

Magnetism

chapter preview

sections

1 What is magnetism?

Lab *Make a Compass*

2 Electricity and Magnetism

Lab *How does an electric motor work?*



Virtual Lab *How does a transformer work?*

Magnetic Suspension


This experimental train can travel at speeds as high as 500 km/h—without even touching the track! It uses magnetic levitation, or maglev, to reach these high speeds. Magnetic forces lift the train above the track, and propel it forward at high speeds.

Science Journal List three ways that you have seen magnets used.

Start-Up Activities



Magnetic Forces

A maglev is moved along at high speeds by magnetic forces. How can a magnet get something to move? The following lab will demonstrate how a magnet is able to exert forces. 

1. Place two bar magnets on opposite ends of a sheet of paper.
2. Slowly slide one magnet toward the other until it moves. Measure the distance between the magnets.
3. Turn one magnet around 180° . Repeat Step 2. Then turn the other magnet and repeat Step 2 again.
4. Repeat Step 2 with one magnet perpendicular to the other, in a T shape.
5. **Think Critically** In your Science Journal, record your results. In each case, how close did the magnets have to be to affect each other? Did the magnets move together or apart? How did the forces exerted by the magnets change as the magnets were moved closer together? Explain.

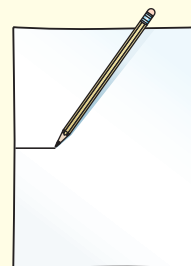


Preview this chapter's content and activities at ips.msscience.com

FOLDABLES™ Study Organizer

Magnetic Forces and Fields
Make the following Foldable to help you see how magnetic forces and magnetic fields are similar and different.

- STEP 1** **Draw** a mark at the midpoint of a vertical sheet of paper along the side edge.



- STEP 2** **Turn** the paper horizontally and **fold** the outside edges in to touch at the midpoint mark.



- STEP 3** **Label** the flaps *Magnetic Force* and *Magnetic Field*.

Compare and Contrast As you read the chapter, write information about each topic on the inside of the appropriate flap. After you read the chapter, compare and contrast the terms *magnetic force* and *magnetic field*. Write your observations under the flaps.

What is magnetism?

as you read

What You'll Learn

- **Describe** the behavior of magnets.
- **Relate** the behavior of magnets to magnetic fields.
- **Explain** why some materials are magnetic.

Why It's Important

Magnetism is one of the basic forces of nature.

Review Vocabulary

compass: a device which uses a magnetic needle that can turn freely to determine direction

New Vocabulary

- magnetic field
- magnetic domain
- magnetosphere

Early Uses

Do you use magnets to attach papers to a metal surface such as a refrigerator? Have you ever wondered why magnets and some metals attract? Thousands of years ago, people noticed that a mineral called magnetite attracted other pieces of magnetite and bits of iron. They discovered that when they rubbed small pieces of iron with magnetite, the iron began to act like magnetite. When these pieces were free to turn, one end pointed north. These might have been the first compasses. The compass was an important development for navigation and exploration, especially at sea. Before compasses, sailors had to depend on the Sun or the stars to know in which direction they were going.

Magnets

A piece of magnetite is a magnet. Magnets attract objects made of iron or steel, such as nails and paper clips. Magnets also can attract or repel other magnets. Every magnet has two ends, or poles. One end is called the north pole and the other is the south pole. As shown in **Figure 1**, a north magnetic pole always repels other north poles and always attracts south poles. Likewise, a south pole always repels other south poles and attracts north poles.

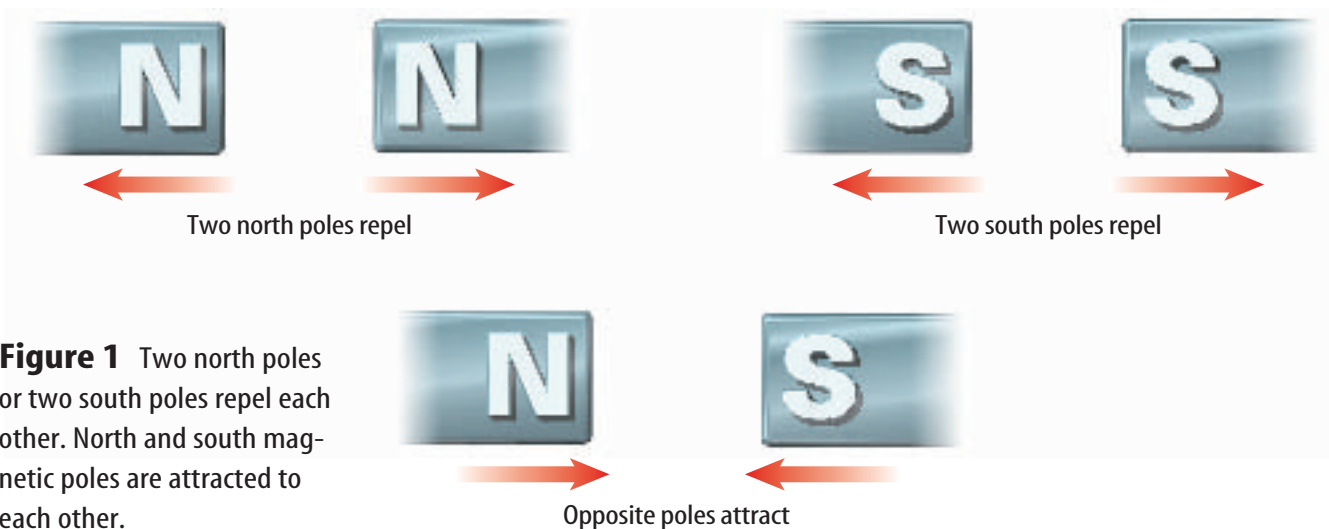


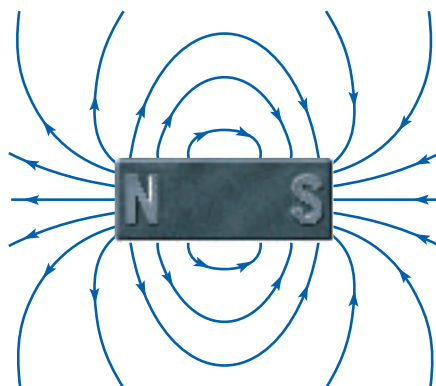
Figure 1 Two north poles or two south poles repel each other. North and south magnetic poles are attracted to each other.

The Magnetic Field You have to handle a pair of magnets for only a short time before you can feel that magnets attract or repel without touching each other. How can a magnet cause an object to move without touching it? Recall that a force is a push or a pull that can cause an object to move. Just like gravitational and electric forces, a magnetic force can be exerted even when objects are not touching. And like these forces, the magnetic force becomes weaker as the magnets get farther apart.

This magnetic force is exerted through a **magnetic field**. Magnetic fields surround all magnets. If you sprinkle iron filings near a magnet, the iron filings will outline the magnetic field around the magnet. Take a look at **Figure 2**. The iron filings form a pattern of curved lines that start on one pole and end on the other. These curved lines are called magnetic field lines. Magnetic field lines help show the direction of the magnetic field.



Iron filings show the magnetic field lines around a bar magnet.



Magnetic field lines start at the north pole of the magnet and end on the south pole.

Reading Check

What is the evidence that a magnetic field exists?

Magnetic field lines begin at a magnet's north pole and end on the south pole, as shown in **Figure 2**. The field lines are close together where the field is strong and get farther apart as the field gets weaker. As you can see in the figures, the magnetic field is strongest close to the magnetic poles and grows weaker farther from the poles.

Field lines that curve toward each other show attraction. Field lines that curve away from each other show repulsion. **Figure 3** illustrates the magnetic field lines between a north and a south pole and the field lines between two north poles.

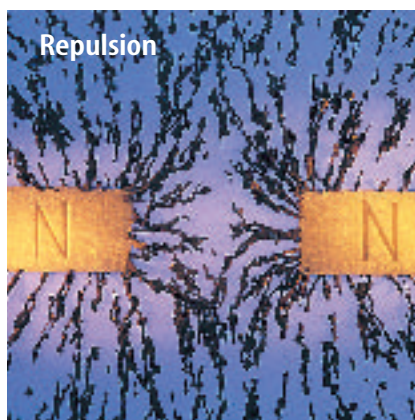
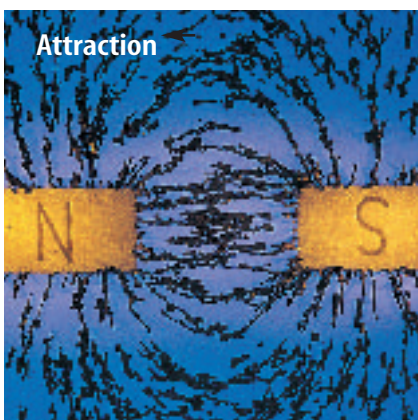


Figure 2 A magnetic field surrounds a magnet. Where the magnetic field lines are close together, the field is strong.

Determine for this magnet where the strongest field is.

Figure 3 Magnetic field lines show attraction and repulsion. **Explain** what the field between two south poles would look like.

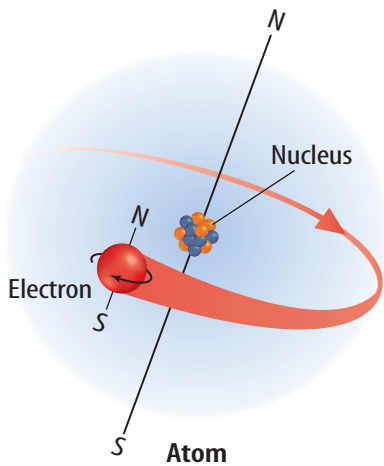


Figure 4 Movement of electrons produces magnetic fields.
Describe what two types of motion are shown in the illustration.

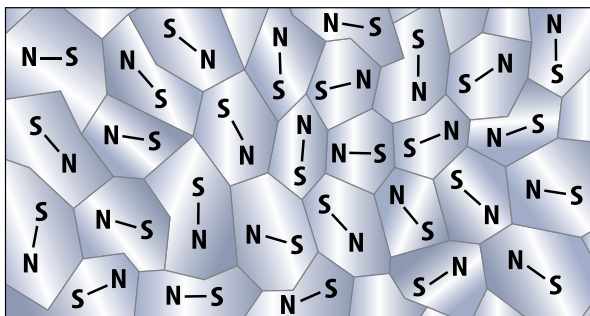
Making Magnetic Fields Only certain materials, such as iron, can be made into magnets that are surrounded by a magnetic field. How are magnetic fields made? A moving electric charge, such as a moving electron, creates a magnetic field.

