Chapter 21 Using Electricity and Magnetism

The BIG Idea

Electric and Magnetic Forces

How are electricity and magnetism related?

Chapter Preview

1 What Is Electromagnetism?

Discover Are Magnetic Fields Limited to Magnets?

Try This On/Off

2 Electricity, Magnetism, and Motion

Discover How Does a Magnet Move a Wire?

Try This Making Motion

Skills Lab Building an Electric Motor

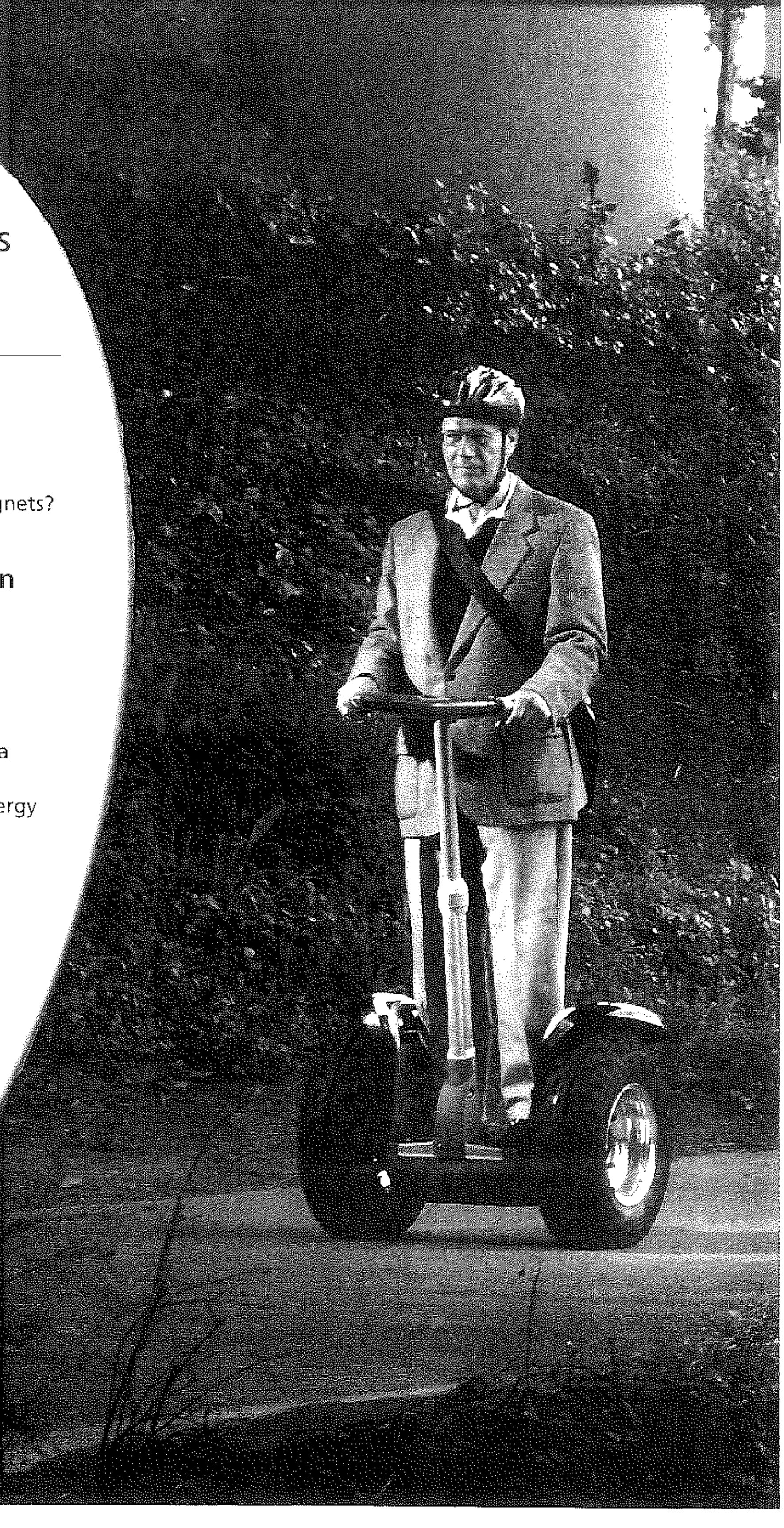
3 Electricity From Magnetism

Discover Can You Produce Current Without a Battery?

Science and History Generating Electrical Energy

Active Art How a Generator Works

At-Home Activity Step-Up and Step-Down



To move in the city, this person travels in a personal transporter—a machine that uses electromagnetism.

Lab zone™ Chapter Project

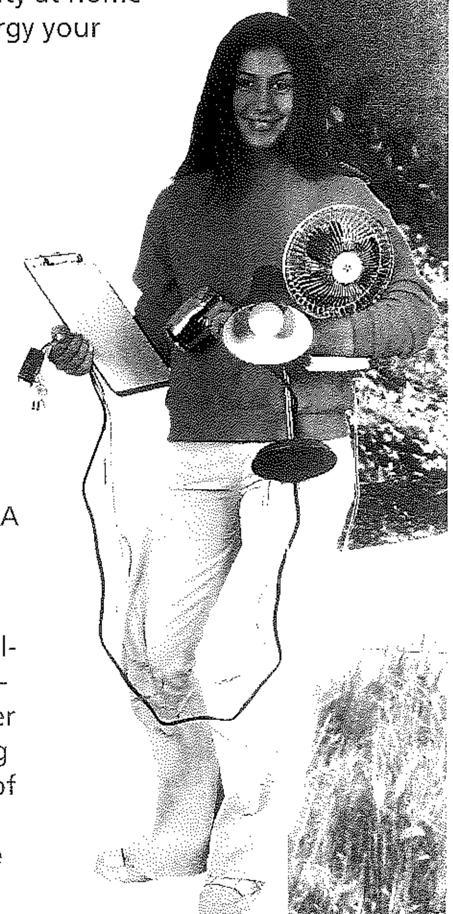
Electrical Energy Audit

In this chapter, you will discover how electricity is generated. You will also study how electrical energy is used in motors and other devices.

Your Goal To analyze how you use electricity at home and to determine how much electrical energy your family uses

To complete the project, you must

- list the appliances in your home that use electrical energy
- record the power rating in kilowatts of each appliance or calculate it using Ohm's law
- record how long each appliance is used during an average week
- calculate how much electrical energy is used by each appliance using the formula Energy = Power × Time
- follow the safety guidelines in Appendix A



Plan It! Begin by listing the appliances in your home. Then prepare a data table to keep track of your observations. Include columns for the name of the appliance, its primary use, its energy source, and the number of hours it is used each day. After collecting data for a full week, calculate the amount of time each appliance was used and the amount of electrical energy each appliance consumed.

Section 1

What Is Electromagnetism?

Reading Preview

Key Concepts

- How is an electric current related to a magnetic field?
- What are some characteristics of a magnetic field produced by a current?
- What are the characteristics of an electromagnet?

Key Terms

- electromagnetism
- solenoid
- electromagnet

Target Reading Skill

Identifying Main Ideas As you read the Solenoid section, write the main idea—the biggest or most important idea—in a graphic organizer like the one below. Then write three supporting details. The supporting details further explain the main idea.

Main Idea

A solenoid is useful because its magnetic field can be changed.

Detail	Detail	Detail

Go Online
SCI LINKS NSTA

For: Links on electromagnetism
Visit: www.SciLinks.org
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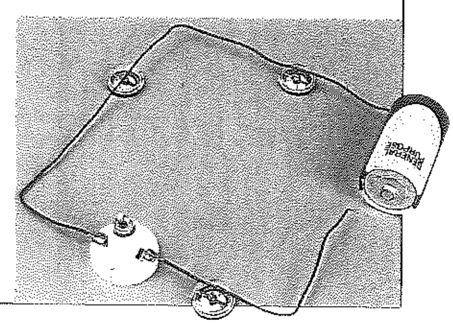
Lab zone Discover Activity

Are Magnetic Fields Limited to Magnets?

1. Obtain two wires with the insulation removed from both ends. Each wire should be 20 to 30 cm long.
2. Connect one end of each wire to a socket containing a small light bulb.
3. Connect the other end of one of those wires to a D-cell battery.
4. Place three compasses near the wire at different positions. Before you continue, note the direction in which each of the compasses is pointing.
5. Center the wire over the compasses. Make sure the compass needles are free to turn.
6. Touch the free end of the remaining wire to the battery. Observe the compasses as charges flow through the wire. Move the wire away from the battery, and then touch it to the battery again. Watch the compasses.



Think It Over

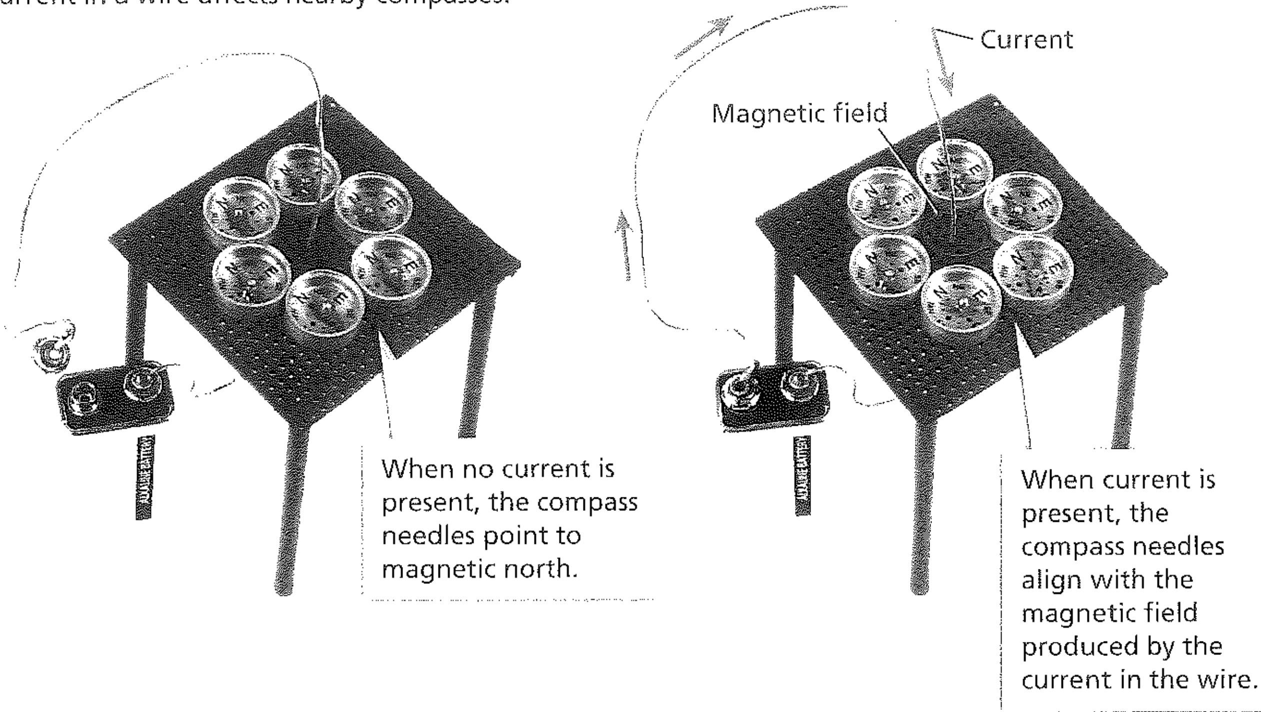
Inferring What happened to the compasses when charges flowed through the wire? What can you infer about electricity and magnetism?

