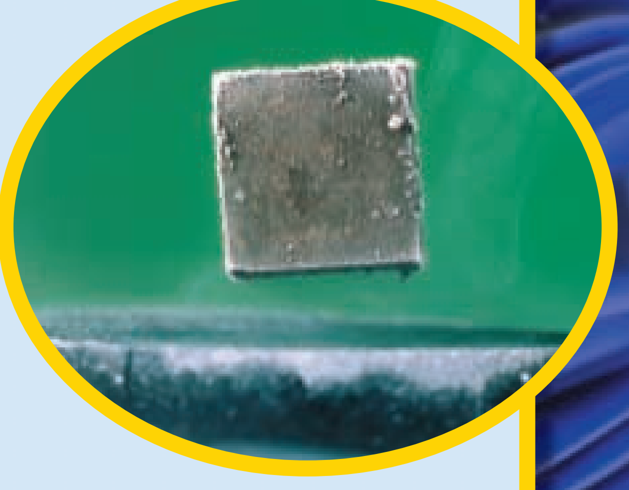
CHAPTER 8

Magnetism and Its Uses

A giant solar flare erupts from the Sun, spewing high energy particles and other forms of radiation toward Earth. Fortunately, Earth's magnetic field deflects most of these particles so they don't damage you and other living creatures. In this chapter, you will learn how magnetism and electricity are related, and how some common devices use magnetism.

What do you think?

Look at the picture below with a classmate. Discuss what this might be or what is happening. Here's a hint: *The force holding up this cube also spins electric motors.* Write your answer or your best guess in your Science Journal.



EXPLORE ACTIVITY

Magnets can do more than hold papers on a refrigerator door. Did you know that they are used in TVs, computers, stereo speakers, and electric motors? Magnets play an important role in making the electricity you use at home. Magnetism also is used to make images of the organs and tissues inside the human body. What properties of magnets make them so useful? This activity will help you find out.

Observe the strength of a magnet

1. Hold a bar magnet horizontally and suspend a paper clip from one end of it. Continue adding paper clips to make a chain until the magnet will hold no more. Record the number of paper clips the magnet held.
2. Repeat step 1 three times. First, suspend the paper clips about 2 cm from the end of the magnet, then near the center of the magnet, and finally at the other end of the magnet.

Observe

In your Science Journal, compare the number of clips suspended from each point on the magnet. Infer which part of the magnet has the strongest attraction for the paper clips.

Before You Read

FOLDABLES Reading & Study Skills

Making a Question Study Fold **Asking yourself questions helps you to stay focused and better understand magnets when you are reading the chapter.**

1. Place a sheet of paper in front of you so the long side is at the top. Fold the paper in half from top to bottom.
2. Make the front and back look like a magnet by writing *N* for north on the left side and *S* for south on the right side as shown.
3. Before you read the chapter, write two questions about magnets inside.
4. As you read the chapter, write answers to your questions.

SECTION 1

Magnetism

As You Read

What You'll Learn

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

Vocabulary

magnetism
magnetic pole
magnetic domain

Why It's Important

Without magnets, you could not use computers, CD players, or even the lights in your home.

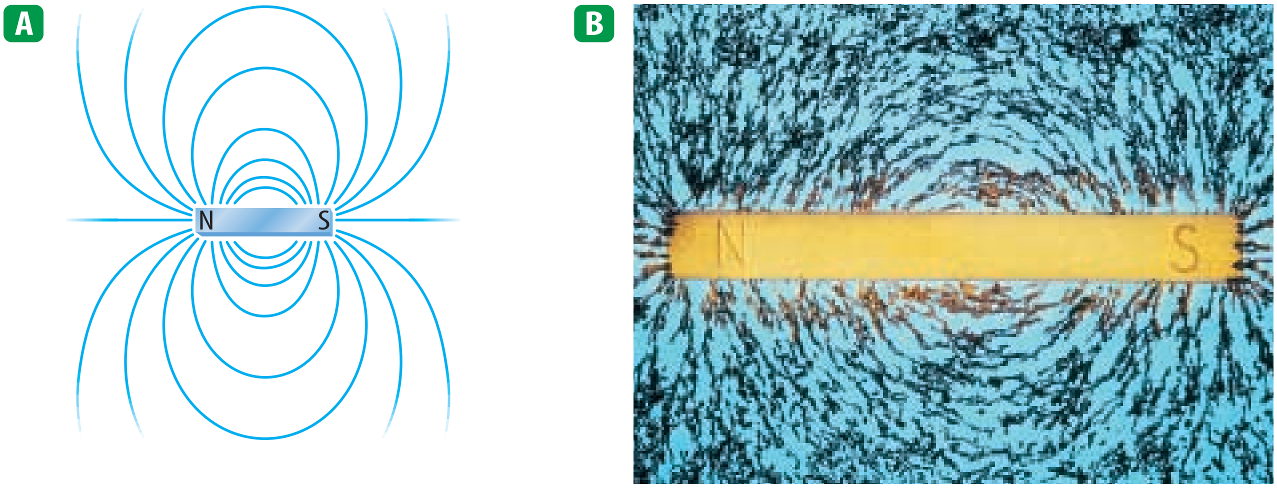
Magnets

You may be familiar with magnets because they help display artwork on refrigerators, but magnets also fascinated early Greek and Chinese cultures long before refrigerators were invented. The Greeks discovered a mineral, shown in **Figure 1,** that was a natural magnet. They found the mineral in a region called Magnesia, so the Greeks called the mineral magnetic. More than 2,000 years later, magnets play an important role in business, medicine, transportation, and science. Today, the word **magnetism** refers to the properties and interactions of magnets.

Reading Check *Why did the Greeks use the term magnetic?*

Magnetic Force You probably have played with magnets to attract a metal object. You might have noticed that two magnets also 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 probably noticed that the interaction between two magnets can be felt even before the magnets touch. This interaction is called magnetic force. Its strength increases as magnets move closer together and decreases as the distance between the magnets increases.

Figure 1
The Greeks found a mineral, now called magnetite, with natural magnetic properties. *What explanations do you think they gave for the behavior of magnetite?*



Magnetic Field A magnet is surrounded by a magnetic field that exerts the magnetic force. When objects made of iron or another magnet is placed in this magnetic field, it reacts to the magnetic force. The magnetic field is strongest close to the magnet and weakest 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.

Figure 2
A magnet is surrounded by a magnetic field. A A magnet's magnetic field is represented by magnetic field lines. B Iron filings sprinkled around a magnet line up along the magnetic field lines.

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. If a bar magnet is suspended so it turns freely, the north pole of the magnet will point north. Even magnets with more complicated shapes have north and south poles, as **Figure 3** shows. 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.

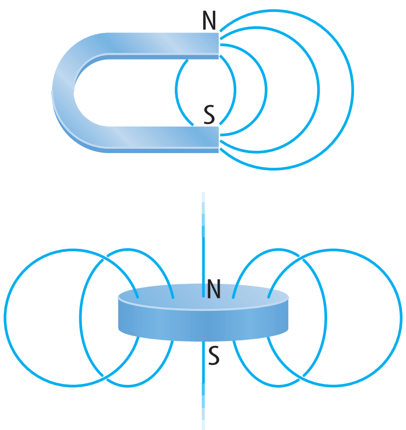


Figure 3
The magnetic field lines around horseshoe and disk magnets are closest together at the magnets' poles. *Where would a horseshoe magnet have the weakest attraction for metal objects?*

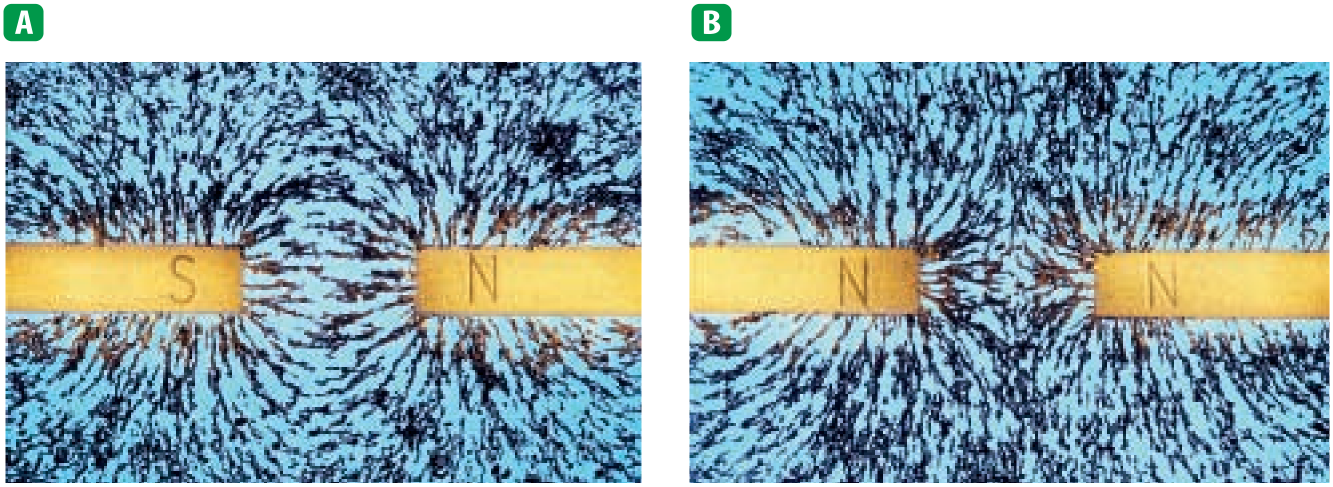


Figure 4
Magnets can attract or repel each other. A Unlike poles attract. When unlike poles are brought together, their magnetic field lines seem to connect with each other. B Like poles repel. When like poles are brought together, their magnetic field lines seem to push away from each other. *How would two horseshoe magnets interact?*

How Magnets Interact Two magnets can either attract or repel each other. If you try to bring the two north poles or the two south poles of two magnets close to each other, you can feel a force preventing the magnets from touching. However, north poles always attract south poles. When two magnets are brought close to each other, their magnetic fields can 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?*

A Compass Needle A magnet that is free to rotate can turn when it is placed in a magnetic field. A compass contains a needle, a small bar magnet, that can freely rotate. If you place a small compass near a bar magnet, the compass needle will turn so that the north pole of the needle points toward the south pole of the bar magnet. The compass needle also lines up along the magnetic field lines that pass near it. **Figure 5** shows how compass needles placed at several positions around a bar magnet are aligned along the magnetic field lines.