Inside every magnet are moving charges. All atoms contain negatively charged particles called electrons. Not only do these electrons swarm around the nucleus of an atom, they also spin, as shown in **Figure 4**. Because of its movement, each electron produces a magnetic field. The atoms that make up magnets have their electrons arranged so that each atom is like a small magnet. In a material such as iron, a large number of atoms will have their magnetic fields pointing in the same direction. This group of atoms, with their fields pointing in the same direction, is called a **magnetic domain**.

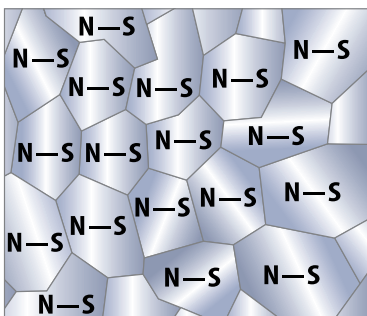
A material that can become magnetized, such as iron or steel, contains many magnetic domains. When the material is not magnetized, these domains are oriented in different directions, as shown in **Figure 5A**. The magnetic fields created by the domains cancel, so the material does not act like a magnet.

A magnet contains a large number of magnetic domains that are lined up and pointing in the same direction. Suppose a strong magnet is held close to a material such as iron or steel. The magnet causes the magnetic field in many magnetic domains to line up with the magnet's field, as shown in **Figure 5B**. As you can see in **Figure 5C** this process magnetizes paper clips.

Figure 5 Some materials can become temporary magnets.



A Microscopic sections of iron and steel act as tiny magnets. Normally, these domains are oriented randomly and their magnetic fields cancel each other.



B When a strong magnet is brought near the material, the domains line up, and their magnetic fields add together.



C The bar magnet magnetizes the paper clips. The top of each paper clip is now a north pole, and the bottom is a south pole.

Earth's Magnetic Field

Magnetism isn't limited to bar magnets. Earth has a magnetic field, as shown in **Figure 6**. The region of space affected by Earth's magnetic field is called the **magnetosphere** (mag NEE tuh sfhr). This deflects most of the charged particles from the Sun. The origin of Earth's magnetic field is thought to be deep within Earth in the outer core layer. One theory is that movement of molten iron in the

outer core is responsible for generating Earth's magnetic field. The shape of Earth's magnetic field is similar to that of a huge bar magnet tilted about 11° from Earth's geographic north and south poles.

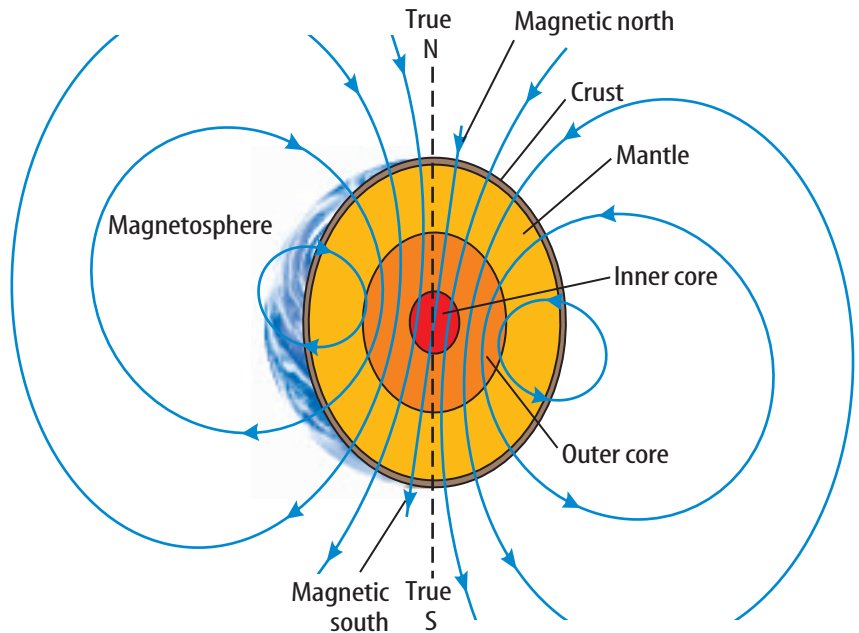


Figure 6 Earth has a magnetic field similar to the field of a bar magnet.

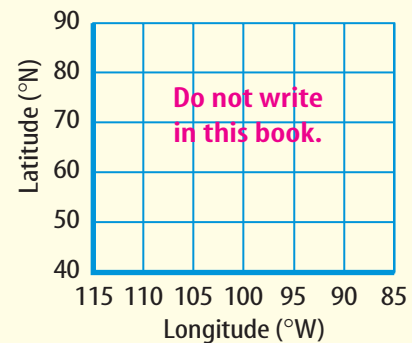
Applying Science

Finding the Magnetic Declination

The north pole of a compass points toward the magnetic pole, rather than true north. Imagine drawing a line between your location and the north pole, and a line between your location and the magnetic pole. The angle between these two lines is called the magnetic declination. Magnetic declination must be known if you need to know the direction to true north. However, the magnetic declination changes depending on your position.

Identifying the Problem

Suppose your location is at 50° N and 110° W. The location of the north pole is at 90° N and 110° W, and the location of the magnetic pole is at about 80° N and 105° W. What is the magnetic declination angle at your location?

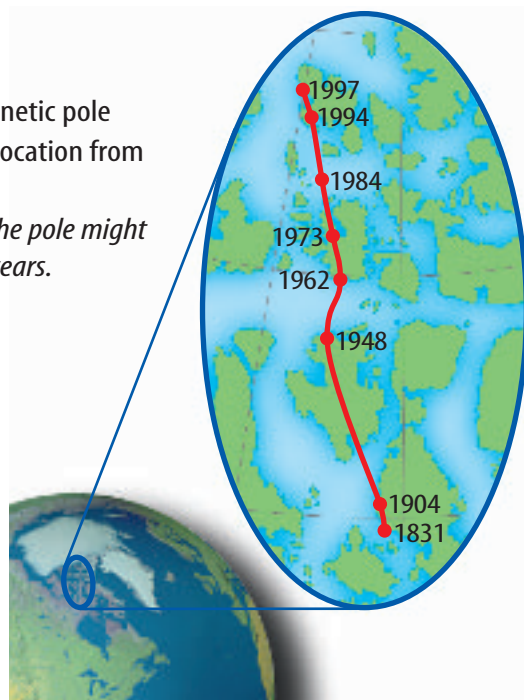


Solving the Problem

1. Draw and label a graph like the one shown above.
2. On the graph, plot your location, the location of the magnetic pole, and the location of the north pole.
3. Draw a line from your location to the north pole, and a line from your location to the magnetic pole.
4. Using a protractor, measure the angle between the two lines.

Figure 7 Earth's magnetic pole does not remain in one location from year to year.

Predict how you think the pole might move over the next few years.



Mini LAB

Observing Magnetic Fields

Procedure

1. Place **iron filings** in a **plastic petri dish**. Cover the dish and seal it with **clear tape**.
2. Collect **several magnets**. Place the magnets on the table and hold the dish over each one. Draw a diagram of what happens to the filings in each case.
3. Arrange two or more magnets under the dish. Observe the pattern of the filings.

Analysis

1. What happens to the filings close to the poles? Far from the poles?
2. Compare the fields of the individual magnets. How can you tell which magnet is strongest? Weakest?



Nature's Magnets Honeybees, rainbow trout, and homing pigeons have something in common with sailors and hikers. They take advantage of magnetism to find their way. Instead of using compasses, these animals and others have tiny pieces of magnetite in their bodies. These pieces are so small that they may contain a single magnetic domain. Scientists have shown that some animals use these natural magnets to detect Earth's magnetic field. They appear to use Earth's magnetic field, along with other clues like the position of the Sun or stars, to help them navigate.

Earth's Changing Magnetic Field Earth's magnetic poles do not stay in one place. The magnetic pole in the north today, as shown in **Figure 7**, is in a different place from where it was 20 years ago. In fact, not only does the position of the magnetic poles move, but Earth's magnetic field sometimes reverses direction. For example, 700 thousand years ago, a compass needle that now points north would point south. During the past 20 million years, Earth's magnetic field has reversed direction more than 70 times. The magnetism of ancient rocks contains a record of these magnetic field changes. When some types of molten rock cool, magnetic domains of iron in the rock line up with Earth's magnetic field. After the rock cools, the orientation of these domains is frozen into position. Consequently, these old rocks preserve the orientation of Earth's magnetic field as it was long ago.

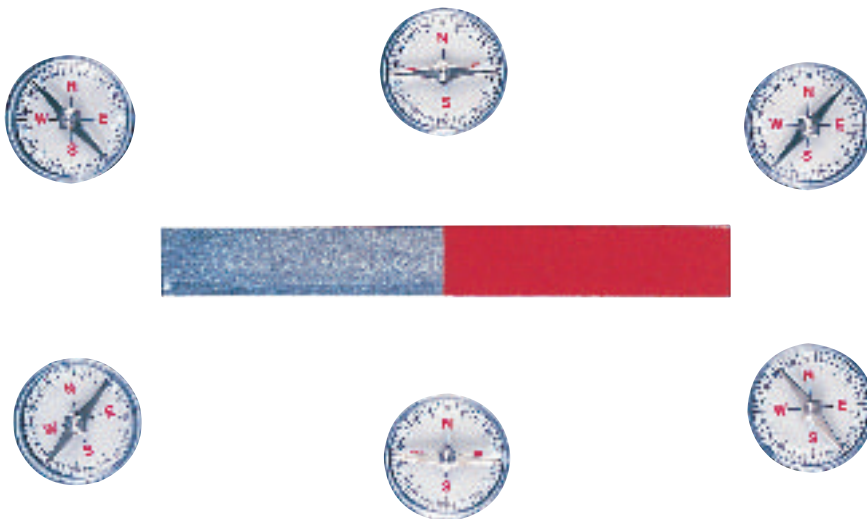


Figure 8 The compass needles align with the magnetic field lines around the magnet.

Explain what happens to the compass needles when the bar magnet is removed.

The Compass A compass needle is a small bar magnet with a north and south magnetic pole. In a magnetic field, a compass needle rotates until it is aligned with the magnetic field line at its location. **Figure 8** shows how the orientation of a compass needle depends on its location around a bar magnet.

Earth's magnetic field also causes a compass needle to rotate. The north pole of the compass needle points toward Earth's magnetic pole that is in the north. This magnetic pole is actually a magnetic south pole. Earth's magnetic field is like that of a bar magnet with the magnet's south pole near Earth's north pole.



