SECTION 1

# The Nature of Magnetism

## DISCOVER — ACTIVITY

### What Do All Magnets Have in Common?

1. Obtain a bar magnet and a horseshoe magnet.
2. See how many paper clips you can make stick to different parts of each magnet.
3. Draw a diagram showing the number and location of paper clips on each magnet.

#### Think It Over

***Observing*** Where does each magnet hold the greatest number of paper clips? What similarities do you observe between the two magnets?

### GUIDE FOR READING

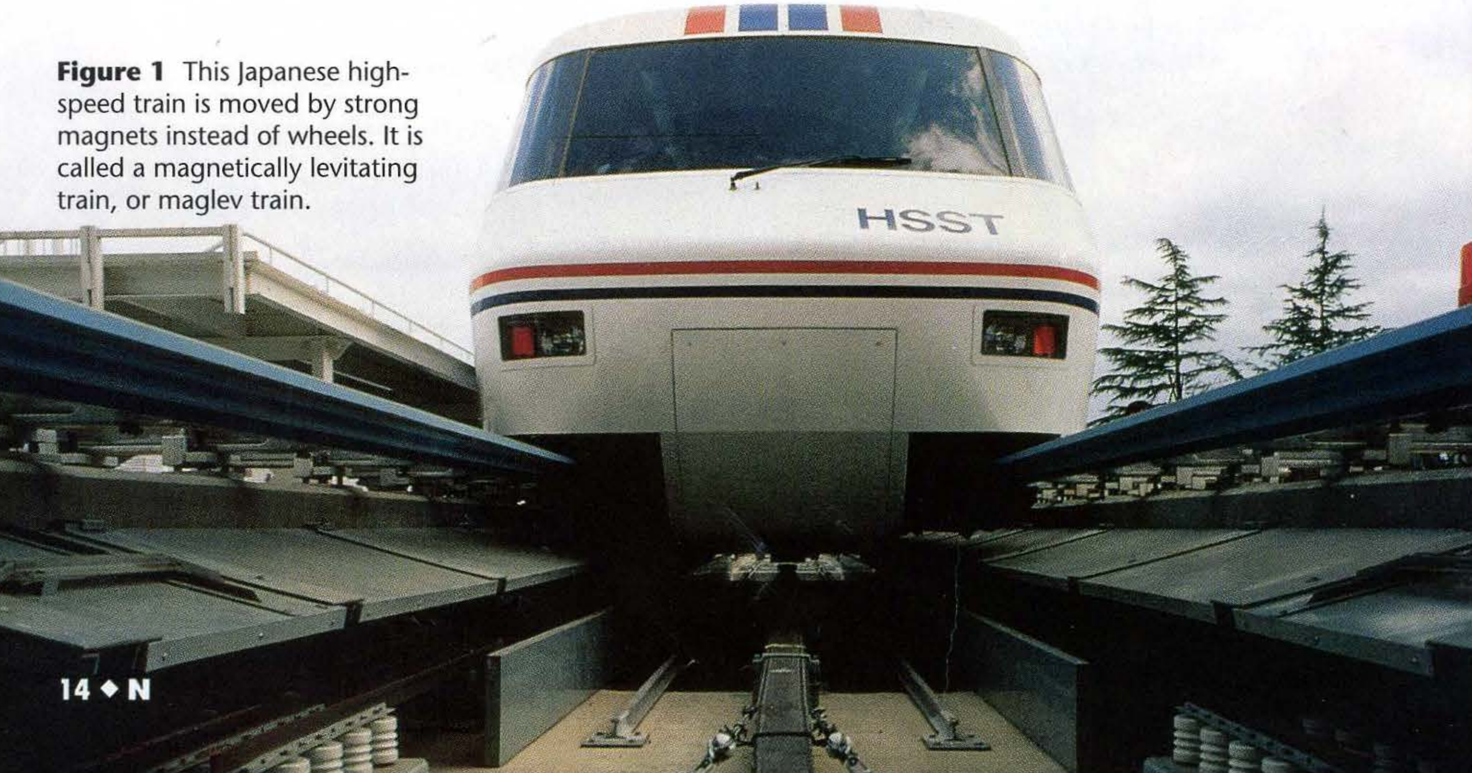
- **How do magnetic poles interact?**
- **What is the shape of magnetic lines of force?**
- **How are the domains of a magnet arranged?**

***Reading Tip*** **As you read, use the headings to make an outline of the main ideas and supporting details about magnetism and electricity.**

Imagine zooming along in a train that glides without even touching the ground. You feel no vibration and hear no noise from solid steel tracks. You can just sit back and relax as you speed toward your destination at nearly 400 kilometers per hour.