In 1820, the Danish scientist Hans Christian Oersted (UR sted) was teaching a class at the University of Copenhagen. During his lecture he produced a current in a wire, just like the current in the wires of your appliances at home. When he brought a compass near the wire, he observed that the compass needle changed direction.

Oersted was surprised. He could have assumed that something was wrong with his equipment and ignored what he saw. Instead, he investigated further. He set up several compasses around a wire. Oersted discovered that whenever he produced a current in the wire, the compass needles lined up around the wire in the shape of a circle.

Oersted's discovery showed that magnetism and electricity are related. But just how are they related?

FIGURE 1
Currents and Magnetic Fields
Current in a wire affects nearby compasses.



Electric Current and Magnetism

Wherever there is electricity, there is magnetism. **An electric current produces a magnetic field.** This relationship between electricity and magnetism is called **electromagnetism.**

You can't see electromagnetism, but you can use a compass and an electric current to observe its effect on objects. A compass needle normally points north because it aligns itself with Earth's magnetic field. It will point in a different direction only if another magnetic field is present. For example, look at the compasses shown in the photo on the left in Figure 1. They surround a straight wire that has no current. Because there is no current, the wire has no magnetic field. Therefore, the compasses align with Earth's magnetic field and point north.

In the photo on the right in Figure 1, the wire has a current. Notice that in this case the compasses no longer point north. The needles of the compasses change direction because a magnetic field is produced around a wire that has a current. The needles of the compasses align with the magnetic field that the current produces.

In Figure 2, iron filings surround a wire that has a current. You can see that the filings form a pattern. They map out the magnetic field produced by the current in the wire.

Reading Checkpoint **What can produce a magnetic field?**

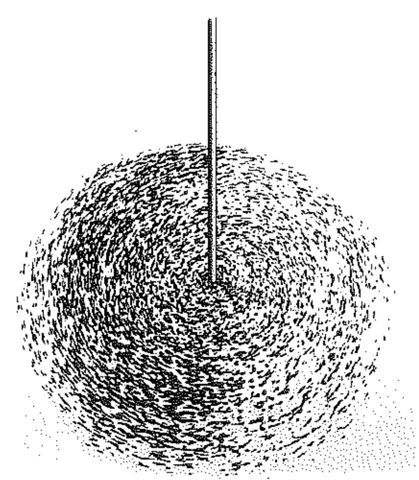
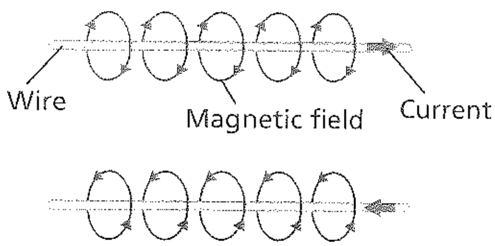


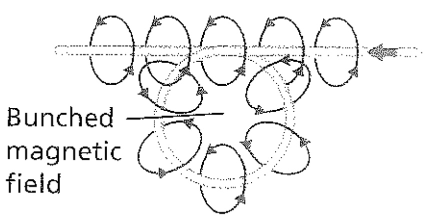
FIGURE 2
A Magnetic Field Map
Iron filings show the magnetic field lines around a wire with a current. Observing *What is the shape of the field lines?*

FIGURE 3
Controlling a Magnetic Field
Both the direction and strength of a magnetic field produced by a current can be controlled.

A Reversing the direction of the current reverses the direction of the magnetic field.



B Looping the wire increases the strength of the magnetic field.



Solenoids

The magnetic field produced by a current has three distinct characteristics. The field can be turned on or off, have its direction reversed, or have its strength changed. Unlike Earth's magnetic field, you can turn a magnetic field produced by a current on or off. To do so you simply turn the current on or off. In addition, you can change the direction of the magnetic field by reversing the direction of the current. When the current reverses, the magnetic field reverses also, as shown in Figure 3A.

You can also change the strength of a magnetic field produced by a current. The magnetic field around a wire with a current forms a cylinder around the wire. If the wire is twisted into a loop, the magnetic field lines become bunched up inside the loop, as shown in Figure 3B. If the wire is bent into a second loop, the concentration of magnetic field lines within the loops is twice as great. So, the strength of the magnetic field increases as the number of loops, or coils, increases.

By winding a wire with a current into many loops you strengthen the magnetic field in the center of the coil. A coil of wire with a current is called a **solenoid.** The two ends of a solenoid act like magnetic poles. In Figure 4 you can see that the iron filings around a solenoid line up much as they would around a bar magnet. However, in a solenoid, the north and south poles change with the direction of the current.

Reading Checkpoint **What happens to the magnetic field lines in a twisted loop of wire?**

FIGURE 4
Magnetic Field Around a Solenoid
The magnetic field around a solenoid resembles that of a bar magnet.
Comparing and Contrasting *How is a solenoid different from a bar magnet?*

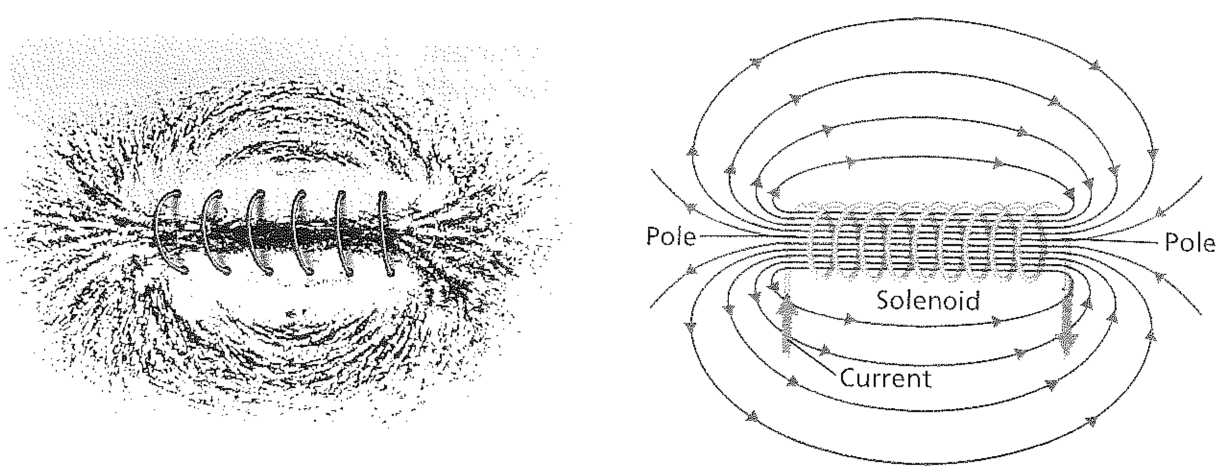


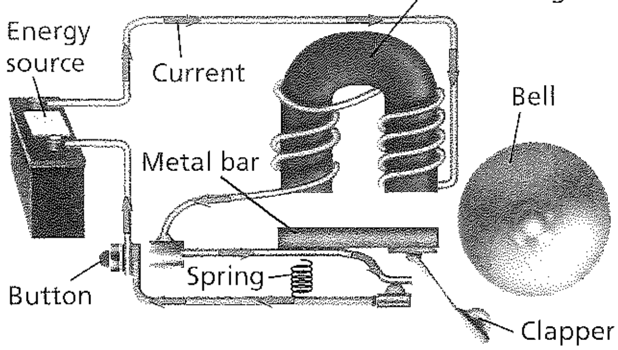
FIGURE 5

How a Doorbell Works

A doorbell rings as the magnetic field of an electromagnet changes.

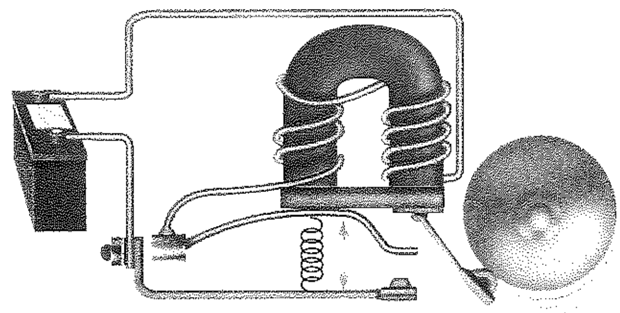
Closed Circuit

Pressing the button closes the circuit of the doorbell. Closing the circuit turns on the electromagnet in the doorbell.



Open Circuit

The electromagnet attracts a metal bar, and the clapper strikes the bell. At the same time, the circuit opens, turning off the electromagnet. The spring returns the metal bar to its resting position.



Electromagnets

If you place a ferromagnetic material such as iron inside a solenoid, the strength of the magnetic field increases. The increase in strength occurs because the ferromagnetic material becomes a magnet.

What Is an Electromagnet? A solenoid with a ferromagnetic core is called an **electromagnet.** The magnetic field of an electromagnet is produced by both the current in the wire and the magnetized core. The overall magnetic field of an electromagnet can be hundreds or thousands of times stronger than the magnetic field produced by the current alone. **An electromagnet is a strong magnet that can be turned on and off.**

You can increase the strength of an electromagnet in a number of ways. First, you can increase the current in the solenoid; second, you can add more loops of wire to the solenoid. Third, you can wind the coils of the solenoid closer together. Finally, you can increase the strength of an electromagnet by using a stronger ferromagnetic material for the core.

Common Electromagnets Electromagnets are very common. You probably use many every day. Electromagnets are used to record information onto audiotapes, videotapes, computer hard drives, and credit cards. In addition, many devices, such as the doorbell shown in Figure 5, use electromagnets.

Lab zone Try This Activity

On/Off

1. Your teacher will give you a piece of insulated copper wire. Tightly wrap it around a nail 10–12 times.
2. Tape one end of the wire to a battery terminal.
3. Touch the other end of the wire to the other battery terminal and dip the nail into a container of paper clips. Slowly lift the nail above the container.
4. Pull the wire away from the battery terminal and observe what happens.

Inferring Why did the paper clips drop when you pulled the wire away from the battery terminal?