Topic: Compasses

Visit ips.msscience.com for Web links to information about different types of compasses.

Activity Find out how far from true north a compass points in your location.

section **1** review

Summary

Magnets

- A magnet has a north pole and a south pole.
- Like magnetic poles repel each other; unlike poles attract each other.
- A magnet is surrounded by a magnetic field that exerts forces on other magnets.
- Some materials are magnetic because their atoms behave like magnets.

Earth's Magnetic Field

- Earth is surrounded by a magnetic field similar to the field around a bar magnet.
- Earth's magnetic poles move slowly, and sometimes change places. Earth's magnetic poles now are close to Earth's geographic poles.

Self Check

1. **Explain** why atoms behave like magnets.
2. **Explain** why magnets attract iron but do not attract paper.
3. **Describe** how the behavior of electric charges is similar to that of magnetic poles.
4. **Determine** where the field around a magnet is the strongest and where it is the weakest.
5. **Think Critically** A horseshoe magnet is a bar magnet bent into the shape of the letter U. When would two horseshoe magnets attract each other? Repel? Have little effect?

Applying Skills

6. **Communicate** Ancient sailors navigated by using the Sun, stars, and following a coastline. Explain how the development of the compass would affect the ability of sailors to navigate.

Make a Compass

A valuable tool for hikers and campers is a compass. Almost 1,000 years ago, Chinese inventors found a way to magnetize pieces of iron. They used this method to manufacture compasses. You can use the same procedure to make a compass.

Real-World Question

How do you construct a compass?

Goals

- **Observe** induced magnetism.
- **Build** a compass.

Materials

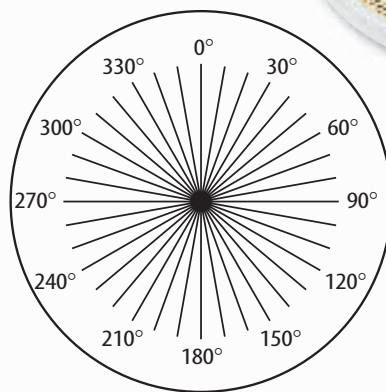
| | |
|---------------|---------------------|
| petri dish | tape |
| *clear bowl | marker |
| water | paper |
| sewing needle | plastic spoon |
| magnet | *Alternate material |

Safety Precautions



Procedure

1. Reproduce the circular protractor shown. Tape it under the bottom of your dish so it can be seen but not get wet. Add water until the dish is half full.
2. Mark one end of the needle with a marker. Magnetize a needle by placing it on the magnet aligned north and south for 1 min.
3. Float the needle in the dish using a plastic spoon to lower the needle carefully onto the water. Turn the dish so the marked part of the needle is above the 0° mark. This is your compass.
4. Bring the magnet near your compass. Observe how the needle reacts. Measure the angle the needle turns.



Conclude and Apply

1. **Explain** why the marked end of the needle always pointed the same way in step 3, even though you rotated the dish.
2. **Describe** the behavior of the compass when the magnet was brought close.
3. **Observe** the marked end of your needle. Does it point to the north or south pole of the bar magnet? **Infer** whether the marked end of your needle is a north or a south pole. How do you know?

Communicating

Your Data

Make a half-page insert that will go into a wilderness survival guide to describe the procedure for making a compass. Share your half-page insert with your classmates. For more help, refer to the **Science Skill Handbook**.

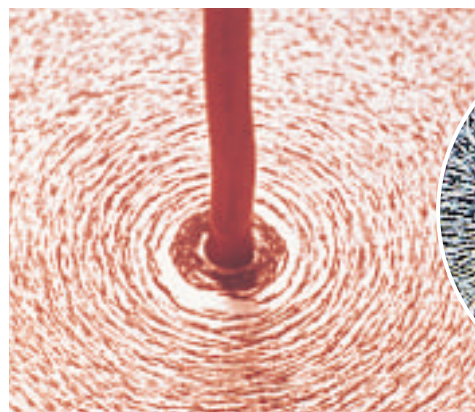
Electricity and Magnetism

Current Can Make a Magnet

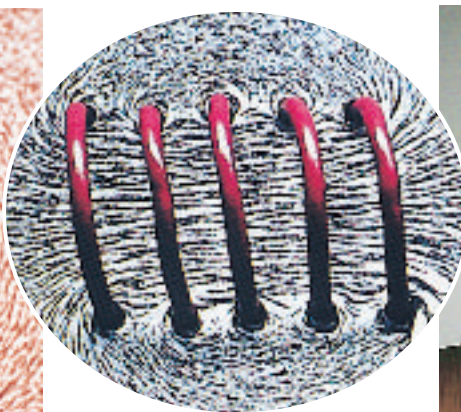
Magnetic fields are produced by moving electric charges. Electrons moving around the nuclei of atoms produce magnetic fields. The motion of these electrons causes some materials, such as iron, to be magnetic. You cause electric charges to move when you flip a light switch or turn on a portable CD player. When electric current flows in a wire, electric charges move in the wire. As a result, a wire that contains an electric current also is surrounded by a magnetic field. **Figure 9A** shows the magnetic field produced around a wire that carries an electric current.

Electromagnets Look at the magnetic field lines around the coils of wire in **Figure 9B**. The magnetic fields around each coil of wire add together to form a stronger magnetic field inside the coil. When the coils are wrapped around an iron core, the magnetic field of the coils magnetizes the iron. The iron then becomes a magnet, which adds to the strength of the magnetic field inside the coil. A current-carrying wire wrapped around an iron core is called an **electromagnet**, as shown in **Figure 9C**.

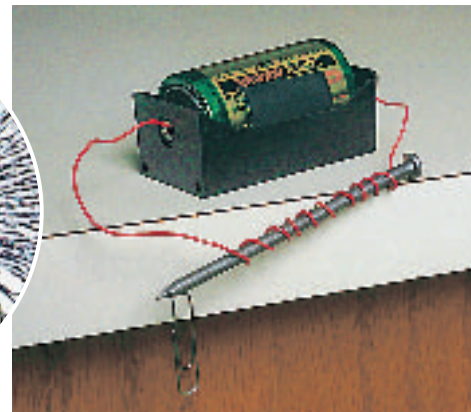
Figure 9 A current-carrying wire produces a magnetic field.



A Iron particles show the magnetic field lines around a current-carrying wire.



B When a wire is wrapped in a coil, the field inside the coil is made stronger.



C An iron core inside the coils increases the magnetic field because the core becomes magnetized.

as you read

What You'll Learn

- **Explain** how electricity can produce motion.
- **Explain** how motion can produce electricity.

Why It's Important

Electricity and magnetism enable electric motors and generators to operate.

Review Vocabulary

electric current: the flow of electric charge

New Vocabulary

- electromagnet
- motor
- aurora
- generator
- alternating current
- direct current
- transformer

Figure 10 An electric doorbell uses an electromagnet. Each time the electromagnet is turned on, the hammer strikes the bell.

Explain how the electromagnet is turned off.

Mini LAB

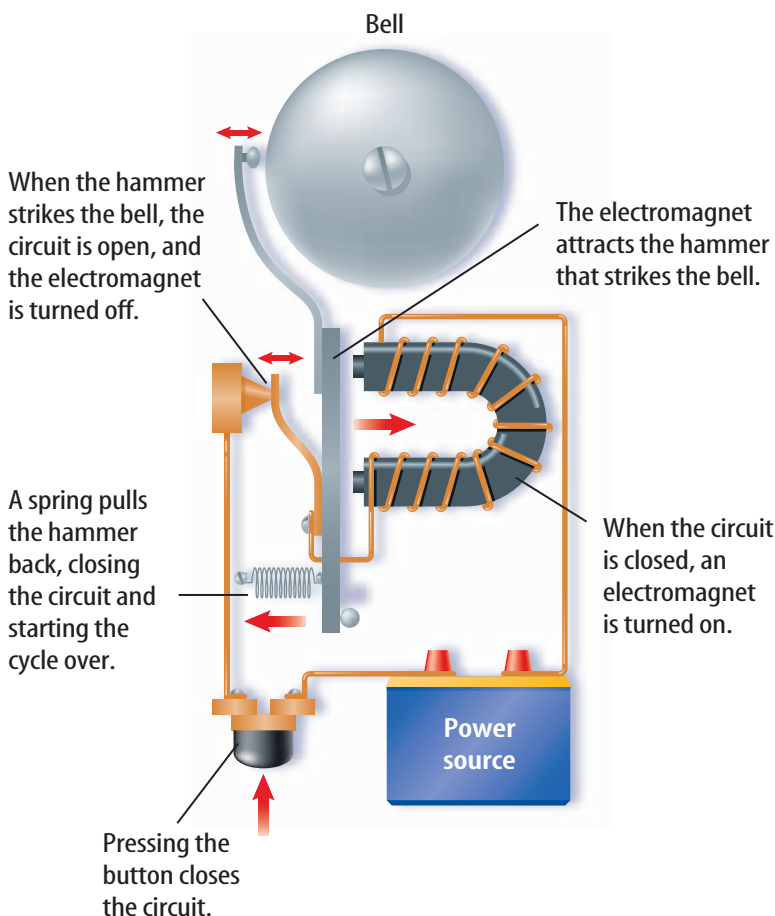
Assembling an Electromagnet

Procedure   

1. Wrap a **wire** around a **16-penny steel nail** ten times. Connect one end of the wire to a **D-cell battery**, as shown in **Figure 9C**. Leave the other end loose until you use the electromagnet. **WARNING:** *When current is flowing in the wire, it can become hot over time.*
2. Connect the wire. Observe how many **paper clips** you can pick up with the magnet.
3. Disconnect the wire and rewrap the nail with 20 coils. Connect the wire and observe how many paper clips you can pick up. Disconnect the wire again.

Analysis

1. How many paper clips did you pick up each time? Did more coils make the electromagnet stronger or weaker?
2. Graph the number of coils versus number of paper clips attracted. Predict how many paper clips would be picked up with five coils of wire. Check your prediction.