Are you dreaming? No, you are not. Although you have probably not ridden on such a train, experimental trains capable of floating a few centimeters in air do exist. What makes them float? Believe it or not, magnets make them float.

**Figure 1** This Japanese high-speed train is moved by strong magnets instead of wheels. It is called a magnetically levitating train, or maglev train.



## Magnets

When you think of magnets, you might think about the magnets that hold notes on your refrigerator. But magnets can also be found in many familiar devices, such as doorbells, televisions, and computers.

Magnets have many modern uses, but they are not new. More than 2000 years ago, people living in a region known as Magnesia discovered an unusual rock. (Magnesia is in Greece.) The rock attracted materials that contained iron. It contained a mineral that we call magnetite. Both the word *magnetite* and the word *magnet* come from the name "Magnesia." **Magnetism** is the attraction of a magnet for another object.

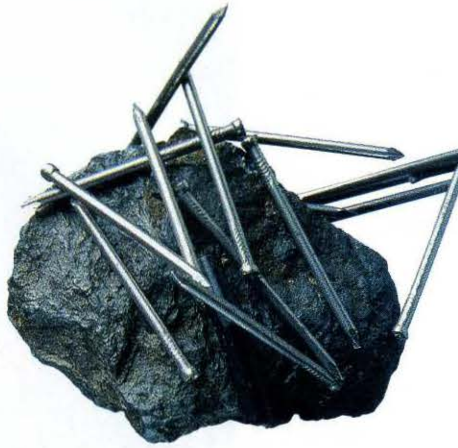


**Figure 2** Magnetic rocks contain the mineral magnetite.

About a thousand years ago, people in other parts of the world discovered another interesting property of magnets. If they allowed the magnetic rock to swing freely from a string, one part of the rock would always point in the same direction. That direction was toward a certain northern star, called the leading star, or lodestar. For this reason, magnetic rocks also became known as lodestones.

## Magnetic Poles

The magnets with which you are familiar are not found in nature, but they are made to have the same properties as lodestone. Any magnet, no matter what its shape, has two ends, each one called a **magnetic pole.** A pole is the area of a magnet where the magnetic effect is strongest. Just as one end of a piece of magnetite always points toward the north star, one pole of a magnet will also point north and is labeled the north pole. The other pole is labeled the south pole. Two north poles or two south poles are a pair of like poles. A north pole and a south pole are a pair of unlike, or opposite poles.