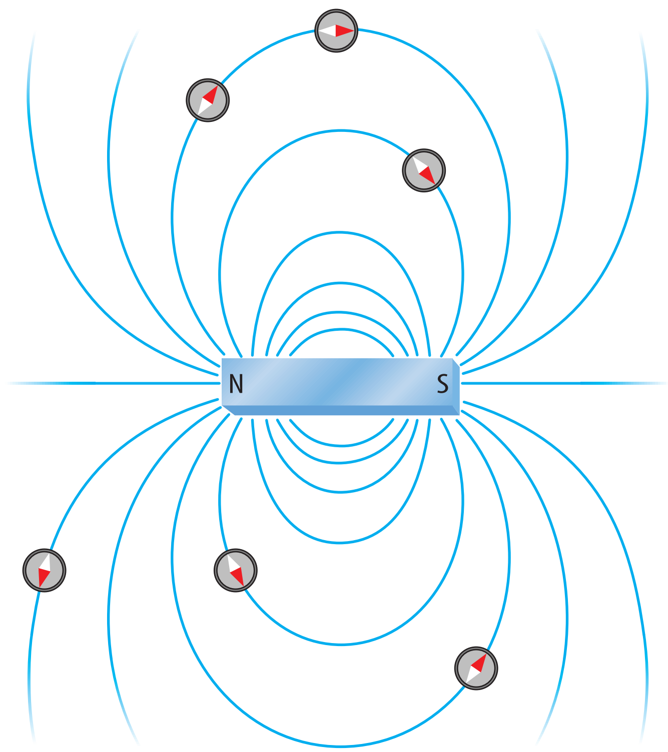


Figure 5
Compass needles rotate to line up with the magnetic field lines of a bar magnet.

Earth Science INTEGRATION

Earth's Magnetic Field Imagine you are in a boat in the middle of an ocean. Without landmarks nearby, how could you tell in which direction you were traveling? A compass would help determine your direction because the north pole of the compass needle always 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.

The location of Earth's south magnetic pole currently is in northern Canada about 1,500 km from the geographic north pole. So if you were north of the south magnetic pole, your compass needle would point south, away from the geographic north pole.

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

Mini LAB

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?

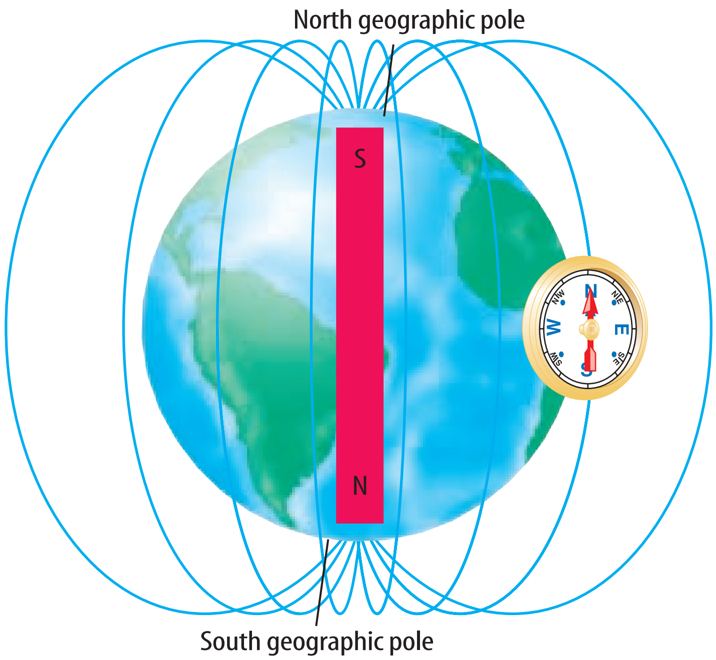


Figure 6
A compass needle aligns with the magnetic field lines of Earth's magnetic field. *Which way would a compass needle point if you held it while you stood directly over the south magnetic pole?*

Life Science INTEGRATION

Some animals 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

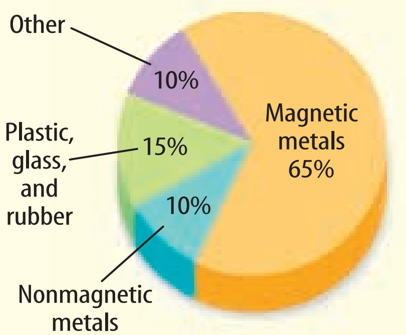
You might have noticed that a magnet will not attract all metal objects. For example, a magnet will not attract pieces of aluminum foil. Only a few metals such as iron, cobalt, or nickel are attracted to magnets or can be made into permanent magnets. What makes these elements magnetic? Remember that 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.

Problem-Solving Activity

How can magnetic parts of a junk car be salvaged?

Every year, over 10 million cars are scrapped. Magnets are often used to help retrieve valuable materials from these cars for recycling. 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? Explain your answer.
2. Plastics are replacing steel in many new cars. How might this affect the future of car recycling?

Magnetic Domains—A Model for Magnetism In iron, cobalt, nickel, and other magnetic materials, the magnetic field created by each atom exerts a force on the other nearby atoms. Because of these forces, groups of atoms align their magnetic poles so that all like poles point in the same direction. The groups of atoms with aligned magnetic poles are called **magnetic domains.** Each domain contains billions of atoms, yet the domains are too small to be seen with your naked 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 7A.** 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 in **Figure 7B.** The like poles of all the domains point in the same direction and no longer cancel each other out. The nail now acts as a magnet itself. 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 a temporary magnet. Paper clips and other objects containing iron also can become temporary magnets.

TRY AT HOME Mini LAB

Making Your Own Compass

Procedure

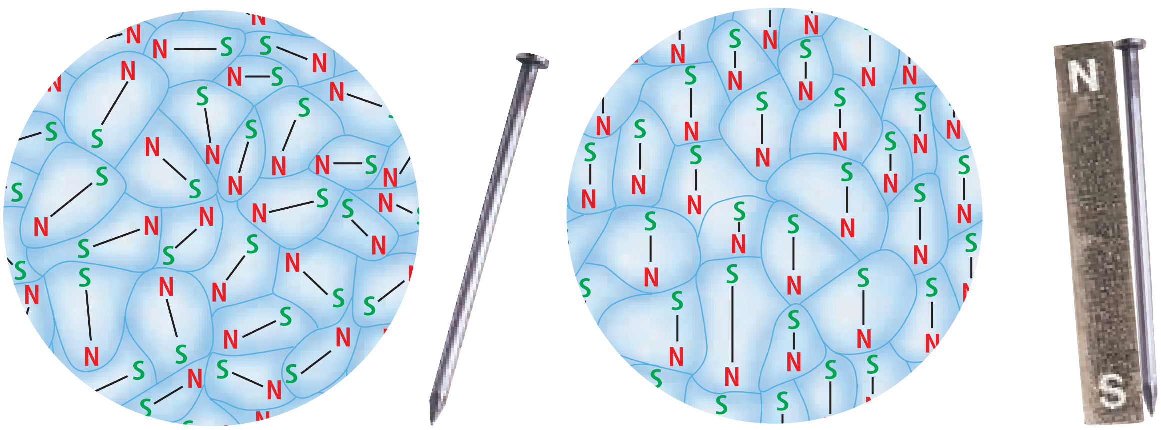
WARNING: *Use care when handling sharp objects.*

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

Figure 7
Magnetic materials contain magnetic domains.



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

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

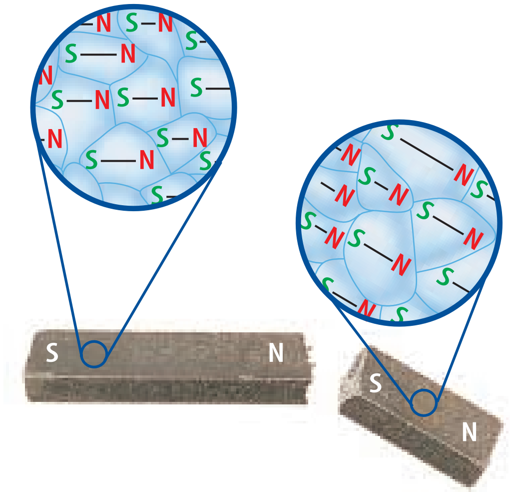


Figure 8
Each piece of a broken magnet still has a north and a south pole.

Permanent Magnets A permanent magnet can be made by placing a piece of magnetic material, such as iron, cobalt, or nickel, in a strong magnetic field. The strong magnetic field causes a large number of the magnetic domains in the material to line up. The magnetic fields of these aligned domains add together and create a magnetic field inside the material that may be several thousand times larger than the magnetic field outside the material. This then prevents the constant motion of the atoms from bumping all the domains out of alignment. The material is then a permanent magnet, and it can retain its magnetic properties for a long time.

But even permanent magnets can lose their magnetic behavior if they are heated or dropped. Heating causes atoms to move faster, so they can jostle magnetic domains out of alignment. If the material is heated enough, its atoms may be moving fast enough to jostle all the domains out of alignment. Then the material 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 a north pole and a south pole. As a result, a magnetic pole cannot be isolated.

Section 1 Assessment

1. Describe what happens when you bring two like magnetic poles together. Draw a picture to illustrate your answer.
2. If a compass is placed in a magnetic field, how does the compass needle move?
3. Why aren't all materials magnetic?
4. What would happen to the properties of a bar magnet if it were broken in half? In thirds? Explain your answer.
5. **Think Critically** Use the magnetic domain model to explain why a magnet sticks to a refrigerator door.

