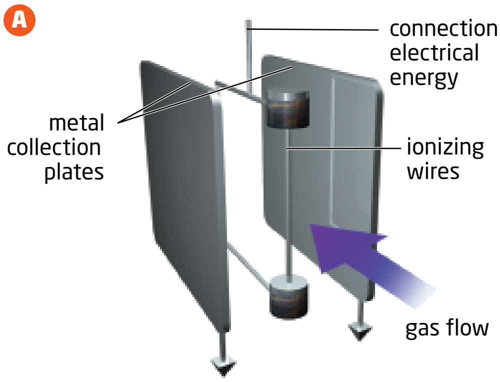
In 1907, Frederick Cottrell patented the first industrial application that made use of the principles of electrostatics (the study of static electricity). Cottrell was a chemistry professor who wanted to remove sulfuric acid droplets from smokestacks. Sulfuric acid, smoke, and ash are by-products of ore smelters, coal-burning plants, and cement kilns. Cottrell invented an **electrostatic precipitator**, a type of cleaner that removes unwanted particles and liquid droplets from a flow of gas. An electrostatic precipitator can be very effective for reducing pollution from smokestacks, such as those shown in **Figure 10.19**.

electrostatic precipitator a type of cleaner that removes unwanted particles and liquid droplets from a flow of gas

Figure 10.19 Most of the "smoke" you see coming from the smokestacks on this steel plant in Hamilton, Ontario, is condensing steam. However, the emissions also contain harmful substances that an electrostatic precipitator can remove.

How an Electric Precipitator Works

An electrostatic precipitator, like the one illustrated in **Figure 10.20**, makes use of the laws of electric charges. Dust particles and liquid droplets in a polluted gas become positively charged when they come in contact with a wire that has a strong positive charge. The positively charged particles and droplets induce a negative charge on the collection plates. When they collide with the collection plates, they are neutralized and collected in large containers called hoppers.



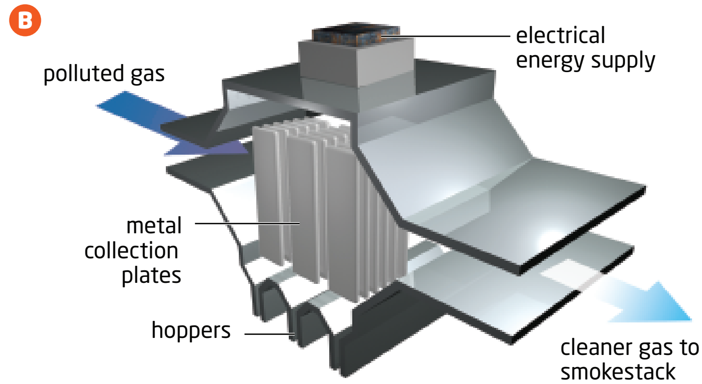


Figure 10.20 **A** An electrostatic precipitator consists of a series of plates and highly charged wires. It can reduce air pollution from dust particles and liquid droplets. **B** In this view, the positively charged wires cannot be seen because they run between the plates.

STSE Case Study

E-waste

Electronics companies are constantly marketing new models of computers, cellphones, and MP3 players. The new models are sleeker and run faster, and they have more memory, better interfaces, and more creative features. They tempt customers with leading-edge technology, inspiring customers to discard their old devices for new ones. What happens to the discarded electronic products?

Electronics that are no longer used can become a hazardous waste called e-waste. E-waste is becoming a serious threat to human and environmental health. Many electronic products, including televisions and computers, have parts that are made from heavy metals, such as mercury, lead, and cadmium. These toxic elements can build up in landfills and can end up in ground water.

Although most e-waste can be recycled, little of it is. Much of the e-waste that is recycled is shipped to developing countries for recycling. Often the recycling methods are dangerous. For example, to collect the glass in computer monitors, workers smash the monitors, releasing toxic lead dust. As well, workers use dangerous acids and open fires to recover valuable metals from the e-waste.

International agreements exist to prevent dangerous recycling. E-waste from developed countries, however, is still being sent to countries that allow the use of high-risk recycling methods. It is cheaper for companies to export the e-waste than to pay for safer recycling methods.