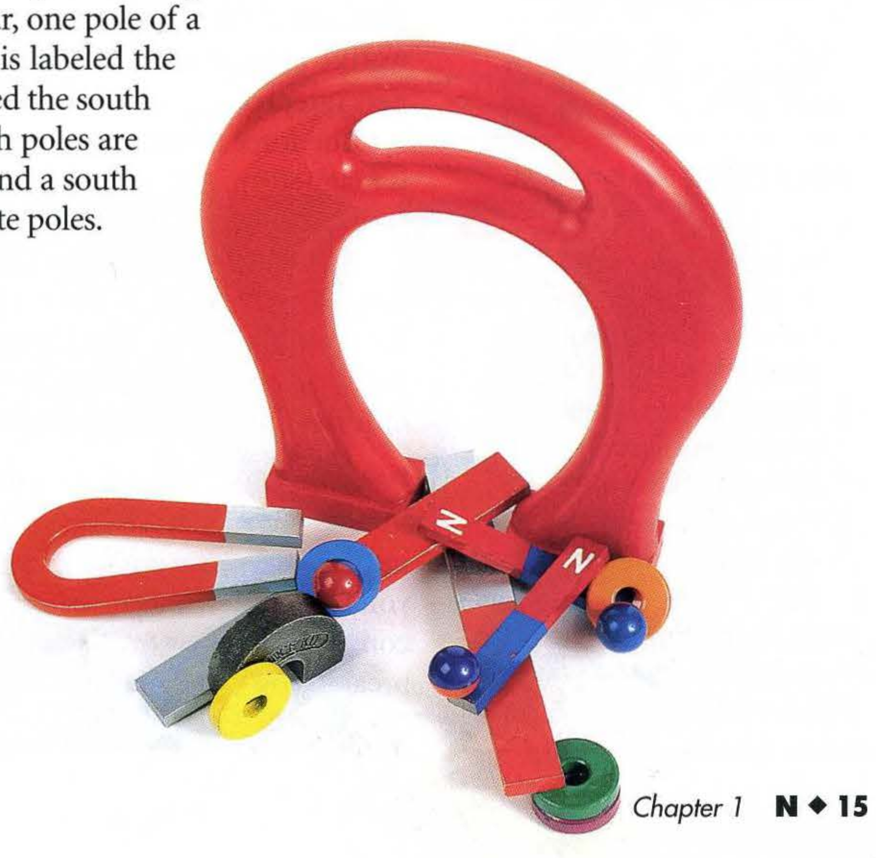


**Figure 3** Modern magnets come in a variety of shapes and sizes. *Classifying How many different shapes of magnets can you identify in the photograph?*

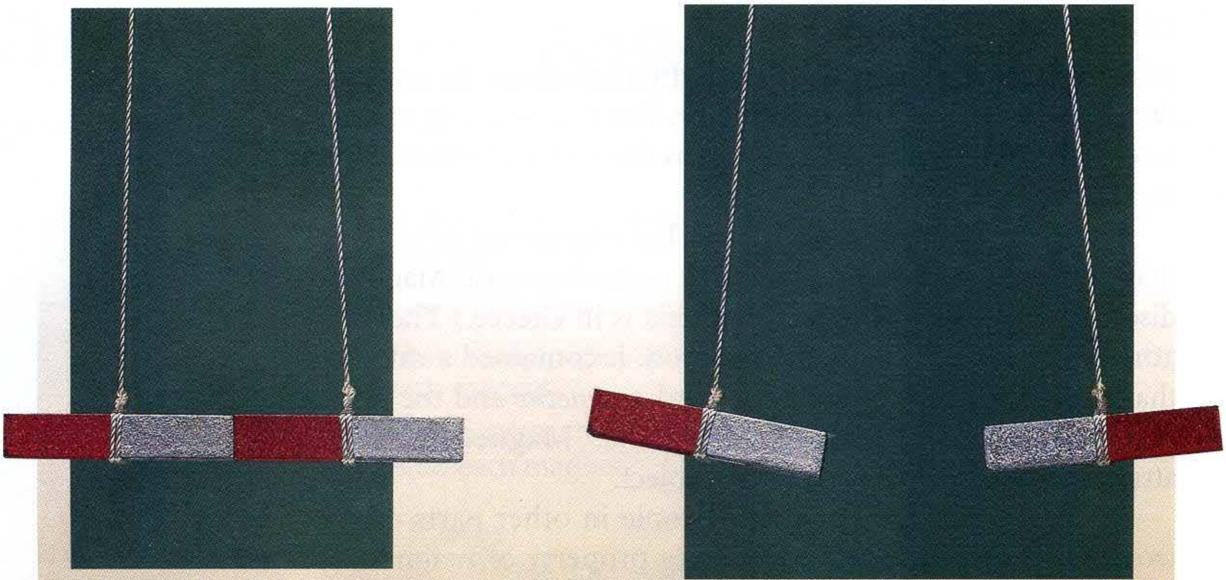


**Figure 4** Two bar magnets suspended by strings are brought near each other. *Interpreting Photographs What force is acting between the magnets in each photograph?*

**Interactions Between Magnetic Poles** What happens if you bring two magnets together? The answer depends on how you hold the poles of the magnets. If you bring two north poles together, the magnets push away from each other. The same is true if two south poles are brought together. However, if you bring the north pole of one magnet near the south pole of another, the two magnets attract one another. **Magnetic poles that are alike repel each other and magnetic poles that are unlike attract each other.** Figure 4 shows how two bar magnets interact.

The force of attraction or repulsion between magnetic poles is magnetism. Any material that exerts magnetic forces is considered a magnet.

The maglev train you read about earlier depends on magnetism. Magnets in the bottom of the train and in the guideway on the ground have like poles. Since like poles repel, the two magnets push each other away. The result is that the train car is lifted up, or levitated. Other magnets push and pull the train forward.