Skill Builder Activities

6. **Forming Hypotheses** Your younger brother or sister played with a bar magnet. Afterward, you noticed that it was barely magnetic. Write a hypothesis to explain what might have happened to your magnet. **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, make a list of all the uses you can think of for magnets. Write a paragraph describing what these magnets seem to have in common. **For more help, refer to the Science Skill Handbook.**

SECTION

2 Electricity and Magnetism

Electric Current and Magnetism

Even in science, it can help to be lucky. In 1820, Hans Christian Oersted, a Danish physics teacher, found that electricity and magnetism are related. While demonstrating the operation of electric circuits to his class, he happened to have a compass near a piece of wire. When current flowed through the wire, he noticed that the compass needle was turned, or deflected. When the current was reversed, he saw that the compass needle was deflected in the opposite direction. The compass needle returned to its normal position when he stopped the current in the wire. 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 It is now known that moving charges, like those in an electric current, produce magnetic fields. Oersted's hypothesis that passing electric current through a wire creates a magnetic field was correct. The magnetic field around a current-carrying wire forms a circular pattern about the wire, as shown in **Figure 9.** The direction of the field depends on the direction of the current. The strength of the magnetic field depends on the amount of current flowing in the wire. When no current flows in a wire, the magnetic field disappears. This discovery of the connection between electricity and magnetism has led to many useful devices.

As You Read

What You'll Learn

- **Understand** the relationship between electric current and magnetism.
- **Explain** how electromagnets are constructed.
- **Describe** how electromagnets are used.
- **Describe** how an electric motor operates.

Vocabulary

electromagnet
galvanometer
electric motor

Why It's Important

Many of the devices you use every day use the relationship between electricity and magnetism to operate.

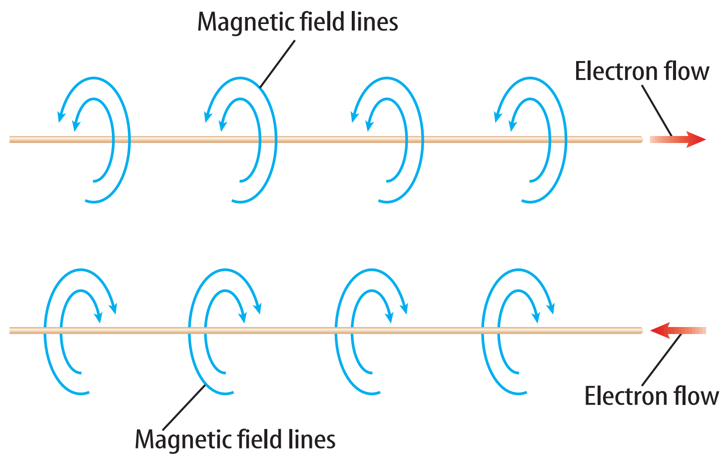


Figure 9
When electric current flows through a wire, a magnetic field forms around the wire. The direction of the magnetic field depends on the direction of the current in the wire.

Electromagnets

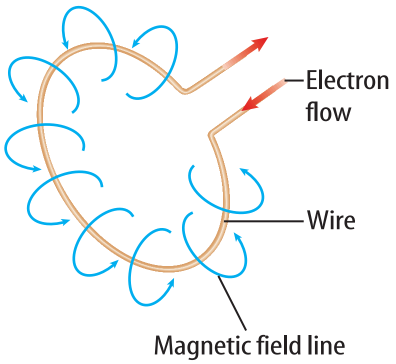
One of the most important devices that uses the connection between electricity and magnetism is the electromagnet (ih lek troh MAG nut). An **electromagnet** is a temporary magnet made by placing a piece of iron inside a current-carrying coil of wire. When a current flows through a circular loop of wire, magnetic-field lines form all around the wire as shown in **Figure 10A.** If more loops of wire are added to make a coil, the magnetic-field lines formed around each loop will overlap and add together, as shown in **Figure 10B.** As a result, the magnetic field inside the coil is made stronger. If an iron core is inserted into the coil as in **Figure 10C,** the magnetic field inside the coil causes the iron core to become magnetized. When a magnetized iron core and a coil are combined this way, the magnetic field comes mostly from the iron core.

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

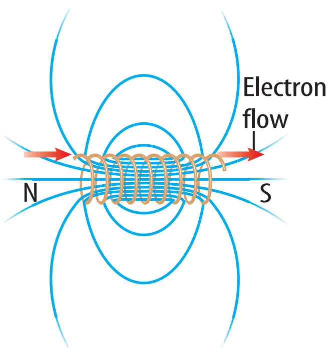
An electromagnet behaves like any other magnet when current flows through the wire coil. One end of the electromagnet is a north pole and the other end is a south pole. If placed in a magnetic field, an electromagnet will align itself along the magnetic field lines, just as a compass needle will. An 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 wire coil.

When current flows through the electromagnet and it moves toward or away from another magnet, it converts electric energy into mechanical energy to do work. Electromagnets do work in various devices such as stereo speakers and electric motors. They also can lift large metal objects.

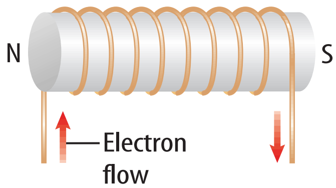
Figure 10
An electromagnet is made from a current-carrying wire.



A Magnetic field lines circle around a loop of current-carrying wire.



B When many loops of current-carrying wire are formed into a coil, the magnetic field is increased inside the coil. The coil has a north pole and a south pole. *What would happen if you switched the direction of the current in the coil?*



C An iron core inserted into the coil becomes a magnet.

Music to Your Ears—Stereo Speakers How does musical information stored on a CD become sound you can hear? The sound is produced by a stereo speaker that contains an electromagnet. The electromagnet changes electrical energy to mechanical energy that vibrates parts of the speaker to produce sound.

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

When you listen to a CD, the CD player produces an electric current that changes according to the musical information on the CD. This varying electric current passes through a coiled wire inside the speaker that is part of an electromagnet, as in **Figure 11.** A magnetic field is generated in the electromagnet. This magnetic field changes depending on the varying characteristics of the electric current. The electromagnet is then attracted to or repelled by a permanent, fixed magnet, making the electromagnet move back and forth. This movement vibrates the speaker's flexible surface and produces sound. The vibration of the speaker cone reproduces the original musical information stored on the CD.

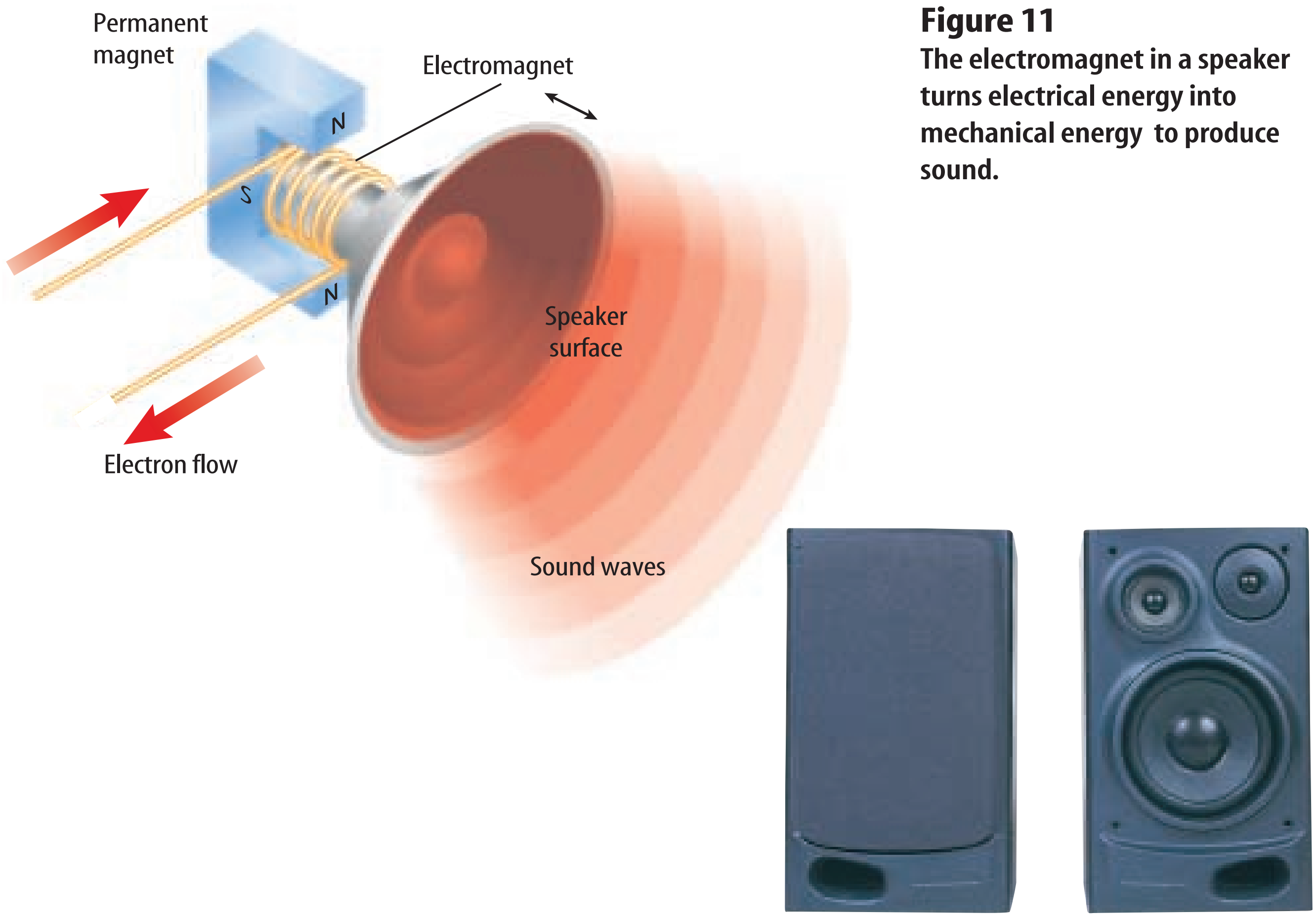


Figure 11
The electromagnet in a speaker turns electrical energy into mechanical energy to produce sound.

