chapter 8

Magnetism and Its Uses

BIG Idea
A magnet is surrounded by a magnetic field that exerts a force on other magnets.

8.1 Magnetism
MAIN Idea Like magnetic poles repel each other and unlike poles attract each other.

8.2 Electricity and Magnetism
MAIN Idea An electric current in a wire is surrounded by a magnetic field.

8.3 Producing Electric Current
MAIN Idea A changing magnetic field can produce an electric current in a wire loop.

A Natural Light Show
Have you ever seen an aurora? Auroras result when the Sun emits a blast of charged particles. These blasts cause charged particles trapped by Earth's magnetic field to collide with atoms in the upper atmosphere. The light you see as an aurora is emitted as these collisions occur.

Science Journal
List three things you know about magnets.

Kennan Ward/CORBIS

Start-Up Activities

Launch LAB

The Strength of Magnets

Did you know that magnets are used in TV sets, computers, stereo speakers, electric motors, and many other devices? Magnets also help create images of the inside of the human body. Even Earth acts like a giant bar magnet. How do magnets work?

1. Hold a bar magnet horizontally and put a paper clip on one end. Touch a second paper clip to the end of the first one. Continue adding paper clips until none will stick to one end of the chain. Copy the data table below and record the number of paper clips the magnet held. Remove the paper clips from the magnet.
2. Repeat step 1 three more times. First, start the chain about 2 cm from the end of the magnet. Second, start the chain near the center of the magnet. Third, start the chain at the other end of the magnet.
3. **Think Critically** Infer which part of the magnet exerts the strongest attraction. Compare the attraction at the center of the magnet with the attraction at the ends.

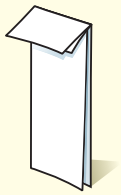
Magnet/Paper Clip Data	
	Paper Clip Chain (number of clips)
Trial 1 (end)	
Trial 2 (2 cm)	
Trial 3 (center)	
Trial 4 (other end)	

FOLDABLES™ Study Organizer

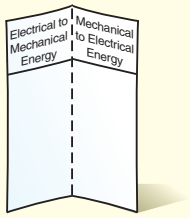
Using Magnets Many devices you use contain magnets that help convert one form of energy to another. Make the following Foldable to help you understand how magnets are used to transform electrical and mechanical energy.

STEP 1 **Fold** a sheet of paper in half lengthwise.

STEP 2 **Fold** the paper down about 2 cm from the top.



STEP 3 **Open and draw** lines along the top fold. **Label** as shown.



Summarize As you read the chapter, summarize how magnets are used to convert electrical energy to mechanical energy in the left column, and how magnets are used to convert mechanical energy to electrical energy in the right column.

Science Online

Preview this chapter's content and activities at gpscience.com

Kennan Ward/CORBIS

section 1

Magnetism

Reading Guide

What You'll Learn

- **Explain** how a magnet exerts a force.
- **Describe** the properties of temporary and permanent magnets.
- **Explain** why some materials are magnetic and some are not.
- **Model** magnetic behavior using magnetic domains.

Why It's Important

Without the forces exerted by magnets, you could not use televisions, computers, CD players, or even refrigerators.

Review Vocabulary

electric field: surrounds an electric charge and exerts a force on other electric charges

New Vocabulary

- magnetism
- magnetic field
- magnetic pole
- magnetic domain

Figure 1 Magnets can be found in many devices you use everyday, such as TVs, video games, telephones. Headphones and CD players also contain magnets.

Magnets

More than 2,000 years ago Greeks discovered deposits of a mineral that was a natural magnet. They noticed that chunks of this mineral could attract pieces of iron. This mineral was found in a region of Turkey that then was known as Magnesia, so the Greeks named the mineral magnetic. The mineral is now called magnetite. In the twelfth century Chinese sailors used magnetite to make compasses that improved navigation. Since then many devices have been developed that rely on magnets to operate. Today, the word **magnetism** refers to the properties and interactions of magnets. **Figure 1** shows a device you might be familiar with that uses magnets and magnetism.

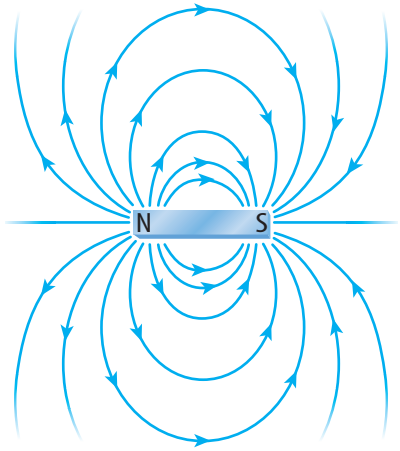
Magnetic Force You probably have played with magnets and might have noticed that two magnets exert a force on each other. Depending on which ends of the magnets are close together, the magnets either repel or attract each other. You might have noticed that the interaction between two magnets can be felt even before the magnets touch. The strength of the force between two magnets increases as magnets move closer together and decreases as the the magnets move farther apart.

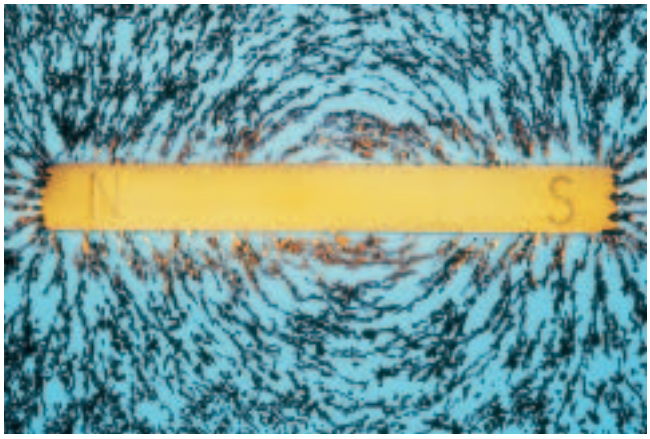
Reading Check *What does the force between two magnets depend on?*

Don Smetzer/Getty Images

Figure 2 A magnet is surounded by a magnetic field.

A magnet's magnetic field is represented by magnetic field lines.





Iron filings sprinkled around a magnet line up along the magnetic field lines.

Magnetic Field A magnet is surrounded by a magnetic field. A **magnetic field** exerts a force on other magnets and objects made of magnetic materials. The magnetic field is strongest close to the magnet and weaker far away. The magnetic field can be represented by lines of force, or magnetic field lines. **Figure 2** shows the magnetic field lines surrounding a bar magnet. A magnetic field also has a direction. The direction of the magnetic field around a bar magnet is shown by the arrows of the left side of **Figure 2.**

Magnetic Poles Look again at **Figure 2.** Do you notice that the magnetic field lines are closest together at the ends of the bar magnet? These regions, called the **magnetic poles,** are where the magnetic force exerted by the magnet is strongest. All magnets have a north pole and a south pole. For a bar magnet, the north and south poles are at the opposite ends.

Figure 3 shows the north and south poles of magnets with more complicated shapes. The two ends of a horseshoe-shaped magnet are the north and south poles. A magnet shaped like a disk has opposite poles on the top and bottom of the disk. Magnetic field lines always connect the north pole and the south pole of a magnet.

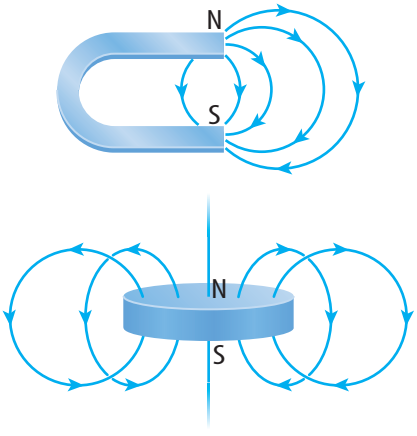
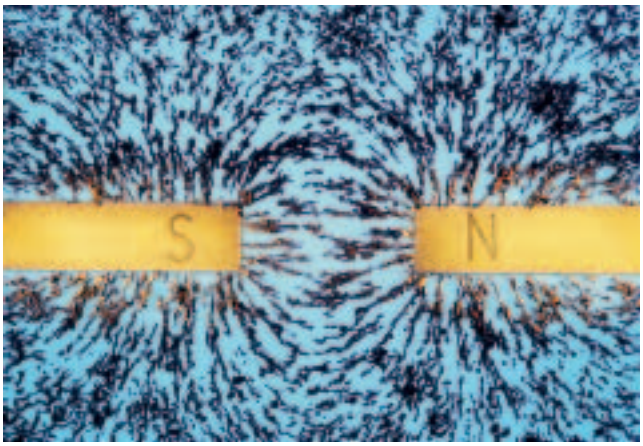
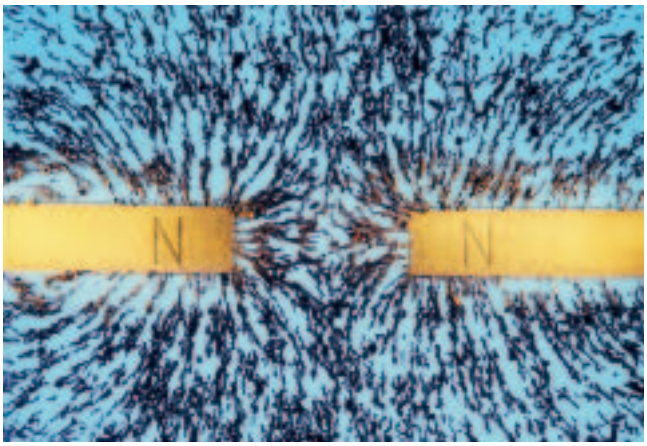


Figure 3 The magnetic field lines around horseshoe and disk magnets begin at each magnet's north pole and end at the south pole.
Identify *where the magnetic field is strongest.*

Richard Megna/Fundamental Photographs



Unlike poles closest together



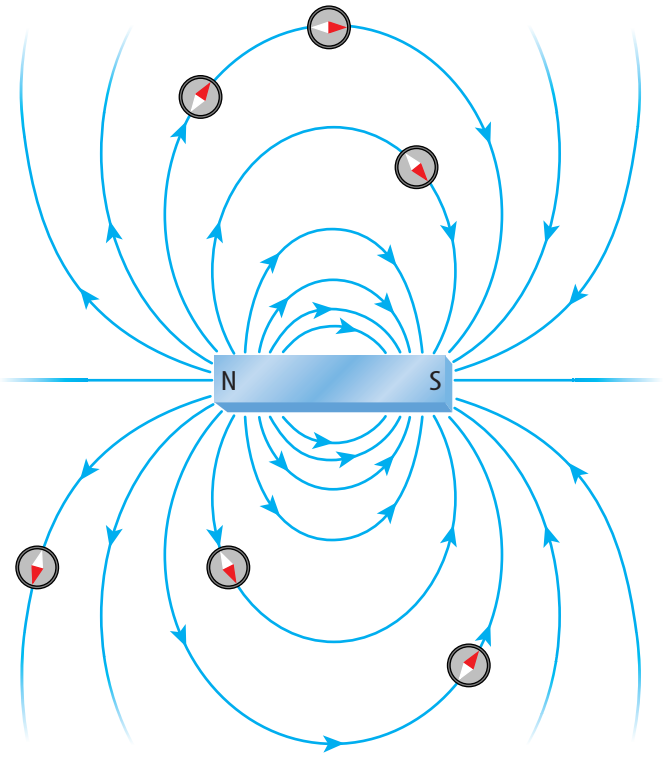
Like poles closest together

Figure 4 Two magnets can attract or repel each other, depending on which poles are closest together.

How Magnets Interact

Two magnets can either attract or repel each other. Two north poles or two south poles of two magnets repel each other. However, north poles and south poles always attract each other. Like magnetic poles repel each other and unlike poles attract each other. When two magnets are brought close to each other, their magnetic fields combine to produce a new magnetic field. **Figure 4** shows the magnetic field that results when like poles and unlike poles of bar magnets are brought close to each other.