**Paired Poles** What do you think happens if you break a magnet in two? Will you have a north pole in one hand and a south pole in the other? The answer is no. Rather than two separate poles, you will have two separate magnets. Each smaller magnet will be complete with its own north pole and south pole. And if you break those two halves again, you will then have four magnets.

✓ ***Checkpoint*** *What is a magnetic pole?*

## Sharpen your Skills

### Observing ACTIVITY

1. Use a pencil to poke a hole in the bottom of a foam cup. Turn the cup upside-down and stand the pencil in the hole.
2. Place two circular magnets on the pencil, so that their like sides are together.
3. Remove the top magnet. Flip it over and replace it on the pencil.

What happens to the magnets in each case? Explain your observations.

## Magnetic Fields

The magnetic force is strongest at the poles of a magnet, but it is not limited to the poles. Magnetic forces are exerted all around a magnet. The region of magnetic force around a magnet is known as its **magnetic field.** Magnetic fields allow magnets to interact without touching.

Figure 5A shows the magnetic field of a bar magnet. The lines, called **magnetic field lines,** map out the magnetic field around a magnet. **Magnetic field lines spread out from one pole, curve around a magnet, and return to the other pole.** The lines form complete loops from pole to pole and never cross.

Although you can't actually see a magnetic field, you can see its effects, as shown in Figure 5B. This photograph shows iron filings sprinkled on a sheet of plastic over a magnet. The magnetic forces act on the iron filings so that they point toward the poles of the magnet. The result is that the iron filings form a pattern similar to the magnetic field lines in Figure 5A.

The iron filings and the diagram are both on flat surfaces. But a magnetic field exists in three dimensions. You can see in Figure 5C that the magnetic field completely surrounds the magnet.