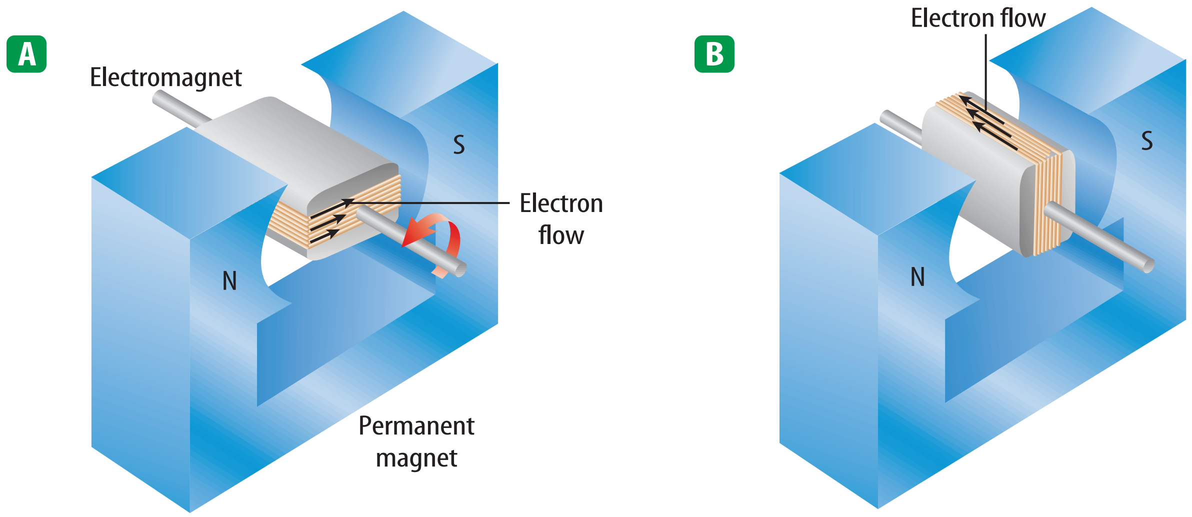
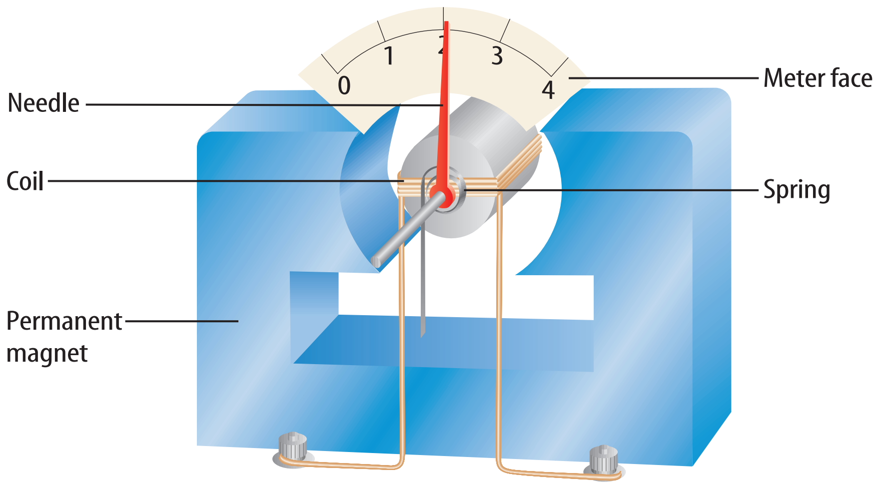


Figure 12
A When current flows through the coil, an electromagnet is formed that is attracted to and repelled by the poles of the permanent magnet. B The magnetic forces on the coil cause it to rotate, aligning it with the field of the permanent magnet.

Galvanometers You've probably noticed the gauges in the dashboard of a car. One gauge shows the amount of gasoline left, 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** (gal vuh NAHM ut urs), which are devices that use an electromagnet to measure electric current. For example, a temperature sensor in the engine sends an electric current to the temperature gauge. This current changes as the engine temperature changes. The needle of the temperature gauge is connected to an electromagnet. This electromagnet is suspended so it can rotate between the poles of a permanent, fixed magnet. When current flows through the coil, the electromagnet rotates so that its north and south poles are aligned along the magnetic-field lines of the permanent magnet, as shown in **Figure 12.**

Reading Check *What is measured by a galvanometer?*

Figure 13
A galvanometer includes a permanent magnet, an electromagnet that rotates against a spring, and a scale that gives a measurement of the current.
Would it matter which way you hooked up the galvanometer to the two terminals of the circuit you were testing? Why?



Using Galvanometers If the coil is connected to a small spring, then the coil can act as a galvanometer. If the current through the coil is small, only a weak magnetic field is produced in the electromagnet. Then the magnetic force between the electromagnet and the permanent magnet is weak. The coil can rotate only a small amount against the resistance of the spring, and the needle moves by only a small amount. When a large current flows in the coil, the magnetic force between the electromagnet and the permanent magnet is stronger. The coil rotates further, and the needle moves further along the scale. To be used as a gauge, a galvanometer must be calibrated by sending a known current through the coil and seeing how much the needle is deflected. **Figure 13** shows an example of a galvanometer.

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.

Like a galvanometer, an electric motor contains an electromagnet that is free to rotate between the poles of a permanent, fixed magnet. The coil in the electromagnet is connected to a source of electric current, such as a battery, as shown in **Figure 14.** When a current flows through the electromagnet, a magnetic field is produced in the coil.

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about how motors do work in electric devices. In your Science Journal, summarize the similarities among the motors you learn about.

CLICK HERE

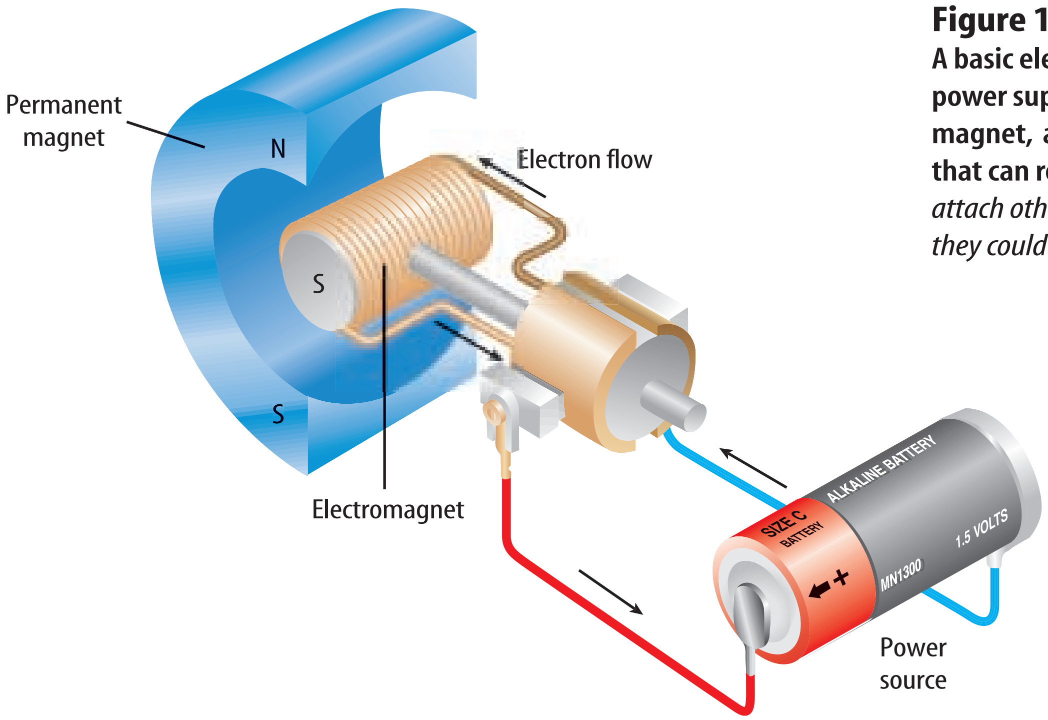
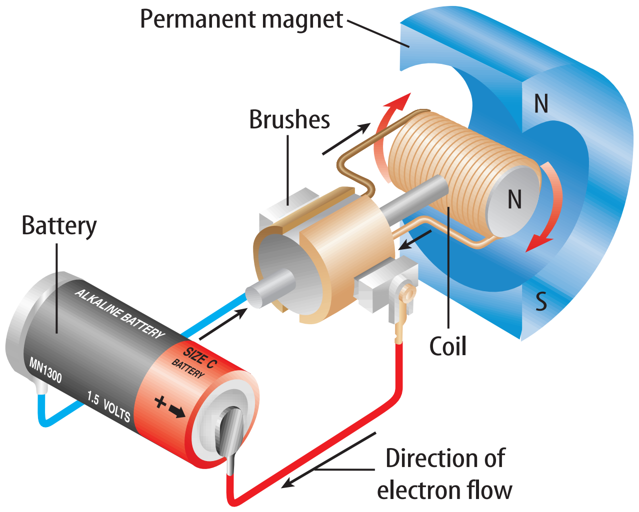
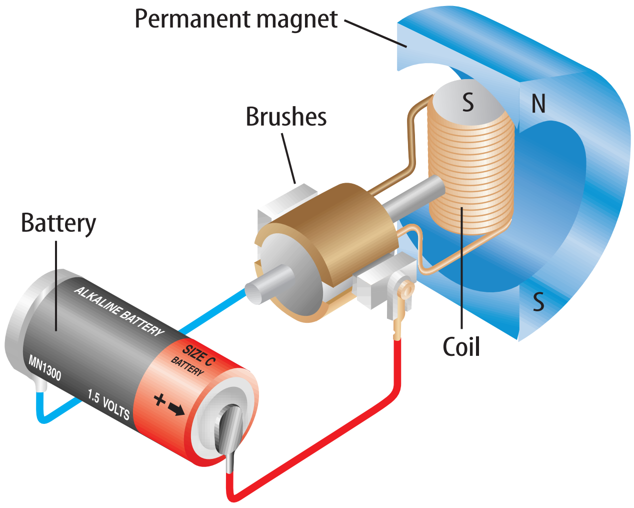


Figure 14
A basic electric motor has a power supply, a permanent magnet, and an electromagnet that can rotate. *How could you attach other components so that they could be moved by the motor?*



A A battery causes an electric current to flow through the coil of the electromagnet.



B Unlike poles of the two magnets attract each other, and the like poles repel. This causes the coil to rotate until the opposite poles are next to each other.

Figure 15
The shaft of an electric motor is made to rotate by the forces between magnets.