To combat e-waste, many countries, including Canada, are adopting a policy called Extended Producer Responsibility. This policy makes companies responsible for their products when consumers are finished with them.

Electrostatic Spray Painting

Look at the objects around you. You can probably see objects made from metal, plastic, wood, and fabric. Most of the manufactured products you see have some kind of coating. For example, think about the painted surface on a car, the enamel finish on a refrigerator, and the flame retardant on some fabrics. For economic and environmental reasons, manufacturers want to apply only as much coating as necessary, with no waste. The solution is to use an electrostatic spray. The paint or powder is given a charge as it leaves the nozzle of the sprayer. The object to be coated is either grounded or given a charge that is opposite to the charge of the particles in the spray. Thus, the particles are attracted to the object being coated, minimizing the amount of over-spray. In **Figure 10.21**, paint leaving the spray gun is given a negative charge. The car fender being painted has a positive charge.

Figure 10.21 Electrostatic spray painting is a good environmental and economic choice because it reduces over-spraying.

How can you help to reduce e-waste?

- Wait longer before replacing electronic devices.
- Upgrade computers and other electronic devices instead of discarding them.
- Donate used electronic devices to charity.
- Buy from electronics manufacturers that take back old devices and safely recycle the materials in them.
- Choose electronic devices that last longer and are made from safer materials.

According to Environment Canada, discarded electronic products create 140 000 tonnes of waste in Canada each year. This is 4.5 kg of electronic waste per Canadian.

Your Turn

1. Create a PMI chart of the advantages and disadvantages of living in a world where billions of people use cellphones. Your chart should have three columns: P for the plus (advantages), M for the minus (disadvantages), and I for interesting points that you consider neither entirely positive nor entirely negative.
2. Research the company that makes your favourite electronic product. What are the company's policies regarding recycling? Is the company responsible for its products at the post-consumer stage? How do the company's policies affect your opinion of its products?
3. Find out more about the Extended Producer Responsibility policy. How do companies pay for the extra costs involved? Create a pamphlet for an electronics company to promote its Extended Producer Responsibility policy. Your pamphlet should highlight the benefits to consumers, as well as explain any costs.

The Van de Graaff Generator

Van de Graaff generator a device that accumulates very large charges

A **Van de Graaff generator** is a device that can accumulate and transfer very large charges, as shown in **Figure 10.22**. The basic operation of the generator is shown in **Figure 10.23**. The sphere rests on an insulated column. Inside the column is a rubber belt that runs over two rollers. A motor drives the lower roller, and, as the belt moves over it, charging by friction takes place. Charges stick to the belt and are carried up as the belt rotates. Near the top roller is a metal collecting comb, which is attached to the inside of the metal sphere. The charged belt induces a redistribution of charges in the comb, and charges accumulate on the metal sphere.

Van de Graaff generators have been used in atom smashers since the 1930s. A Van de Graaff generator can accelerate particles to very high speeds. Beams of high-speed particles can be focussed so they crash into each other, breaking the particles into fragments and sometimes forming new subatomic particles. Van de Graaff generators have also been used to test the electronic circuits used in space technology.

Figure 10.22 The girl in the photograph has received a large charge from the Van de Graff generator.

Study Toolkit

Interpreting Diagrams If the metal sphere becomes positively charged, why does this illustration show some – symbols on the sphere?