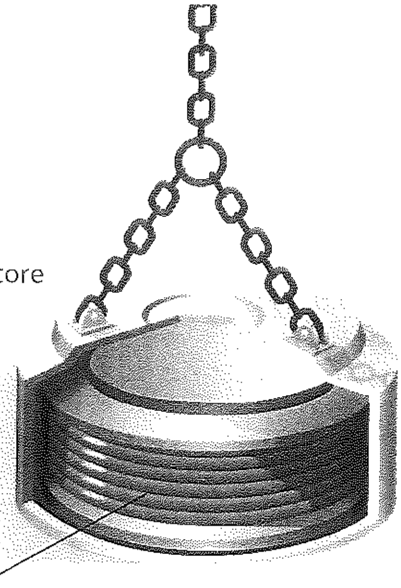


FIGURE 6
Electromagnets at Work
These heavy loads can be lifted easily because of powerful electromagnets.

Using Electromagnets Electromagnets are used to lift heavy objects. For example, at a junkyard, old cars and other heavy metal objects can be moved by a strong electromagnet on a crane. To lift the object a switch is turned on in the crane so that a current is produced in the electromagnet. The current forms a strong magnetic field that attracts metal objects. When the object needs to be dropped, the switch is turned off and the object falls from the magnet.

Section 1 Assessment

Target Reading Skill Identifying Main Ideas
Use your graphic organizer to help you answer Question 2 below.

Reviewing Key Concepts

1. a. Identifying Who discovered that electricity and magnetism are related?
   b. Explaining What is the relationship between an electric current and a magnetic field?
   c. Relating Cause and Effect How can a magnetic field be produced around a wire?
2. a. Defining What is a solenoid?
   b. Explaining What are the three characteristics of a magnetic field produced by a current?
   c. Applying Concepts How could you increase the strength of a solenoid?
3. a. Reviewing What makes an electromagnet stronger than a solenoid?
   b. Describing What are four ways to make an electromagnet stronger?

Writing in Science

Product Description Suppose you are an inventor who just built a device that will lift heavy objects using an electromagnet. Write a description for your product brochure that explains how the magnet can move heavy objects.

Section 2

Electricity, Magnetism, and Motion

Reading Preview

Key Concepts

- How can electrical energy be transformed into mechanical energy?
- How does a galvanometer work?
- What does an electric motor do?

Key Terms

- energy
- electrical energy
- mechanical energy
- galvanometer
- electric motor

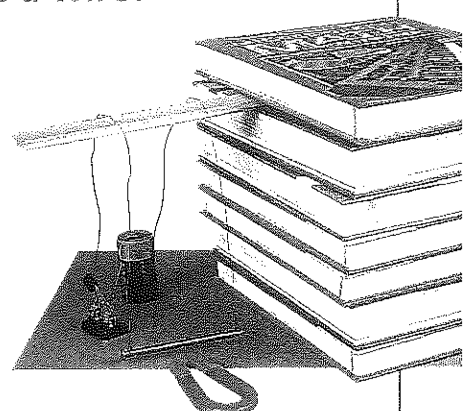
Target Reading Skill

Outlining As you read, make an outline about the section that you can use for review. Use the red headings for the main ideas and the blue headings for the supporting ideas.

Electricity, Magnetism, and Motion
I. Electrical Energy and Motion
A. Types of Energy
B.
II. Galvanometers
III. Electric Motors
A.

Lab zone Discover Activity

How Does a Magnet Move a Wire?

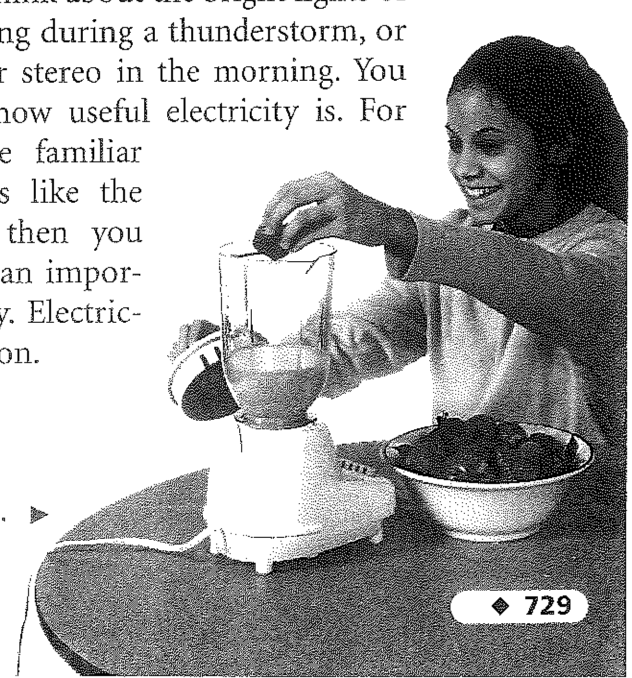


1. Make an electromagnet by winding insulated copper wire around a steel nail. Leave 30–40 cm of wire at each end of the electromagnet.
2. Pile up some books. Place a ruler between the top two books.
3. Hang the electromagnet over the ruler so that it hangs free.
4. Complete the circuit by connecting the electromagnet to a switch and a battery.
5. Place a horseshoe magnet near the electromagnet. Then close the switch briefly and observe what happens to the electromagnet.
6. Reverse the wires connected to the battery and repeat Step 5.

Think It Over

Inferring What happened to the electromagnet when you closed the switch? Was anything different when you reversed the wires? How can you use electricity to produce motion?

What do you think about when you hear the word *electricity?* You may think about the bright lights of a big city, the lightning during a thunderstorm, or the music from your stereo in the morning. You might think about how useful electricity is. For example, if you are familiar with electric motors like the one in a blender, then you already know about an important use of electricity. Electricity can produce motion.

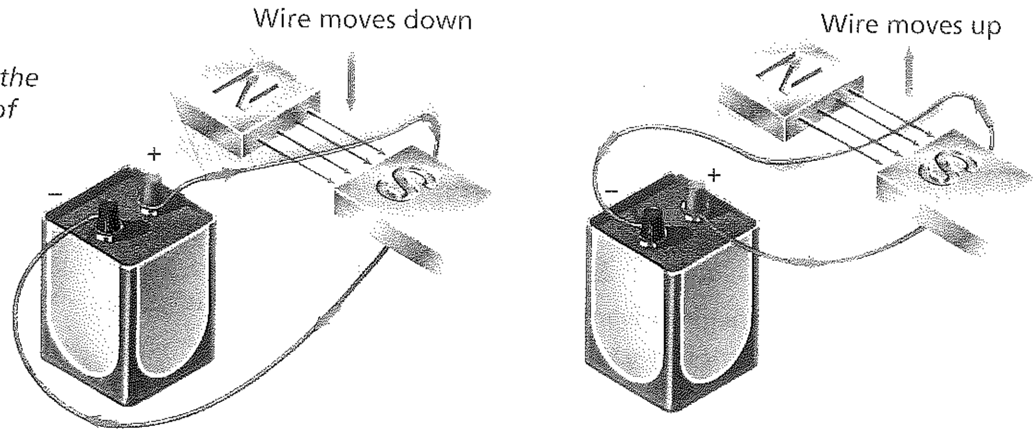


Electricity makes the blades spin. ▶

FIGURE 7
Producing Motion
The magnetic field of a permanent magnet interacts with the magnetic field produced by a current.
Relating Cause and Effect *How does the direction of the current affect the motion of the wire?*

The wire moves when current is present.

When the current is reversed, the wire moves in the opposite direction.



Lab zone Try This Activity

Making Motion

1. Attach one end of the wire your teacher gives you to a terminal of a 6-volt battery. Let the wire hang over the edge of a table.
2. Slowly move the north pole of a bar magnet toward the wire and observe what happens. Switch poles and repeat.
3. Attach the other end of the wire to the other terminal. Let the loop of wire hang over the edge of the table.
4. Repeat Step 2. Then immediately disconnect the wire.

Drawing Conclusions What happened each time you moved the magnet near the wire? What can you conclude from your observations?

Electrical Energy and Motion

As you know, magnetic force can produce motion. Magnets can move together or move apart, depending on how their poles are arranged. You also know that an electric current in a wire produces a magnetic field similar to that of a permanent magnet. So a magnet can move a wire with a current, just as it would move another magnet.

In Figure 7 you can see how a wire placed in the magnetic field of two permanent magnets can move. With current in the wire, the magnetic field of the wire interacts with the magnetic field of the permanent magnets. The wire moves down. If the current is reversed, the wire moves up. The direction in which the wire moves depends on the direction of the current.

Types of Energy When electricity and magnetism interact, something can move—in this case, a wire moved. The ability to move an object over a distance is called **energy.** The energy associated with electric currents is called **electrical energy.** And the energy an object has due to its movement or position is called **mechanical energy.**

Energy Transformation Energy can be transformed from one form into another. **When a wire with a current is placed in a magnetic field, electrical energy is transformed into mechanical energy.** This happens when the magnetic field produced by the current causes the wire to move.

Reading Checkpoint **What is mechanical energy?**

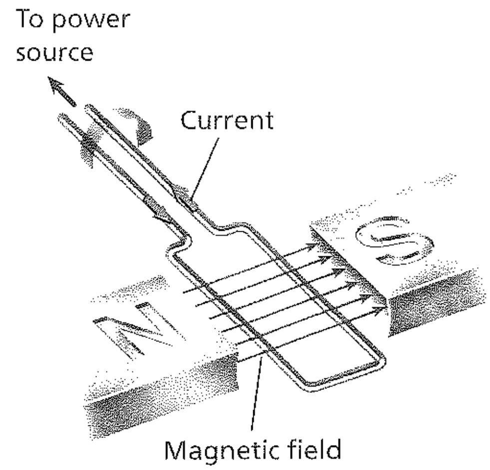
Galvanometers

The wire shown in Figure 7 that moves in the magnetic field is straight. But what happens if you place a loop with a current in a magnetic field? Look at Figure 8. The current in one side of the loop is in the opposite direction than the current in the other side of the loop. Because the direction of the current determines the direction in which the wire moves, the two sides of the loop move in opposite directions. Once each side has moved as far up or down as it can go, it will stop moving. As a result, the loop can rotate a half turn.

The rotation of a wire loop in a magnetic field is the basis of a galvanometer. A **galvanometer** is a device that measures small currents. In a galvanometer, an electromagnet is suspended between opposite poles of two permanent magnets. The electromagnet's coil is attached to a pointer, as shown in Figure 9. When a current is in the electromagnet's coil, a magnetic field is produced. This field interacts with the permanent magnet's field, causing the loops of wire and the pointer to rotate. **An electric current is used to turn the pointer of a galvanometer.** The distance the loops and the pointer rotate depends on the amount of current in the wire.