Reading Check *How do magnetic poles interact with each other?*



Magnetic Field Direction

When a compass is brought near a bar magnet, the compass needle rotates. The compass needle is a small bar magnet with a north pole and a south pole. The force exerted on the compass needle by the magnetic field causes the needle to rotate. The compass needle rotates until it lines up with the magnetic field lines, as shown in **Figure 5.** The north pole of a compass points in the direction of the magnetic field. This direction is always away from a north magnetic pole and toward a south magnetic pole.

Figure 5 Compass needles placed around a bar magnet line up along magnetic field lines. The north poles of the compass needles are shaded red.

Richard Megna/Fundamental Photographs

Earth's Magnetic Field A compass can help determine direction because the north pole of the compass needle points north. This is because Earth acts like a giant bar magnet and is surrounded by a magnetic field that extends into space. Just as with a bar magnet, the compass needle aligns with Earth's magnetic field lines, as shown in **Figure 6.**

Earth's Magnetic Poles The north pole of a magnet is defined as the end of the magnet that points toward the geographic north. Sometimes the north pole and south pole of magnets are called the north-seeking pole and the south-seeking pole. Because opposite magnetic poles attract, the north pole of a compass is being attracted by a south magnetic pole. So Earth is like a bar magnet with its south magnetic pole near its geographic north pole.

Currently, Earth's south magnetic pole is located in northern Canada about 1,500 km from the geographic north pole. However, Earth's magnetic poles move slowly with time. Sometimes Earth's magnetic poles switch places so that Earth's south magnetic pole is the southern hemisphere near the geographic south pole. Measurements of magnetism in rocks show that Earth's magnetic poles have changed places over 150 times in the past seventy million years.

No one is sure what produces Earth's magnetic field. Earth's inner core is made of a solid ball of iron and nickel, surrounded by a liquid layer of molten iron and nickel. According to one theory, circulation of the molten iron and nickel in Earth's outer core produces Earth's magnetic field.

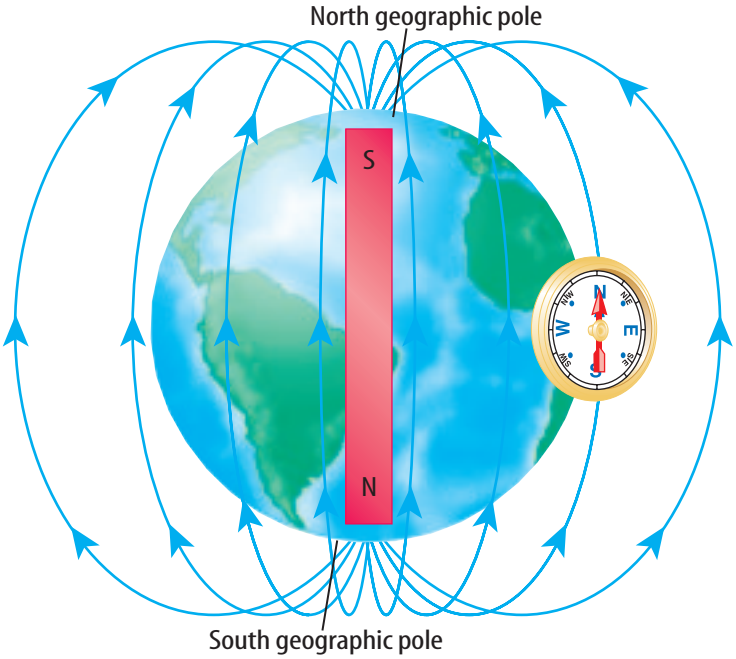


Figure 6 A compass needle aligns with the magnetic field lines of Earth's magnetic field. **Predict** *Which way would a compass needle point if Earth's magnetic poles switched places?*

Observing Magnetic Interference

Procedure

1. Clamp a **bar magnet** to a **ring stand.** Tie a **thread** around one end of a **paper clip** and stick the paper clip to one pole of the magnet.
2. Anchor the other end of the thread under a **book** on the table. Slowly pull the thread until the paper clip is suspended below the magnet but not touching the magnet.
3. Without touching the paper clip, slip a piece of paper between the magnet and the paper clip. Does the paper clip fall?
4. Try other materials, such as **aluminum foil, fabric,** or a **butter knife.**

Analysis

1. Which materials caused the paper clip to fall? Why do you think these materials interfered with the magnetic field?
2. Which materials did not cause the paper clip to fall? Why do you think these materials did not interfere with the magnetic field?

Magnets in Organisms
Some organisms may use Earth's magnetic field to help find their way around. Some species of birds, insects, and bacteria have been shown to contain small amounts of the mineral magnetite. Research how one species uses Earth's magnetic field, and report your findings to your class.

Magnetic Materials

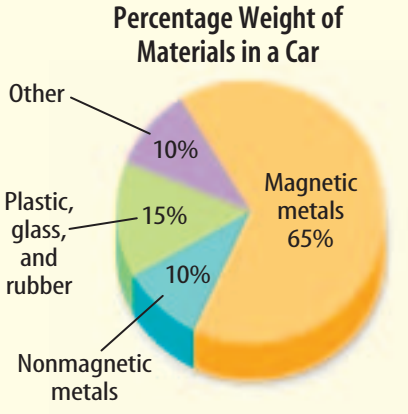
You might have noticed that a magnet will not attract all metal objects. For example, a magnet will not attract pieces of aluminum foil. Only a few metals, such as iron, cobalt, or nickel, are attracted to magnets or can be made into permanent magnets. What makes these elements magnetic? Remember that every atom contains electrons. Electrons have magnetic properties. In the atoms of most elements, the magnetic properties of the electrons cancel out. But in the atoms of iron, cobalt, and nickel, these magnetic properties don't cancel out. Each atom in these elements behaves like a small magnet and has its own magnetic field.

Even though these atoms have their own magnetic fields, objects made from these metals are not always magnets. For example, if you hold an iron nail close to a refrigerator door and let go, it falls to the floor. However, you can make the nail behave like a magnet temporarily.

Applying Science

How can magnetic parts of a junk car be salvaged?

Every year over 10 million cars containing plastics, glass, rubber, and various metals are scrapped. Magnets are often used to help retrieve some of these materials from scrapped cars. The materials can then be reused, saving both natural resources and energy. Once the junk car has been fed into a shredder, big magnets can easily separate many of its metal parts from its nonmetal parts. How much of the car does a magnet actually help separate? Use your ability to interpret a circle graph to find out.



Identifying the Problem

The graph at the right shows the average percent by weight of the different materials in a car. Included in the magnetic metals are steel and iron. The nonmagnetic metals refer to aluminum, copper, lead, zinc, and magnesium. According to the chart, how much of the car can a magnet separate for recycling?

Solving the Problem

1. What percent of the car's weight will a magnet recover?
2. A certain scrapped car has a mass of 1,500 kg. What is the mass of the materials in this car that cannot be recovered using a magnet?
3. If the average mass of a scrapped car is 1,500 kg, and 10 million cars are scrapped each year, what is the total mass of iron and steel that could be recovered from scrapped cars each year?

Magnetic Domains—A Model for Magnetism

In iron, cobalt, nickel, and some other magnetic materials, the magnetic field created by each atom exerts a force on the other nearby atoms. Because of these forces, large groups of atoms align their magnetic poles so that almost all like poles point in the same direction. The groups of atoms with aligned magnetic poles are called **magnetic domains.** Each domain contains an enormous number of atoms, yet the domains are too small to be seen with the unaided eye. Because the magnetic poles of the individual atoms in a domain are aligned, the domain itself behaves like a magnet with a north pole and a south pole.

Lining Up Domains

An iron nail contains an enormous number of these magnetic domains, so why doesn't the nail behave like a magnet? Even though each domain behaves like a magnet, the poles of the domains are arranged randomly and point in different directions, as shown in **Figure 7.** As a result, the magnetic fields from all the domains cancel each other out.

If you place a magnet against the same nail, the atoms in the domains orient themselves in the direction of the nearby magnetic field, as shown on the right in **Figure 7.** The like poles of the domains point in the same direction and no longer cancel each other out. The nail itself now acts as a magnet. But when the external magnetic field is removed, the constant motion and vibration of the atoms bump the magnetic domains out of their alignment. The magnetic domains in the nail return to random arrangement. For this reason, the nail is only a temporary magnet. Paper clips and other objects containing iron also can become temporary magnets.

Mini LAB

Making Your Own Compass

Procedure

WARNING: *Use care when handling sharp objects.*

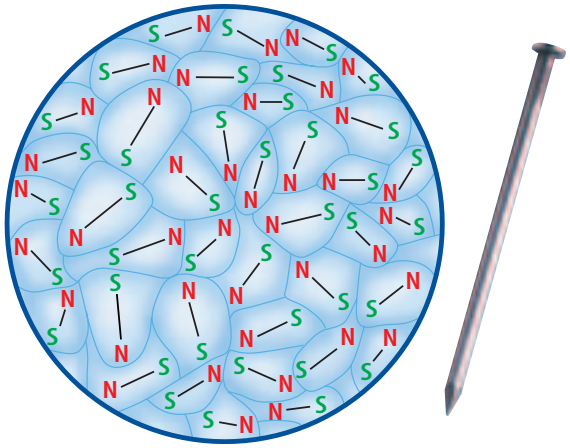
1. Cut off the bottom of a **plastic foam cup** to make a polystyrene disk.
2. Magnetize a **sewing needle** by continuously stroking the needle in the same direction with a magnet for 1 min.
3. **Tape** the needle to the center of the foam disk.
4. Fill a **plate** with **water** and float the disk, needle-side up, in the water.
5. Bring the magnet close to the foam disk.

Analysis

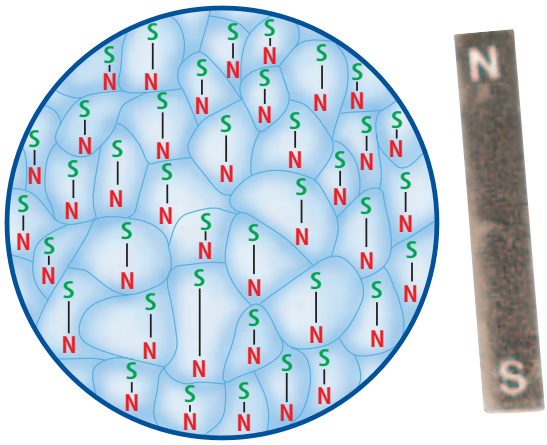
1. How did the needle and disk move when you placed them in the water? Explain.
2. How did the needle and disk move when the magnet was brought near it? Explain.

Try at Home

Figure 7 Magnetic materials contain magnetic domains.



A normal iron nail is made up of microscopic domains that are arranged randomly.



The domains will align themselves along the magnetic field lines of a nearby magnet.

(l)Stephen Frisch/Stock Boston, (r)Mark Burnett

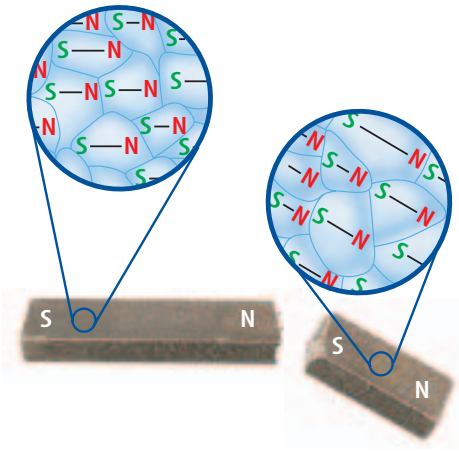


Figure 8 Each piece of a broken magnet still has a north and a south pole.

Permanent Magnets A permanent magnet can be made by placing a magnetic material, such as iron, in a strong magnetic field. The strong magnetic field causes the magnetic domains in the material to line up. The magnetic fields of these aligned domains add together and create a strong magnetic field inside the material. This field prevents the constant motion of the atoms from bumping the domains out of alignment. The material is then a permanent magnet.