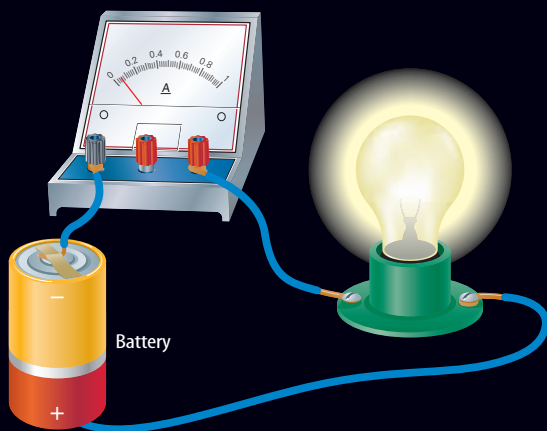
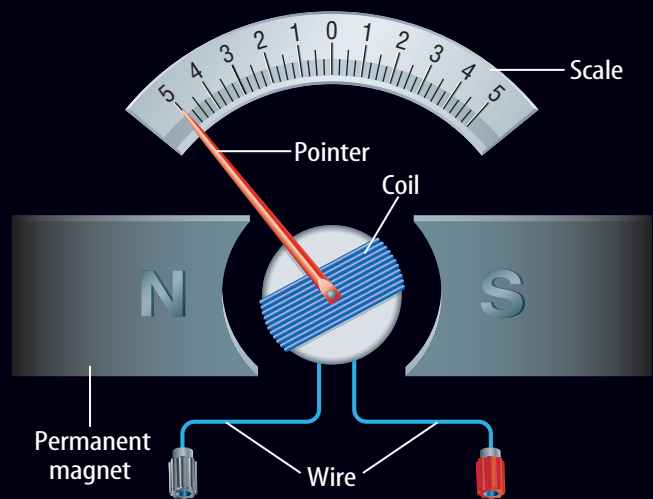
Using Electromagnets The magnetic field of an electromagnet is turned on or off when the electric current is turned on or off. By changing the current, the strength and direction of the magnetic field of an electromagnet can be changed. This has led to a number of practical uses for electromagnets. A doorbell, as shown in **Figure 10**, is a familiar use of an electromagnet. When you press the button by the door, you close a switch in a circuit that includes an electromagnet. The magnet attracts an iron bar attached to a hammer. The hammer strikes the bell. When the hammer strikes the bell, the hammer has moved far enough to open the circuit again. The electromagnet loses its magnetic field, and a spring pulls the iron bar and hammer back into place. This movement closes the circuit, and the cycle is repeated as long as the button is pushed.

Some gauges, such as the gas gauge in a car, use a galvanometer to move the gauge pointer. **Figure 11** shows how a galvanometer makes a pointer move. Ammeters and voltmeters used to measure current and voltage in electric circuits also use galvanometers, as shown in **Figure 11**.

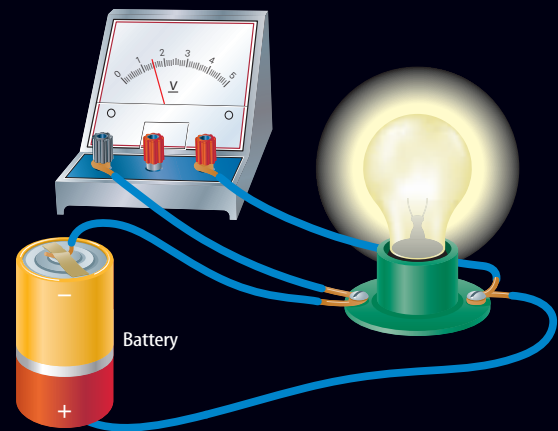
Figure 11

The gas gauge in a car uses a device called a galvanometer to make the needle of the gauge move. Galvanometers are also used in other measuring devices. A voltmeter uses a galvanometer to measure the voltage in a electric circuit. An ammeter uses a galvanometer to measure electric current. Multimeters can be used as an ammeter or voltmeter by turning a switch.

A galvanometer has a pointer attached to a coil that can rotate between the poles of a permanent magnet. When a current flows through the coil, it becomes an electromagnet. Attraction and repulsion between the magnetic poles of the electromagnet and the poles of the permanent magnet makes the coil rotate. The amount of rotation depends on the amount of current in the coil.



To measure the current in a circuit an ammeter is used. An ammeter contains a galvanometer and has low resistance. To measure current, an ammeter is connected in series in the circuit, so all the current in the circuit flows through it. The greater the current in the circuit, the more the needle moves.



To measure the voltage in a circuit a voltmeter is used. A voltmeter also contains a galvanometer and has high resistance. To measure voltage, a voltmeter is connected in parallel in the circuit, so almost no current flows through it. The higher the voltage in the circuit, the more the needle moves.

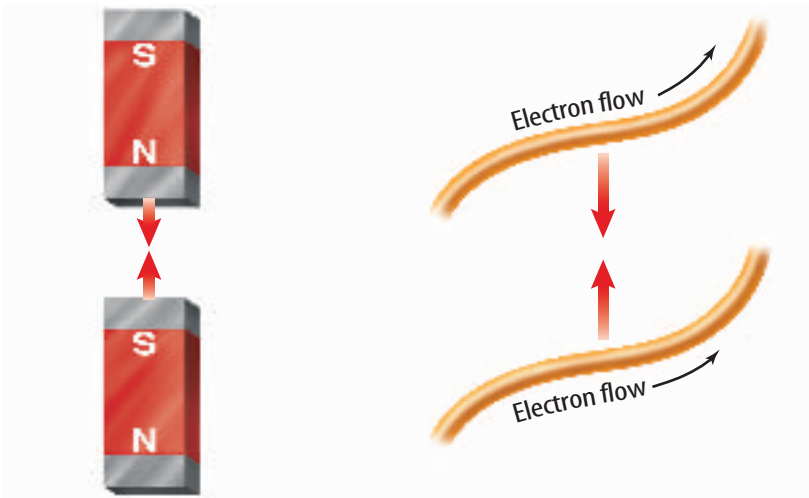
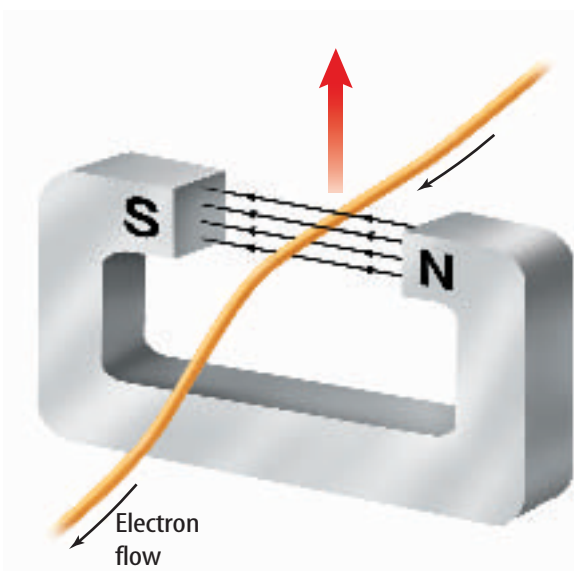
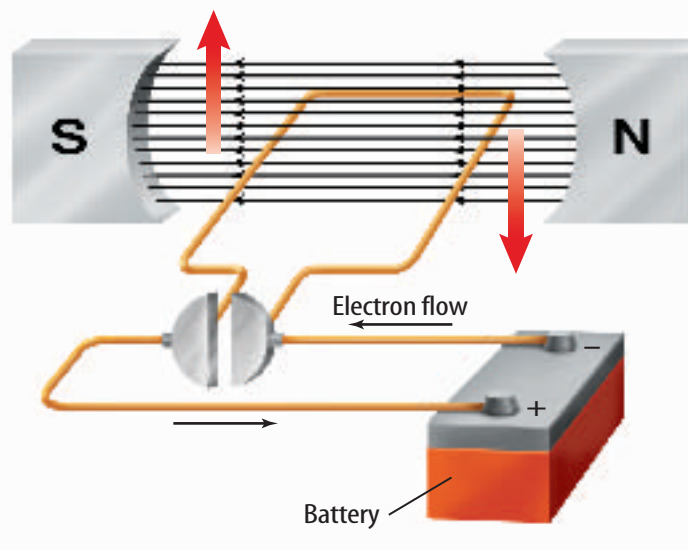


Figure 12 Two wires carrying current in the same direction attract each other, just as unlike magnetic poles do.

Figure 13 In an electric motor, the force a magnet exerts on a current-carrying wire transforms electric energy into kinetic energy.



A magnetic field like the one shown will push a current-carrying wire upward.



The magnetic field exerts a force on the wire loop, causing it to spin as long as current flows in the loop.

Magnets Push and Pull Currents

Look around for electric appliances that produce motion, such as a fan. How does the electric energy entering the fan become transformed into the kinetic energy of the moving fan blades? Recall that current-carrying wires produce a magnetic field. This magnetic field behaves the same way as the magnetic field that a magnet

produces. Two current-carrying wires can attract each other as if they were two magnets, as shown in **Figure 12**.

Electric Motor Just as two magnets exert a force on each other, a magnet and a current-carrying wire exert forces on each other. The magnetic field around a current-carrying wire will cause it to be pushed or pulled by a magnet, depending on the direction the current is flowing in the wire. As a result, some of the electric energy carried by the current is converted into kinetic energy of the moving wire, as shown on the left in **Figure 13**. Any device that converts electric energy into kinetic energy is a **motor**. To keep a motor running, the current-carrying wire is formed into a loop so the magnetic field can force the wire to spin continually, as shown on the right in **Figure 13**.

