18

Electromagnetism

The Big Idea

Forces of attraction and repulsion result from magnetic and electric fields.

SECTION

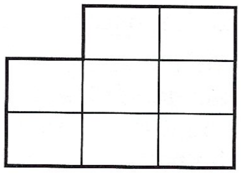
About the PHOTO

Superhot particles at millions of degrees Celsius shoot out of the sun. But they do not escape. They loop back and crash into the sun's surface at more than 100 km/s (223,000 mi/h). The image of Earth has been added to show how large these loops can be. What directs the particles? The particles follow along the path of the magnetic field lines of the sun. You depend on magnetic fields in electric motors and generators. And you can use them to show off a good report card on the refrigerator.

PRE-READING ACTIVITY

Graphic Organizer

Comparison Table Before you read the chapter, create the graphic organizer entitled "Comparison Table" described in the **Study Skills** section of the Appendix. Label the columns with "Motor" and "Generator." Label the rows with "Energy in" and "Energy out." As you read the chapter, fill in the table with details about the energy conversion that happens in each device.



SECTION 1

Magnets and Magnetism

You've probably seen magnets stuck to a refrigerator door. These magnets might be holding notes or pictures. Or they might be just for looks.

What You Will Learn

- Describe the properties of magnets.
- Explain why some materials are magnetic and some are not.
- Describe four kinds of magnets.
- Give two examples of the effect of Earth's magnetic field.

Vocabulary

magnet
magnetic pole
magnetic force

READING STRATEGY

Prediction Guide Before reading this section, predict whether each of the following statements is true or false:

- Every magnet has a north pole and a south pole.
- The magnetic pole near the South Pole in Antarctica is a north pole.

If you have ever experimented with magnets, you know that they stick to each other and to some kinds of metals. You also know that magnets can stick to things without directly touching them—such as a magnet used to hold a piece of paper to a refrigerator door.

Properties of Magnets

More than 2,000 years ago, the Greeks discovered a mineral that attracted things made of iron. Because this mineral was found in a part of Turkey called Magnesia, the Greeks called it magnetite. Today, any material that attracts iron or things made of iron is called a **magnet.** All magnets have certain properties. For example, all magnets have two poles. Magnets exert forces on each other and are surrounded by a magnetic field.

Reading Check **What is a magnet?** (*See the Appendix for answers to Reading Checks.*)

magnet any material that attracts iron or materials containing iron

magnetic pole one of two points, such as the ends of a magnet, that have opposing magnetic qualities

Magnetic Poles

The magnetic effects are not the same throughout a magnet. What would happen if you dipped a bar magnet into a box of paper clips? Most of the clips would stick to the ends of the bar, as shown in **Figure 1.** This shows that the strongest effects are near the ends of the bar magnet. Each end of the magnet is a magnetic pole. As you will see, **magnetic poles** are points on a magnet that have opposite magnetic qualities.