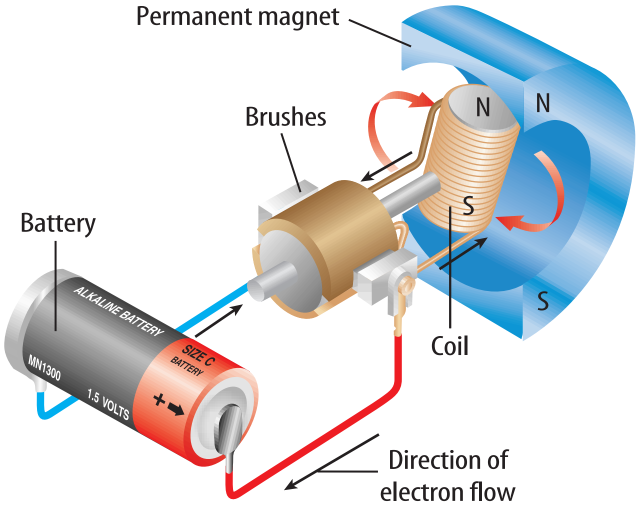
Switching Poles **Figures 15A** and **15B** show how the magnetic force between the electromagnet and the permanent magnet causes the coil to turn. Just as in a galvanometer, the coil in an electric motor turns so that its north and south poles are aligned along the magnetic-field lines of the permanent magnet.

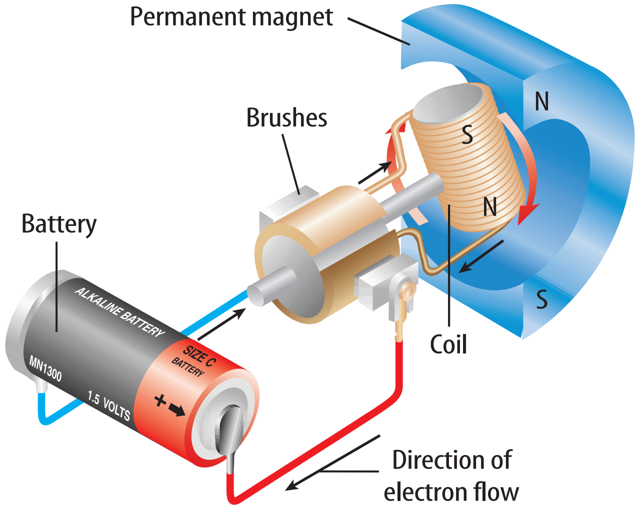
However, once the coil is aligned, there is no longer a force that will keep the coil rotating. Now suppose that the magnetic field in the coil is flipped so the north and south poles switch ends. The direction of the coil's magnetic field can be flipped by reversing the direction of the electric current in the coil. Then the like poles of the coil and magnet will be next to each other.

After flipping the field, the coil will be repelled and will rotate further, as shown in **Figures 15C** and **15D**. The coil will then rotate until it is once again aligned along the field lines of the permanent magnet. Then the current is reversed again. In this way, the coil is kept rotating.

In some motors a switch called a commutator reverses the current in the coil. Other motors don't need a commutator because they use household alternating current, which reverses direction 120 times a second.

Controlling Electric Motors Electric motors can be more useful if their rotation speed can be controlled. One way to do this is to vary the amount of current flowing through the coil. Because the coil is an electromagnet, its magnetic field becomes stronger if more current flows through the coil. This causes the magnetic force between the coil and the permanent magnet to increase. As a result, the coil turns faster.





C **If the current in the coil is switched, the direction of the coil's magnetic field also switches. The north and south poles of the magnet trade places.**

D **The coil is repelled by and attracted once again to the poles of the permanent magnet. The coil rotates until it is again aligned with the permanent magnet's field.**

Using Electric Motors The first electric motor to be widely used was developed in 1873. This motor used direct current. The first motor to use alternating current was invented in 1888. Since that time many additional developments have made electric motors smaller, more powerful, and more efficient. Today electric motors are used everywhere. Almost every appliance with moving parts uses an electric motor. Can you find an electric motor in every room of your home?

Section 2 Assessment

1. Does a straight wire or a looped wire have a stronger magnetic field when both carry the same amount of current? Explain.
2. How is the magnetic field of an electromagnet controlled?
3. What are galvanometers used for?
4. How does an electric motor rotate once its electromagnet is aligned along the magnetic field of its permanent magnet?
5. **Think Critically** Could an electromagnet use a nickel core in the coil of wire instead of iron? Why or why not?

Skill Builder Activities

6. **Comparing and Contrasting** Compare and contrast galvanometers and electric motors. **For more help, refer to the Science Skill Handbook.**
7. **Using an Electronic Spreadsheet** Take an inventory of all the devices in your home or school that use an electric motor. Organize your inventory using a database or spreadsheet to indicate the following: *name of the device, the place you found it, the power source used, and which parts the motor causes to move.* **For more help, refer to the Technology Skill Handbook.**

SECTION

3 Producing Electric Current

As You Read

***What* You'll Learn**

- **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.

Vocabulary

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

***Why* It's Important**

Power plants use electromagnetic induction to generate electricity for you to use at home and school.

From Mechanical to Electrical Energy

After it was discovered that an electric current could produce a magnetic field, some people wondered whether the opposite could happen: could a magnetic field produce an electric current? Working independently in 1831, Michael Faraday in Britain and Joseph Henry in the United States 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 electrical current in the wire. Producing an electric current by moving a loop of wire through a magnetic field or moving a magnet through a wire loop is called **electromagnetic induction** (ihn DUK shun). The discovery of electromagnetic induction has led to many applications.

Generators How is the electricity that comes to your home and school produced? Most of the electricity you use each day is produced by generators using electromagnetic induction. A **generator** produces electric current by rotating a coil of wire in a magnetic field. Just as in a galvanometer or an electric motor, the wire coil is wrapped around an iron core and placed between the poles of a permanent magnet. The coil is rotated by an outside source of mechanical energy, as shown in **Figure 16.** As the coil turns within the magnetic field of the permanent magnet, an electric current flows through the coil.

Reading Check *How does a generator use electromagnetic induction?*

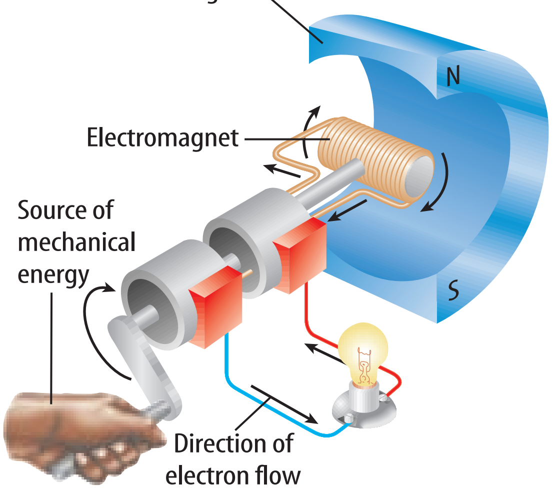


Figure 16
The electromagnet in a generator is rotated by some outside source of mechanical energy. In this setup, a student can rotate a crank to turn the electromagnet.

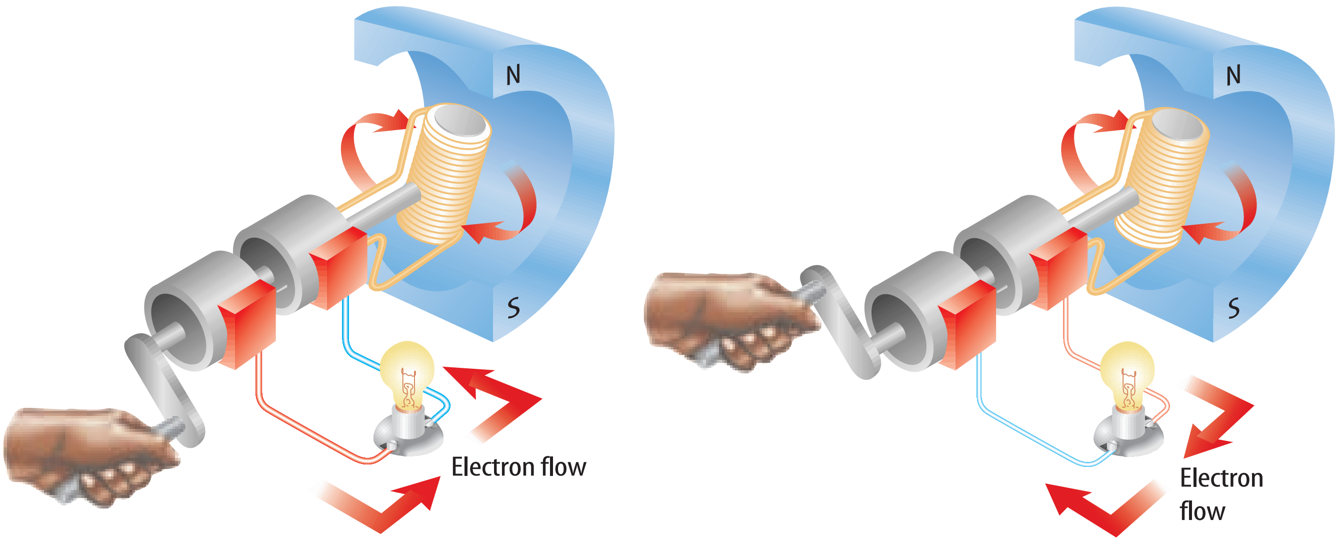


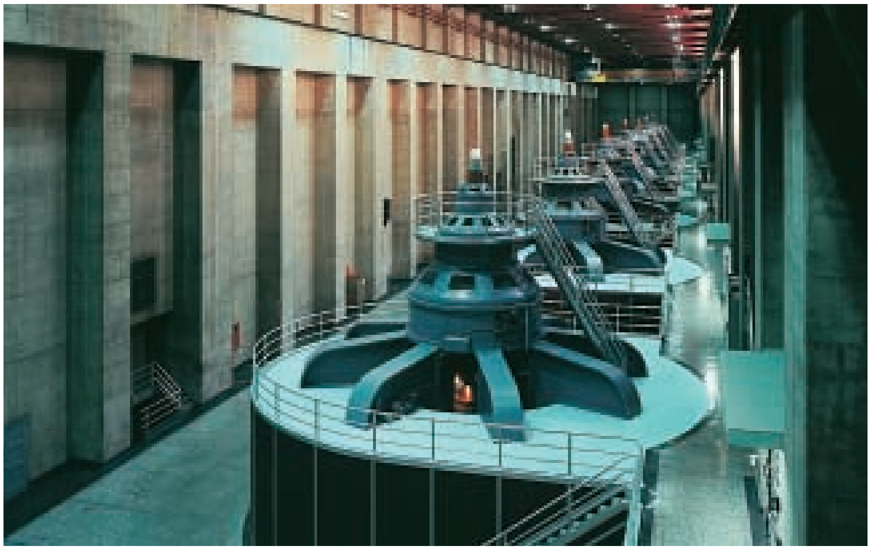
Figure 17
The direction that current flows in a wire coil depends on how the wire coil is aligned with the permanent magnet. *Would a generator still work if the electromagnet were held steady and the permanent magnet moved around it? Explain.*

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. Remember that the current flowing to a motor must switch directions periodically so the electromagnetic coil can keep turning. In a generator, as the electromagnetic coil continuously turns, the current that is produced periodically changes direction, as **Figure 17** shows. The direction of the current in the coil changes twice with each revolution. 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.