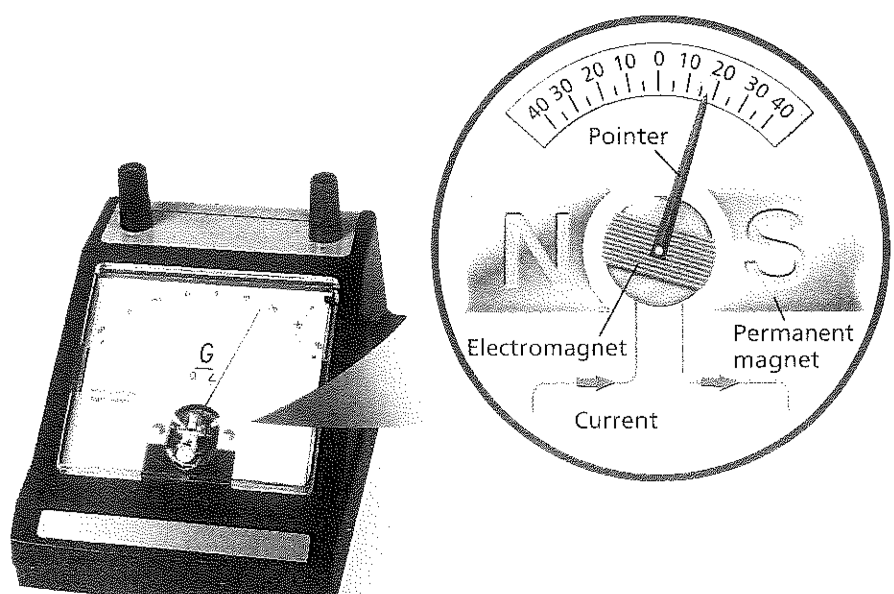
A galvanometer has a scale that is marked to show how much the pointer turns for a known current. An unknown current can then be measured using the galvanometer. So galvanometers are very useful in everyday life. For example, electricians use them in their work and drivers of cars use them to know when to stop for fuel.

FIGURE 8
How a Galvanometer Works
Current is in different directions in each side of the wire loop, so one side of the loop moves down as the other side moves up. This causes the loop to rotate.



Reading Checkpoint **Where are galvanometers used?**

FIGURE 9
Inside a Galvanometer
An electromagnet turns the pointer to indicate the amount of current present. The amount of current can be read on the scale.



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Electric Motors

The electromagnet in the magnetic field of a galvanometer cannot rotate more than half a turn. But suppose you could make it rotate continuously. Instead of moving a pointer, the electromagnet could turn a rod, or axle. The axle could then turn something else, such as the blades of a fan or a blender. Such a device would be what is called an electric motor. An **electric motor** is a device that uses an electric current to turn an axle. **An electric motor transforms electrical energy into mechanical energy.**

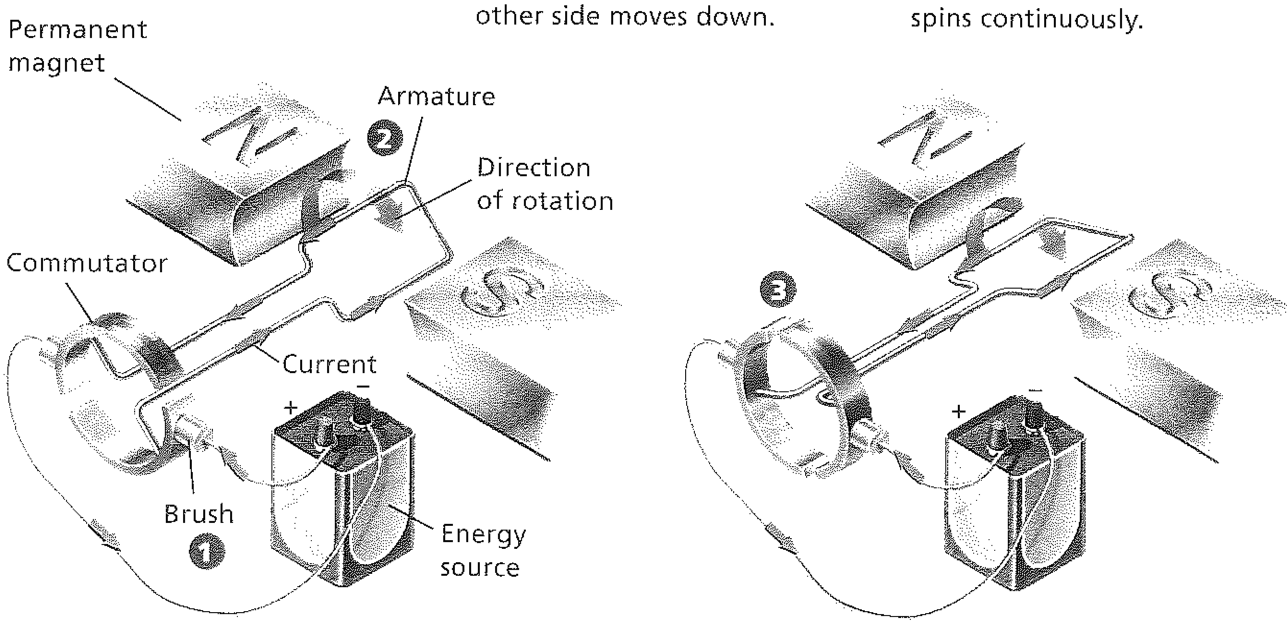
How a Motor Works How can you make a loop of wire continue to spin? Recall that the direction in which the loop moves in a magnetic field depends on the direction of the current in the loop. In a motor, current is reversed just as the loop, or armature, gets to the vertical position. This reverses the direction of the movement of both sides of the loop. The side of the loop that moved up on the left now moves down on the right. The side of the loop that moved down on the right now moves up on the left. The current reverses after each half turn so that the loop spins continuously in the same direction. You can see how a motor works in Figure 10.

FIGURE 10
An Electric Motor
A loop of wire in a motor spins continuously because the current reverses every half turn.
Observing *What part of an electric motor must be attached directly to the energy source?*

1 Brushes
The brushes that touch the commutator conduct current to the armature. The brushes do not move.

2 Armature
The current is in opposite directions on each side of the armature causing one side to move up while the other side moves down.

3 Commutator
The commutator rotates with the armature. The direction of current reverses with each half turn so the armature spins continuously.



Parts of a Motor Notice that the armature in Figure 10 is only one loop of wire. However, practical armatures, like the one shown in Figure 11, have dozens or hundreds of wire loops wrapped around a ferromagnetic core. Using many loops increases the strength of the motor and allows it to rotate more smoothly. Large electric motors also use electromagnets instead of permanent magnets to increase the strength of the magnetic field.

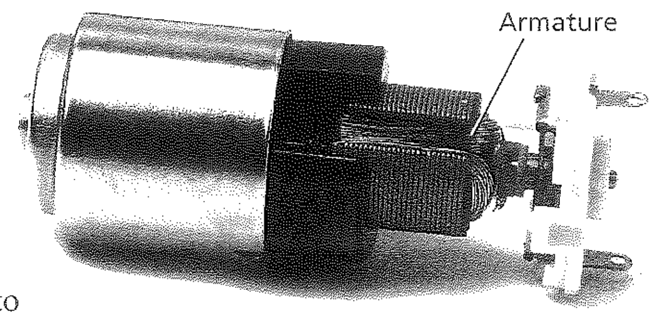


FIGURE 11
Inside a Motor
The armature inside this motor contains hundreds of loops of copper wire wrapped around a ferromagnetic core.
Applying Concepts *How does a motor transform energy?*

A commutator repeatedly reverses the flow of current through the armature. A commutator is a ring split in half. Each half is attached to one end of the armature. When the armature rotates, the commutator rotates as well. As it moves, the commutator slides past two contact points called brushes. Each half of the commutator is connected to the current source by one of the brushes. As the armature rotates, each part of the commutator contacts one brush and then the other. Because the brushes conduct the current, changing brushes reverses the direction of the current in the armature. The reversing of the direction of the current causes the armature to spin continuously.

Reading Checkpoint **How can the strength of a motor be increased?**

Section 2 Assessment

Target Reading Skill Outlining Use the information in your outline about electricity, magnetism, and motion to help you answer the questions below.

Reviewing Key Concepts

1. a. Identifying What is energy?
   b. Applying Concepts What energy transformation occurs when a wire with a current is placed in a magnetic field?
   c. Predicting If a wire with a current moved upward in a magnetic field, how would it move when the direction of the current reversed?
2. a. Reviewing What does a galvanometer measure?
   b. Describing What energy transformation occurs in a galvanometer?
   c. Relating Cause and Effect What causes the pointer to move in a galvanometer?
3. a. Defining What is an electric motor?
   b. Classifying What type of energy transformation occurs in a motor?
   c. Relating Cause and Effect What does the commutator do in an electric motor?

Writing in Science

Make a List Make a list of at least ten motor-operated devices in your community. Beside each device, describe the motion produced by the motor.

Lab zone **Skills Lab**

Building an Electric Motor

Problem

Electric trolley cars, food blenders, garage door openers, and computer disk drives are only some of the everyday devices that have electric motors. How does an electric motor operate?

Skills Focus

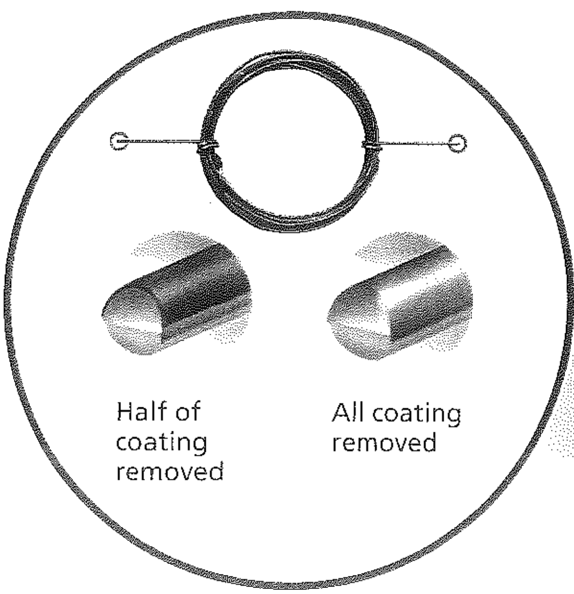
classifying, inferring, drawing conclusions