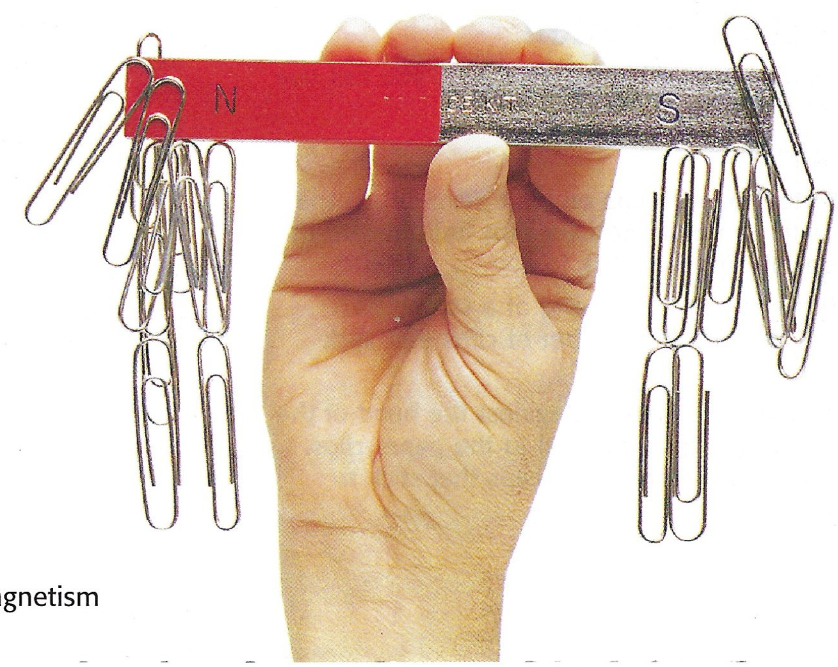


Figure 1 *More paper clips stick to the ends, or magnetic poles, of a magnet because the magnetic effects are strongest there.*

North and South

Suppose you hang a magnet by a string so that the magnet can spin. You will see that one end of the magnet always ends up pointing to the north, as shown in **Figure 2.** The pole of a magnet that points to the north is called the magnet's *north pole*. The opposite end of the magnet points to the south. It is called the magnet's *south pole*. Magnetic poles are always in pairs. You will never find a magnet that has only a north pole or only a south pole.

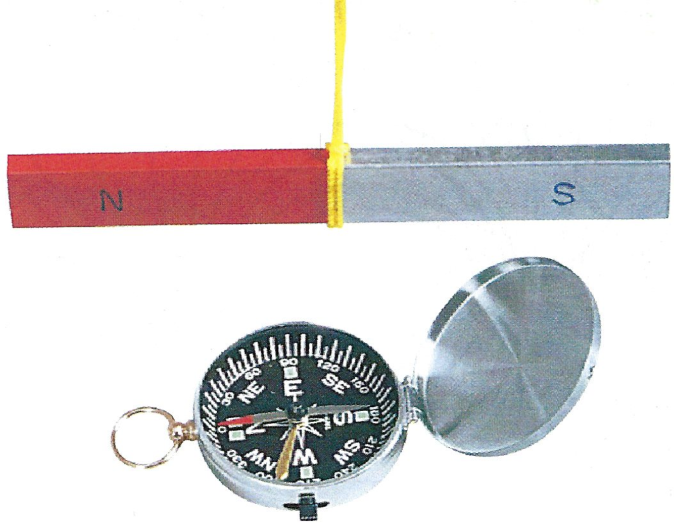


Figure 2 *The needle in a compass is a magnet that is free to rotate.*

Magnetic Forces

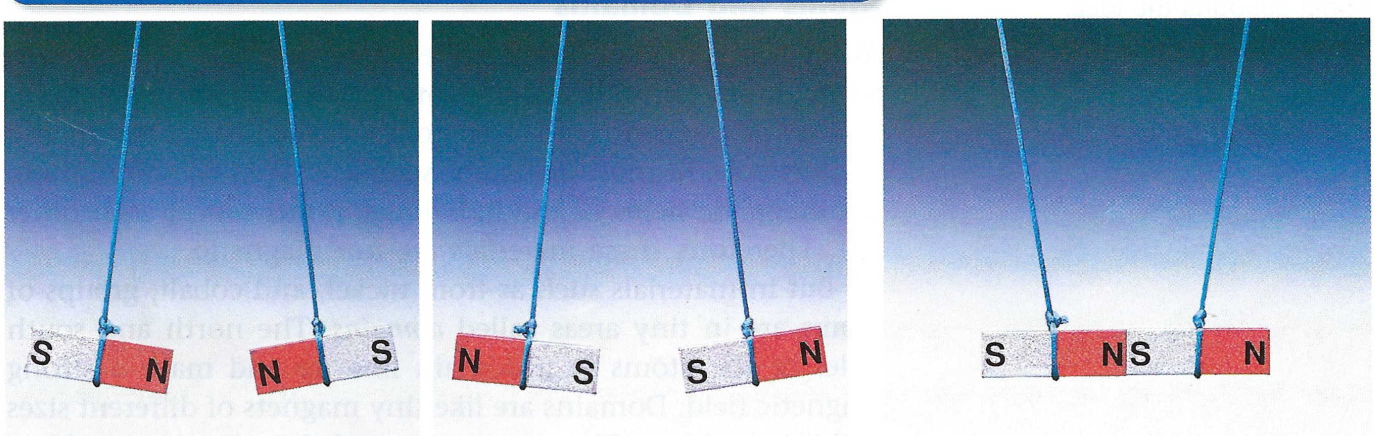
When you bring two magnets close together, the magnets each exert a **magnetic force** on the other. These magnetic forces result from spinning electric charges in the magnets. The force can either push the magnets apart or pull them together. The magnetic force is a universal force. It is always present when magnetic poles come near one another.