But even permanent magnets can lose their magnetic behavior if they are heated. Heating causes atoms in the magnet to move faster. If the permanent magnet is heated enough, its atoms may be moving fast enough to jostle the domains out of alignment. Then the permanent magnet loses its magnetic field and is no longer a magnet.

Can a pole be isolated? What happens when a magnet is broken in two? Can one piece be a north pole and one piece be a south pole? Look at the domain model of the broken magnet in **Figure 8.** Recall that even individual atoms of magnetic materials act as tiny magnets. Because every magnet is made of many aligned smaller magnets, even the smallest pieces have both a north pole and a south pole.

section 1 review

Summary

Magnets

- Magnets are surrounded by a magnetic field that exerts a force on magnetic materials.
- Magnets have a north pole and a south pole.
- Like magnetic poles repel and unlike poles attract.

Magnetic Materials

- Iron, cobalt, and nickel are magnetic elements because their atoms behave like magnets.
- Magnetic domains are regions in a material that contain an enormous number of atoms with their magnetic poles aligned.
- A magnetic field causes domains to align. In a temporary magnet, the domains return to random alignment when the field is removed.
- In a permanent magnet, a stong magnetic field aligns domains and they remain aligned when the field is removed.

Self Check

1. **Describe** what happens when you move two unlike magnetic poles closer together. Draw a diagram to illustrate your answer.
2. **Describe** how a compass needle moves when it is placed in a magnetic field.
3. **Explain** why only certain materials are magnetic.
4. **Predict** how the properties of a bar magnet would change if it were broken in half.
5. **Explain** how heating a bar magnet would change its magnetic field.
6. **Think Critically** Use the magnetic domain model to explain why a magnet sticks to a refrigerator door.

Applying Math

7. **Calculate Number of Domains** The magnetic domains in a magnet have an average volume of 0.0001 mm^3. If the magnet has dimensions 50 mm by 10 mm by 4 mm, how many domains does the magnet contain?

Mark Burnett

section 2

Electricity and Magnetism

Reading Guide

What You'll Learn

- **Describe** the magnetic field produced by an electric current.
- **Explain** how an electromagnet produces a magnetic field.
- **Describe** how electromagnets are used.
- **Explain** how an electric motor operates.

Why It's Important

Electric motors contained in many of the devices you use every day operate because electric currents produce magnetic fields.

Review Vocabulary

electric current: the flow of electric charges in a wire or any conductor

New Vocabulary

- electromagnet
- solenoid
- galvanometer
- electric motor

Electric Current and Magnetism

In 1820, Hans Christian Oersted, a Danish physics teacher, found that electricity and magnetism are related. While doing a demonstration involving electric current, he happened to have a compass near an electric circuit. He noticed that the flow of the electric current affected the direction the compass needle pointed. Oersted hypothesized that the electric current must produce a magnetic field around the wire, and the direction of the field changes with the direction of the current.

Moving Charges and Magnetic Fields Oersted's hypothesis that an electric current creates a magnetic field was correct. It is now known that moving charges, like those in an electric current, produce magnetic fields. Around a current-carrying wire the magnetic field lines form circles, as shown in **Figure 8.** The direction of the magnetic field around the wire reverses when the direction of the current in the wire reverses. As the current in the wire increases the strength of the magnetic field increases. As you move farther from the wire the strength of the magnetic field decreases.

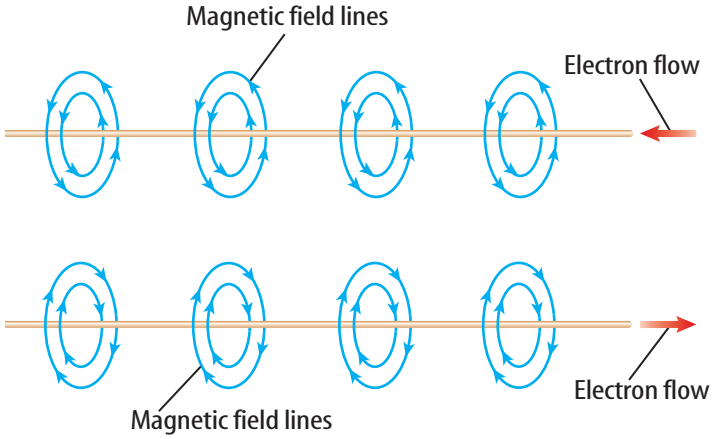


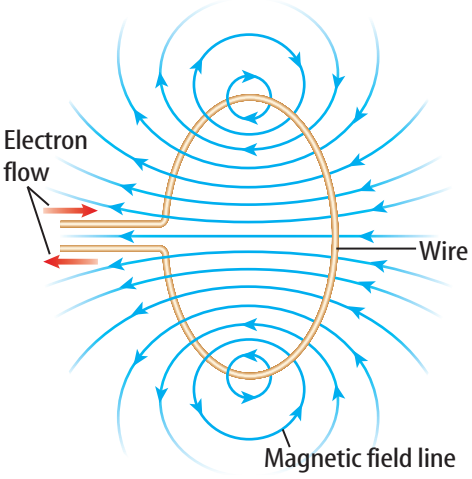
Figure 8 When electric current flows through a wire, a magnetic field forms around the wire. The direction of the magnetic field depends on the direction of the current in the wire.

Electromagnets

The magnetic field that surrounds a current-carrying wire can be made much stronger in an electromagnet. An **electromagnet** is a temporary magnet made by wrapping a wire coil carrying a current around an iron core. When a current flows through a wire loop, such as the one shown in **Figure 9A,** the magnetic field inside the loop is stronger than the field around a straight wire. A single wire wrapped into a cylindrical wire coil is called a **solenoid.** The magnetic field inside a solenoid is stronger than the field in a single loop. The magnetic field around each loop in the solenoid combines to form the field shown in **Figure 9B.**

If the solenoid is wrapped around an iron core, an electromagnet is formed, as shown in **Figure 9C.** The solenoid's magnetic field magnetizes the iron core. As a result, the field inside the solenoid with the iron core can be more than 1,000 times greater than the field inside the solenoid without the iron core.

Figure 9 An electromagnet is made from a current-carrying wire.



A The magnetic fields around different parts of the wire loop combine to form the field inside the loop.

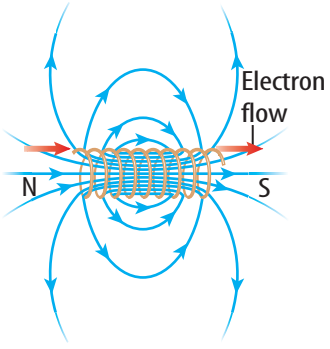
Properties of Electromagnets

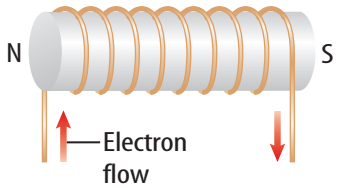
Electromagnets are temporary magnets because the magnetic field is present only when current is flowing in the solenoid. The strength of the magnetic field can be increased by adding more turns of wire to the solenoid or by increasing the current passing through the wire.

An electromagnet behaves like any other magnet when current flows through the solenoid. One end of the electromagnet is a north pole and the other end is a south pole. If placed in a magnetic field, an electromagnet will align itself along the magnetic field lines, just as a compass needle will. An electromagnet also will attract magnetic materials and be attracted or repelled by other magnets. What makes electromagnets so useful is that their magnetic properties can be controlled by changing the electric current flowing through the solenoid.

When current flows in the electromagnet and it moves toward or away from another magnet, electric energy is converted into mechanical energy to do work. Electromagnets do work in various devices such as stereo speakers and electric motors.

B When many loops of current-carrying wire are formed into a solenoid, the magnetic field is increased inside the solenoid. The solenoid has a north pole and a south pole.
Predict *how the field would change if the current reversed direction.*





C A solenoid wrapped around an iron core forms an electromagnet.

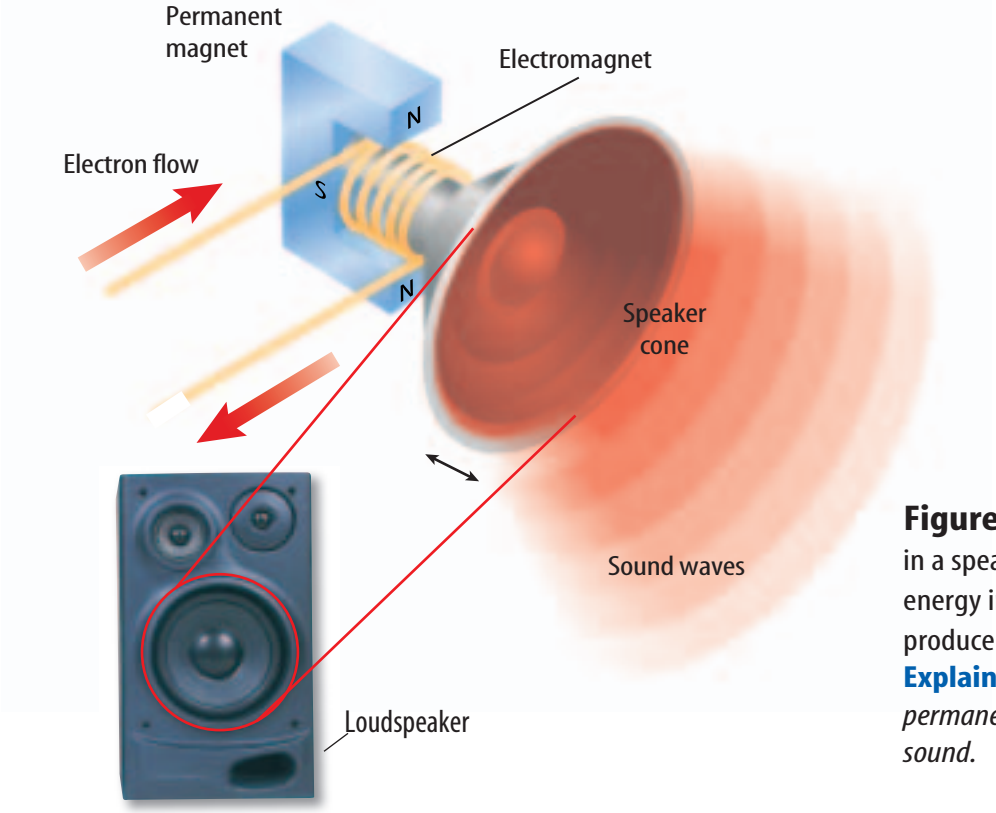


Figure 10 The electromagnet in a speaker converts electrical energy into mechanical energy to produce sound.
Explain *why a speaker needs a permanent magnet to produce sound.*

Using Electromagnets to Make Sound

How does musical information stored on a CD become sound you can hear? The sound is produced by a loudspeaker that contains an electromagnet connected to a flexible speaker cone that is usually made from paper, plastic, or metal. The electromagnet changes electrical energy to mechanical energy that vibrates the speaker cone to produce sound, as shown on **Figure 10.**

Reading Check ***How does a stereo speaker use an electromagnet to produce sound?***

When you listen to a CD, the CD player produces a voltage that changes according to the musical information on the CD. This varying voltage produces a varying electric current in the electromagnet connected to the speaker cone. Both the amount and the direction of the electric current change, depending on the information on the CD. The varying electric current causes both the strength and the direction of the magnetic field in the electromagnet to change. The electromagnet is surrounded by a permanent, fixed magnet. The changing direction of the magnetic field in the electromagnet causes the electromagnet to be attracted to or repelled by the permanent magnet. This makes the electromagnet move back and forth, causing the speaker cone to vibrate and reproduce the sound that was recorded on the CD.