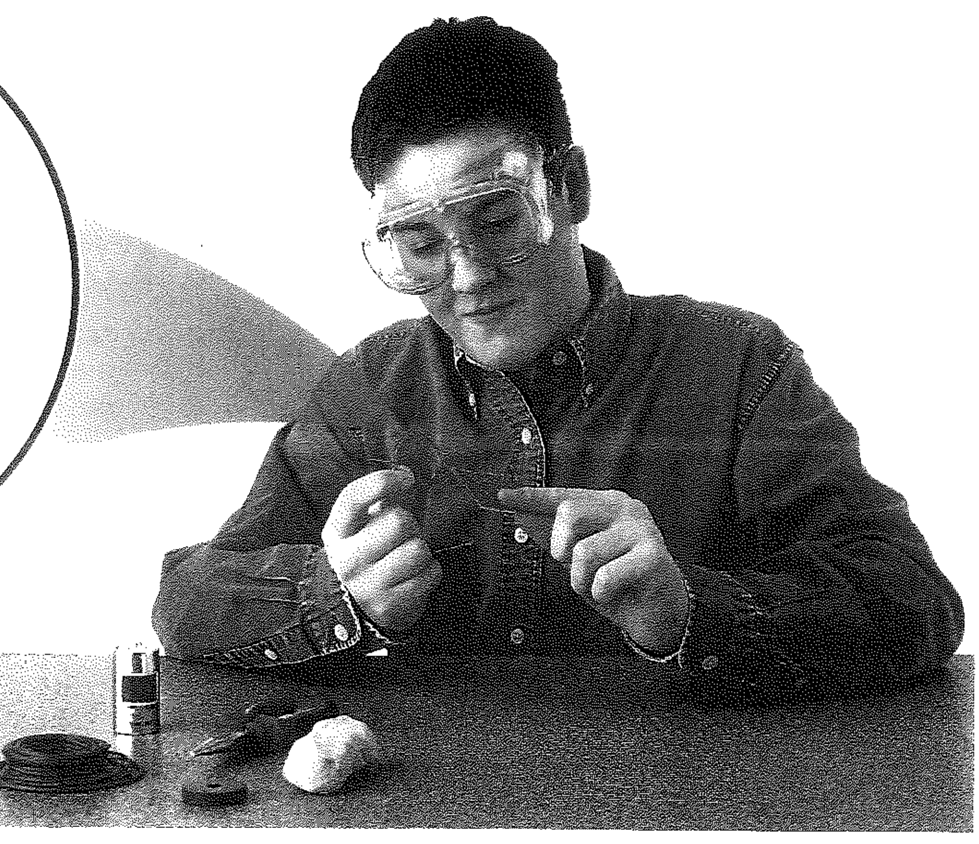
Materials

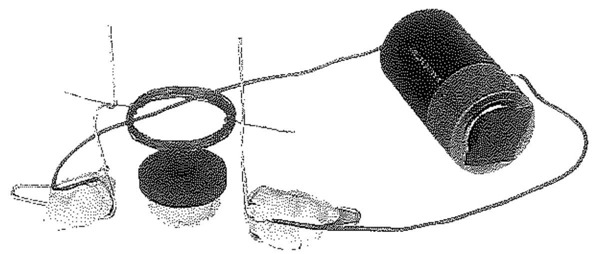
- D-cell
- 2 large paper clips
- permanent disk magnet
- 3 balls of clay
- empty film canister
- pliers
- sandpaper
- 2 insulated wires, approximately 15 cm each
- enamel-coated wire, 22–24 gauge, approximately 1 meter

Procedure

1. Wrap about 1 meter of enamel-coated wire around a film canister to produce a wire coil. Leave approximately 5 cm free at each end.
2. Remove the film canister and wrap the two free ends three or four times around the wire coil to keep the coil from unwinding.
3. Use sandpaper to scrape off all the enamel from about 2 or 3 centimeters of one end of the wire coil.
4. Use sandpaper to scrape off one side of the enamel from about 2 or 3 centimeters of the other end of the wire. See the illustration below.
5. Bend two paper clips as shown in the photo on the next page.







6. Place the free ends of the wire coil on the paper clips. Make sure the coil is perfectly balanced. Adjust the paper clips and wire so that the coil can rotate freely.
7. Use clay to hold a permanent magnet in place directly below the wire coil. The coil needs to be able to rotate without hitting the magnet.
8. Remove the insulation from the ends of two 15-cm insulated wires. Use these wires to connect the paper clips to a D-cell.
9. Give the coil a gentle push to start it turning. If it does not spin or stops spinning after a few seconds, check the following:
   - Are the paper clips in good contact with the D-cell?
   - Will the coil spin in the opposite direction?
   - Will the coil work on someone else's apparatus?

Analyze and Conclude

1. Observing Describe the movement of the wire coil when your setup was complete and working.
2. Classifying Which part of your setup contained a permanent magnet? Describe the location of the magnetic field produced by that magnet.
3. Inferring What was the effect of removing all the insulation from one end of the wire coil but only half from the other end?
4. Inferring Explain how a magnetic field is produced when the motor is connected to the D-cell.
5. Drawing Conclusions How do magnetism and electricity interact to cause the wire coil to rotate?
6. Communicating Your motor produced motion, but it does not yet do useful work. Think of an object your motor might cause to move. Consider how you could modify the motor to move that object. Write a procedure for changing your motor to carry out the task.

Design an Experiment

You have built a simple electric motor. List three factors that may affect the motion of the coil. Design an experiment to test one of those factors. *Obtain your teacher's permission before carrying out your investigation.*

Section 3 • Tech & Design •

Electricity From Magnetism

Reading Preview

Key Concepts

- How can an electric current be produced in a conductor?
- How does a generator work?
- What is the function of a transformer?

Key Terms

- electromagnetic induction
- direct current
- alternating current
- electric generator
- transformer
- step-up transformer
- step-down transformer

Target Reading Skill

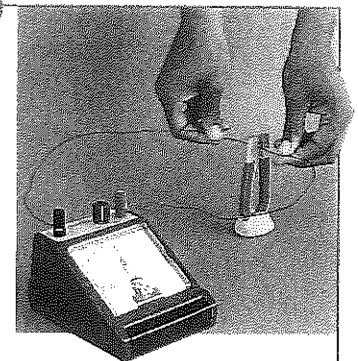
Previewing Visuals When you preview, you look ahead at the material to be read. Preview Figure 13. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Generators

Q. What are the parts of a generator?
A.
Q.

Lab zone Discover Activity

Can You Produce Current Without a Battery?



1. Obtain one meter of wire with the insulation removed from both ends.
2. Connect the wire to the terminals of a galvanometer or a sensitive multimeter.
3. Hold the wire between the poles of a strong horseshoe magnet. Observe the meter.
4. Move the wire up and down between the poles. Observe the meter.
5. Move the wire faster, and again observe the meter.

Think It Over

Developing Hypotheses In which steps does the meter indicate a current? Propose a hypothesis to explain why a current is present. Try using an "If . . . then . . ." statement.

An electric motor uses electrical energy to produce motion. Is the reverse true? Can motion produce electrical energy? In 1831, scientists found out that moving a wire in a magnetic field can cause an electric current. That discovery has allowed electrical energy to be supplied to homes, schools, and businesses all over the world.

Induction of Electric Current

Before you can understand how electrical energy is supplied by your electric company, you need to know how it is produced. A magnet and a conductor, such as a wire, can be used to induce a current in the conductor. The key is motion. **An electric current is induced in a conductor when the conductor moves through a magnetic field.** Generating an electric current from the motion of a conductor through a magnetic field is called **electromagnetic induction.** Current that is generated in this way is called induced current.

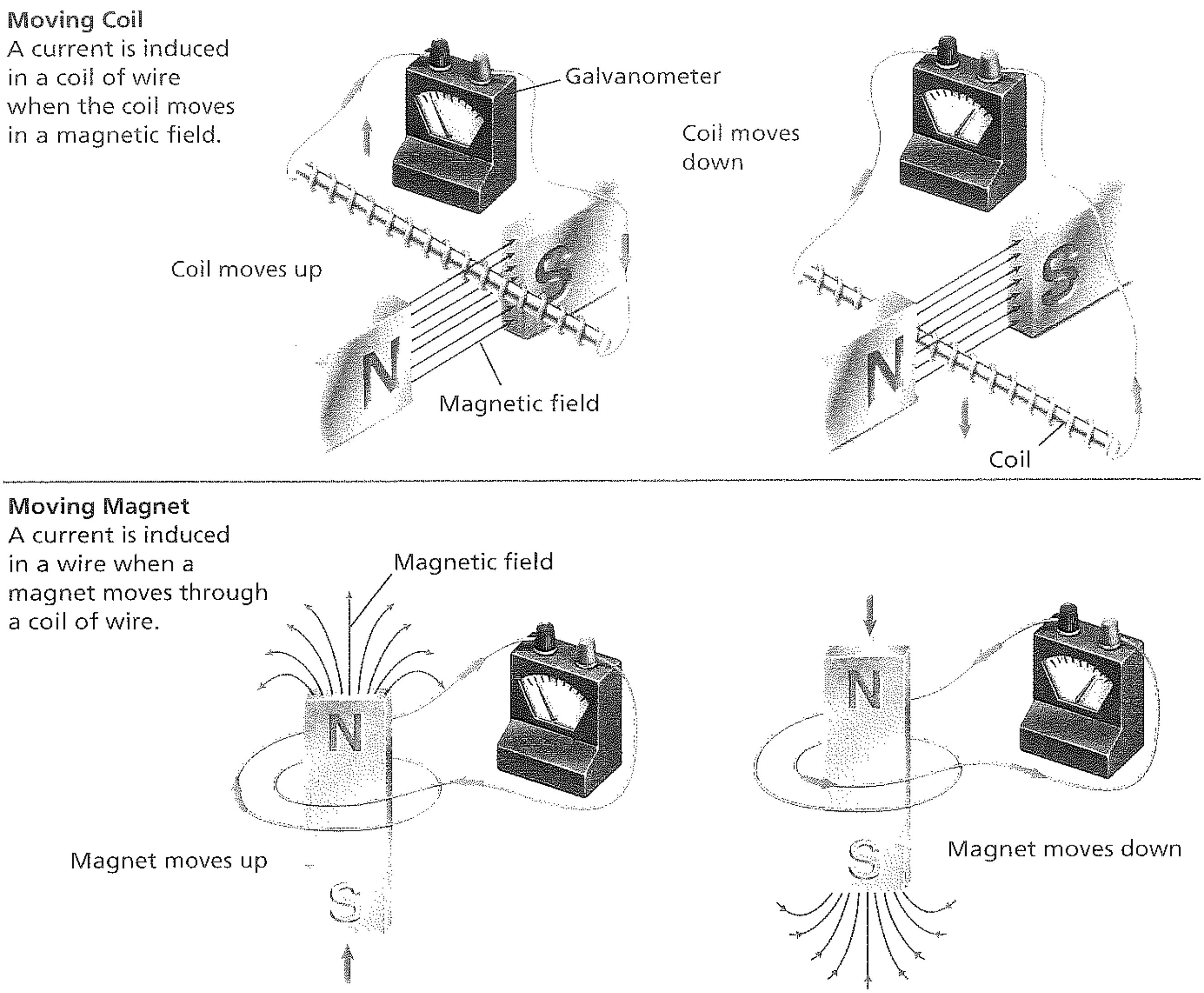


FIGURE 12
Inducing Current
When a coil of wire moves up or down in a magnetic field, a current is induced in the wire. If a magnet moves up or down through a coil of wire, a current is induced in the wire.
Interpreting Diagrams *How does the direction in which you move the wire and magnet affect the current?*

To induce a current in a conductor, either the conductor can move through the magnetic field or the magnet itself can move. In Figure 12, you can see what happens when a wire coil moves in a magnetic field. The coil of wire is connected to a galvanometer forming a closed circuit. If the wire coil is held still, the galvanometer will not register any current. But if the coil is moved up or down, the galvanometer shows an electric current is present. A current is induced without a battery or other voltage source by moving the coil! You saw this for yourself if you did the Discover Activity. In Figure 12, you can also see what happens when a magnet placed inside a wire coil is moved instead of the wire. The result is the same as moving the coil in the magnetic field. An electric current is induced in the coil.