magnetic force the force of attraction or repulsion generated by moving or spinning electric charges

Think of the last time you worked with magnets. If you held two magnets in a certain way, they pulled together. When you turned one of the magnets around, they pushed apart. Why? The magnetic force between magnets depends on how the poles of the magnets line up. Like poles repel, and opposite poles attract, as shown in **Figure 3.**

Reading Check **If two magnets push each other away, what can you conclude about their poles?**

Figure 3 **Magnetic Force Between Magnets**



▲ If you hold the north poles of two magnets close together, the magnetic force will push the magnets apart. The same is true if you hold the south poles close together.

▲ If you hold the north pole of one magnet close to the south pole of another magnet, the magnetic force will pull the magnets together.

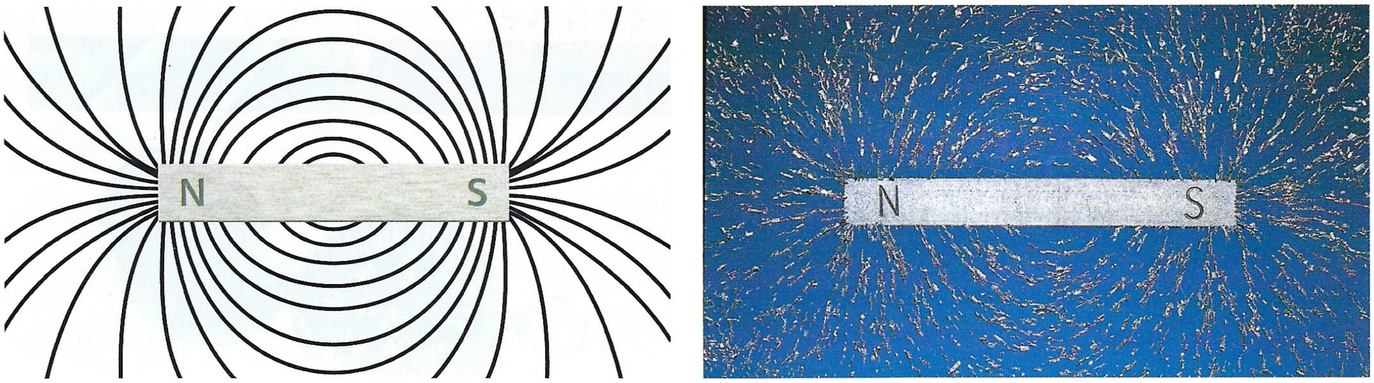


Figure 4 *Magnetic field lines show the shape of a magnetic field around a magnet. You can model magnetic field lines by sprinkling iron filings around a magnet.*

Magnetic Fields

A *magnetic field* exists in the region around a magnet in which magnetic forces can act. The shape of a magnetic field can be shown with lines drawn from the north pole of a magnet to the south pole, as shown in **Figure 4.** These lines map out the magnetic field and are called *magnetic field lines*. The closer together the field lines are, the stronger the magnetic field is. The lines around a magnet are closest together at the poles, where the magnetic force on an object is strongest.