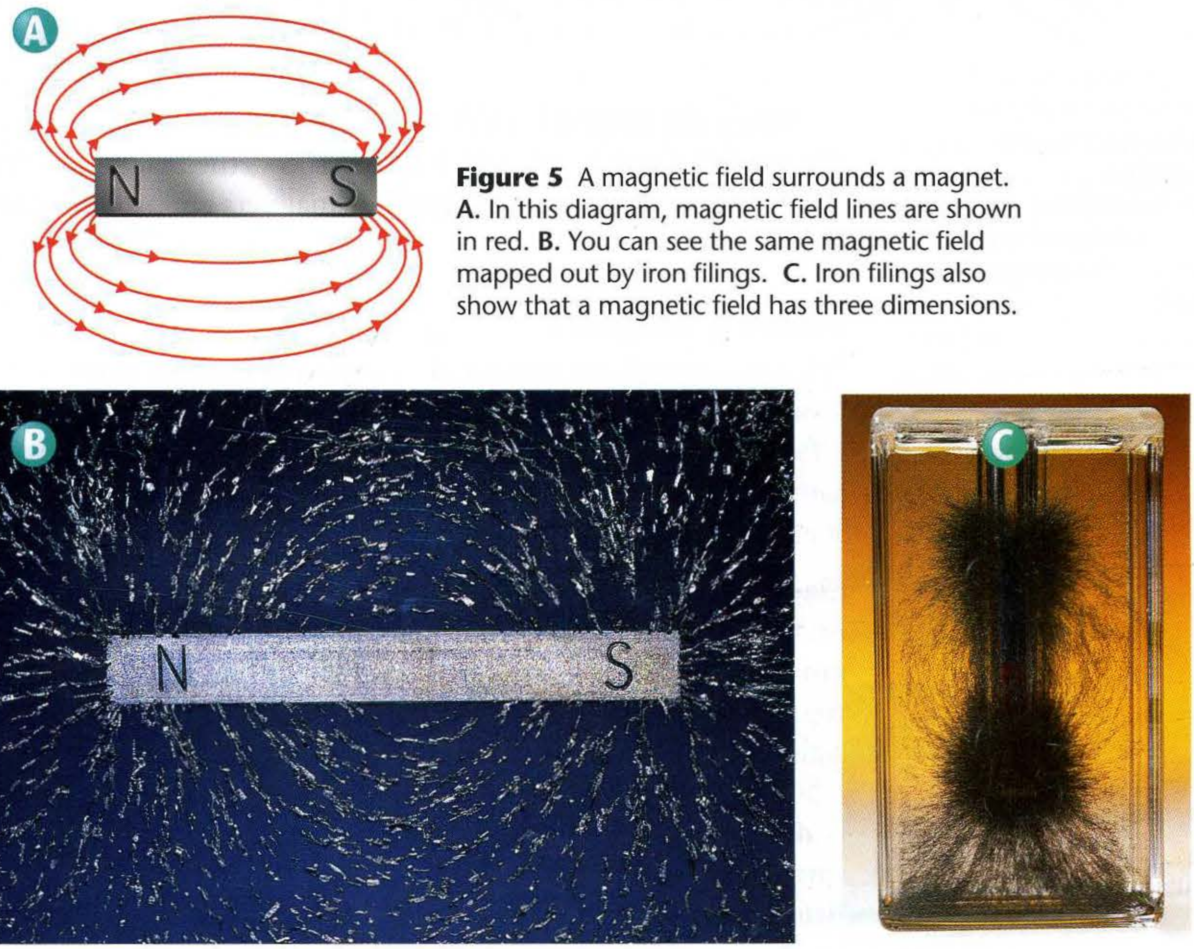



**Figure 5** A magnetic field surrounds a magnet. **A.** In this diagram, magnetic field lines are shown in red. **B.** You can see the same magnetic field mapped out by iron filings. **C.** Iron filings also show that a magnetic field has three dimensions.