Using Electric Generators The type of generator shown in **Figure 17** 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 electricity 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 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 18
Electric power plants use huge generators such as the ones shown here to produce the electric current you use every day.



Environmental Science INTEGRATION

A dam can be placed on a river to create a lake. Water can then be released slowly from the dam to turn the turbines in a generator. Discuss with your classmates what effects a dam would have on the environment.

Generating Electricity for Your Home You probably do not have a generator in your home that supplies all the electricity you need to watch television or wash your clothes. Your electricity comes from a power plant with huge generators like the one in **Figure 18.** The electromagnets in these generators are made of 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.

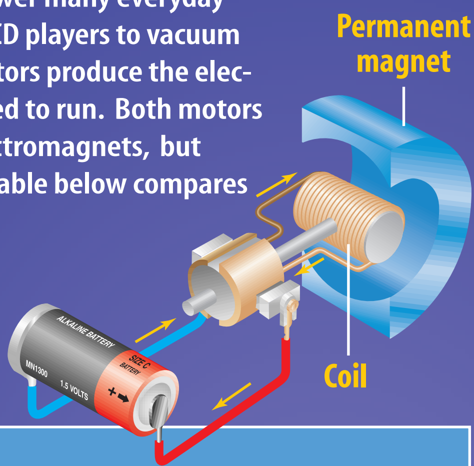
For example, some power plants first produce thermal energy by burning fossil fuels or using the heat produced by nuclear reactions. This thermal energy is used to heat water and produce steam. Thermal energy is then converted to mechanical energy as the steam pushes the turbine blades. The generator then changes the mechanical energy of the rotating turbine into an electric current that flows to your home. In some areas, fields of windmills like those in **Figure 19** 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. Look at **Figure 20** to compare and contrast the characteristics of generators and motors.

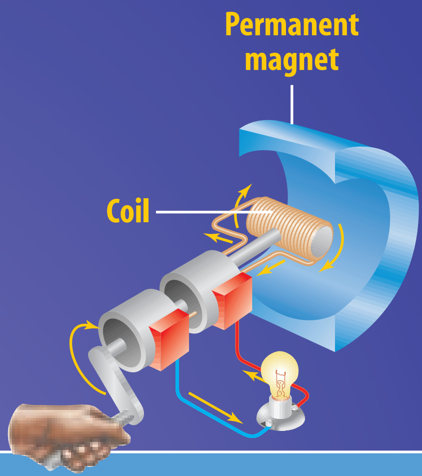
Figure 19
These windmills harness the energy in wind so it can be transformed into electrical energy by a generator. *What are some advantages and disadvantages of using windmills?*

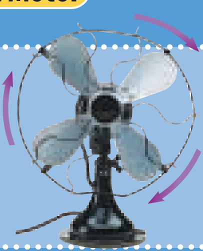
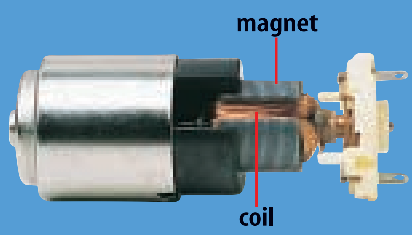
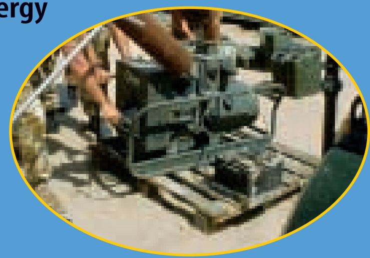
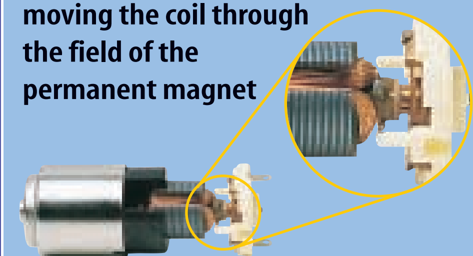
VISUALIZING MOTORS AND GENERATORS

Figure 20

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

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about how transformers are used in transmitting electric current. Communicate to your class what you learned.

CLICK HERE

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 occur, some electrical devices, like the one in **Figure 21,** use batteries as a backup source of electrical energy. Is the current produced by a battery the same as the current from a generator? Both devices cause electrons to move through a wire. However, the currents produced by these electric sources are different from each other in an important way.

A battery produces a direct current. **Direct current** (**DC**) flows in only 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 flow in a regular way. 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.

Transformers

The current that flows in an electric circuit carries electrical energy. This electrical energy is related to the voltage in the circuit. The alternating current traveling through power lines is at an extremely high voltage. Before alternating current from the power plant can enter your home safely, its voltage must be decreased. The voltage is decreased by passing the current through a transformer. A **transformer** is a device that increases or decreases the voltage of an alternating current.

A transformer is made of two coils of wire called the primary and secondary coils. These coils are wrapped around the same iron core. As an alternating current passes through the primary coil, the iron core becomes an electromagnet. The current changes direction many times each second, so the magnetic field of the iron core also changes direction. This changing magnetic field induces an alternating current in the secondary coil.

Figure 21
Some devices can use either direct or alternating current.
Why might it be a good idea to keep batteries in a clock or a VCR?

Stepping Up and Stepping Down If the secondary coil in a transformer has more turns of wire than the primary coil does, then the transformer increases, or steps up, voltage. For example, the secondary coil of the step-up transformer in **Figure 22A** has two times more turns than the primary coil has. This means than an input voltage in the primary coil of 60 V would increase by two times to 120 V in the secondary coil.

A transformer that reduces voltage is called a step-down transformer. **Figure 22B** shows how the output voltage of a transformer is decreased if the number of turns in the secondary coil is less than the number of turns in the primary coil. If the secondary coil of a transformer has half as many turns as the primary coil does, the output voltage will be half the input voltage.

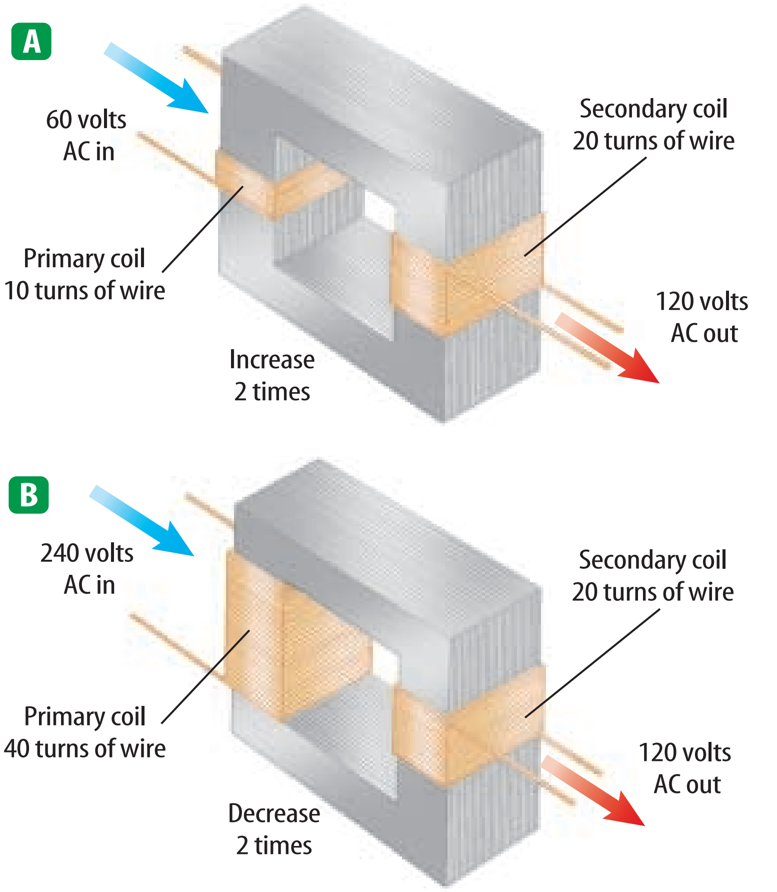


Figure 22
Transformers can increase or decrease voltage.
A **A step-up transformer increases voltage. The secondary coil has more turns than the primary coil does.**
B **A step-down transformer decreases voltage. The secondary coil has fewer turns than the primary coil does.**

Reading Check *What type of transformer has more turns of wire in the secondary coil than the primary coil?*

Transmitting Alternating Current When an electric current flows in a wire, some of the energy carried by the current is lost as heat. This heat loss is due to the resistance of the wire and increases as the wire is made longer. If the current produced by a power plant is transmitted over long distances, as much as ten percent of the electrical energy can be lost as heat. This energy loss can be reduced greatly by transmitting the power at high voltages. Power plants commonly produce alternating current because the voltage can be increased or decreased with transformers. In the United States, some power lines carry power at voltages as high as 750,000 V—high voltage indeed although most power lines you see carry lower voltages.

Such high voltage is dangerous and cannot be used in home appliances. Step-down transformers reduce the voltage of the alternating current to 120 V before it enters your home. You can then operate devices such as microwaves and hair dryers with 120-V household current.