CONNECTION TO Biology

WRITING SKILL Animal Compasses

Scientists think that birds and other animals may use Earth's magnetic field to help them navigate. Write a one-page paper in your **science journal** that tells which animals might find their way using Earth's magnetic field. Include evidence scientists have found that supports the idea.

The Cause of Magnetism

Some materials are magnetic. Some are not. For example, a magnet can pick up paper clips and iron nails. But it cannot pick up paper, plastic, pennies, or aluminum foil. What causes the difference? Whether a material is magnetic depends on the material's atoms.

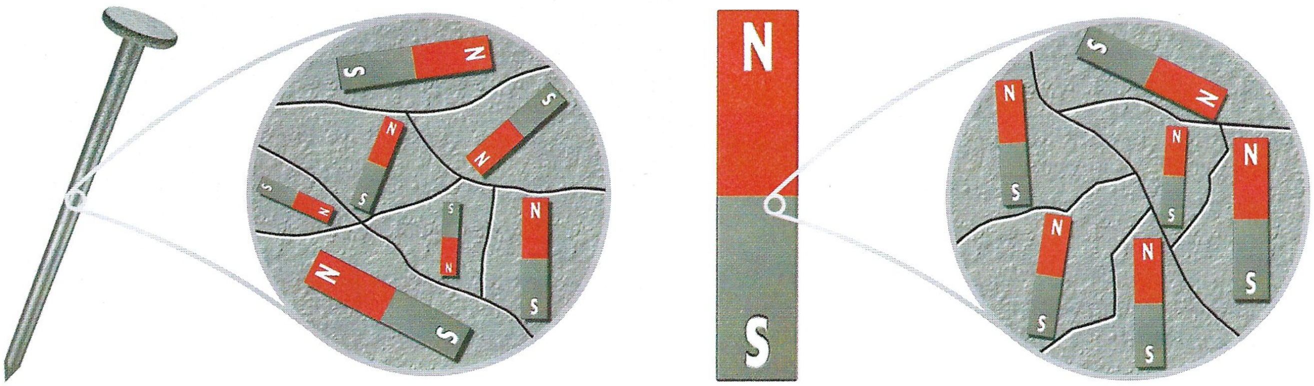
Atoms and Domains

All matter is made of atoms. Electrons are negatively charged particles of atoms. As an electron moves around, it makes, or induces, a magnetic field. The atom will then have a north and a south pole. In most materials, such as copper and aluminum, the magnetic fields of the individual atoms cancel each other out. Therefore, these materials are not magnetic.

But in materials such as iron, nickel, and cobalt, groups of atoms are in tiny areas called *domains*. The north and south poles of the atoms in a domain line up and make a strong magnetic field. Domains are like tiny magnets of different sizes within an object. The arrangement of domains in an object determines whether the object is magnetic. **Figure 5** shows how the arrangement of domains works.

Reading Check Why are copper and aluminum not magnetic?

Figure 5 **Arrangement of Domains in an Object**



If the domains in an object are randomly arranged, the magnetic fields of the individual domains cancel each other out, and the object has no magnetic properties.

If most of the domains in an object are aligned, the magnetic fields of the individual domains combine to make the whole object magnetic.

Losing Alignment

The domains of a magnet may not always stay lined up. When domains move, the magnet is demagnetized, or loses its magnetic properties. Dropping a magnet or hitting it too hard can move the domains. Putting the magnet in a strong magnetic field that is opposite to its own can also move domains. Increasing the temperature of a magnet can also demagnetize it. At higher temperatures, atoms in the magnet vibrate faster. As a result, the atoms in the domains may no longer line up.