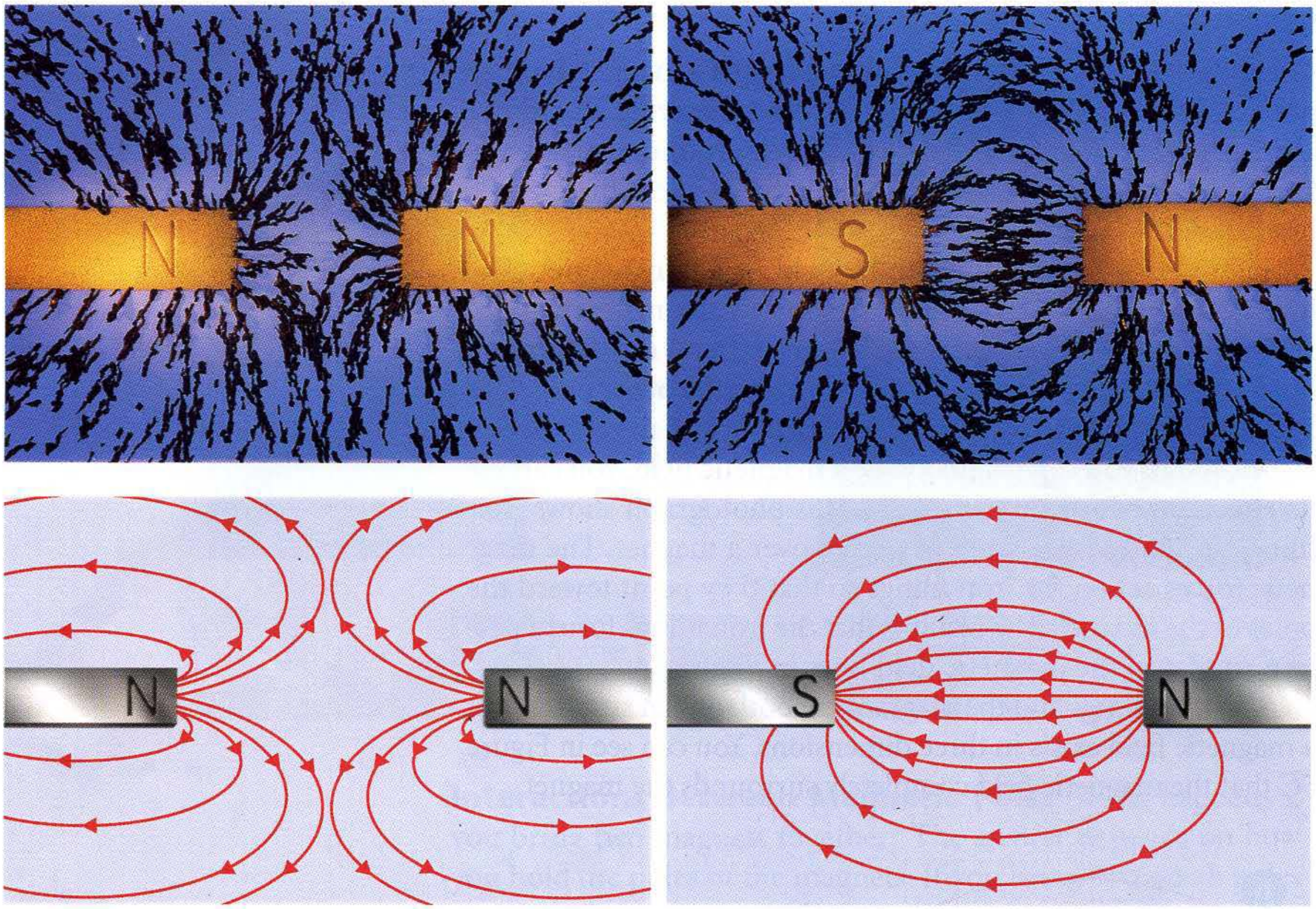



**Figure 6** The magnetic field of each bar magnet is altered when two bar magnets are brought together.
***Applying Concepts*** *What do these photos and diagrams show about the interaction between magnetic poles?*

When the magnetic fields of two or more magnets overlap, the result is a combined field. Figure 6 shows the magnetic fields produced when the poles of two bar magnets are brought near each other.

## Inside a Magnet

What happens if you bring a piece of wood, glass, or plastic near a pile of paper clips? Nothing happens. These materials have no effect on the paper clips. But if you bring a bar magnet near the same pile, the paper clips will cling to the magnet. Why do some materials have strong magnetic fields while others do not?

**Electron Spin** The magnetic properties of a material depend on the structure of its atoms. All matter is made up of atoms. An **atom** is the smallest particle of an element that has the properties of that element. An **element** is one of about 100 basic materials that make up all matter.

The center of every atom is called a **nucleus.** The nucleus contains particles within it. **Protons** are nuclear particles that carry a positive charge. Orbiting the nucleus are other tiny particles called **electrons,** which carry a negative charge. All of the electrons in an atom spin as they orbit the nucleus. A moving electron produces a magnetic field. The spinning and orbiting motion of the electrons make each atom a tiny magnet.

**Magnetic Domains** In most materials the magnetic fields of the atoms point in random directions. The result is that the magnetic fields cancel one another almost entirely. The magnetism of most materials is so weak that you cannot usually detect it.

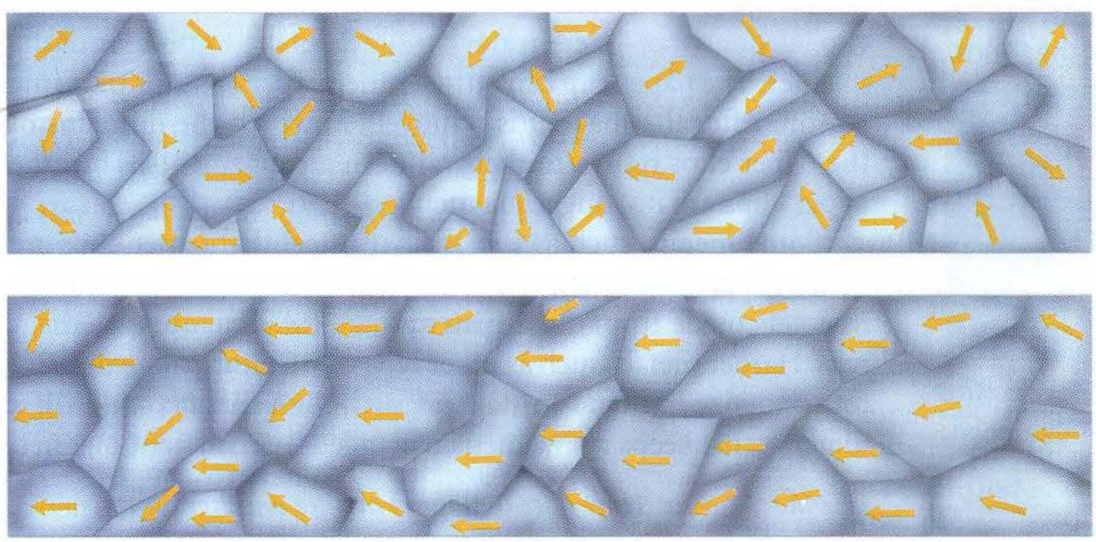
In certain materials, the magnetic fields of the spinning electrons of many atoms are aligned with one another. A cluster of billions of atoms that all have magnetic fields that are lined up in the same way is known as a **magnetic domain.** The entire domain acts like a bar magnet with a north pole and a south pole.