Icon Images

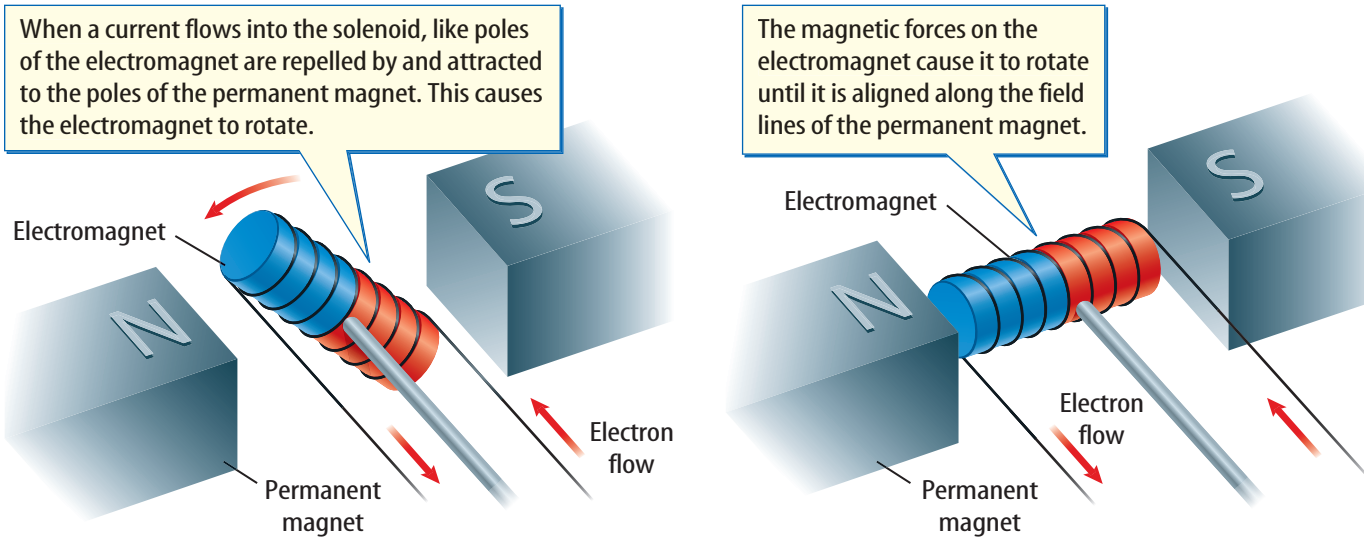


Figure 11 An electromagnet can be made to rotate in a magnetic field.

Making an Electromagnet Rotate The forces exerted on an electromagnet by another magnet can be used to make the electromagnet rotate. **Figure 11** shows an electromagnet suspended between the poles of a permanent magnet. The poles of the electromagnet are repelled by the like poles and attracted by the unlike poles of the permanent magnet. When the electromagnet is in the position shown on the left side of **Figure 11,** there is a downward force on the left side and an upward force on the right side of the electromagnet forces. These forces cause the electromagnet to rotate as shown.

Reading Check ***How can a permanent magnet cause an electromagnet to rotate?***

The electromagnet continues to rotate until its poles are next to the opposite poles of the permanent magnet, as shown on the right side of **Figure 11.** In this position, the forces on the north and south poles of the electromagnet are in opposite directions. Then the net force on the electromagnet is zero, and the electromagnet stops rotating.

One way to change the forces that make the electromagnet rotate is to change the current in the electromagnet. Increasing the current increases the strength of the forces between the two magnets.

Galvanometers You've probably noticed the gauges in the dashboard of a car. One gauge shows the amount of gasoline left in the tank, and another shows the engine temperature. How does a change in the amount of gasoline in a tank or the water temperature in the engine make a needle move in a gauge on the dashboard? These gauges are **galvanometers,** which are devices that use an electromagnet to measure electric current.

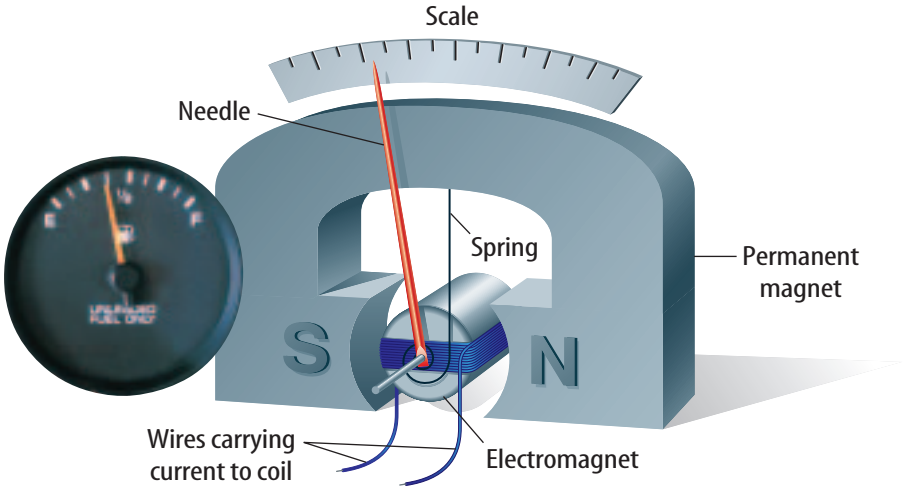


Figure 12 The rotation of the needle in a galvanometer depends on the amount of current flowing in the electromagnet. The current flowing into the galvanometer in a car's fuel gauge changes as the amount of fuel changes.

Using Galvanometers An example of a galvanometer is shown in **Figure 12.** In a galvanometer, the electromagnet is connected to a small spring. Then the electromagnet rotates until the force exerted by the spring is balanced by the magnetic forces on the electromagnet. Changing the current in the electromagnet causes the needle to rotate to different positions on the scale.

For example, a car's fuel gauge uses a galvanometer. A float in the fuel tank is attached to a sensor that sends a current to the fuel gauge galvanometer. As the level of the float in the tank changes, the current sent by the sensor changes. The changing current in the galvanometer causes the needle to rotate by different amounts. The gauge is calibrated so that the current sent when the tank is full causes the needle to rotate to the full mark on the scale.

Electric Motors

On sizzling summer days, do you ever use an electric fan to keep cool? A fan uses an **electric motor,** which is a device that changes electrical energy into mechanical energy. The motor in a fan turns the fan blades, moving air past your skin to make you feel cooler.

Electric motors are used in all types of industry, agriculture, and transportation, including airplanes and automobiles. If you were to look carefully, you probably could find electric motors in every room of your house. Almost every appliance in which something moves contains an electric motor. Electric motors are used in devices such as in VCRs, CD players, computers, hair dryers, and other appliances shown in **Figure 13.**

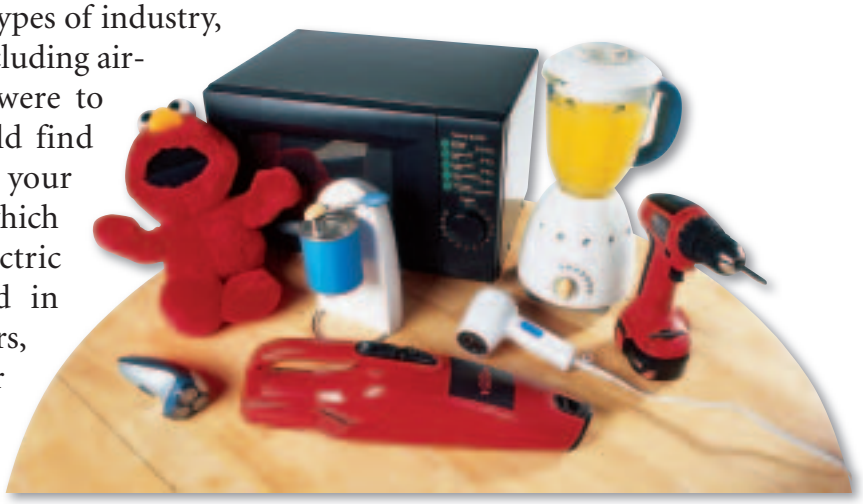
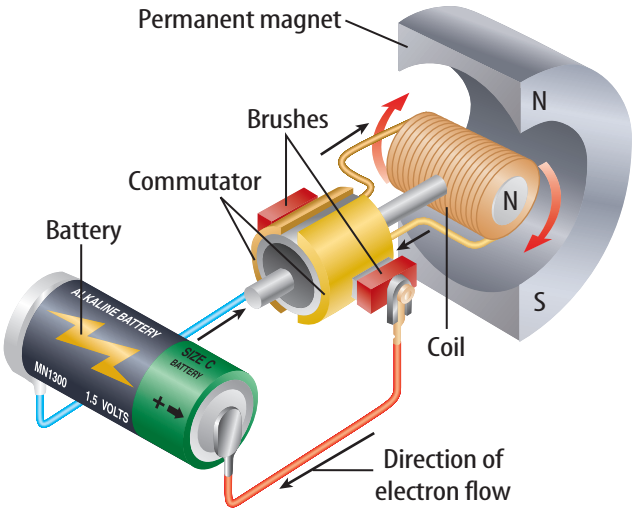
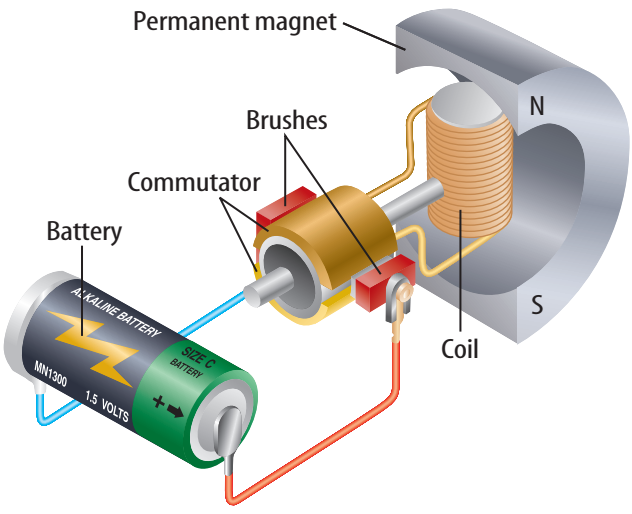


Figure 13 All the devices shown here contain electric motors. **List** *three additional devices that contain electric motors.*

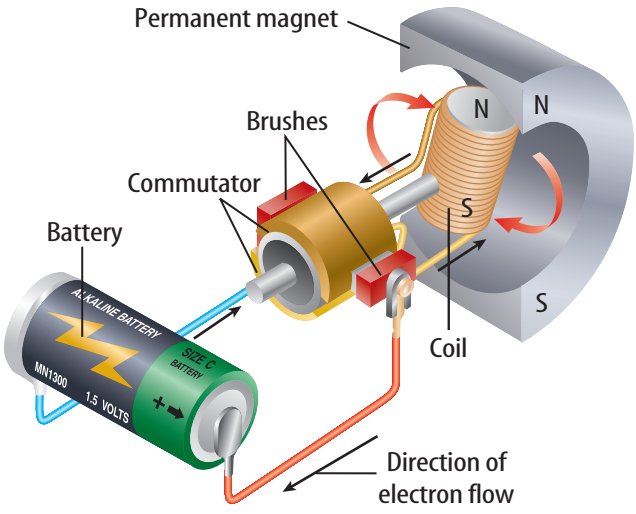
(t)Allen Zak, (b)Tim Courlas/Horizons Companies



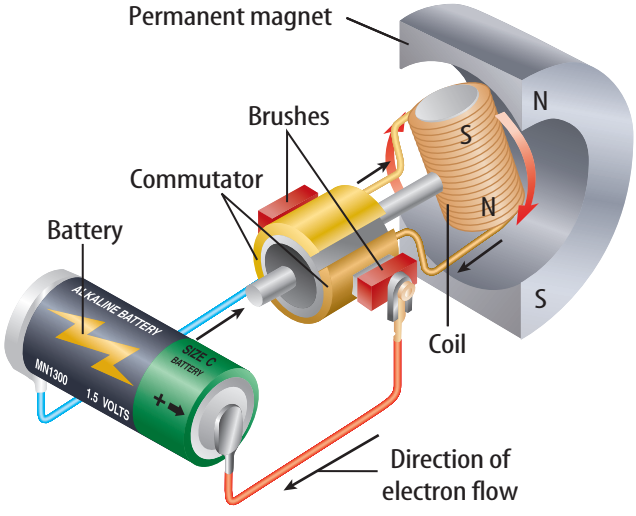
Step 1 When a current flows in the coil, the magnetic forces between the permanent magnet and the coil cause the coil to rotate.