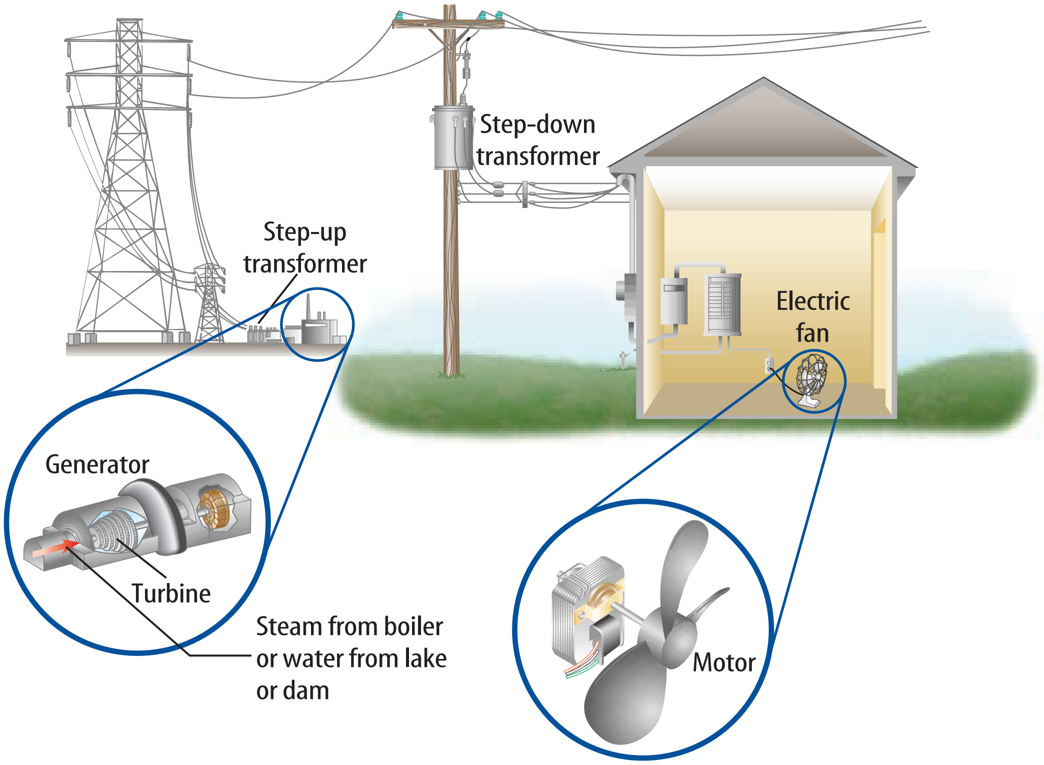


Figure 23
Many steps are involved in the creation, transportation, and use of the electric current in your home. *Which steps involve electromagnetic induction?*

Electric current in your home Think back over this section. You have learned how electromagnetic induction, generators, alternating current, and transformers all work together to make your electric fan operate. **Figure 23** illustrates the series of steps used in producing, transporting, and delivering alternating current to your home in a form that you can use safely.

Section 3 Assessment

1. How does a generator use electromagnetic induction to produce a current?
2. A transformer contains 20 turns in the primary coil and 80 turns in the secondary coil. Which is greater—the output voltage or the input voltage?
3. Contrast alternating and direct current.
4. What type of current do power plants produce? Why is it convenient?
5. **Think Critically** Why can't a transformer step up the voltage in a direct current?

Skill Builder Activities

6. **Concept Mapping** Prepare an events chain concept map to show how electricity is produced by a generator. **For more help, refer to the Science Skill Handbook.**
7. **Using Proportions** An alternating current in a wire has a voltage of 2,800 V. It needs to be reduced to 70 V. The wire makes 120 turns in the primary coil of a step-down transformer. How many turns of wire need to be in the secondary coil? **For more help, refer to the Math Skill Handbook.**

Activity

Electricity and Magnetism

Huge generators in power plants produce electricity by moving magnets past coils of wire. How can you use a magnet to make your own electric current?

What You'll Investigate

How can a magnet be used to create an electric current?

Materials

cardboard tube
scissors
bar magnet
thin, flexible, insulated wire
galvanometer or ammeter

Goals

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

Safety Precautions

Be careful with scissors. Do not touch bare wires when current is running through them.

Procedure

1. Wrap the wire around a cardboard tube to make a coil of about 20 turns. Leave about 15 cm for a lead at each end of the wire.
2. Use the scissors to cut through the insulation 2 cm from each end of the wire. Pull the insulation off with your fingers. Remove the tube from the coil.
3. Connect the ends of the wire to a galvanometer or ammeter. Record the reading on your meter.
4. While closely watching the meter, insert one end of the bar magnet into the coil.

5. Pull the magnet out of the coil and repeat. Record the reading on the meter. Move the magnet at different speeds and record your measurements.
6. Watch the meter and move the bar magnet in different directions around the outside of the coil. Record your observations.

Conclude and Apply

1. Which circumstances that you tested generated the greatest current?
2. Does the current generated by moving the magnet always flow in the same direction? How do you know?
3. **Predict** what would happen if you tried the experiment with 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. **For more help, refer to the Science Skill Handbook.**

Activity

Design Your Own Experiment

Putting Electromagnets to Work

You have learned that a current flowing through loops of wire around an iron core forms an electromagnet. You use electromagnets every day in electric motors, stereo speakers, power door locks and many other devices. To make electromagnets work in these devices, you must be able to control the strength of their magnetic fields. When might you want to make a magnet stronger? When would you want to make it weaker?

Recognize the Problem

How can you control the strength of an electromagnet?

Form a Hypothesis

Think about how an electromagnet is constructed. As a group, write down the components of an electromagnet which might affect the strength of its magnetic field. Which component could have the most effect on the strength of the electromagnet? Which could be easiest to control? Form a hypothesis about the best way to control an electromagnet's strength.

Goals

- **Make** electromagnets.
- **Measure** relative strengths of electromagnets.
- **Modify** electromagnets to change their strength.
- **Determine** which factors affect the strength of an electromagnet.
- **Determine** which factor has the most effect on its strength.
- **Describe** how you could control 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)

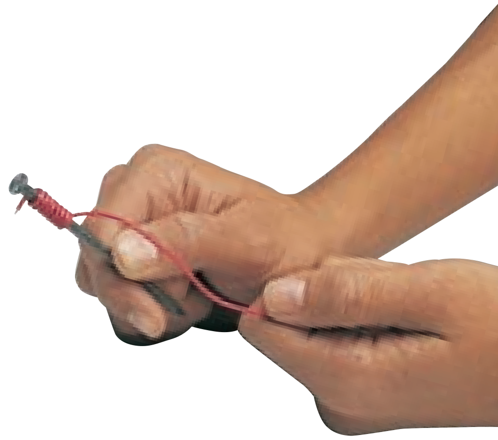
Safety Precautions

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

Test Your Hypothesis

Plan

1. Write your hypothesis for the best way to control the strength of an electromagnet.
2. As a group, decide how you will assemble and test the electromagnets. Which features will you change to determine 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.
4. Write your plan of investigation. Make sure your plan tests only one variable at a time.



Do

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

Analyze Your Data

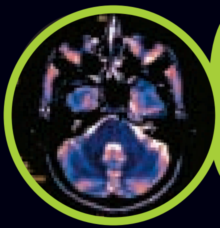
1. **Make a table** showing how the strength of your electromagnet depends on changes you made in its construction or operation.
2. **Examine** the trends shown by your data. Are there any data points which seem out of line? How can you account for them?

Draw Conclusions

1. How did the strength of the electromagnet depend on its construction or operation?
2. Which feature of the electromagnet's construction had the greatest effect on its strength? Which do you think would be easiest to control?
3. How might you use your electromagnet to make a doorbell? Would it work with both AC and DC?
4. Did your results support your hypothesis? Why or why not?

Communicating Your Data

Compare your group's results 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?

Bdy Art

The invention of a machine that uses magnetism means better lives for many

The year is 1975. A surgeon stands facing an exposed human brain. She has already removed part of the patient's skull and is looking for a growth on the brain. From the patient's symptoms, the surgeon can only infer where to find the tumor. But can she find it and remove it without causing more damage than the tumor was causing? "We're going in," the doctor says. She puts out her hand to the nurse. "Scalpel."

Flash forward to the present day.

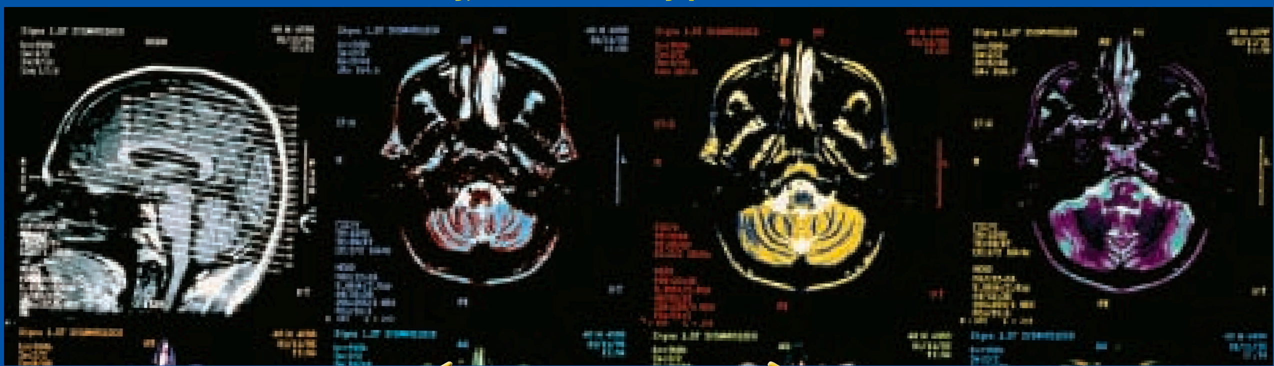
The surgeon turns the computer screen so the patient can see it. Pointing to a dark area on a colorful image of the patient's brain, she reassures the worried patient. "This MRI shows exactly where your tumor is. We can remove it with very little danger to you." "Thank goodness for the MRI," the patient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

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.

MRIs were originally used to identify substances in chemistry and physics labs.

These are MRI scans of brains from different people. The colors help doctors read the scans more easily, and detect any problems.