In a material that is not magnetized, the domains point in random directions as shown in Figure 7. The magnetic fields exerted by some of the domains cancel the magnetic fields exerted by other domains. The result is that the material is not a magnet. **In a magnetized material all or most of the domains are arranged in the same direction.** In other words, the domains are aligned.

**Magnetic Materials** A material can be a strong magnet if it forms magnetic domains. A material that shows strong magnetic effects is said to be a **ferromagnetic material.** The word *ferromagnetic* comes from the Latin *ferrum*, which means "iron." Iron, nickel, and cobalt are the common ferromagnetic materials. Others include the elements samarium and neodymium, which can be made into magnets that are extremely powerful. Some very strong magnets are also made from mixtures, or alloys, of several metals.

☑ ***Checkpoint*** *How is magnetism related to domains?*

**Figure 7** The arrows represent the domains of a material. The arrows point toward the north pole of each domain. **Comparing and Contrasting** *How does the arrangement of domains differ between magnetized iron and unmagnetized iron?*



*Unmagnetized Iron*

*Magnetized Iron*

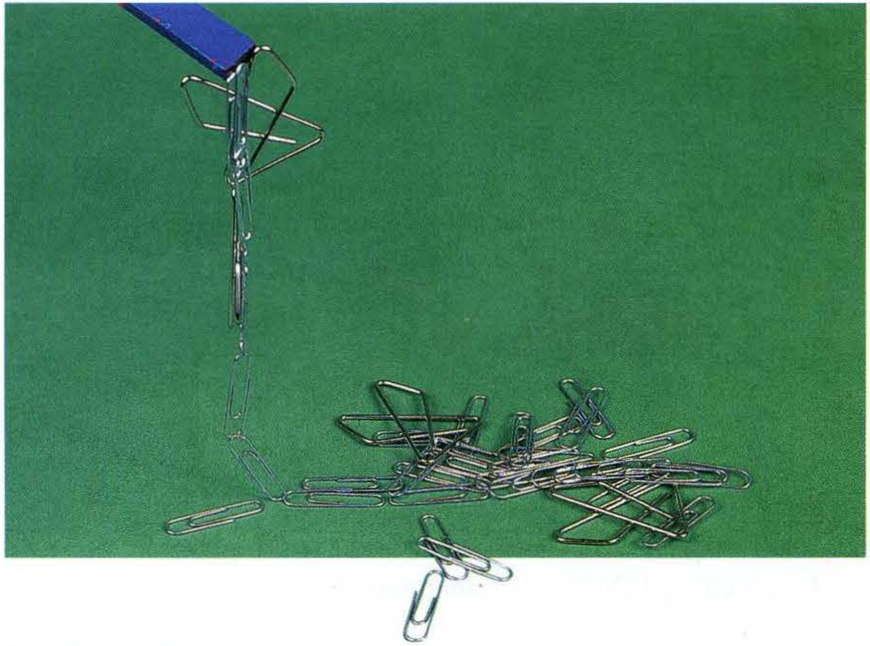


**Figure 8** The magnet attracts the metal paper clips. *Applying Concepts How can a paper clip be attracted to a magnet?*

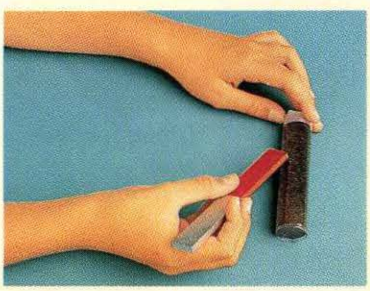
## TRY THIS

### How Attractive!

ACTIVITY

You can use iron filings to find out how materials become magnetic.

1. Fill a clear plastic tube about two-thirds full with iron filings. Seal the tube.
2. Observe the arrangement of the filings.
3. Rub the tube lengthwise about 30 times in the same direction with one end of a strong magnet.
4. Again observe the arrangement of the filings.



***Making Models*** How do the iron filings in the tube model magnetic domains?

## Making Magnets

You know that magnetite exists in nature. The magnets you use everyday, however, are made by people. A magnet can be made from a ferromagnetic material. This is done by placing the unmagnetized material in a strong magnetic field or by rubbing it with one pole of a strong magnet.