Step 2 In this position, the brushes are not in contact with the commutator and no current flows in the coil. The inertia of the coil keeps it rotating.



Step 3 The commutator reverses the direction of the current in the coil. This flips the north and south poles of the magnetic field around the coil.



Step 4 The coil rotates until its poles are opposite the poles of the permanent magnet. The commutator reverses the current, and the coil keeps rotating.

Figure 14 In a simple electric motor, a coil rotates between the poles of a permanent magnet. To keep the coil rotating, the current must change direction twice during each rotation.

A Simple Electric Motor A diagram of the simplest type of electric motor is shown in **Figure 14.** The main parts of a simple electric motor include a wire coil, a permanent magnet, and a source of electric current, such as a battery. The battery produces the current that makes the coil an electromagnet. A simple electric motor also includes components called brushes and a commutator. The brushes are conducting pads connected to the battery. The brushes make contact with the commutator, which is a conducting metal ring that is split. Each half of the commutator is connected to one end of the coil so that the commutator rotates with the coil. The brushes and the commutator form a closed electric circuit between the battery and the coil.

Making the Motor Spin When current flows in the coil, the forces between the coil and the permanent magnet cause the coil to rotate, as shown in step 1 of **Figure 14.** The coil continues to rotate until it reaches the position shown in step 2. Then the brushes no longer make contact with the commutator, and no current flows in the coil. As a result, there are no magnetic forces exerted on the coil. However, the inertia of the coil causes it to continue rotating.

In step 3 the coil has rotated so that the brushes again are in contact with the commutator. However, the halves of the commutator that are in contact with the positive and negative battery terminals have switched. This causes the current in the commutator to reverse direction. Now the top of the electromagnet is a north magnetic pole and the bottom is a south pole. These poles are repelled by the nearby like poles of the permanent magnet, and the magnet continues to rotate.

In step 4, the coil rotates until its poles are next to the opposite poles of the permanent magnet. Then the commutator again reverses the direction of the current, enabling the coil to keep rotating. In this way, the coil is kept rotating as long the battery remains connected to the commutator.

Science online

Topic: Electric Motors

Visit gpscience.com for Web links to information about electric motors.

Activity Using the information provided at these links, construct a simple electric motor.

section 2 review

Summary

Electric Current and Magnetic Fields

- A magnetic field surrounds a moving electric charge.
- The strength of the magnetic field surrounding a current-carrying wire depends on the amount of current.

Electromagnets

- An electromagnet is a temporary magnet consisting of a current-carrying wire wrapped around an iron core.
- The magnetic properties of an electromagnet can be controlled by changing the current in the coil.
- A galvanometer uses an electromagnet to measure electric current.

Electric Motors

- In a simple electric motor, an electromagnet rotates between the poles of a permanent magnet.

Self Check

1. **Explain** why, if the same current flows in a wire coil and a single wire loop, the magnetic field inside the coil is stronger than the field inside the loop.
2. **Describe** two ways you could change the strength of the magnetic field produced by an electromagnet.
3. **Predict** how the magnetic field produced by an electromagnet would change if the iron core were replaced by an aluminum core.
4. **Explain** why it is necessary to continually reverse the direction of current flow in the coil of an electric motor.
5. **Think Critically** A bar magnet is repelled when an electromagnet is brought close to it. Describe how the bar magnet would have moved if the current in the electromagnet had been reversed.

Applying Math

6. **Use a Ratio** The magnetic field strength around a wire at a distance of 1 cm is twice as large as at a distance of 2 cm. How does the field strength at 0.5 cm compare to the field strength at 1 cm?

section 3

Producing Electric Current

Reading Guide

What You'll Learn

- **Define** electromagnetic induction.
- **Describe** how a generator produces an electric current.
- **Distinguish** between alternating current and direct current.
- **Explain** how a transformer can change the voltage of an alternating current.

Why It's Important

Electromagnetic induction enables power plants to generate the electric current an appliance uses when you plug it into an electric outlet.

Review Vocabulary

voltage difference: a measure of the electrical energy provided by charges as they flow in a circuit

New Vocabulary

- electromagnetic induction
- generator
- turbine
- direct current (DC)
- alternating current (AC)
- transformer

From Mechanical to Electrical Energy

Working independently in 1831, Michael Faraday in Britain and Joseph Henry in the United States both found that moving a loop of wire through a magnetic field caused an electric current to flow in the wire. They also found that moving a magnet through a loop of wire produces a current. In both cases, the mechanical energy associated with the motion of the wire loop or the magnet is converted into electrical energy associated with the current in the wire. The magnet and wire loop must be moving relative to each other for an electric current to be produced. This causes the magnetic field inside the loop to change with time. In addition, if the current in a wire changes with time, the changing magnetic field around the wire can also induce a current in a nearby coil. The generation of a current by a changing magnetic field is **electromagnetic induction.**

Figure 15 The coil in a generator is rotated by an outside source of mechanical energy. Here the student supplies the mechanical energy that is converted into electrical energy by the generator.

Generators Most of the electrical energy you use every day is provided by generators. A **generator** uses electromagnetic induction to transform mechanical energy into electrical energy. **Figure 15** shows one way a generator converts mechanical energy to electrical energy. The mechanical energy is provided by turning the handle on the generator.

An example of a simple generator is shown in **Figure 16.** In this type of generator, a current is produced in the coil as the coil rotates between the poles of a permanent magnet.

Tim Courlas/Horizons Companies

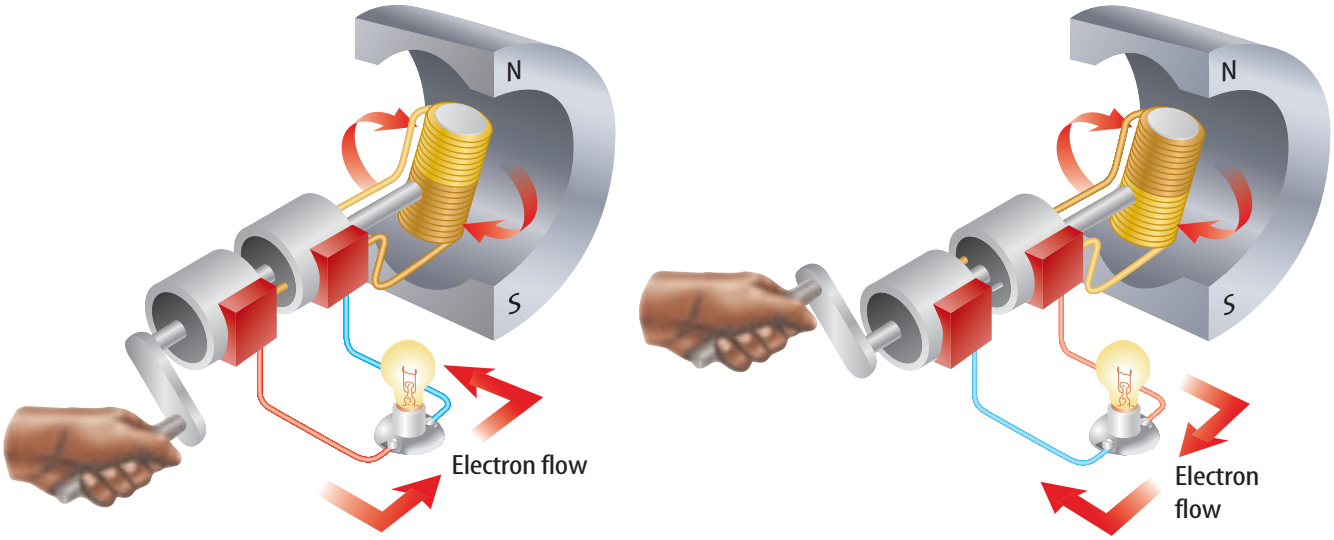


Figure 16 The current in the coil changes direction each time the ends of the coil move past the poles of the permanent magnet. **Explain** *how the frequency of the changing current can be controlled.*

Switching Direction As the generator's wire coil rotates through the magnetic field of the permanent magnet, current flows through the coil. After the wire coil makes one-half of a revolution, the ends of the coil are moving past the opposite poles of the permanent magnet. This causes the current to change direction. In a generator, as the coil keeps rotating, the current that is produced periodically changes direction. The direction of the current in the coil changes twice with each revolution, as **Figure 16** shows. The frequency with which the current changes direction can be controlled by regulating the rotation rate of the generator. In the United States, current is produced by generators that rotate 60 times a second, or 3,600 revolutions per minute.

Reading Check ***For each revolution of the coil, how many times does the current change direction?***

Using Electric Generators The type of generator shown in **Figure 16** is used in a car, where it is called an alternator. The alternator provides electrical energy to operate lights and other accessories. Spark plugs in the car's engine also use this electrical energy to ignite the fuel in the cylinders of the engine. Once the engine is running, it provides the mechanical energy that is used to turn the coil in the alternator.

Suppose that instead of using mechanical energy to rotate the coil in a generator, the coil was fixed, and the permanent magnet rotated instead. In fact, the current generated would be the same as when the coil rotates and the magnet doesn't move. The huge generators used in electric power plants are made this way. The current is produced in the stationary coil, and mechanical energy is used to rotate the magnet.

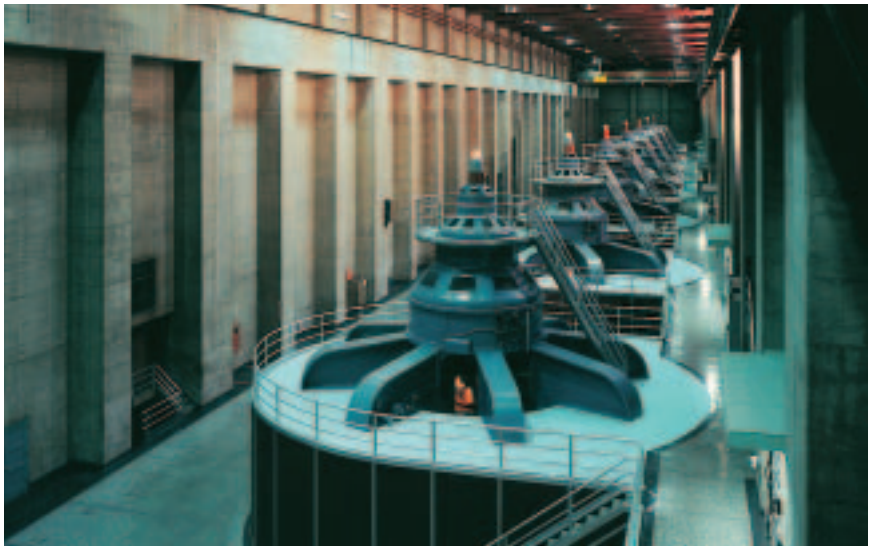


Figure 17 Each of these generators at Hoover Dam can produce over 100,000 kW of electric power. In these generators, a rotating magnet induces an electric current in a stationary wire coil.

Power Plant Operator
Many daily activities require electricity. Power plant operators control the machinery that generates electricity. Operators must have a high school diploma. College-level courses may be helpful. Research to find employers in your area that hire power plant operators.