Reading Checkpoint **What happens when a wire coil moves in a magnetic field?**

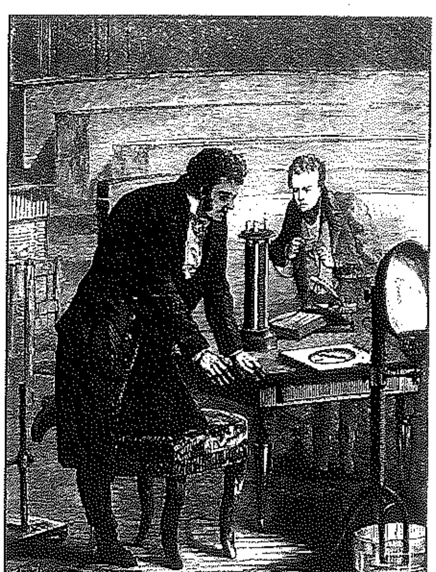
Direct Current In an induced current, charges may flow in one direction only, or they may alternate directions. The direction of an induced current depends on the direction in which the wire or magnet moves. You probably noticed in Figure 12 on the previous page that when the direction of the motion of the wire coil changed, the direction of the current reversed.

A current consisting of charges that flow in one direction only is called **direct current,** or DC. A direct current can be induced from a changing magnetic field or produced from an energy source such as a battery. When a battery is placed in a circuit, charges flow away from one end of the battery, around the circuit, and into the other end of the battery. Thomas Edison used direct current in his first electric generating plant.

Science and **History**

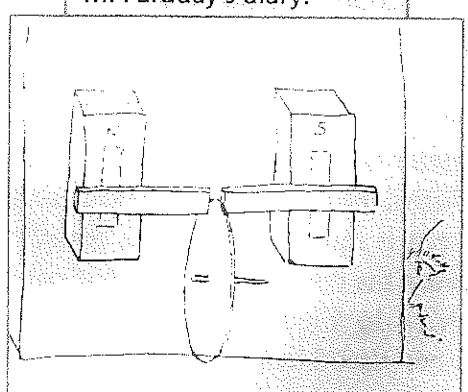
Generating Electrical Energy

Several scientists were responsible for bringing electricity from the laboratory into everyday use.



1820 Electromagnetism
Hans Christian Oersted discovers that an electric current creates a magnetic field. The relationship between electricity and magnetism is called electromagnetism.

1830–1831
Electric Induction
Michael Faraday and Joseph Henry each discover that an electric current can be induced by a changing magnetic field. Understanding induction makes possible the development of motors and generators. This illustration of a generator is from M. Faraday's diary.



1800 **1820** **1840**

Alternating Current What would happen if a wire in a magnetic field were moved up and down repeatedly? The induced current in the wire would reverse direction repeatedly as well. This kind of current is called **alternating current,** or AC. An alternating current consists of charges that move back and forth in a circuit. The electric current in the circuits in homes, schools, and other buildings is alternating current.

Alternating current has a major advantage over direct current. An AC voltage can be easily raised or lowered to a higher or lower voltage. This means that a high voltage can be used to send electrical energy over great distances. Then the voltage can be reduced to a safer level for everyday use.

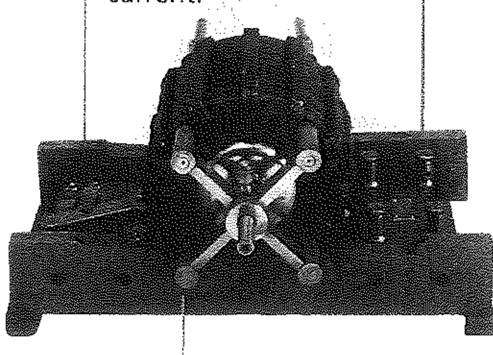
Reading Checkpoint **What is the advantage of using alternating current?**

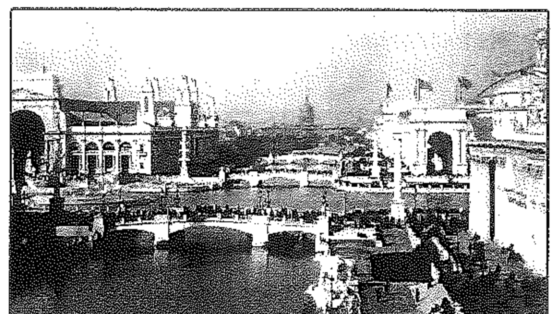
Writing in Science

Letter Find out more about the work of Michael Faraday, Joseph Henry, or Hans Christian Oersted. Write a letter to a friend in which you describe your work as a research assistant for the scientist you choose. Include descriptions of his experimental procedures and the equipment he uses. Tell how his work has led to surprising discoveries.

1882
Direct Current
Thomas Edison opens a generating plant in New York City. The Pearl Street Station consists of six DC generators, serving an area of about 2.6 square kilometers.

1888
Alternating Current
Nikola Tesla receives patents for a system of distributing alternating current.





1893
World's Columbian Exposition
Nikola Tesla's system of alternating current is used to light the world's fair in Chicago.

1860 1880 1900

Generators

An **electric generator** is a device that transforms mechanical energy into electrical energy. An electric generator is the opposite of an electric motor. An electric motor uses an electric current in a magnet field to produce motion. **A generator uses motion in a magnetic field to produce an electric current.**

AC Generators In Figure 13 you can see how a simple AC generator works. As the crank is turned, the armature rotates in the magnetic field. One side of the armature moves up, and the other side moves down. The up and down motion induces a current in the wire. The current is in opposite directions on the two sides of the armature.

After the armature turns halfway, each side of it reverses direction in the magnetic field. The side that moved up moves down, and vice versa. The current in the wire changes direction as well. The result is an alternating current is induced.

As the armature turns, slip rings turn with it. Slip rings may remind you of the commutator in a motor. They are attached to the ends of the armature. As they turn, they make contact with the brushes. The brushes can be connected to the rest of the circuit. In this way, a generator becomes an energy source.

DC Generators A DC generator is like an AC generator, except that it contains a commutator instead of slip rings. In fact, a DC generator and the motor you read about in Section 2 are the same thing. If you supply electrical energy to the motor, it will spin. But if you spin the motor, you will produce electrical energy. The motor becomes a DC generator.

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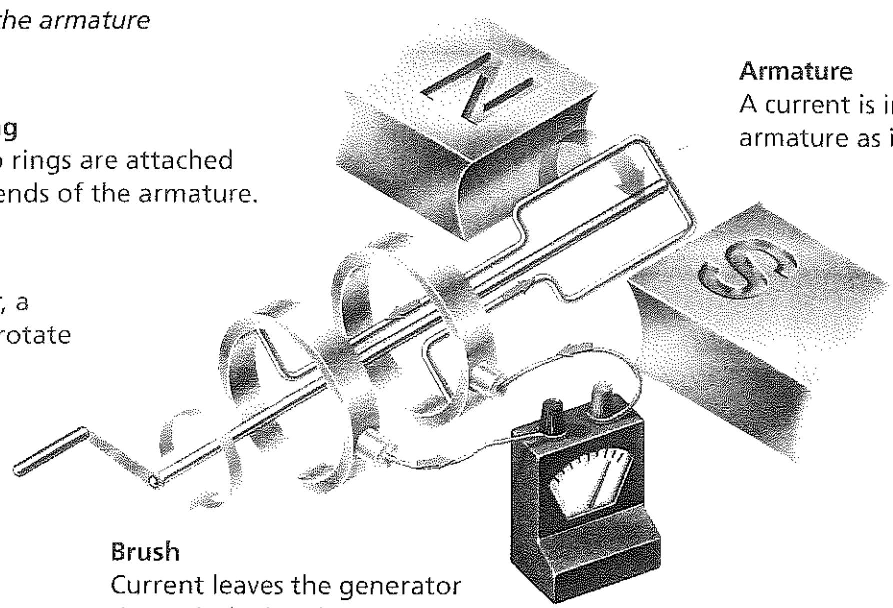
FIGURE 13
How a Generator Works

In an AC generator, an armature is rotated in a magnetic field. This induces an electric current in the armature. Applying Concepts *How many times does the current reverse direction each time the armature rotates?*



Armature
A current is induced in the armature as it rotates.

Slip Ring
The slip rings are attached to the ends of the armature.

Crank
In this generator, a crank is used to rotate the armature.

Brush
Current leaves the generator through the brushes

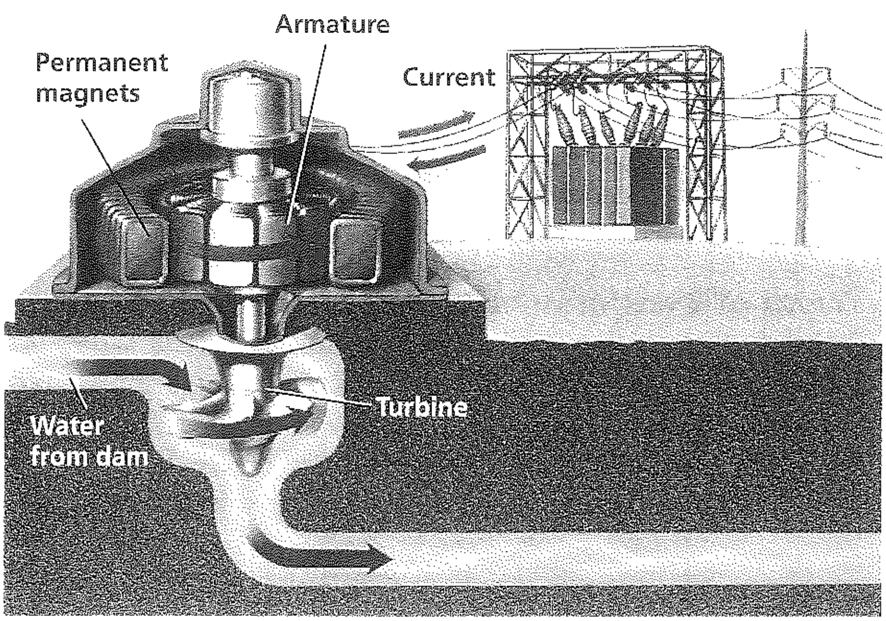


FIGURE 14
Turbines
In most generators, a source of mechanical energy turns huge turbines such as this one. The turbine is attached to the armature of a generator, which produces current.