If the magnetic field is strong enough, two processes take place. First, the domains that point in the direction of the magnetic field become larger by lining up the fields of neighboring domains. Second, domains that are not pointing in the same direction as the magnetic field rotate toward the magnetic field. The result is that the majority of domains line up in the same direction. With its domains aligned, the material is a magnet.

The ability to make a magnet explains why an unmagnetized object, such as a paper clip, can be attracted to a magnet. Paper clips are made of steel, which is mostly iron. The magnet's field causes domains in the paper clip to line up slightly so that the clip becomes a magnet. Its north pole faces the south pole of the magnet. The paper clip can attract other paper clips for the same reason. After the magnet is removed, however, the domains of the paper clips return to their random arrangements. Thus the paper clips are no longer magnetic.

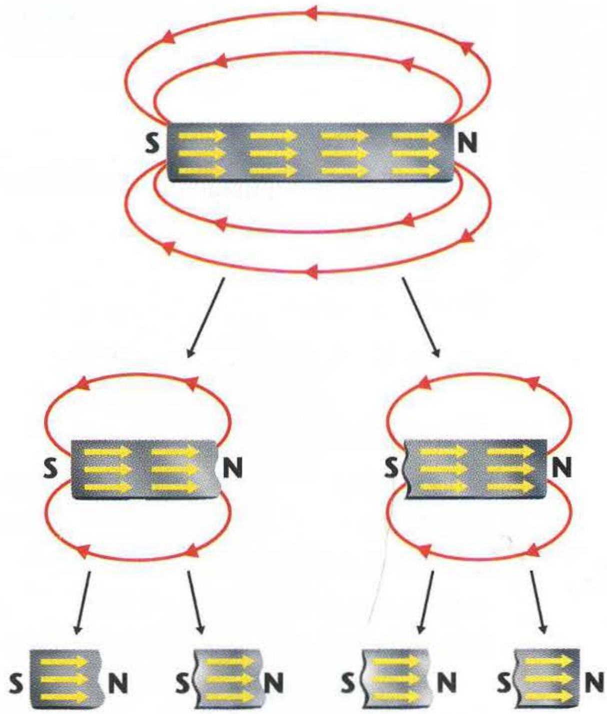
Some metals, such as the ordinary steel that paper clips are made of, are easy to magnetize but lose their magnetism quickly. Magnets made from these materials are called temporary magnets. Harder metals, such as other types of steel, are more difficult to magnetize but tend to stay magnetized. A magnet made of a material that keeps its magnetism is called a **permanent magnet.**

☑ *Checkpoint* ***How does a magnet attract another object?***

## Destroying Magnets

Just as paper clips lose their magnetism when their domains become randomly arranged, a permanent magnet can also become unmagnetized. One way is to drop it or strike it hard. If a magnet is hit hard, its domains can be knocked out of alignment. Heating a magnet will also destroy its magnetism. When an object is heated, its particles move faster and more randomly. This makes it more difficult for all the domains to stay lined up. In fact, above a certain temperature a material loses the property of ferromagnetism. The temperature depends on the material.

**Figure 9** No matter how many times a magnet is cut in half, each piece retains its magnetic properties.




## Breaking Magnets

Now that you know about domains, you can understand why breaking a magnet in half does not result in two pieces that are individual poles. Within the original bar magnet shown in Figure 9, there are many north and south poles facing each other. These poles balance each other.

At the ends of the magnet, there are many poles that are not facing an opposite pole. This produces strong magnetic effects at the north and south poles. If the magnet is cut in half, the domains will still be lined up in the same way. So the shorter pieces will still have strong ends made up of many north or south poles. Figure 9 shows the results of dividing a magnet into four pieces.

## Section 1 Review

1. What happens if you bring together two like poles? Two unlike poles?
2. How are magnetic domains arranged in a magnet? How are they arranged in an unmagnetized object?
3. What parts of an atom produce magnetism?
4. How is a magnet made?
5. **Thinking Critically** **Applying Concepts** Iron filings align with the magnetic field of a bar magnet. What must be happening to the domains in the iron filings in the magnetic field?

**Check Your Progress**

CHAPTER PROJECT 1

Gather materials for the different parts of your fishing rod. Consider such items as a broom handle, dowel, or meter stick for the rod. You'll also need a string. Draw a basic design for your fishing rod. Make a model of the rod with a permanent magnet. Test how easily you can maneuver your model.