Generating Electricity for Your Home You probably do not have a generator in your home that supplies the electrical energy you need to watch television or wash your clothes. This electrical energy comes from a power plant with huge generators like the one in **Figure 17.** The coils in these generators have many coils of wire wrapped around huge iron cores. The rotating magnets are connected to a **turbine** (TUR bine)—a large wheel that rotates when pushed by water, wind, or steam.

For example, some power plants first produce thermal energy by burning fossil fuels or using the heat produced by nuclear reactions. This thermal energy is used to heat water and produce steam. Thermal energy is then converted to mechanical energy as the steam pushes the turbine blades. The generator then changes the mechanical energy of the rotating turbine into the electrical energy you use. In some areas, fields of windmills, like those in **Figure 18,** can be used to capture the mechanical energy in wind to turn generators. Other power plants use the mechanical energy in falling water to drive the turbine. Both generators and electric motors use magnets to produce energy conversions between electrical and mechanical energy. **Figure 19** summarizes the differences between electric motors and generators.

Figure 18 The propeller on each of these windmills is connected to an electric generator. The rotating propeller rotates a coil or a permanent magnet.

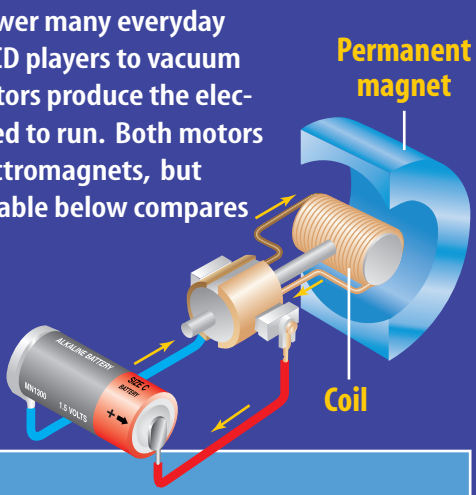
(t)Tom Campbell/FPG/Getty Images, (b)Russell D. Curtis/Photo Researchers

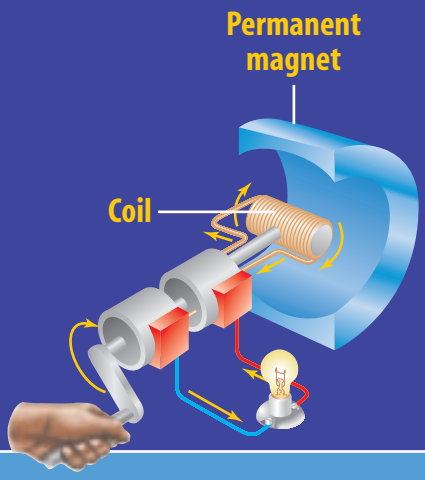
NATIONAL GEOGRAPHIC

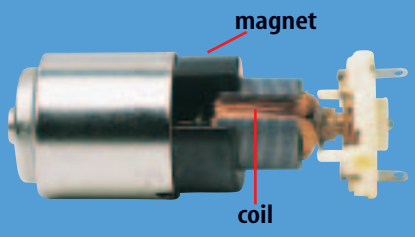
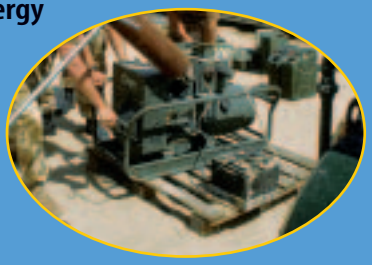
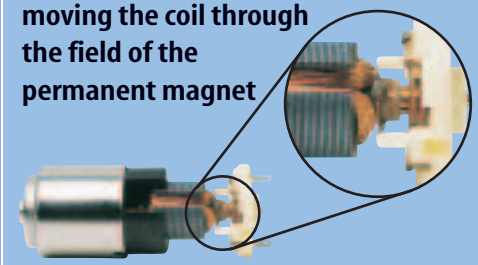
VISUALIZING MOTORS AND GENERATORS

Figure 19

Electric motors power many everyday machines, from CD players to vacuum cleaners. Generators produce the electricity those motors need to run. Both motors and generators use electromagnets, but in different ways. The table below compares motors and generators.





	Electric Motor	Generator
What does it do?	Changes electricity into movement	Changes movement into electricity
What makes its electromagnetic coil rotate?	Attractive and repulsive forces between the coil and the permanent magnet 	An outside source of mechanical energy 
What is the source of the current that flows in its coil?	An outside power source	Electromagnetic induction from moving the coil through the field of the permanent magnet 
How often does the current in the coil change direction?	Twice during each rotation of the coil	Twice during each rotation of the coil

(tl)Clement Mok/PictureQuest, (tr)Joseph Palmieri/Pictor, (cl, br)Tim Ridley/DK Images, (cr)Robin Adshead/Military Picture Library/CORBIS, (bl)Brian Gordon Green

Direct and Alternating Currents

Modern society relies heavily on electricity. Just how much you rely on electricity becomes obvious during a power outage. Out of habit, you might walk into a room and flip on the light switch. You might try to turn on a radio or television or check the clock to see what time it is. Because power outages sometimes occur, some electrical devices, like the radio in **Figure 20,** use batteries as a backup source of electrical energy. However, the current produced by a battery is different than the current from an electric generator.

A battery produces a direct current. **Direct current** (DC) flows only in one direction through a wire. When you plug your CD player or any other appliance into a wall outlet, you are using alternating current. **Alternating current** (AC) reverses the direction of the current in a regular pattern. In North America, generators produce alternating current at a frequency of 60 cycles per second, or 60 Hz. The electric current produced by a generator changes direction twice during each cycle, or each rotation, of the coil. So a 60-Hz alternating current changes direction 120 times each second.

Electronic devices that use batteries as a backup energy source usually require direct current to operate. When the device is plugged into a wall outlet, electronic components inside the device convert the alternating current to direct current and also reduce the voltage of the alternating current.

Science Online

Topic: Transformers

Visit gpscience.com for links to information about how transformers transmit electric current.

Activity In England, voltage from an outlet is greater than required for U.S. appliances. Using information found at these links, diagram a transformer that would allow a U.S. appliance to operate in England.

Figure 20 Some devices, like this radio, can use either direct or alternating current. Electronic components in these devices change alternating current from an electric outlet to direct current.

Mark Burnett

Transmitting Electrical Energy

The alternating current produced by an electric power plant carries electrical energy that is transmitted along electric transmission lines. However, when the electric energy is transmitted along power lines, some of the electrical energy is converted into heat due to the electrical resistance of the wires. The heat produced in the power lines warms the wires and the surrounding air and can't be used to power electrical devices. Also, the electrical resistance and heat production increases as the wires get longer. As a result, large amounts of heat can be produced when electrical energy is transmitted over long distances.

One way to reduce the heat produced in a power line is to transmit the electrical energy at high voltages, typically around 150,000 V. However, electrical energy at such high voltage cannot enter your home safely, nor can it be used in home appliances. Instead, a transformer is used to decrease the voltage.

Transformers

A **transformer** is a device that increases or decreases the voltage of an alternating current. A transformer is made of a primary coil and a secondary coil. These wire coils are wrapped around the same iron core, as shown in **Figure 21.** As an alternating current passes through the primary coil, the coil's magnetic field magnetizes the iron core. The magnetic field in the primary coil changes direction as the current in the primary coil changes direction. This produces a magnetic field in the iron core that changes direction at the same frequency. The changing magnetic field in the iron core then induces an alternating current with the same frequency in the secondary coil.

The voltage in the primary coil is the input voltage and the voltage in the secondary coil is the output voltage. The output voltage divided by the input voltage equals the number of turns in the secondary coil divided by the number of turns in the primary coil.

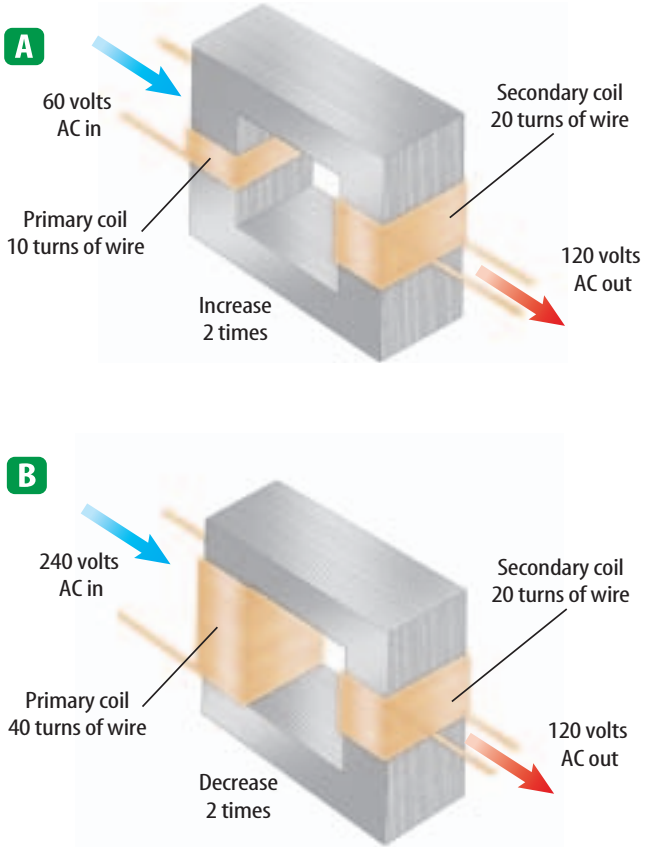


Figure 21 Transformers can increase or decrease voltage. **A** A step-up transformer increases voltage. The secondary coil has more turns than the primary coil does. **B** A step-down transformer decreases voltage. The secondary coil has fewer turns than the primary coil does.
Infer *whether a transformer could change the voltage of a direct current.*

Reading Check ***How does a transformer produce an alternating current in the secondary coil?***

Step-Up Transformer A transformer that increases the voltage so that the output voltage is greater than the input voltage is a step-up transformer. In a step-up transformer the number of wire turns on the secondary coil is greater than the number of turns on the primary coil. For example, the secondary coil of the step-up transformer in **Figure 21A** has twice as many turns as the primary coil has. So the ratio of the output voltage to the input voltage is two, and the output voltage is twice as large as the input voltage. For this transformer an input voltage of 60 V in the primary coil would be increased to 120 V in the secondary coil.

Step-Down Transformer A transformer that decreases the voltage so that the output voltage is less than the input voltage is a step-down transformer. In a step-down transformer the number of wire turns on the secondary coil is less than the number of turns on the primary coil. In **Figure 21B** the secondary coil has half as many turns as the primary coil has, so the ratio of the output voltage to the input voltage is one-half. The input voltage of 240 V in the primary coil is reduced to a voltage of 120 V in the secondary coil.