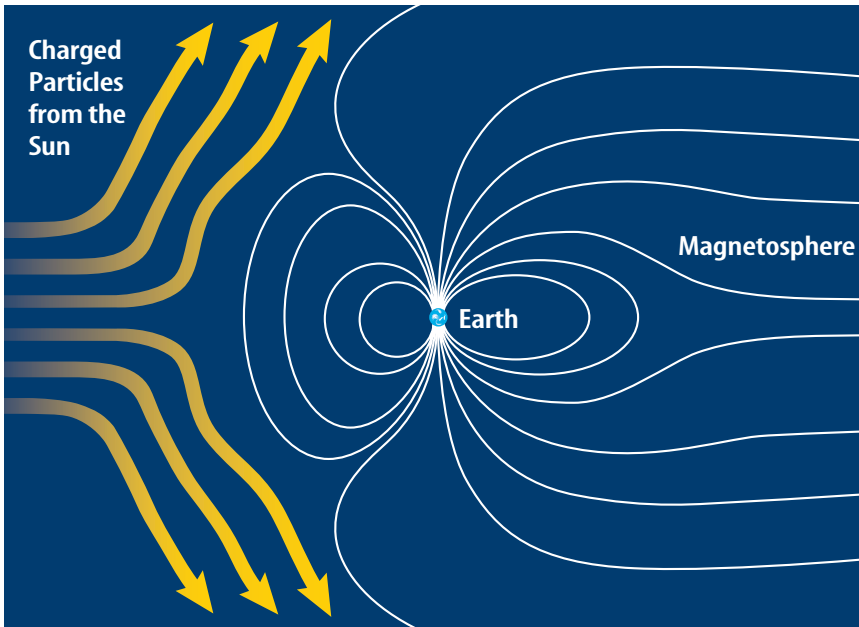


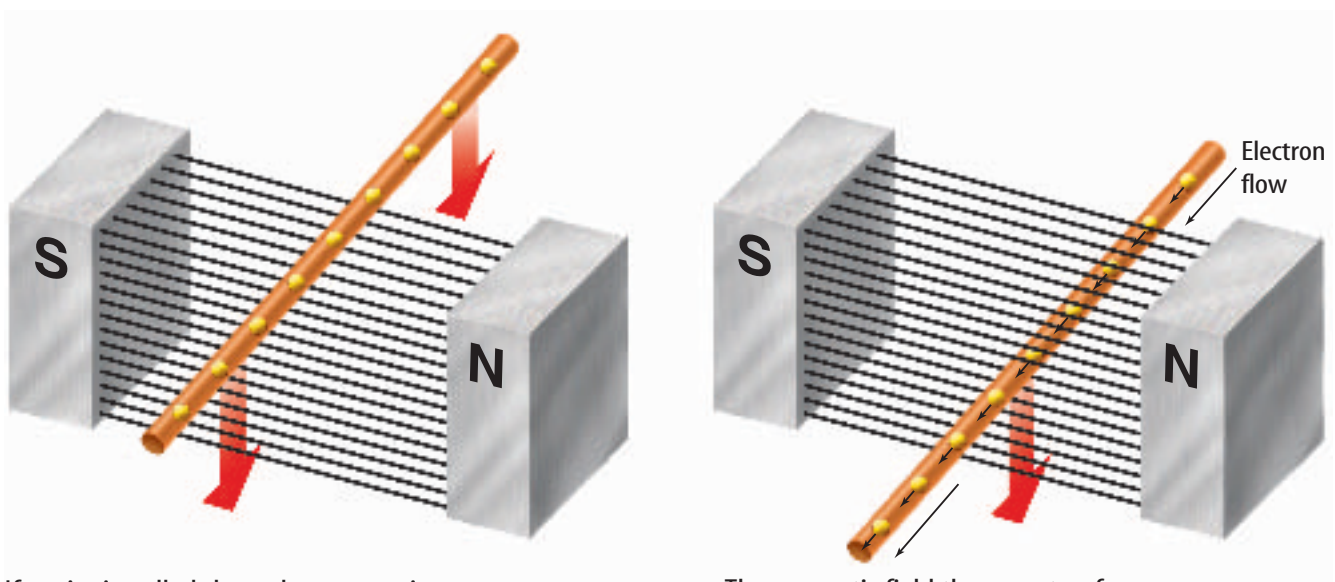
Figure 14 Earth's magnetosphere deflects most of the charged particles streaming from the Sun. **Explain** why the magnetosphere is stretched away from the Sun.

Earth's Magnetosphere The Sun emits charged particles that stream through the solar system like an enormous electric current. Just like a current-carrying wire is pushed or pulled by a magnetic field, Earth's magnetic field pushes and pulls on the electric current generated by the Sun. This causes most of the charged particles in this current to be deflected so they never strike Earth, as shown in **Figure 14**. As a result, living things on Earth are protected from damage that might be caused by these charged particles. At the same time, the solar current pushes on Earth's magnetosphere so it is stretched away from the Sun.

The Aurora Sometimes the Sun ejects a large number of charged particles all at once. Most of these charged particles are deflected by Earth's magnetosphere. However, some of the ejected particles from the Sun produce other charged particles in Earth's outer atmosphere. These charged particles spiral along Earth's magnetic field lines toward Earth's magnetic poles. There they collide with atoms in the atmosphere. These collisions cause the atoms to emit light. The light emitted causes a display known as the **aurora** (uh ROR uh), as shown in **Figure 15**. In northern latitudes, the aurora sometimes is called the northern lights.



Figure 15 An aurora is a natural light show that occurs far north and far south.



If a wire is pulled through a magnetic field, the electrons in the wire also move downward.

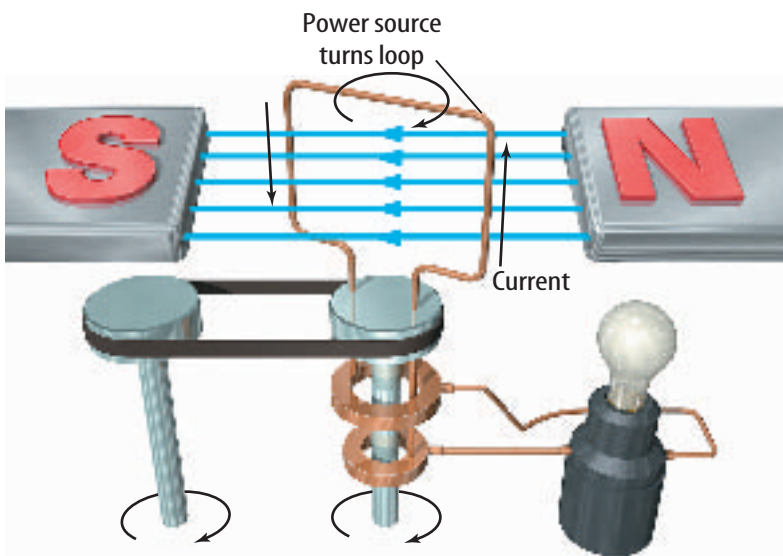
The magnetic field then exerts a force on the moving electrons, causing them to move along the wire.

Figure 16 When a wire is made to move through a magnetic field, an electric current can be produced in the wire.

Using Magnets to Create Current

In an electric motor, a magnetic field turns electricity into motion. A device called a **generator** uses a magnetic field to turn motion into electricity. Electric motors and electric generators both involve conversions between electric energy and kinetic energy. In a motor, electric energy is changed into kinetic energy. In a generator, kinetic energy is changed into electric energy. **Figure 16** shows how a current can be produced in a wire that moves in a magnetic field. As the wire moves, the electrons in the wire also move in the same direction, as shown on the left. The magnetic field exerts a force on the moving electrons that pushes them along the wire on the right, creating an electric current.

Figure 17 In a generator, a power source spins a wire loop in a magnetic field. Every half turn, the current will reverse direction. This type of generator supplies alternating current to the lightbulb.



Electric Generators To produce electric current, the wire is fashioned into a loop, as in **Figure 17**. A power source provides the kinetic energy to spin the wire loop. With each half turn, the current in the loop changes direction. This causes the current to alternate from positive to negative. Such a current is called an **alternating current** (AC). In the United States, electric currents change from positive to negative to positive 60 times each second.

Types of Current A battery produces direct current instead of alternating current. In a **direct current** (DC) electrons flow in one direction. In an alternating current, electrons change their direction of movement many times each second. Some generators are built to produce direct current instead of alternating current.

 **Reading Check** *What type of currents can be produced by a generator?*

Power Plants Electric generators produce almost all of the electric energy used all over the world. Small generators can produce energy for one household, and large generators in electric power plants can provide electric energy for thousands of homes. Different energy sources such as gas, coal, and water are used to provide the kinetic energy to rotate coils of wire in a magnetic field. Coal-burning power plants, like the one pictured in **Figure 18**, are the most common. More than half of the electric energy generated by power plants in the United States comes from burning coal.

Voltage The electric energy produced at a power plant is carried to your home in wires. Recall that voltage is a measure of how much energy the electric charges in a current are carrying. The electric transmission lines from electric power plants transmit electric energy at a high voltage of about 700,000 V. Transmitting electric energy at a low voltage is less efficient because more electric energy is converted into heat in the wires. However, high voltage is not safe for use in homes and businesses. A device is needed to reduce the voltage.

 Science online

Topic: Power Plants

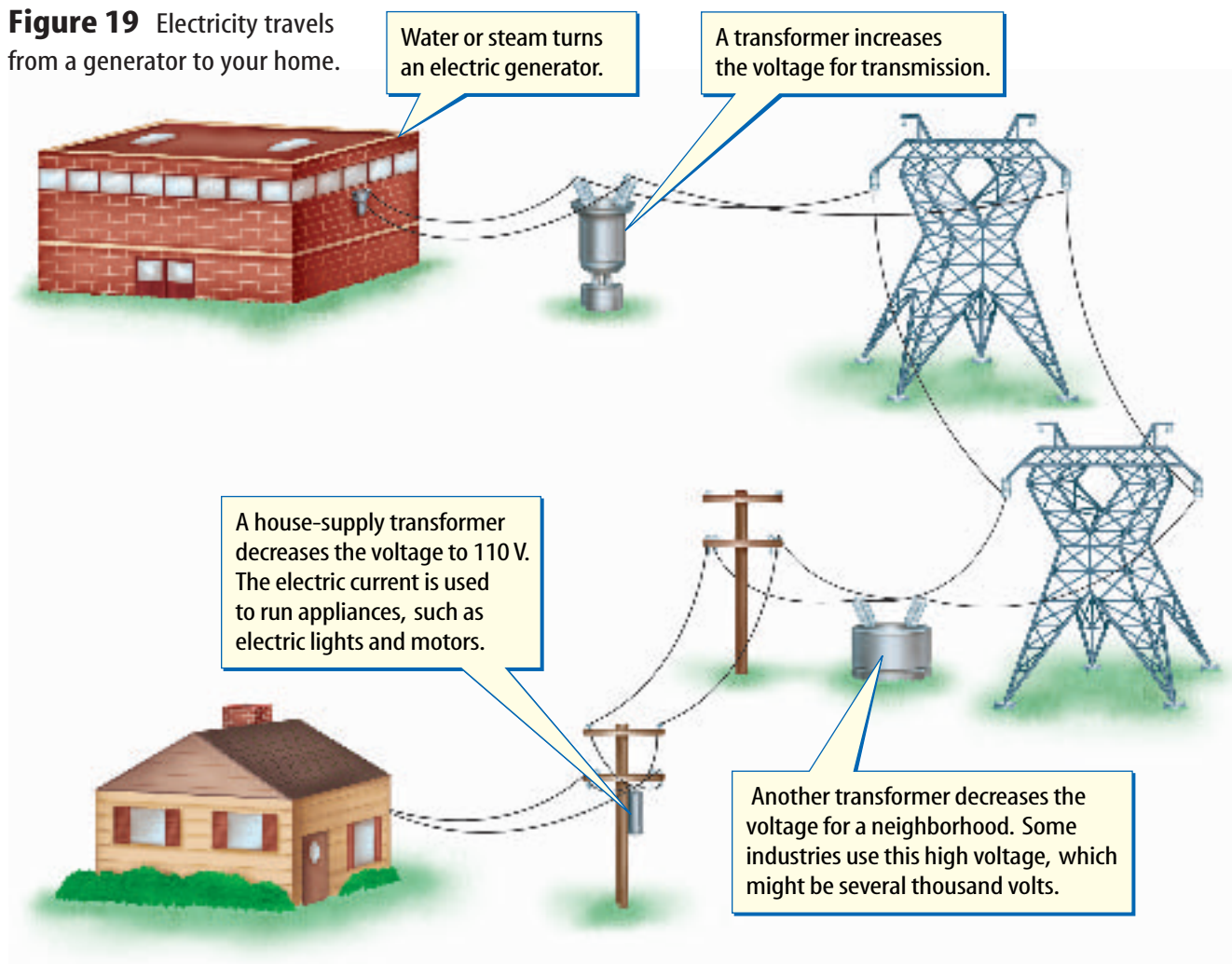
Visit ips.msscience.com for Web links to more information about the different types of power plants used in your region of the country.