Using Generators The electric company uses giant generators to produce most of the electrical energy you use in your home and school. But, instead of using a crank to supply the mechanical energy to turn the armature, a turbine is used. Turbines are large circular devices made up of many blades. Figure 14 shows how a turbine is attached to the armature in a generator. The turbine spins as the water flows by it. As a result, the armature spins and generates electric current.

Reading Checkpoint **What is a turbine?**

Transformers

The electrical energy generated by electric companies is transmitted over long distance at very high voltages. However in your home, electrical energy is used at much lower voltages. What changes the voltage of the electrical energy? The answer is transformers.

What is a Transformer? **A transformer is a device that increases or decreases voltage.** A **transformer** consists of two separate coils of insulated wire wrapped around an iron core. One coil, called the primary coil, is connected to a circuit with a voltage source and alternating current. The other coil, the secondary coil, is connected to a separate circuit that does not contain a voltage source.

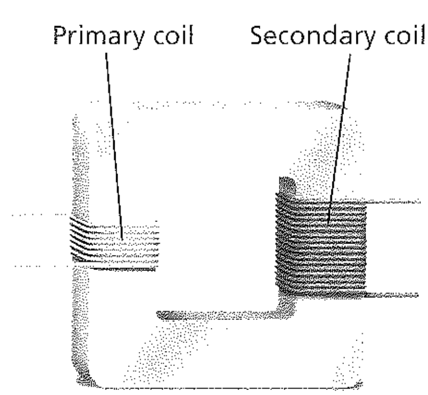


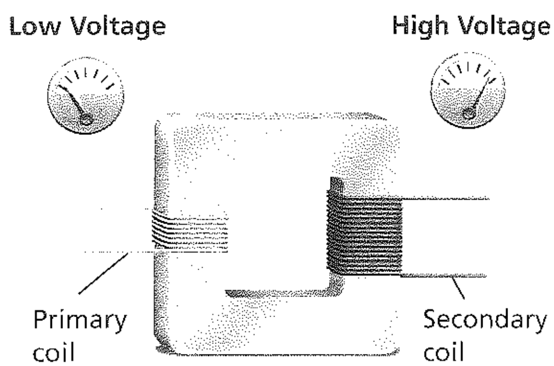
FIGURE 15
A Transformer
The primary coil of a transformer is connected to a voltage source. The secondary coil is not connected to a voltage source.

A Transformer at Work When a current is in the primary coil of the transformer, it produces a magnetic field. The magnetic field changes as the current alternates. This changing magnetic field is like a moving magnetic field. It induces a current in the secondary coil. A transformer works only if the current in the primary coil is changing. If the current does not change, the magnetic field does not change. No current will be induced in the secondary coil. So a transformer will not work with direct current.

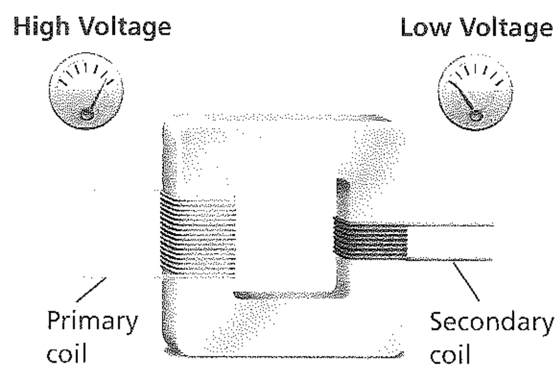
Types of Transformers If the number of loops in the primary and secondary coils of a transformer is the same, the voltage of the induced current is the same as the original voltage. But if the secondary coil has more loops than the primary coil, the voltage in the secondary coil will be greater. A transformer that increases voltage is called a **step-up transformer.**

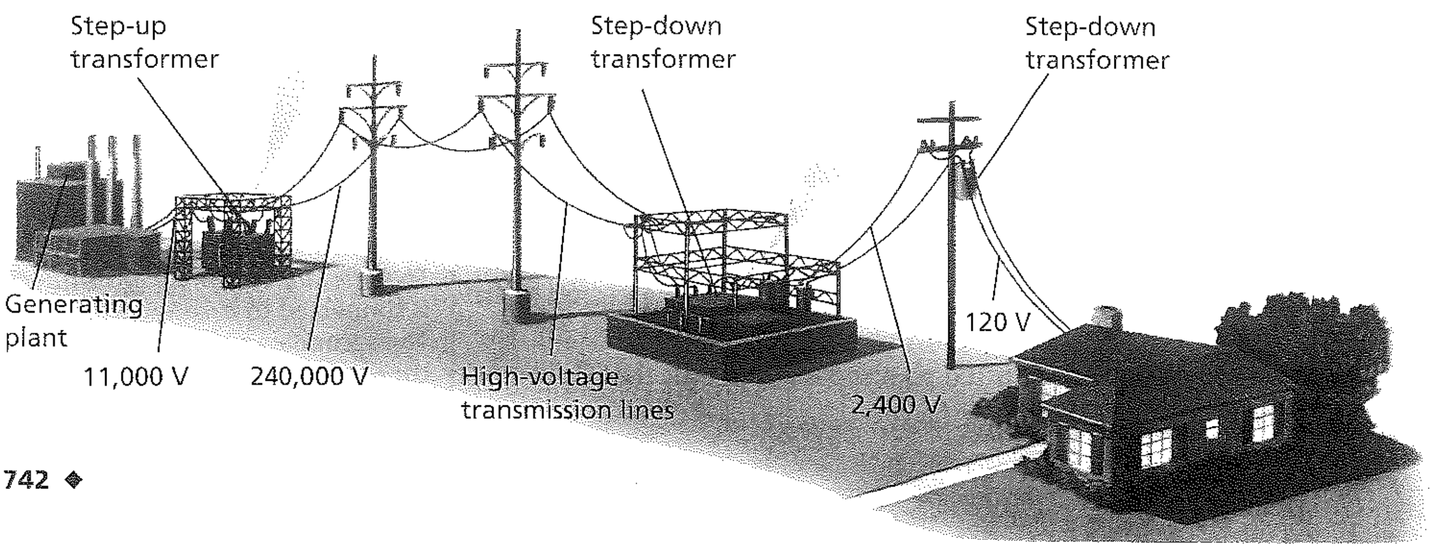
FIGURE 16
Changing Voltage
Transformers are involved in the transmission of electrical energy from an electric plant to a home.
Relating Cause and Effect *How does the number of loops in the primary and secondary coils affect the voltage of the induced current?*

Step-up Transformer
A step-up transformer increases voltage. The secondary coil has more loops than the primary coil.



Step-down Transformer
A step-down transformer decreases voltage. The primary coil has more loops than the secondary coil.





Suppose there are fewer loops in the secondary coil than in the primary coil. The voltage in the secondary coil will be less than in the primary coil. A transformer that decreases voltage is called a **step-down transformer.** Figure 16 shows both types of transformers.

Uses of Transformers An important use of transformers is in the transmission of electrical energy from generating plants. The most efficient way to transmit current over long distances is to maintain high voltages—about 11,000 volts to 765,000 volts. But the high voltage must be decreased to be used safely in your home. The use of step-up and step-down transformers allows safe transmission of electrical energy from generating plants to the consumer.

Transformers are also used in some electrical devices. Fluorescent lights, televisions, and X-ray machines require higher voltages than the current in your home, which is about 120 volts. These devices contain step-up transformers. Other devices, such as doorbells, electronic games, and portable CD players, require lower voltages, about 6 to 12 volts. They contain step-down transformers.

Reading Checkpoint **What is the voltage in your house?**

Section 3 Assessment

Target Reading Skill Previewing Visuals Refer to your questions and answers about Figure 13 to help you answer Question 2 below.

Reviewing Key Concepts

1. a. Defining What is electromagnetic induction?
   b. Describing What are two ways to induce an electric current?
   c. Relating Cause and Effect What determines whether an induced current is a direct current or an alternating current?
2. a. Reviewing How is energy transformed by a generator?
   b. Summarizing How does a generator produce an alternating current?
   c. Comparing and Contrasting How are an AC generator and a DC generator the same? How are they different?
3. a. Reviewing What does a transformer do?
   b. Interpreting Diagrams Look at Figure 16. What is the difference between a step-up transformer and a step-down transformer?
   c. Applying Concepts Why do some appliances have step-down transformers built into them?

Lab zone At-Home Activity

Step-Up and Step-Down Draw a diagram that shows how electric current gets to your home from the place it is generated. Include in your diagram the likely locations of step-up and step-down transformers. Explain your diagram to a family member. Then with your family member, try to locate the step-down transformer that provides your home's electricity.

Chapter 21 Study Guide

The BIG Idea

Electric and Magnetic Forces An electric current produces a magnetic field. Moving a conductor through a magnetic field or a magnet through a wire loop produces an electric current.

1 What Is Electromagnetism?

Key Concepts

- An electric current produces a magnetic field.
- The magnetic field produced by a current has three characteristics. The field can be turned on or off, have its direction reversed, or have its strength changed.
- An electromagnet is a strong magnet that can be turned on and off.

Key Terms

electromagnetism
electromagnet
solenoid

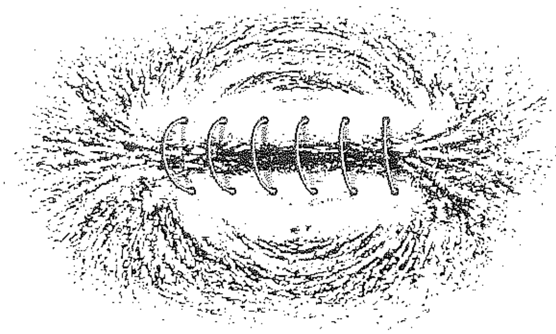
2 Electricity, Magnetism, and Motion

Key Concepts

- When a wire with a current is placed in a magnetic field, electrical energy is transformed into mechanical energy.
- Electric current is used to turn the pointer of a galvanometer.
- An electric motor transforms electrical energy into mechanical energy.