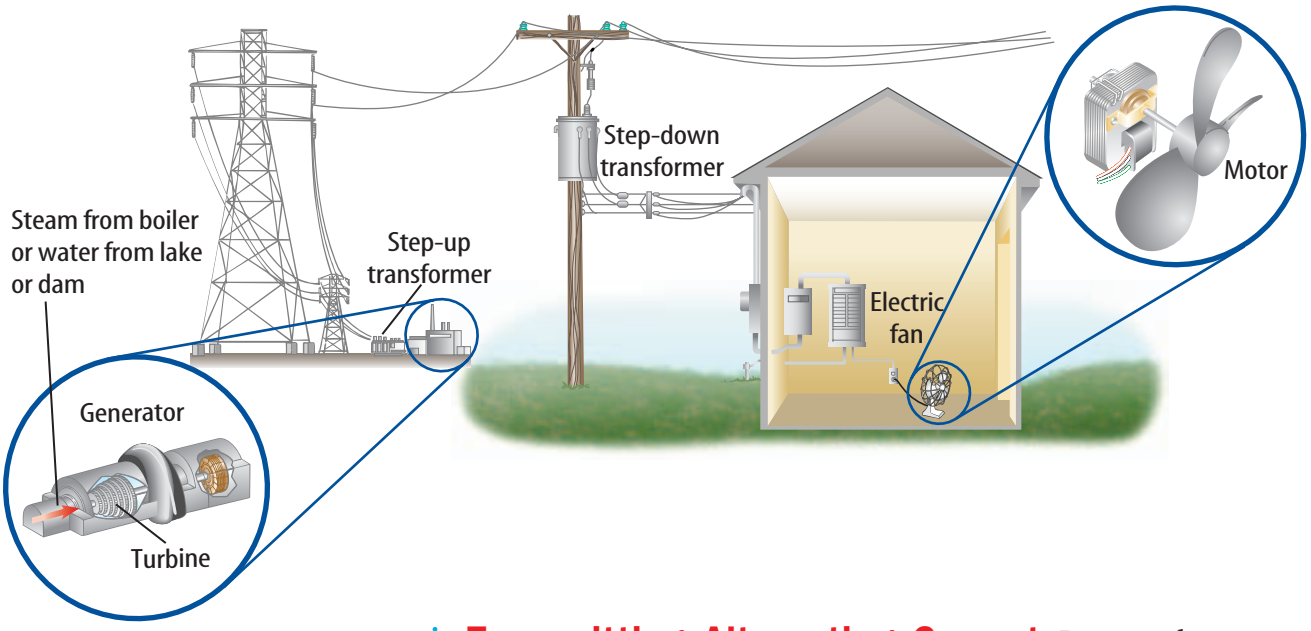


Figure 22 Many steps are involved in the creation, transportation, and use of the electric current in your home.
Identify *the steps that involve electromagnetic induction.*

Transmitting Alternating Current Power plants commonly produce alternating current because the voltage can be increased or decreased with transformers. Although step-up transformers and step-down transformers change the voltage at which electrical energy is transmitted, they do not change the amount of electrical energy transmitted. **Figure 22** shows how step-up and step-down transformers are used in transmitting electrical energy from power plants to your home.

section 3 review

Summary

From Mechanical to Electrical Energy

- An electric current is produced by moving a wire loop through a magnetic field or a magnet through a wire loop.
- A generator can produce an electric current by rotating a wire coil in a magnetic field.

Direct and Alternating Currents

- A direct current flows in one direction. An alternating current changes direction in a regular pattern.

Transformers

- A transformer changes the voltage of an alternating current. The voltage can be increased or decreased.
- The changing magnetic field in the primary coil of a transformer induces an alternating current in the secondary coil.

Self Check

1. **Describe** the energy conversions that occur when water falls on a paddle wheel connected to a generator that is connected to electric lights.
2. **Compare and contrast** a generator with an electric motor.
3. **Explain** why the output voltage from a transformer is zero if a direct current flows through the primary coil.
4. **Explain** why electric current produced by power plants is transmitted as alternating current.
5. **Think Critically** A magnet is pushed into the center of a wire loop, and then stops. What is the current in the wire loop after the magnet stops moving? Explain.

Applying Math

6. **Use a Ratio** A transformer has 1,000 turns of wire in the primary coil and 50 turns in the secondary coil. If the input voltage is 2400 V, what is the output voltage?

ScienceOnline gpscience.com/self_check_quiz

LAB

Magnets, Coils, and Currents

Huge generators in power plants produce electricity by moving magnets past coils of wire. How does that produce an electric current?

Real-World Question

How can a magnet and a wire coil be used to produce an electric current?

Goals

- **Observe** how a magnet and a wire coil can produce an electric current in a wire.
- **Compare** the currents created by moving the magnet and the wire coil in different ways.

Materials

cardboard tube
bar magnet
insulated wire
scissors
galvanometer or ammeter

Safety Precautions

WARNING: *Do not touch bare wires when current is running through them.*

Procedure

1. Wrap the wire around the cardboard tube to make a coil of about 20 turns. Remove the tube from the coil.
2. Use the scissors to cut and remove 2 cm of insulation from each end of the wire.
3. Connect the ends of the wire to a galvanometer or ammeter. Record the reading on your meter.
4. Insert one end of the magnet into the coil and then pull it out. Record the current. Move the magnet at different speeds inside the coil and record the current.
5. Watch the meter and move the bar magnet in different ways around the outside of the coil. Record your observations.
6. Repeat steps 3 through 4, keeping the magnet stationary and moving the wire coil.

Conclude and Apply

1. How was the largest current generated?
2. Does the current generated always flow in the same direction? How do you know?
3. **Predict** what would happen if you used a coil made with fewer turns of wire.
4. **Infer** whether a current would have been generated if the cardboard tube were left in the coil. Why or why not? Try it.

Communicating Your Data

Compare the currents generated by different members of the class. What was the value of the largest current that was generated? How was this current generated?

Tim Courlas/Horizons Companies

LAB

Design Your Own

Controlling Electromagnets

Goals

- **Measure** relative strengths of electromagnets.
- **Determine** which factors affect the strength of an electromagnet.

Possible Materials

22-gauge insulated wire
16-penny iron nail
aluminum rod or nail
0-6 V DC power supply
three 1.5-V "D" cells
steel paper clips
magnetic compass
duct tape (to hold "D" cells together)

Safety Precautions

WARNING: *Do not leave the electromagnet connected for long periods of time because the battery will run down. Magnets will get hot with only a few turns of wire. Use caution in handling them when current is flowing through the coil. Do not apply voltages higher than 6 V to your electromagnets.*

Real-World Question

You use electromagnets every day when you use stereo speakers, power door locks, and many other devices. To make these devices work properly, the strength of the magnetic field surrounding an electromagnet must be controlled. How can the magnetic field produced by an electromagnet be made stronger or weaker? Think about the components that form an electromagnet. Make a hypothesis about how changing these components would affect the strength of the electromagnet's magnetic field.

Form a Hypothesis

As a group, write down the components of an electromagnet that might affect the strength of its magnetic field.

Make a Plan

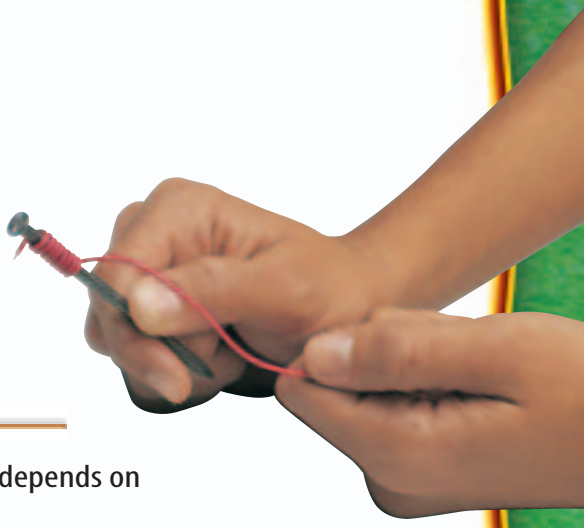
1. Write your hypothesis for the best way to control the magnetic field strength of an electromagnet.
2. **Decide** how you will assemble and test the electromagnets. Which features will you change to determine the effect on the strength of the magnetic fields? How many changes will you need to try? How many electromagnets do you need to build?
3. **Decide** how you are going to test the strength of your electromagnets. Several ways are possible with the materials listed. Which way would be the most sensitive? Be prepared to change test methods if necessary.

KS Studios

4. Write your plan of investigation. Make sure your plan tests only one variable at a time.

Follow Your Plan

1. Before you begin to build and test the electromagnets, make sure your teacher approves of your plan.
2. Carry out your planned investigation.
3. Record your results.



Analyze Your Data

1. **Make a table** showing how the strength of your electromagnet depends on changes you made in its construction or operation.
2. **Examine** the trends shown by your data. Are there any data points which seem out of line? How can you account for them?

Testing Electromagnets

Trial	Electromagnet Construction Features	Strength of of Electromagnet
	Do not write in this book.	

Conclude and Apply

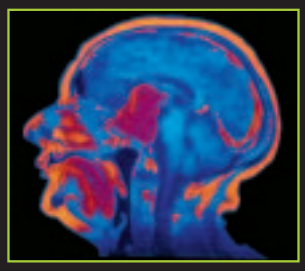
1. **Describe** how the electromagnet's magnetic-field strength depended on its construction or operation.
2. **Identify** the features of the electromagnet's construction that had the greatest effect on its magnetic-field strength. Which do you think would be easiest to control?
3. **Explain** how you could use your electromagnet to make a switch. Would it work with both AC and DC?
4. **Evaluate** whether or not your results support your hypothesis. Why or why not?

Communicating Your Data

Compare your group's result with those of other groups. Did any other group use a different method to test the strength of the magnet? Did you get the same results?

KS Studios

Body Art



The surgeon turns the computer screen so the patient can see it. Pointing to a colorful image of the patient's brain, she reassures the worried patient. "This MRI shows exactly where your tumor is. We can remove it with little danger to you."

MRI for the Soft Stuff

MRI stands for "magnetic resonance imaging." It's a way to take 3-D pictures of the inside of your body. Before the 1980s, doctors could x-ray solid tissue like bones, but had no way to see soft tissue like the brain. Well, they had one way—surgery, which sometimes caused injury and infection, risking a patient's health.

MRI uses a strong magnet and radio waves. Tissues in your body contain water molecules that are made of oxygen and hydrogen atoms.

The nucleus of a hydrogen atom is a proton, which behaves like a tiny magnet. A strong magnetic field inside the MRI tube makes these proton magnets line up in the direction of the field. Radio waves are then applied to the body. The protons absorb some of the radio-wave energy, and flip their direction.

When the radio waves are turned off, the protons realign themselves with the magnetic field and emit the energy they absorbed. Different tissues in the body absorb and emit different amounts of energy. The emitted energy is detected, and a computer uses this information to form images of the body.

Your brain is getting bigger!

MRI has turned into an important research tool. For example, researchers using MRI have found that the brain grows rapidly through adolescence. Before this research, people thought that the brain stopped growing in childhood. MRI has proved that adolescents are getting bigger brains all the time.

This patient is about to be placed in an MRI machine.

Interview As an oral history project, interview a retired physician or surgeon. Ask him or her to discuss with you how tools such as the MRI changed during his or her career. Make a list of the tools and how they have helped improve medicine.

ScienceOnline

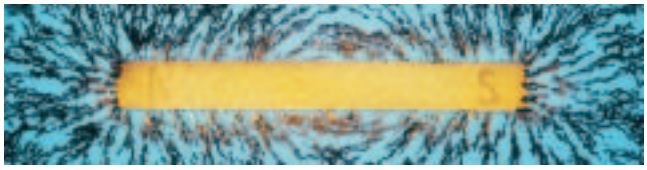
For more information, visit gpscience.com/time

(t)Brian Blauser/Stock Shop, (b)Laurence Dutton/Stone/Getty Images

Reviewing Main Ideas

Section 1 Magnetism

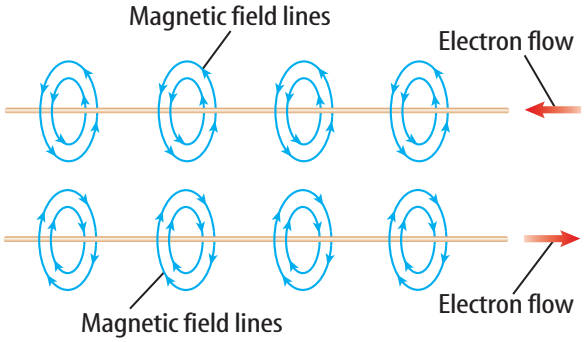
1. A magnetic field surrounds a magnet and exerts a magnetic force.
2. All magnets have two poles: a south pole and a north pole.



3. Opposite poles of magnets attract; like poles repel.
4. Groups of atoms with aligned magnetic poles are called magnetic domains.