✓ Reading Check **Describe two ways a magnet can lose its magnetic properties.**

Making Magnets

You can make a magnet from something made of iron, cobalt, or nickel. You just need to line up the domains in it. For example, you can magnetize an iron nail if you rub it in one direction with one pole of a magnet. The domains in the nail line up with the magnetic field of the magnet. So, the domains in the nail become aligned. As more domains line up, the magnetic field of the nail grows stronger. The nail will become a magnet, as shown in **Figure 6.**

The process of making a magnet also explains how a magnet can pick up an unmagnetized object, such as a paper clip. When a magnet is close to a paper clip, some domains in the paper clip line up with the field of the magnet. So, the paper clip becomes a temporary magnet. The north pole of the paper clip points toward the south pole of the magnet. The paper clip is attracted to the magnet. When the magnet is removed, the domains of the paper clip become scrambled again.

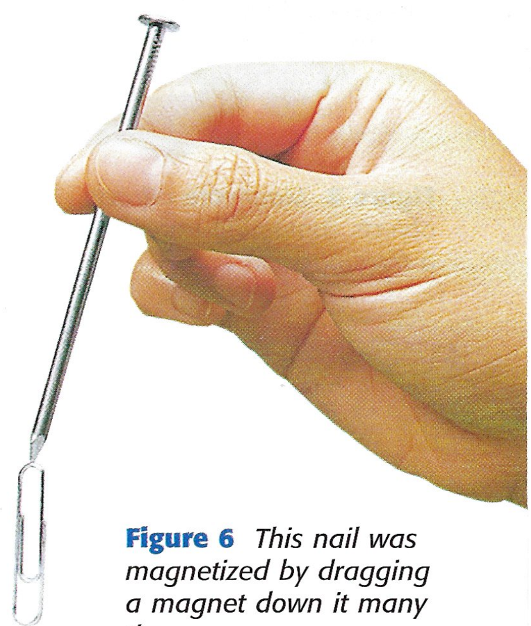


Figure 6 *This nail was magnetized by dragging a magnet down it many times.*

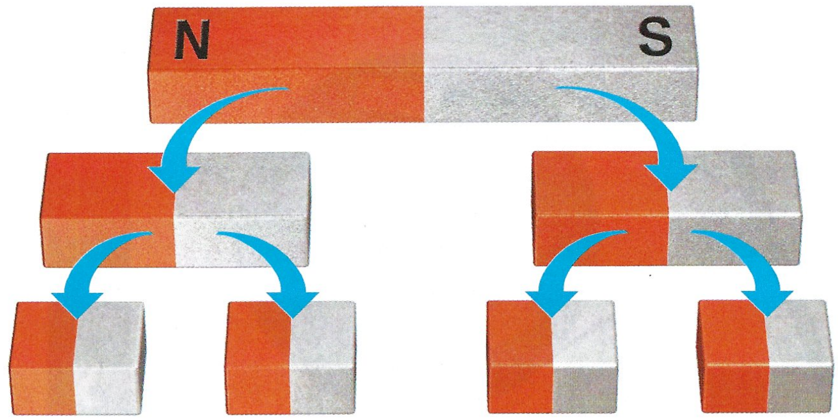


Figure 7 *If you cut a magnet in pieces, each piece will still be a magnet with two poles.*

Cutting a Magnet

What do you think would happen if you cut a magnet in half? You might think that you would end up with one north-pole piece and one south-pole piece. But that's not what happens. When you cut a magnet in half, you end up with two magnets. Each piece has its own north pole and south pole, as shown in **Figure 7.** A magnet has poles because its domains are lined up. Each domain within a magnet is like a tiny magnet with a north pole and a south pole. Even the smallest pieces of a magnet have two poles.

Kinds of Magnets

Figure 8 *Magnetite attracts objects containing iron and is a ferromagnet.*

There are different ways to describe magnets. Some magnets are made of iron, nickel, cobalt, or mixtures of those metals. Magnets made with these metals have strong magnetic properties and are called *ferromagnets*. Look at **Figure 8.** The mineral magnetite is an example of a naturally occurring ferromagnet. Another kind of magnet is the *electromagnet*. This is a magnet made by an electric current. An electromagnet usually has an iron core.