Activity Describe the different types of power plants.



Figure 18 Coal-burning power plants supply much of the electric energy for the world.

Figure 19 Electricity travels from a generator to your home.



Changing Voltage

A **transformer** is a device that changes the voltage of an alternating current with little loss of energy. Transformers are used to increase the voltage before transmitting an electric current through the power lines. Other transformers are used to decrease the voltage to the level needed for home or industrial use. Such a power system is shown in **Figure 19**. Transformers also are used in power adaptors. For battery-operated devices, a power adaptor must change the 120 V from the wall outlet to the same voltage produced by the device's batteries.

 **Reading Check** What does a transformer do?

A transformer usually has two coils of wire wrapped around an iron core, as shown in **Figure 20**. One coil is connected to an alternating current source. The current creates a magnetic field in the iron core, just like in an electromagnet. Because the current is alternating, the magnetic field it produces also switches direction. This alternating magnetic field in the core then causes an alternating current in the other wire coil.

Figure 20 A transformer can increase or decrease voltage. The ratio of input coils to output coils equals the ratio of input voltage to output voltage.

Determine the output voltage if the input voltage is 60 V.



The Transformer Ratio Whether a transformer increases or decreases the input voltage depends on the number of coils on each side of the transformer. The ratio of the number of coils on the input side to the number of coils on the output side is the same as the ratio of the input voltage to the output voltage. For the transformer in **Figure 20**, the ratio of the number of coils on the input side to the number of coils on the output side is three to nine, or one to three. If the input voltage is 60 V, the output voltage will be 180 V.

In a transformer the voltage is greater on the side with more coils. If the number of coils on the input side is greater than the number of coils on the output side, the voltage is decreased. If the number of coils on the input side is less than the number on the output side, the voltage is increased.

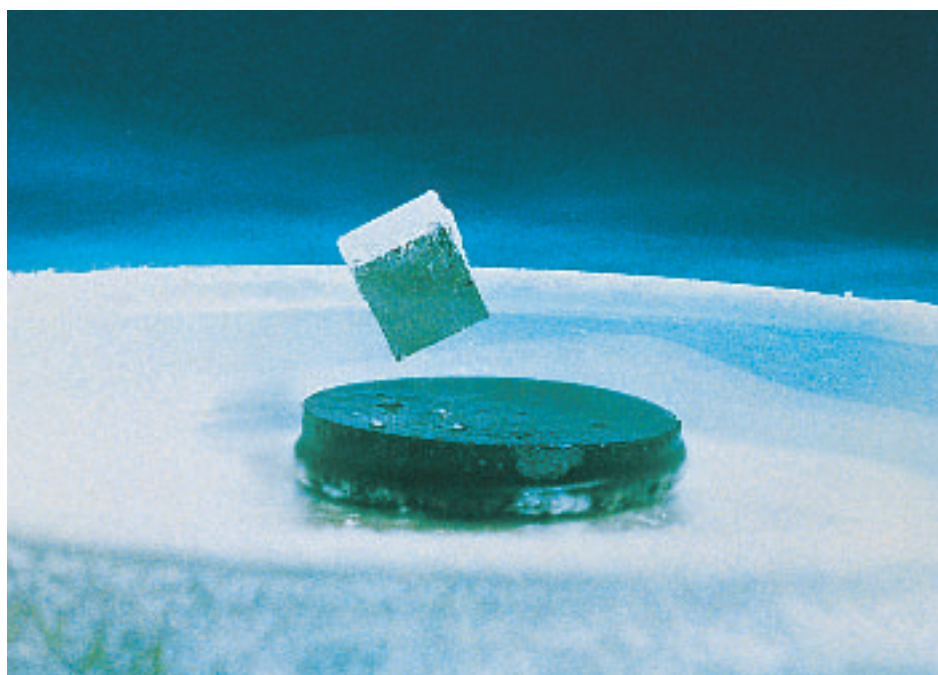
Superconductors

Electric current can flow easily through materials, such as metals, that are electrical conductors. However, even in conductors, there is some resistance to this flow and heat is produced as electrons collide with atoms in the material.

Unlike an electrical conductor, a material known as a superconductor has no resistance to the flow of electrons. Superconductors are formed when certain materials are cooled to low temperatures. For example, aluminum becomes a superconductor at about -272°C . When an electric current flows through a superconductor, no heat is produced and no electric energy is converted into heat.

Superconductors and Magnets

Superconductors also have other unusual properties. For example, a magnet is repelled by a superconductor. As the magnet gets close to the superconductor, the superconductor creates a magnetic field that is opposite to the field of the magnet. The field created by the superconductor can cause the magnet to float above it, as shown in **Figure 21**.



The Currents War In the late 1800s, electric power was being transmitted using a direct-current transmission system developed by Thomas Edison. To preserve his monopoly, Edison launched a public-relations war against the use of alternating-current power transmission, developed by George Westinghouse and Nikola Tesla. However, by 1893, alternating current transmission had been shown to be more efficient and economical, and quickly became the standard.

Figure 21 A small magnet floats above a superconductor. The magnet causes the superconductor to produce a magnetic field that repels the magnet.

Figure 22 The particle accelerator at Fermi National Accelerator Laboratory near Batavia, Illinois, accelerates atomic particles to nearly the speed of light. The particles travel in a beam only a few millimeters in diameter. Magnets made of superconductors keep the beam moving in a circular path about 2 km in diameter.



Figure 23 A patient is being placed inside an MRI machine. The strong magnetic field inside the machine enables images of tissues inside the patient's body to be made.



Using Superconductors Large electric currents can flow through electromagnets made from superconducting wire and can produce extremely strong magnetic fields. The particle accelerator shown in **Figure 22** uses more than 1,000 superconducting electromagnets to help accelerate subatomic particles to nearly the speed of light.

Other uses for superconductors are being developed. Transmission lines made from a superconductor could transmit electric power over long distances without having any electric energy converted to heat. It also may be possible to construct extremely fast computers using microchips made from superconductor materials.

Magnetic Resonance Imaging



A method called magnetic resonance imaging, or MRI, uses magnetic fields to create images of the inside of a human body. MRI images can show if tissue is damaged or diseased, and can detect the presence of tumors.

Unlike X-ray imaging, which uses X-ray radiation that can damage tissue, MRI uses a strong magnetic field and radio waves. The patient is placed inside a machine like the one shown in **Figure 23**. Inside the machine an electromagnet made from superconductor materials produces a magnetic field more than 20,000 times stronger than Earth's magnetic field.

Producing MRI Images About 63 percent of all the atoms in your body are hydrogen atoms. The nucleus of a hydrogen atom is a proton, which behaves like a tiny magnet. The strong magnetic field inside the MRI tube causes these protons to line up along the direction of the field. Radio waves are then applied to the part of the body being examined. The protons absorb some of the energy in the radio waves, and change the direction of their alignment.

When the radio waves are turned off, the protons realign themselves with the magnetic field and emit the energy they absorbed. The amount of energy emitted depends on the type of tissue in the body. This energy emitted is detected and a computer uses this information to form an image, like the one shown in **Figure 24**.

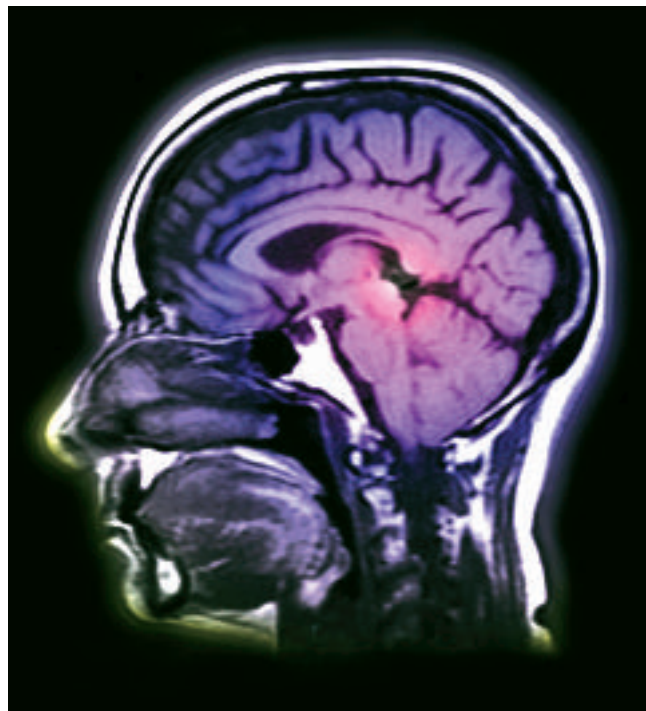


Figure 24 This MRI image shows a side view of the brain.

Connecting Electricity and Magnetism Electric charges and magnets are related to each other. Moving electric charges produce magnetic fields, and magnetic fields exert forces on moving electric charges. It is this connection that enables electric motors and generators to operate.

section 2 review

Summary

Electromagnets

- A current-carrying wire is surrounded by a magnetic field.
- An electromagnet is made by wrapping a current-carrying wire around an iron core.

Motors, Generators, and Transformers

- An electric motor transforms electrical energy into kinetic energy. An electric motor rotates when current flows in a wire loop that is surrounded by a magnetic field.
- An electric generator transforms kinetic energy into electrical energy. A generator produces current when a wire loop is rotated in a magnetic field.
- A transformer changes the voltage of an alternating current.