Key Terms

- energy
- electrical energy
- mechanical energy
- galvanometer
- electric motor



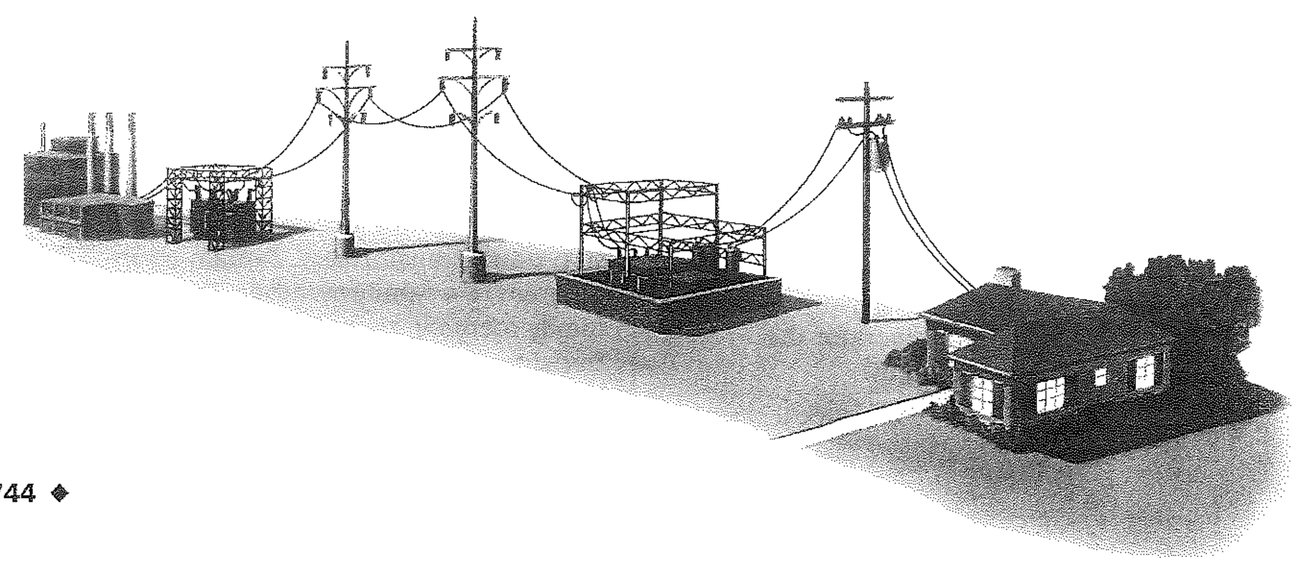
3 Electricity From Magnetism

Key Concepts

- An electric current is induced in a conductor when the conductor moves through a magnetic field.
- A generator uses motion in a magnetic field to produce an electric current.
- A transformer is a device that increases or decreases voltage.

Key Terms

electromagnetic induction
direct current
alternating current
electric generator
transformer
step-up transformer
step-down transformer



Review and Assessment

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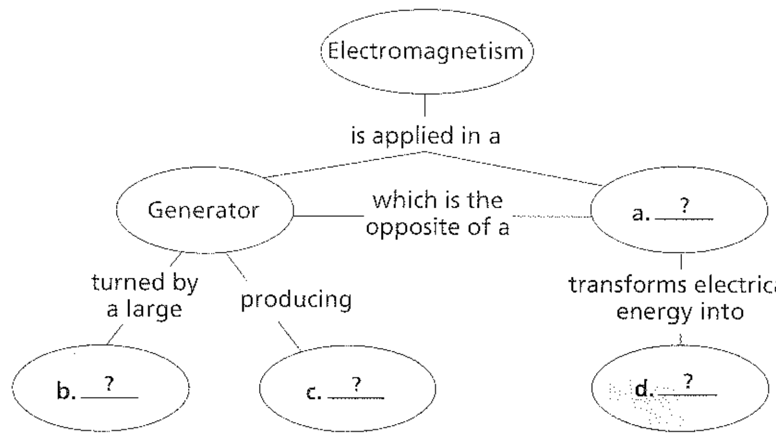
Organizing Information

Concept Mapping Copy the concept map about electromagnetism onto a separate sheet of paper. Then complete the concept map and add a title. (For more about concept maps, see the Skills Handbook.)



Reviewing Key Terms

Choose the letter of the best answer.

1. The relationship between electricity and magnetism is called
   a. electrical energy.
   b. an electromagnet.
   c. electromagnetism.
   d. induced current.
2. A coil of wire with a current is called a
   a. generator.
   b. motor.
   c. solenoid.
   d. transformer.
3. When a ferromagnetic material is placed within a solenoid, the resulting device is called a(n)
   a. galvanometer. b. electromagnet.
   c. motor. d. transformer.
4. Electrical energy is transformed into mechanical energy in a
   a. motor. b. generator.
   c. transformer. d. electromagnet.
5. A device that changes the voltage of alternating current is a
   a. transformer. b. motor.
   c. generator. d. galvanometer.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. The device that turns a needle in a galvanometer is called an <u>electromagnet</u>.
7. Several loops of wire wrapped around an iron core form the <u>armature</u> of a motor.
8. Generating a current by moving a conductor in a magnetic field is <u>induction</u>.
9. An <u>electric motor</u> transforms mechanical energy into electrical energy.
10. A <u>solenoid</u> increases or decreases voltage.

Writing in Science

News Report You are a television news reporter covering the opening of a new dam that generates electrical energy. Write a short news story describing how the dam transforms mechanical energy from the motion of the water into electrical energy.

Review and Assessment

Checking Concepts

11. How can the magnetic field produced by a current be changed?

12. How is a galvanometer similar to a motor? How is it different?

13. What are the roles of the commutator and the brushes in an electric motor?

14. How are alternating current and direct current the same? How are they different?

15. Describe how an AC generator operates.

16. What role does a turbine play in generating electricity?

17. Explain how transformers are used to efficiently transmit electrical energy from the electric company where it is produced to your home where it is used.

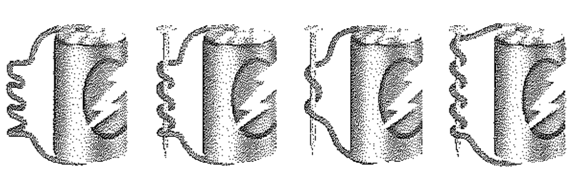
Thinking Critically

18. Relating Cause and Effect Why does a compass needle move when placed near a wire with an electric current? What do you think happens to the compass needle when the circuit is shut off?

19. Inferring How could you modify a solenoid to produce a stonger magnetic field?

20. Applying Concepts Make a diagram of a wire loop in a magnetic field. Show how the direction of a current in the wire is related to the direction of rotation of the loop.

21. Predicting Four electromagnets are illustrated in the diagram below. Will the electromagnet labeled A or B produce a stronger magnetic field? Will the electromagnet B or C produce a stronger field? Explain your choices.

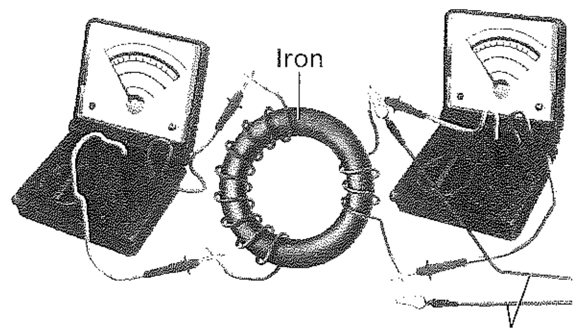


22. Comparing and Contrasting Compare a motor and a generator. Include information about the kind of energy conversion that takes place in each device.

23. Applying Concepts How are the uses of an electromagnet different from those of a permanent magnet?

Applying Skills

Use the illustration of a transformer to answer Questions 24–26.



24. Classifying What type of transformer is shown in the illustration above? Explain how you know.

25. Inferring Which coil is the primary coil and which is the secondary coil?

26. Predicting What will the two voltmeters show when the circuit on the right side of the diagram is completed?

Lab zone Chapter Project

Performance Assessment Present the results of your energy audit to the class in a visual format. Make a bar, circle, or line graph showing the appliances and the energy they used. Identify the appliance that uses the most electrical energy in a week. Also discuss the way you calculated energy use. What problems did you have? What information couldn't you collect?

Standardized Test Prep

Test-Taking Tip

Interpreting a Graph

If you are asked to interpret a line graph, look at the labels of the horizontal and vertical axes. The labels inform you what relationship is plotted on the graph—in other words, what variables are being compared. Study the graph for Questions 4–5 and answer the sample question.

Sample Question

What variable is plotted on the *x*-axis?

A the number of solenoids
B the magnetic field strength
C the number of loops in the solenoid
D the length of solenoid

Answer

Choice C is correct. You can eliminate A and D, because neither axis mentions the number of solenoids or the length of the solenoid. B is incorrect because it is on the vertical axis, or *y*-axis.

Choose the letter of the best answer.

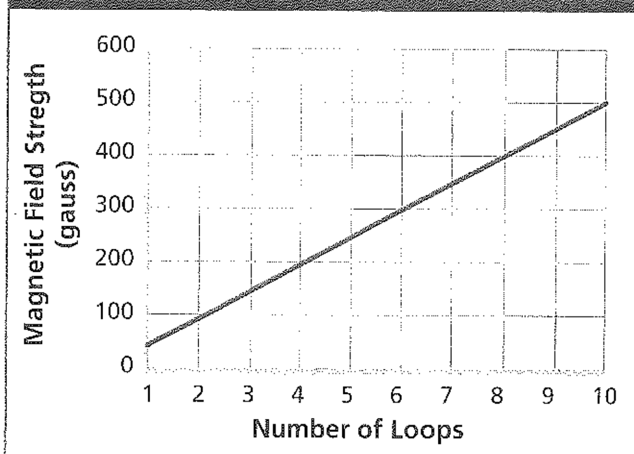
1. If a step-up transformer is to increase voltage, it needs
   A a DC source connected to the primary coil.
   B a DC source connected to the secondary coil.
   C more turns in the primary coil than in the secondary coil.
   D more turns in the secondary coil than in the primary coil.

2. To measure the current induced from moving a wire through a magnetic field, which piece of equipment would a scientist need?
   F a galvanometer G a flashlight bulb
   H an insulated wire J an LED

3. What happens when a magnet moves through a coil of wire?
   A The magnet loses magnetism.
   B A current is induced in the magnet.
   C A current is induced in the wire.
   D Electrical energy is transformed into mechanical energy.

A scientist measured the magnetic field strength of a solenoid after increasing the number of loops. Magnetic field strength is measured using a unit called a gauss. The graph below plots the results. Use the graph to answer Questions 4–5.

Magnetic Field Strength of a Solenoid



4. Which of the following statements expresses the relationship shown on the graph?
   F As the number of loops decreases, the magnetic field strength increases.
   G As the number of loops increases, the magnetic field strength decreases.
   H As the number of loops increases, the magnetic field strength increases.
   J The number of loops does not affect the magnetic field strength.

5. What would you expect the magnetic field strength of the solenoid with 12 loops to be?
   A 300 gauss
   B 600 gauss
   C 700 gauss
   D 1200 gauss

Constructed Response

6. Explain how a generator transforms mechanical energy into electrical energy.