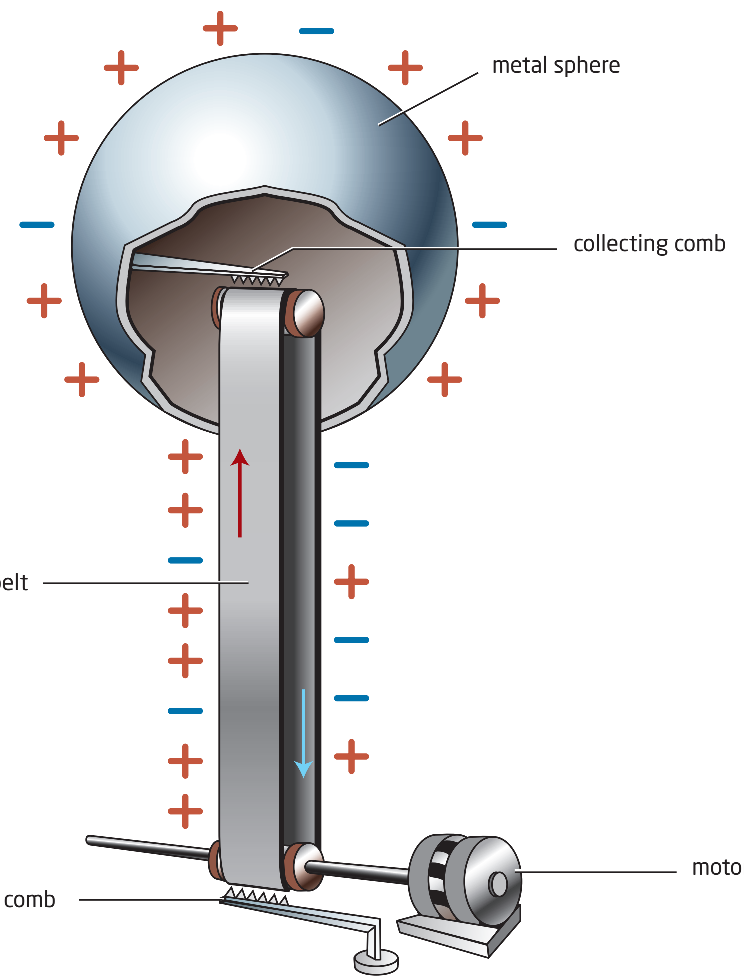


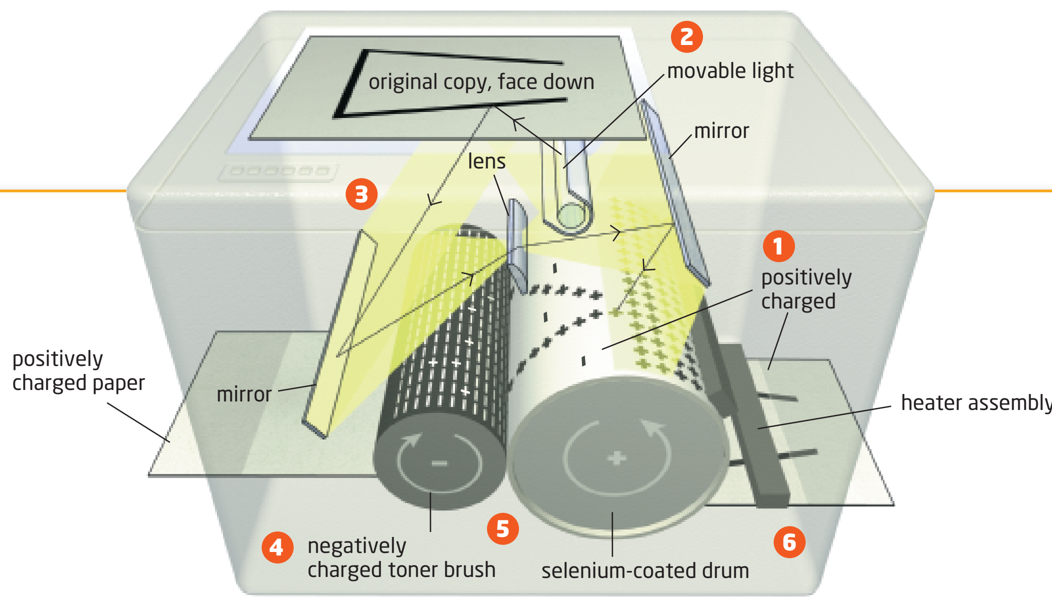
Figure 10.23 In a Van de Graaff generator, positive charges are collected on the metal sphere.