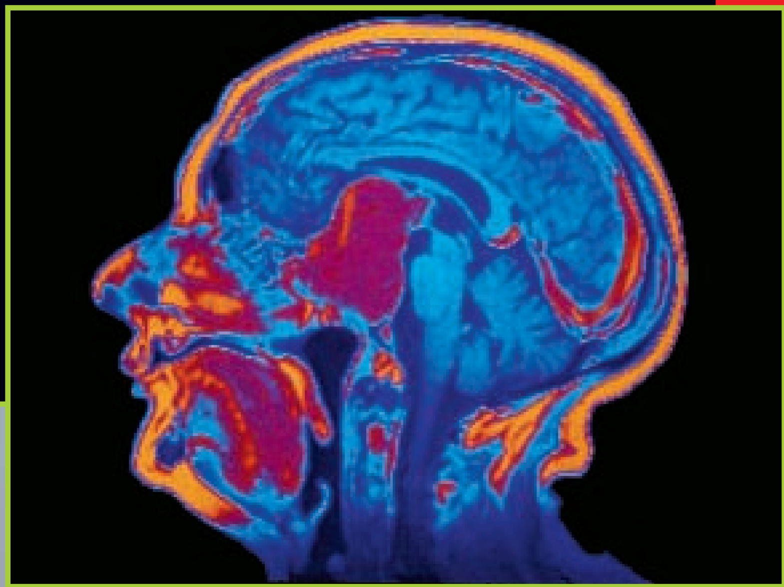
Then after research and modifications in the method, doctors began to use MRIs to make images of the tissues inside the human body.

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 been most useful in finding and treating tumors. But it has also turned into an important research tool. For example, Elizabeth Sowell's research team at the University of California, Los Angeles, used MRIs to study the brain growth of middle school students. She and other researchers have found that the brain grows rapidly during adolescence. Before this ground-breaking research, people thought that the brain stopped growing in childhood. MRI has proved that adolescents are getting bigger brains all the time.



An MRI scan of a brain shows a tumor on the pituitary gland. The gland is the large pink area in the middle of the photo.

A girl gets ready for an MRI scan. It doesn't hurt!

CONNECTIONS 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.

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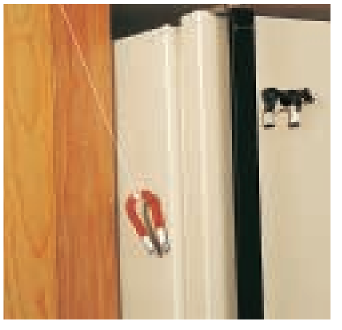
CONTENTS

Chapter 8 Study Guide

Reviewing Main Ideas

Section 1 Magnetism



1. A magnetic field surrounds a magnet and exerts a magnetic force. *Why is this magnet attracted to the refrigerator but not to the cupboard?*
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 produced by an electromagnet depends on the current and the number of coils. *How is an electromagnet used in this temperature gauge from a car?*

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. *How does the dam in the picture below help make electricity?*

3. Direct current flows in one direction through a wire. Alternating current reverses the direction of current flow in a regular way.
4. The number of turns of wire in the primary and secondary coils of a transformer determines whether it increases or decreases voltage.

After You Read

FOLDABLES Reading & Study Skills

To help you review what you've learned about magnets, use the Question Study Fold you made at the beginning of this chapter.

Chapter 8 Study Guide

Visualizing Main Ideas

Complete the following concept map on how an electric motor works.

Place electromagnet between poles of a permanent, fixed magnet.

↓

Connect coil of electromagnet to source of electric current.

↓

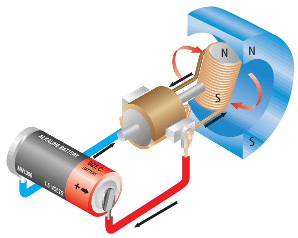
Coil turns in order to align its north and south poles to magnetic field lines of ________________

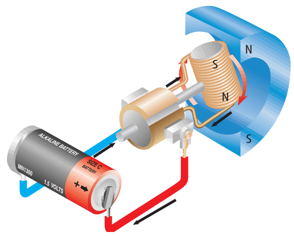
↓

Reverse________________

↓

Coil flips to ________________





Vocabulary Review

Vocabulary Words

a. alternating current (AC)
b. direct current (DC)
c. electric motor
d. electromagnet
e. electromagnetic induction
f. galvanometer
g. generator
h. magnetic domain
i. magnetic pole
j. magnetism
k. transformer
l. turbine

Using Vocabulary

Each of the following sentences is false. Make the sentence true by replacing the underlined word with a vocabulary word.

1. An <u>electric motor</u> can be used to change the voltage of an alternating current.
2. <u>Flat current</u> does not change direction.
3. A <u>magnetic domain</u> is the region where the magnetic force of a magnet is strongest.
4. Current flows in the coil of a <u>galvanometer</u> because of electromagnetic induction.
5. The properties and interactions of magnets are called <u>electricity</u>.
6. A <u>transformer</u> can rotate in a magnetic field when a current passes through it.
7. A generator uses <u>alternating current</u> to produce an electric current.

THE PRINCETON REVIEW Study Tip

Study the material you *don't* understand as well first! It's easy to review the material you know, but harder to force yourself to really go over the tough stuff.

Chapter 8 Assessment

Checking Concepts

Choose the word or phrase that best answers the question.

1. Where is the magnetic force exerted by a magnet strongest?
   A) both poles **C)** north pole
   B) south pole **D)** center

2. What happens to the magnetic force as the distance between two magnetic poles decreases?
   A) stays constant **C)** increases
   B) decreases sharply **D)** decreases slightly

3. What type of magnetic poles do the domains at the north pole of a magnet have?
   A) north magnetic poles only
   B) south magnetic poles only
   C) no magnetic poles
   D) north and south magnetic poles

4. 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

5. Which of the following would NOT be part of a generator?
   A) turbine **C)** electromagnet
   B) battery **D)** permanent magnet

6. Which conversion does an electric motor make?
   A) electrical energy to mechanical energy
   B) thermal energy to wind energy
   C) mechanical energy to electrical energy
   D) wind energy to electrical energy

7. Which of the following describes the direction of the electric current in AC?
   A) remains constant **C)** changes regularly
   B) is direct **D)** changes irregularly

8. Before current in power lines can enter your home, what must it pass through?
   A) step-up transformer
   B) step-down transformer
   C) commutator
   D) motor

9. A generator creates a 40-Hz alternating current. How many times does the current change direction every second?
   A) 40 times **C)** 80 times
   B) 60 times **D)** 20 times

10. When current flows through a wire, what is created around the wire?
    A) an electromagnet **C)** a magnetic field
    B) a galvanometer **D)** a direct current

Thinking Critically

11. How could you use a horseshoe magnet to find the direction north?

12. In Europe, generators produce alternating current at a frequency of 50 Hz. How is the frequency of this current changed by a step-down transformer? How is it changed by a step-up transformer?

13. Audiotapes, computer disks, and videotapes are recorded using magnets, and their information is coded magnetically. Why would it be harmful to a tape or computer disk, to expose it to a strong magnetic field?

14. A step-down transformer reduces a 1,200-V current to 120 V. If the primary coil has 100 turns, how many must its secondary coil have?

15. Suppose the magnetic fields of magnets were not strongest at the magnets' poles. Would motors, galvanometers, and generators still work? Why or why not?

Chapter 8 Assessment

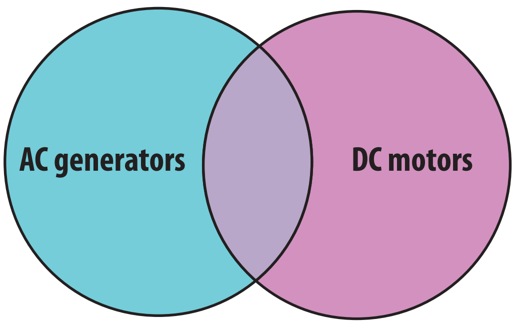
16. Comparing and Contrasting Compare and contrast electric and magnetic forces.

17. Forming Hypotheses A compass needle will point north due to the magnetic field of Earth. When a bar magnet is brought near the compass, the needle is attracted or repelled by the bar magnet. Propose a hypothesis about the relative strengths of a bar magnet and Earth's magnetic field.

18. Interpreting Scientific Illustrations Review **Figure 14** and describe the function of each labeled part of the motor.

19. Comparing and Contrasting Compare and contrast electromagnetic induction and the formation of electromagnets.

20. Concept Mapping Complete the following Venn diagram of AC generators and DC motors.



Performance Assessment

21. Invention Invent a device that uses an electric motor. Describe it to your class.

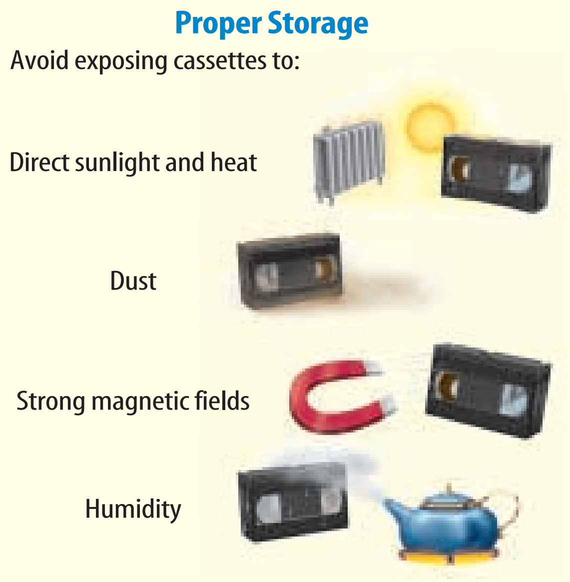
Technology

Go to the Glencoe Science Web site at **science.glencoe.com** or use the **Glencoe Science CD-ROM** for additional chapter assessment.

CLICK HERE

THE PRINCETON REVIEW Test Practice

The diagram below is taken from the instructions that come with a blank videocassette.



Study the diagram and answer the following questions.

1. Why do videocassettes come with a warning to avoid strong magnetic fields?

A) The videocassette will be turned into a powerful magnet.
B) The information on the videocassette will be damaged.
C) The videocassette's case will become electrically charged.
D) The videocassette will melt.

2. According to this diagram, all of the following could be harmful to a videocassette EXCEPT______.

F) air conditioning
G) moisture
H) direct sunlight and heat
J) dust

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