Reading Check What are ferromagnets?

Temporary and Permanent Magnets

Magnets can also be described as temporary magnets or permanent magnets. *Temporary magnets* are made from materials that are easy to magnetize. But they tend to lose their magnetization easily. Soft iron is iron that is not mixed with any other materials. It can be made into temporary magnets. *Permanent magnets* are difficult to magnetize. But they tend to keep their magnetic properties longer than temporary magnets do. Some permanent magnets are made with alnico (AL ni KOH)—an alloy of aluminum, nickel, cobalt, and iron.

Earth as a Magnet

One end of every magnet points to the north if the magnet can spin. For more than 2,000 years, travelers have used this property to find their way. In fact, you use this when you use a compass, because a compass has a freely spinning magnet.

One Giant Magnet

In 1600, an English physician named William Gilbert suggested that magnets point to the north because Earth is one giant magnet. In fact, Earth behaves as if it has a bar magnet running through its center. The poles of this imaginary magnet are located near Earth's geographic poles.

Poles of a Compass Needle

If you put a compass on a bar magnet, the marked end of the needle points to the south pole of the magnet. Does that surprise you? Opposite poles of magnets attract each other. A compass needle is a small magnet. And the tip that points to the north is the needle's north pole. Therefore, the point of a compass needle is attracted to the south pole of a magnet.

South Magnetic Pole near North Geographic Pole

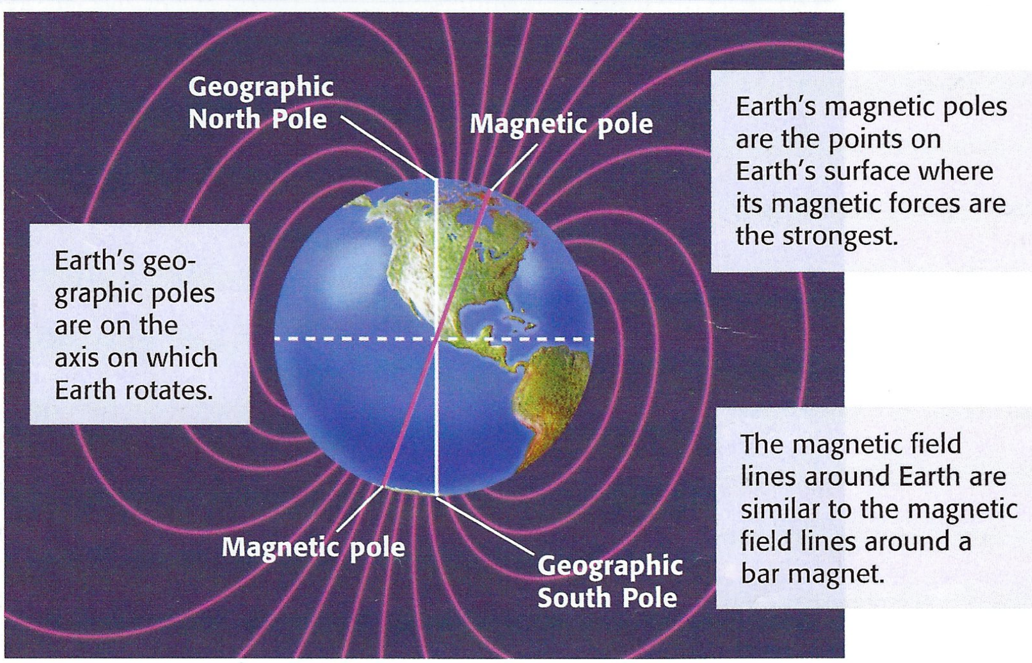
Look at **Figure 9.** A compass needle points north because the magnetic pole of Earth that is closest to the geographic North Pole is a magnetic *south* pole. A compass needle points to the north because its north pole is attracted to a very large magnetic south pole.