Photocopiers, Laser Printers, and Scanners

Selenium is an element that is essential for good health. It also has a peculiar and useful electrical property. In 1873, Willoughby Smith was the chief engineer at the Telegraph Construction and Maintenance Company in Britain. Smith began testing selenium as a possible material for use in telegraph cables. He was puzzled to find that bars made of selenium did not give consistent results when their conductivity was measured. Eventually, Smith discovered that different light conditions affected the ability of selenium to conduct. Selenium is only a fair conductor in the dark, but it becomes a very good conductor when exposed to light.

Chester Carlson, an American inventor, used this unique property of selenium in the first photocopier machine, which he patented in 1942. In a photocopier, laser printer, or scanner, an electrostatic image is made on an aluminum drum coated with selenium. As you read through the description in **Figure 10.24** of how a photocopier works, try to identify the parts of the photocopier and the principles involved.

Figure 10.24 The parts of a photocopier use the principles of electrostatics.



1. The sheet of paper to be copied is placed face down on the glass surface of the copier. When the copy button is pressed, the selenium-coated drum is given a positive charge in the darkness.
2. A bright light moves across the paper. An optical system, which consists of mirrors and a lens, projects an image of the paper on the selenium-coated drum.
3. Light reflects from white portions of the paper being copied. Where the reflected light strikes the drum, selenium conducts charge. Electrons from the aluminum base of the drum move to these light areas, neutralizing the charge that was there. Dark areas on the drum, representing the information being copied, retain a positive charge. The surface of the drum contains an electrostatic image of the information being copied.
4. The machine spreads toner over the surface of the drum. Toner is a fine black powder, consisting of pigments that coat tiny plastic beads. (The pigments give the powder its black colour.) The toner is attracted to the positive parts of the drum, which represent an image of the paper being copied.
5. As the drum rotates, it pulls a sheet of paper from the input tray. The sheet of paper is given a larger positive charge than the drum. The toner is transferred to the paper as the paper presses against the drum.
6. The paper next passes through heated Teflon® rollers. The heat melts the plastic beads in the toner, and the rollers press the black powder into the paper. As the copy emerges from the machine, it is still warm.

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Learning Check

5. Explain how electrostatic spray painting works.
6. What electrical property of selenium is used in photocopiers and laser printers?
7. What function does a Van de Graaff generator play in an atom smasher?
8. How does an electrostatic precipitator reduce pollution?

Activity 10-4

A Static Spice Separator

As you know, a static charge attracts a neutral material. How can an electrostatic charge be used to separate particles that have different masses?

Materials

- salt
- pepper
- plastic spoon or ruler
- paper
- wool cloth

Procedure

1. Spread a mixture of salt and pepper in a thin layer on a sheet of paper.
2. Rub the plastic spoon or ruler with the wool cloth.
3. Slowly bring the charged plastic down toward the salt and pepper mixture. Record your observations.

Questions

1. Which substance in the mixture collected on the charged plastic?
2. Explain why the salt and pepper can be separated using a charged object.
3. Could the same principle be used to separate nuts from their shells (after first cracking the shells)? Explain.
4. An electrostatic separator is any device that can use an electrostatic charge to separate different particles that have different masses. Propose another application for an electrostatic separator.

This activity depends on the relationship between electric charge and mass.

Radiation Dosimeters

A **radiation dosimeter** is a small device that detects and measures exposure to radiation. People who work with radioactive materials or equipment that produces radiation often need to wear a radiation dosimeter. Astronauts wear a radiation dosimeter when they are above Earth's atmosphere, which protects Earth from radiation emitted by the Sun. Nuclear and solar radiation and X rays can be very hazardous, and the damage tends to be cumulative. A single high exposure, or a large dose accumulated over time, places a worker at risk.