Self-Check

1. **Describe** how the magnetic field of an electromagnet depends on the current and the number of coils.
2. **Explain** how a transformer works.
3. **Describe** how a magnetic field affects a current-carrying wire.
4. **Describe** how alternating current is produced.
5. **Think Critically** What are some advantages and disadvantages to using superconductors as electric transmission lines?

Applying Math

6. **Calculate Ratios** A transformer has ten turns of wire on the input side and 50 turns of wire on the output side. If the input voltage is 120 V, what will the output voltage be?

How does an electric motor work?

Goals

- **Assemble** a small electric motor.
- **Observe** how the motor works.

Materials

- 22-gauge enameled wire (4 m)
- steel knitting needle
- *steel rod
- nails (4)
- hammer
- ceramic magnets (2)
- 18-gauge insulated wire (60 cm)
- masking tape
- fine sandpaper
- approximately 15-cm square wooden board
- wooden blocks (2)
- 6-V battery
- *1.5-V batteries connected in a series (4)
- wire cutters
- *scissors
- *Alternate materials

Safety Precautions



WARNING: Hold only the insulated part of a wire when it is attached to the battery. Use care when hammering nails. After cutting the wire, the ends will be sharp.

Real-World Question

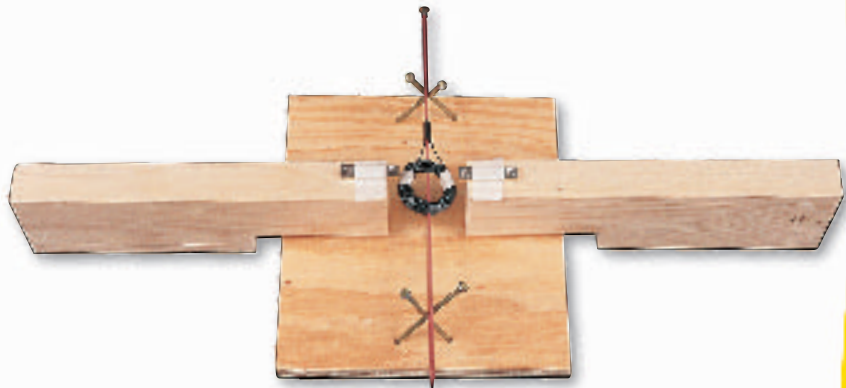
Electric motors are used in many appliances. For example, a computer contains a cooling fan and motors to spin the hard drive. A CD player contains electric motors to spin the CD. Some cars contain electric motors that move windows up and down, change the position of the seats, and blow warm or cold air into the car's interior. All these electric motors consist of an electromagnet and a permanent magnet. In this activity you will build a simple electric motor that will work for you. How can you change electric energy into motion?



Using Scientific Methods

► Procedure

1. Use sandpaper to strip the enamel from about 4 cm of each end of the 22-gauge wire.
2. Leaving the stripped ends free, make this wire into a tight coil of at least 30 turns. A D-cell battery or a film canister will help in forming the coil. Tape the coil so it doesn't unravel.
3. Insert the knitting needle through the coil. Center the coil on the needle. Pull the wire's two ends to one end of the needle.
4. Near the ends of the wire, wrap masking tape around the needle to act as insulation. Then tape one bare wire to each side of the needle at the spot where the masking tape is.
5. Tape a ceramic magnet to each block so that a north pole extends from one and a south pole from the other.
6. Make the motor. Tap the nails into the wood block as shown in the figure. Try to cross the nails at the same height as the magnets so the coil will be suspended between them.
7. Place the needle on the nails. Use bits of wood or folded paper to adjust the positions of the magnets until the coil is directly between the magnets. The magnets should be as close to the coil as possible without touching it.
8. Cut two 30-cm lengths of 18-gauge wire. Use sandpaper to strip the ends of both wires. Attach one wire to each terminal of the battery. Holding only the insulated part of each wire, place one wire against each of the bare wires taped to the needle to close the circuit. Observe what happens.



► Conclude and Apply

1. **Describe** what happens when you close the circuit by connecting the wires. Were the results expected?
2. **Describe** what happens when you open the circuit.
3. **Predict** what would happen if you used twice as many coils of wire.

Communicating Your Data

Compare your conclusions with other students in your class. For more help, refer to the **Science Skill Handbook**.



“Aagjuuk¹ and Sivulliit²”

from Intellectual Culture of the Copper Eskimos

by Knud Rasmussen, told by Tatilgak



The following are “magic words” that are spoken before the Inuit (IH noo wut) people go seal hunting. Inuit are native people that live in the arctic region. Because the Inuit live in relative darkness for much of the winter, they have learned to find their way by looking at the stars to guide them. The poem is about two constellations

that are important to the Inuit people because their appearance marks the end of winter when the Sun begins to appear in the sky again.

By which way, I wonder the mornings—
You dear morning, get up!
See I am up!

By which way, I wonder,
the constellation *Aagjuuk* rises up in the sky?
By this way—perhaps—by the morning
It rises up!

Morning, you dear morning, get up!
See I am up!

By which way, I wonder,
the constellation *Sivulliit*
Has risen to the sky?
By this way—perhaps—by the morning.
It rises up!

¹Inuit name for the constellation of stars called Aquila (A kwuh luh)

²Inuit name for the constellation of stars called Bootes (boh OH teez)

Understanding Literature

Ethnography Ethnography is a description of a culture. To write an ethnography, an ethnographer collects cultural stories, poems, or other oral tales from the culture that he or she is studying. Why must the Inuit be skilled in navigation?

Respond to the Reading

1. How can you tell the importance of constellations to the Inuit for telling direction?
2. How is it possible that the Inuit could see the constellations in the morning sky?
3. **Linking Science and Writing** Research the constellations in the summer sky in North America and write a paragraph describing the constellations that would help you navigate from south to north.



Earth’s magnetic field causes the north pole of a compass needle to point in a northerly direction. Using a compass helps a person to navigate and find his or her way. However, at the far northern latitudes where the Inuit live, a compass becomes more difficult to use. Some Inuit live north of Earth’s northern magnetic pole. In these locations a compass needle points in a southerly direction. As a result, the Inuit developed other ways to navigate.

Reviewing Main Ideas

Section 1 What is magnetism?

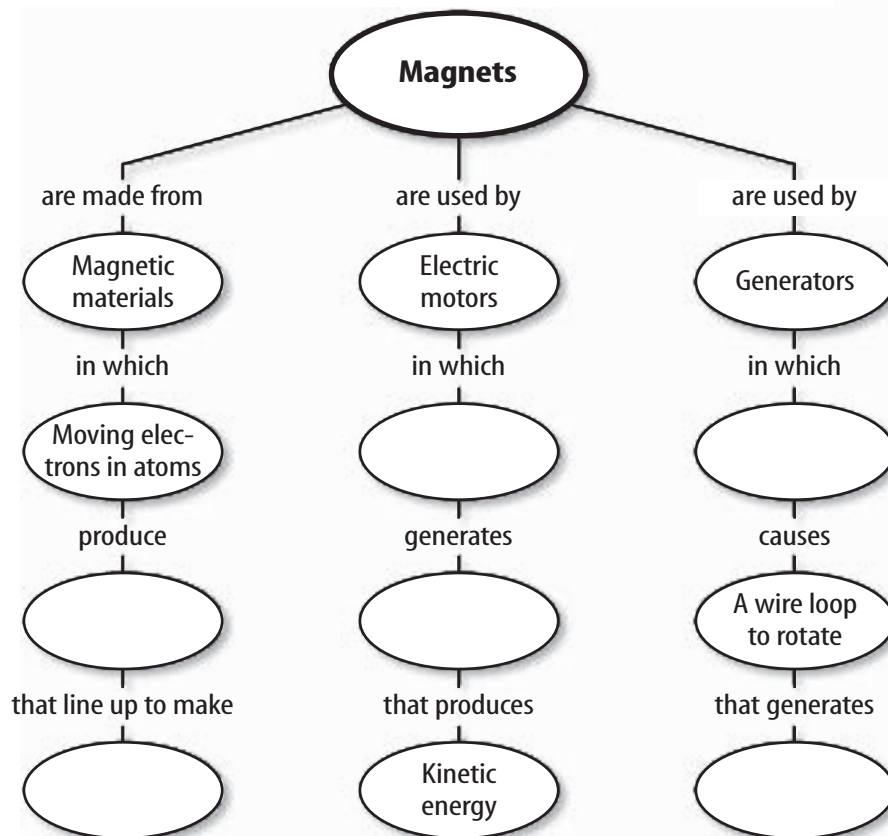
1. All magnets have two poles—north and south. Like poles repel each other and unlike poles attract.
2. A magnet is surrounded by a magnetic field that exerts forces on other magnets.
3. Atoms in magnetic materials are magnets. These materials contain magnetic domains which are groups of atoms whose magnetic poles are aligned.
4. Earth is surrounded by a magnetic field similar to the field around a bar magnet.

Section 2 Electricity and Magnetism

1. Electric current creates a magnetic field. Electromagnets are made from a coil of wire that carries a current, wrapped around an iron core.
2. A magnetic field exerts a force on a moving charge or a current-carrying wire.
3. Motors transform electric energy into kinetic energy. Generators transform kinetic energy into electric energy.
4. Transformers are used to increase and decrease voltage in AC circuits.

Visualizing Main Ideas

Copy and complete the following concept map on magnets.



Using Vocabulary

| | |
|---------------------------|-----------------------|
| alternating current p.626 | magnetic domain p.616 |
| aurora p.625 | magnetic field p.615 |
| direct current p.627 | magnetosphere p.617 |
| electromagnet p.621 | motor p.624 |
| generator p.626 | transformer p.628 |

Explain the relationship that exists between each set of vocabulary words below.

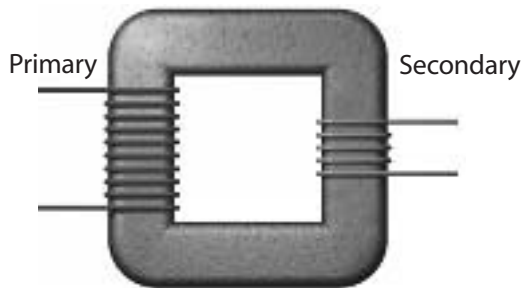
1. generator—transformer
2. magnetic force—magnetic field
3. alternating current—direct current
4. current—electromagnet
5. motor—generator
6. electron—magnetism
7. magnetosphere—aurora
8. magnet—magnetic domain

Checking Concepts

Choose the word or phrase that best answers the question.