Quick Lab

Model of Earth's Magnetic Field

1. Place a **bar magnet** on a **sheet of butcher paper.** Draw a circle on the paper with a diameter larger than the bar magnet. This represents the surface of the Earth. Label Earth's North Pole and South Pole.
2. Place the bar magnet under the butcher paper, and line up the bar magnet with the poles.
3. Sprinkle some **iron filings** lightly around the perimeter of the circle. Describe and sketch the pattern you see.

Figure 9 Earth's Geographic and Magnetic Poles



The Core of the Matter

Although you can think of Earth as having a giant bar magnet through its center, there isn't really a magnet there. The temperature of Earth's core (or center) is very high. The atoms in it move too violently to stay lined up in domains.

Scientists think that Earth's magnetic field is made by the movement of electric charges in the Earth's core. The Earth's core is made mostly of iron and nickel. The inner core is solid because it is under great pressure. The outer core is liquid because the pressure is not as high. As Earth rotates, the liquid in the core flows. Electric charges move, which makes a magnetic field.

Reading Check **What do scientists think causes Earth's magnetic field?**

CONNECTION TO Social Studies

History of the Compass Records from the first century BCE found in China show that people knew that the mineral lodestone (magnetite) would align to the north. But not until about 1,200 years later were floating compasses used for navigation. Research early compasses, and build a working model of one. Demonstrate to your class how it works.

ACTIVITY

A Magnetic Light Show

Look at **Figure 10.** The beautiful curtain of light is called an *aurora* (aw RAWR uh). Earth's magnetic field plays a part in making auroras. An aurora is formed when charged particles from the sun hit oxygen and nitrogen atoms in the air. The atoms become excited and then give off light of many colors.

Earth's magnetic field blocks most of the charged particles from the sun. But the field bends inward at the magnetic poles. As a result, the charged particles can crash into the atmosphere at and near the poles. Auroras seen near Earth's North Pole are called the *northern lights,* or aurora borealis (aw RAWR uh BAWR ee AL is). Auroras seen near the South Pole are called the *southern lights,* or aurora australis (aw RAWR uh aw STRAY lis).

Figure 10 *An aurora is an amazing light show in the sky.*

SECTION Review

Summary

- All magnets have two poles. The north pole will always point to the north if allowed to rotate freely. The other pole is called the south pole.
- Like magnetic poles repel each other. Opposite magnetic poles attract.
- Every magnet is surrounded by a magnetic field. The shape of the field can be shown with magnetic field lines.
- A material is magnetic if its domains line up.
- Magnets can be classified as ferromagnets, electromagnets, temporary magnets, and permanent magnets.
- Earth acts as if it has a big bar magnet through its core. Compass needles and the north poles of magnets point to Earth's magnetic south pole, which is near Earth's geographic North Pole.
- Auroras are most commonly seen near Earth's magnetic poles because Earth's magnetic field bends inward at the poles.

Using Key Terms

1. Use the following terms in the same sentence: *magnet, magnetic force,* and *magnetic pole.*

Understanding Key Ideas

2. What metal is used to make ferromagnets?
   a. iron
   b. cobalt
   c. nickel
   d. All of the above
3. Name three properties of magnets.
4. Why are some iron objects magnetic and others not magnetic?
5. How are temporary magnets different from permanent magnets?

Critical Thinking

6. **Forming Hypotheses** Why are auroras more commonly seen in places such as Alaska and Australia than in places such as Florida and Mexico?
7. **Applying Concepts** Explain how you could use magnets to make a small object appear to float in air.
8. **Making Inferences** Earth's moon has no atmosphere and has a cool, solid core. Would you expect to see auroras on the moon? Explain your answer.

Interpreting Graphics

The image below shows a model of Earth as a large magnet. Use the image below to answer the questions that follow.

9. Which magnetic pole is closest to the geographic North Pole?
10. Is the magnetic field of Earth stronger near the middle of Earth (in Mexico) or at the bottom of Earth (in Antarctica)? Explain your answer.

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