There are different types of radiation dosimeters. Some dosimeters are like a photographic film. Radiation darkens the film, just as higher levels of light produce a darker image on a photograph. Other dosimeters resemble a metal leaf electroscope surrounded by a gas. Imagine a charged metal leaf electroscope, with its leaves fully spread apart. Normally a gas is a non-conductor, but radiation knocks electrons from the gas atoms. When this happens, the gas surrounding the electroscope becomes a conductor and there is a charge transfer between the gas and the electroscope. As the charge is conducted away from the electroscope, the leaves come closer together and return to the non-charged position. The pen-style dosimeter shown in **Figure 10.25** uses these principles. It consists of a fibre surrounded by a gas.

radiation dosimeter a small device that detects and measures exposure to radiation

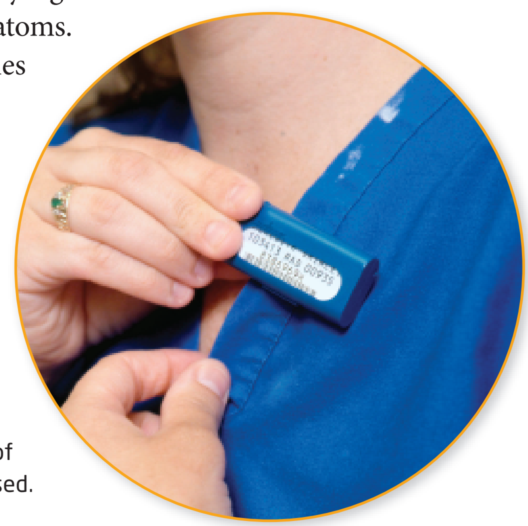

Figure 10.25 In a pen-style radiation dosimeter, any change in the position of the fibre, which is illuminated against a scale, is calibrated to show the amount of radiation to which the worker was exposed.

Making a Difference

Katie Pietrzakowski was brushing her hair when she came up with the idea for her award-winning science fair project. She observed how different particles were attracted to her brush and wondered if these forces of attraction could be used to clean recycled grey water.

Grey water is household waste water from sinks, showers, washing machines, and dishwashers. It can be collected and re-used for lawn irrigation. Re-using grey water helps to conserve water safely and appropriately. Using a system she designed, Katie found that introducing an electric field to grey water could reduce the particulates suspended in the water.

Katie took her project, "Shock the Grey," to the 2006 Canada Wide Science Fair in Saguenay, Québec. There, she won a bronze medal in the Junior Earth and Environmental Sciences division and a scholarship to the University of Western Ontario. Katie is now a high school student in Sault Ste. Marie and hopes to become a teacher.

What other uses for grey water can you think of, to help conserve water?

Section 10.3 Review

Section Summary

- A lightning rod is a metal sphere or point that is attached to the highest part of a building and connected to the ground.
- A lightning rod reduces the likelihood of a lightning strike. If there is a lightning strike, the lightning is more likely to strike the lightning rod than the building it protects, and then to be conducted to the ground.
- An electrostatic precipitator removes unwanted dust particles and liquid droplets from a flow of gas.
- An electrostatic separator uses induced charges to separate particles that have different masses.
- A Van de Graaff generator is capable of generating very large charges.
- In the dark, selenium is only a fair conductor. When exposed to light, it becomes a very good conductor. Selenium-coated drums are used in photocopiers, laser printers, and scanners.
- A radiation dosimeter is a small device that detects and measures exposure to radiation.

Review Questions

T/I **1.** Why does lightning follow a jagged path?

K/U **2.** Make a table about a lightning rod's parts and their functions.

C **3.** Write a short brochure for an electrostatic air purifier, describing how it removes dust and pollen from air.

A **4.** Sandpaper is usually made from an abrasive material, such as aluminum oxide or silicon carbide, which is attached to a backing of cotton, polyester, or rayon. How could electrostatics be used to attach abrasive grains to the sticky coating on a backing of polyester "paper"?

K/U **5.** Briefly describe a Van de Graaff generator and two of its uses.

K/U **6.** See **Figure 10.24**. In a photocopier, why does the toner spread from the drum to the paper?

K/U **7.** Air and other gases are normally good insulators. Explain how a gas can become a good conductor.

T/I **8.** The diagram at the right shows parts of a pen-style dosimeter. A particle of radiation has just entered the dosimeter and is about to strike one of the gas molecules shown.

a. Suppose that the movable fibre has a positive charge. The gas molecule is neutral, because the radiation has not yet hit it. Draw a diagram to show the charges on the dosimeter and the gas molecule.

b. Draw one or more diagrams to show what the radiation does to the gas molecule. Also show why the movable fibre indicates a decrease in the charge on the dosimeter.