9. What can iron filings be used to show?
 - A) magnetic field
 - B) electric field
 - C) gravitational field
 - D) none of these
10. Why does the needle of a compass point to magnetic north?
 - A) Earth's north pole is strongest.
 - B) Earth's north pole is closest.
 - C) Only the north pole attracts compasses.
 - D) The compass needle aligns itself with Earth's magnetic field.
11. What will the north poles of two bar magnets do when brought together?
 - A) attract
 - B) create an electric current
 - C) repel
 - D) not interact
12. How many poles do all magnets have?
 - A) one
 - B) two
 - C) three
 - D) one or two
13. When a current-carrying wire is wrapped around an iron core, what can it create?
 - A) an aurora
 - B) a magnet
 - C) a generator
 - D) a motor
14. What does a transformer between utility wires and your house do?
 - A) increases voltage
 - B) decreases voltage
 - C) leaves voltage the same
 - D) changes DC to AC

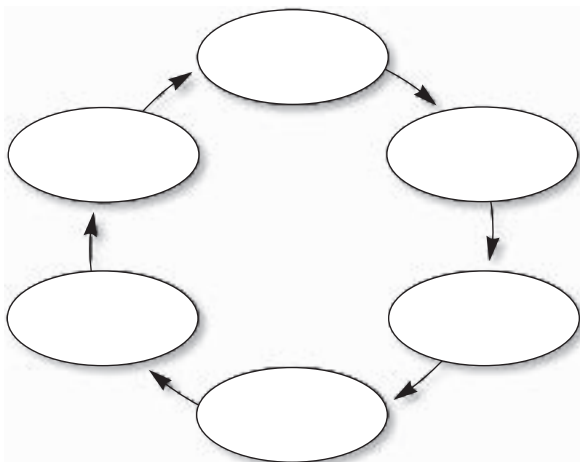
Use the figure below to answer question 15.



15. For this transformer which of the following describes how the output voltage compares with the input voltage?
 - A) larger
 - B) the same
 - C) smaller
 - D) zero voltage
16. Which energy transformation occurs in an electric motor?
 - A) electrical to kinetic
 - B) electrical to thermal
 - C) potential to kinetic
 - D) kinetic to electrical
17. What prevents most charged particles from the Sun from hitting Earth?
 - A) the aurora
 - B) Earth's magnetic field
 - C) high-altitude electric fields
 - D) Earth's atmosphere

Thinking Critically

- 18. Concept Map** Explain how a doorbell uses an electromagnet by placing the following phrases in the cycle concept map: *circuit open, circuit closed, electromagnet turned on, electromagnet turned off, hammer attracted to magnet and strikes bell, and hammer pulled back by a spring.*



- 19. Infer** A nail is magnetized by holding the south pole of a magnet against the head of the nail. Does the point of the nail become a north pole or a south pole? Include a diagram with your explanation.
- 20. Explain** why an ordinary bar magnet doesn't rotate and align itself with Earth's magnetic field when you place it on a table.
- 21. Determine** Suppose you were given two bar magnets. One magnet has the north and south poles labeled, and on the other magnet the magnetic poles are not labeled. Describe how you could use the labeled magnet to identify the poles of the unlabeled magnet.
- 22. Explain** A bar magnet touches a paper clip that contains iron. Explain why the paper clip becomes a magnet that can attract other paper clips.

- 23. Explain** why the magnetic field produced by an electromagnet becomes stronger when the wire coils are wrapped around an iron core.
- 24. Predict** Magnet A has a magnetic field that is three times as strong as the field around magnet B. If magnet A repels magnet B with a force of 10 N, what is the force that magnet B exerts on magnet A?
- 25. Predict** Two wires carrying electric current in the same direction are side by side and are attracted to each other. Predict how the force between the wires changes if the current in both wires changes direction.

Performance Activities

- 26. Multimedia Presentation** Prepare a multimedia presentation to inform your classmates on the possible uses of superconductors.

Applying Math

Use the table below to answer questions 27 and 28.

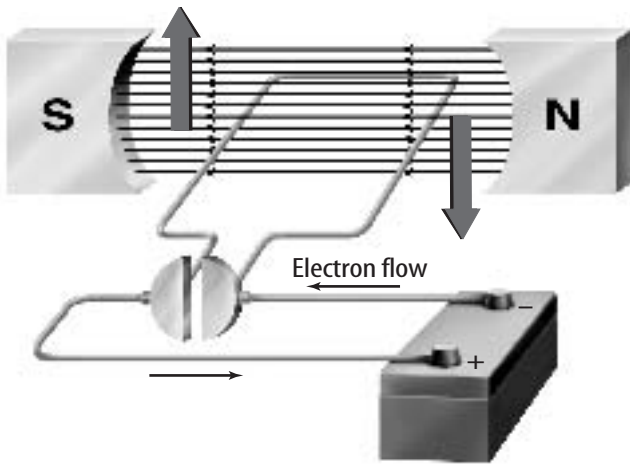
| Transformer Properties | | |
|------------------------|-----------------------|------------------------|
| Transformer | Number of Input Coils | Number of Output Coils |
| R | 4 | 12 |
| S | 10 | 2 |
| T | 3 | 6 |
| U | 5 | 10 |

- 27. Input and Output Coils** According to this table, what is the ratio of the number of input coils to the number of output coils on transformer T?
- 28. Input and Output Voltage** If the input voltage is 60 V, which transformer gives an output voltage of 12 V?

Part 1 Multiple Choice

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

Use the figure below to answer questions 1 and 2.



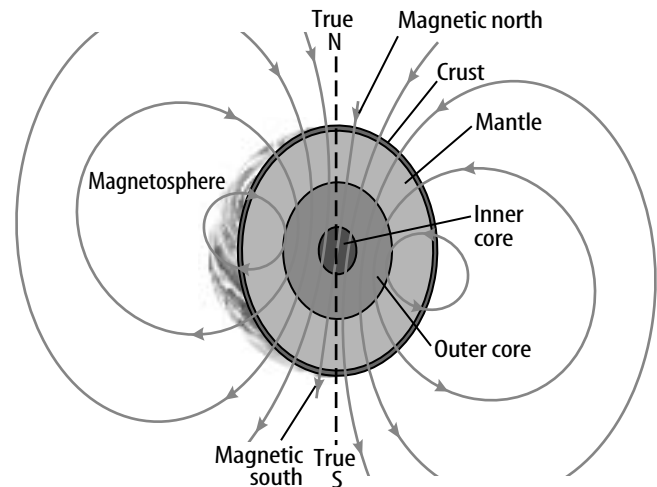
- What is the device shown?
 - electromagnet
 - generator
 - electric motor
 - transformer
- Which of the following best describes the function of this device?
 - It transforms electrical energy into kinetic energy.
 - It transforms kinetic energy into electrical energy.
 - It increases voltage.
 - It produces an alternating current.
- How is an electromagnet different from a permanent magnet?
 - It has north and south poles.
 - It attracts magnetic substances.
 - Its magnetic field can be turned off.
 - Its poles cannot be reversed.

Test-Taking Tip

Check the Question Number For each question, double check that you are filling in the correct answer bubble for the question number you are working on.

- Which of the following produces alternating current?
 - electromagnet
 - superconductor
 - generator
 - motor
- Which statement about the domains in a magnetized substance is true?
 - Their poles are in random directions.
 - Their poles cancel each other.
 - Their poles point in one direction.
 - Their orientation cannot change.

Use the figure below to answer questions 6–8.



- What is the region of space affected by Earth's magnetic field called?
 - declination
 - magnetosphere
 - aurora
 - outer core
- What is the shape of Earth's magnetic field similar to?
 - that of a horseshoe magnet
 - that of a bar magnet
 - that of a disk magnet
 - that of a superconductor
- In which of Earth's layers is Earth's magnetic field generated?
 - crust
 - mantle
 - outer core
 - inner core

Part 2 Short Response/Grid In

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

Use the figure below to answer questions 9 and 10.



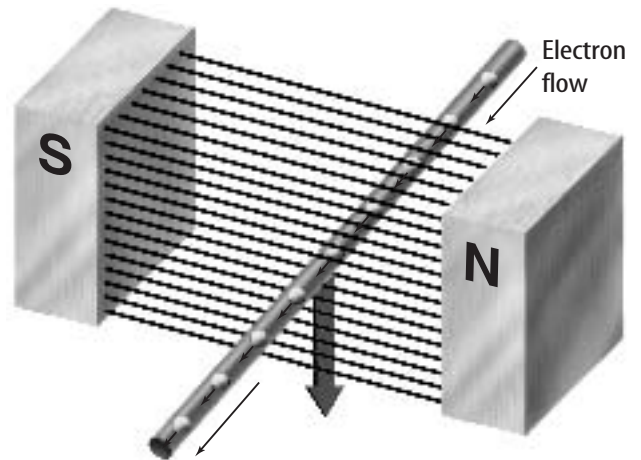
9. Explain why the compass needles are pointed in different directions.
10. What will happen to the compass needles when the bar magnet is removed? Explain why this happens.
11. Describe the interaction between a compass needle and a wire in which an electric current is flowing.
12. What are two ways to make the magnetic field of an electromagnet stronger?
13. The input voltage in a transformer is 100 V and the output voltage is 50 V. Find the ratio of the number of wire turns on the input coil to the number of turns on the output coil.
14. Explain how you could magnetize a steel screwdriver.
15. Suppose you break a bar magnet in two. How many magnetic poles does each of the pieces have?
16. Alnico is a mixture of steel, aluminum, nickel, and cobalt. It is very hard to magnetize. However, once magnetized, it remains magnetic for a long time. Explain why it would not be a good choice for the core of an electromagnet.

Part 3 Open Ended

Record your answers on a sheet of paper.

17. Explain why the aurora occurs only near Earth's north and south poles.
18. Why does a magnet attract an iron nail to either of its poles, but attracts another magnet to only one of its poles?
19. A battery is connected to the input coil of a step-up transformer. Describe what happens when a lightbulb is connected to the output coil of the transformer.
20. Explain how electric forces and magnetic forces are similar.

Use the figure below to answer questions 21 and 22.



21. Describe the force that is causing the electrons to flow in the wire.
22. Infer how electrons would flow in the wire if the wire were pulled upward.
23. Explain why a nail containing iron can be magnetized, but a copper penny that contains no iron cannot be magnetized.
24. Every magnet has a north pole and a south pole. Where would the poles of a magnet that is in the shape of a disc be located?