Section 2 Electricity and Magnetism

1. An electric current flowing through a wire produces a magnetic field.
2. An electric current passing through a coil of wire can produce a magnetic field inside the coil. The coil becomes an electromagnet. One end of the coil is the north pole, and the other end is the south pole.



3. The magnetic field around an electromagnet depends on the current and the number of coils.
4. An electric motor contains a rotating electromagnet that converts electrical energy to mechanical energy.

Section 3 Producing Electric Current

1. By moving a magnet near a wire, you can create an electric current in the wire. This is called electromagnetic induction.

2. A generator produces electric current by rotating a coil of wire in a magnetic field. Generators at the base of this dam convert the kinetic energy in falling water into electric energy.
3. Direct current flows in one direction through a wire; alternating current reverses the direction of current flow in a regular pattern.
4. The number of turns of wire in the primary and secondary coils of a transformer determines whether it increases or decreases voltage.

FOLDABLES™ Use the Foldable that you made at the beginning of this chapter to help you review magnets and magnetism.

(l)Richard Megna/Fundamental Photographs, (r)Jeff Greenberg/Peter Arnold

chapter 8 Review

Using Vocabulary

alternating current (AC) p. 242
direct current (DC) p. 242
electric motor p. 235
electromagnet p. 232
electromagnetic induction p. 238
galvanometer p. 234
generator p. 238
magnetic domains p. 229
magnetic field p. 225
magnetic pole p. 225
magnetism p. 224
solenoid p. 232
transformer p. 243
turbine p. 240

Complete each statement with the correct vocabulary word or words.

1. A(n) _____ can be used to change the voltage of an alternating current.
2. A(n) _____ is the region where the magnetic field of a magnet is strongest.
3. _____ does not change direction.
4. The properties and interactions of magnets are called _____.
5. A(n) _____ can rotate in a magnetic field when a current passes through it.
6. The magnetic poles of atoms are aligned in a(n) _____.
7. A device that uses an electromagnet to measure electric current is a(n) _____.

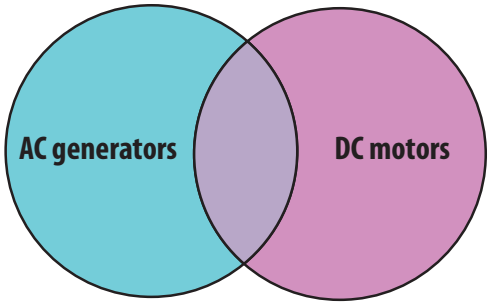
Checking Concepts

Choose the word or phrase that best answers the question.

8. Where is the magnetic force exerted by a magnet strongest?
   A) both poles **C)** north poles
   B) south poles **D)** center
9. Which change occurs in an electric motor?
   A) electrical energy to mechanical energy
   B) thermal energy to wind energy
   C) mechanical energy to electrical energy
   D) wind energy to electrical energy
10. What happens to the magnetic force as the distance between two magnetic poles decreases?
    A) remains constant **C)** increases
    B) decreases **D)** decreases then increases
11. Which of the following best describes what type of magnetic poles the domains at the north pole of a bar magnet have?
    A) north magnetic poles only
    B) south magnetic poles only
    C) no magnetic poles
    D) north and south magnetic poles
12. Which of the following would not change the strength of an electromagnet?
    A) increasing the amount of current
    B) changing the current's direction
    C) inserting an iron core inside the coil
    D) increasing the number of loops
13. Which of the following would NOT be part of a generator?
    A) turbine **C)** electromagnet
    B) battery **D)** permanent magnet
14. Which of the following describes the direction of the electric current in AC?
    A) is constant **C)** changes regularly
    B) is direct **D)** changes irregularly

Interpreting Graphics

15. Copy and complete this Venn diagram. Include the functions, part names, and power sources for these devices.



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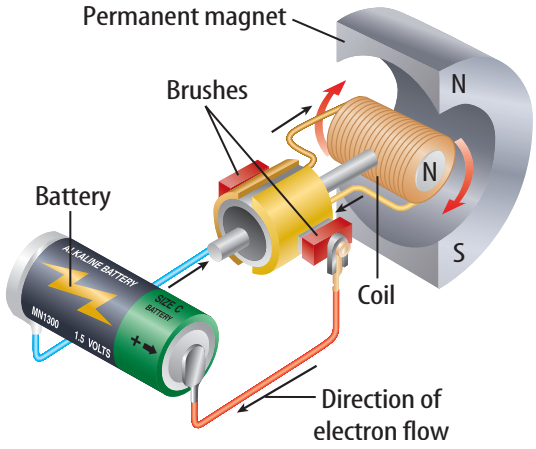
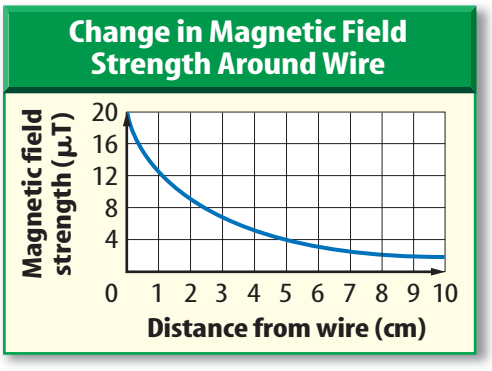
Use the diagram below to answer questions 16 and 17.



16. Using the diagram, describe the function of the permanent magnet, the electromagnet, and the current source in a simple electric motor.

17. Describe the sequence of steps that occur in an electric motor that forces the coil to spin. Include the role of the commutator in your description.

Use the graph below to answer questions 18–20.



18. How much larger is the magnetic field strength 1 cm from the wire compared to 5 cm from the wire?

19. Does the magnetic field strength decrease more rapidly with distance closer to the wire or farther from the wire? Explain.

20. Using the graph, estimate the magnetic field strength 11 cm from the wire.

Thinking Critically

21. Infer how you could you use a horseshoe magnet to find the direction north.

22. Explain In Europe, generators produce alternating current at a frequency of 50 Hz. Would the electric appliances you use in North America work if you plugged them into an outlet in Europe? Why or why not?

23. Predict Two generators are identical except for the loops of wire that rotate through their magnetic fields. One has twice as many turns of wire as the other one does. Which generator would produce the most electric current? Why?

24. Explain why a bar magnet will attract an iron nail to either its north pole or its south pole, but attract another magnet to only one of its poles.

25. Compare and contrast electromagnetic induction and the formation of electromagnets.

Applying Math

26. Calculate A step-down transformer reduces a 2,400-V current to 120 V. If the primary coil has 500 turns of wire, how many turns of wire are there on the secondary coil?

27. Use a Ratio To produce a spark, a spark plug requires a current at about 12,000 V. A car's engine uses a type of transformer called an induction coil to change the input voltage from 12 V to 12,000 V. In the induction coil, what is the ratio of the number of wire turns on the primary coil to the number of turns on the secondary coil?

Part 1 Multiple Choice

Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

A group of students built a transformer by wrapping 50 turns of wire on one side of an iron ring to form the primary coil. They then wrapped 10 turns of wire around the opposite side to form the secondary coil. Their results are shown in the table below.

Use the table below to answer questions 1–3.

Voltage and Current in a Transformer

Trial	Input Voltage (V)	Primary Coil Current (A)	Output Voltage (V)	Secondary Coil Current (A)
1	5	0.1	1	0.5
2	10	0.2	2	1.0
3	20	0.2	4	1.0
4	50	0.5	10	2.5

1. What is the ratio of the input voltage to the output voltage for this transformer?

A. 1:2.5 **C.** 5:1
B. 4:1 **D.** 1:5

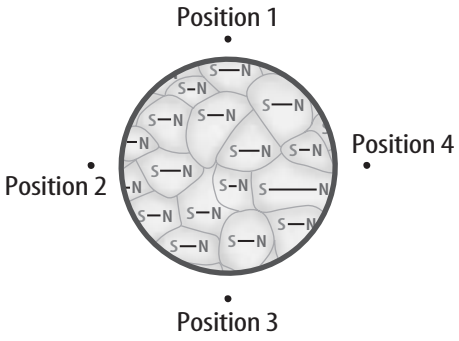
2. What is the ratio of the primary coil current to the secondary coil current?

A. 1:2.5 **C.** 5:1
B. 4:1 **D.** 1:5

3. The ratio of the secondary coil current to the primary coil current equals which of the following?

A. the ratio of the secondary coil wire turns to the primary coil wire turns
B. the ratio of the output voltage to the input voltage
C. the ratio of the primary coil wire turns to the secondary wire turns
D. It always equals one.

Use the figure below to answer questions 4 and 5.



4. A steel paper clip is sitting on a desk. The figure above shows the magnetic domains in a section of the paper clip after the north pole of a magnet has been moved close to it. According to the diagram, the magnet's north pole is most likely at which of the following positions?

A. position 1 **C.** position 3
B. position 2 **D.** position 4

5. Which of the following diagrams shows the orientation of the needle of a compass that is placed at position 2?

A.

C.

B.

D.

Test-Taking Tip

Read All the Information If a question includes a text passage and a graphic, carefully read the information in the text passage and the graphic before answering the question.

Question 3 Review the information in the text above the table and the information in the table.

Part 2 Short Response/Grid In

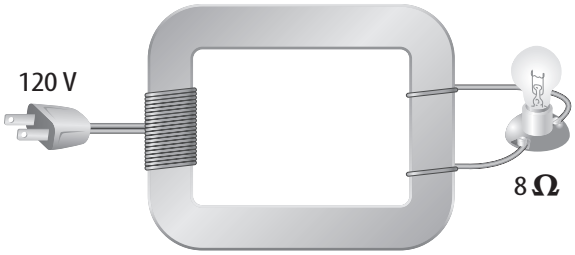
Record your answers on the answer sheet provided by your teacher or on a sheet of paper.

6. A hydroelectric power plant uses water to spin a turbine attached to a generator. The generator produces 30,000 kW of electric power. If the turbine and generator are 85 percent efficient, how much power does the falling water supply to the turbine?

7. A bicycle has a small electric generator that is used to light a headlight. The generator is made to spin by rubbing against a wheel. Will the bicycle coast farther on a level surface if the light is turned on or turned off?

8. An electric motor rotates 60 times per second if the current source is 60 Hz alternating current. How many times will an electric motor rotate in one hour if the current source is changed to 50 Hz alternating current?

Use the figure below to answer questions 9 and 10.



9. A step-down transformer is plugged into a 120-V electric outlet and a light is plugged into the transformer. The transformer has 20 turns on the primary coil and 2 turns on the secondary coil. What is the voltage at the output coil?

10. If the light has a resistance of 8 Ω, what is the current in the light?

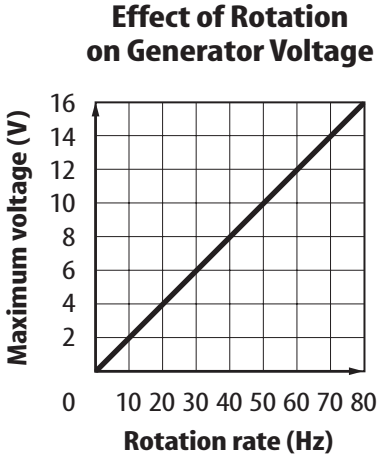
Part 3 Open Ended

Record your answers on a sheet of paper.

11. A bar magnet is placed inside a wire coil. The bar magnet and coil are then carried across a room. Explain whether an electric current will flow in the coil as the magnet and coil are moving.

12. A student connects a battery to a step-up transformer in order to boost the voltage. Explain why a small electric motor does not spin when it is connected to the secondary coil of the transformer.

Use the figure below to answer question 13.



13. The graphic above shows how the voltage produced by a generator depends on the rotation rate of the coil. Explain whether this generator could produce household AC current which is 120 V at 60 Hz.

14. Describe how a permanent magnet is similar to and different from a piece of unmagnetized iron.

15. Compare and contrast the behavior and properties of positive and negative electric charges with north and south magnetic poles.