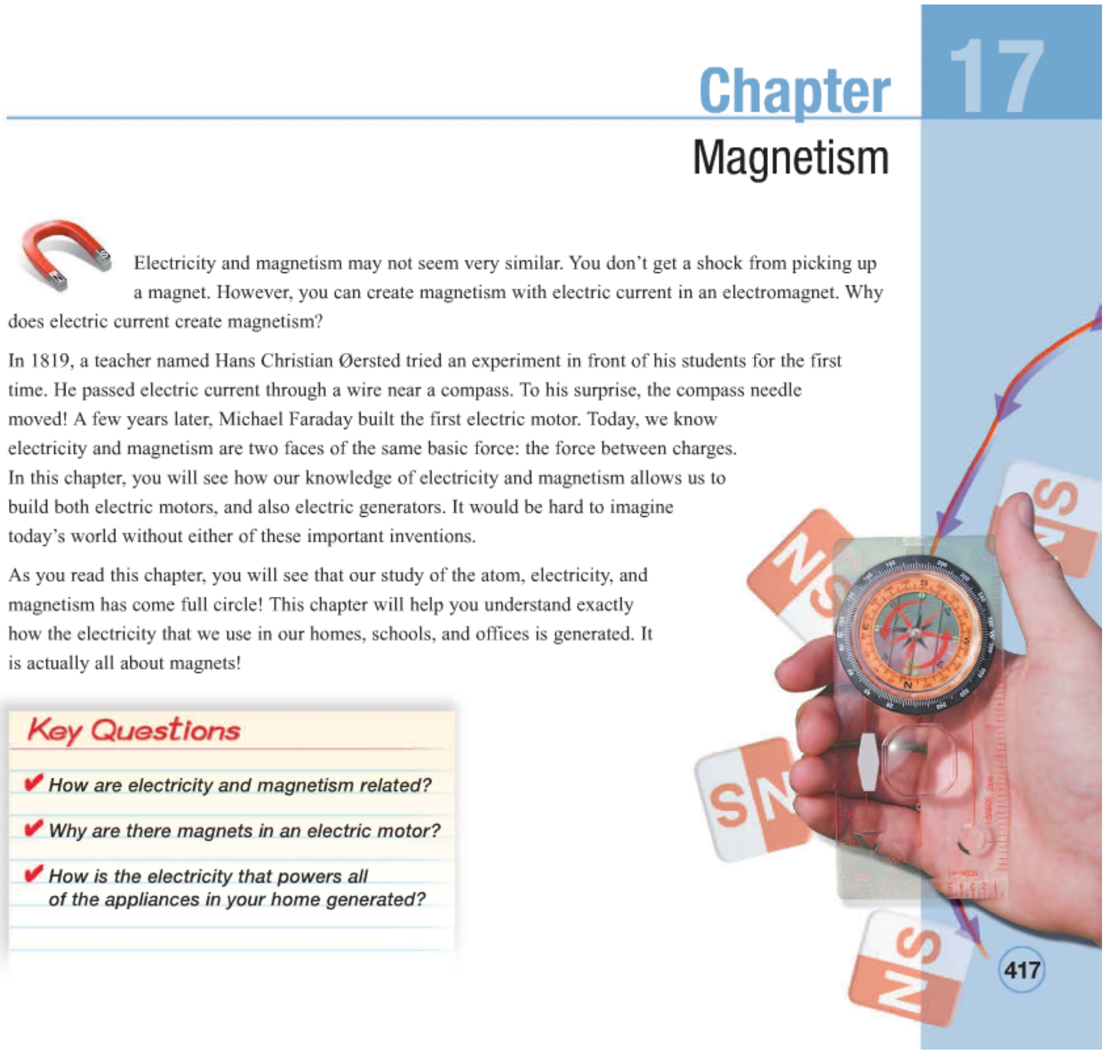


Chapter 17

Magnetism

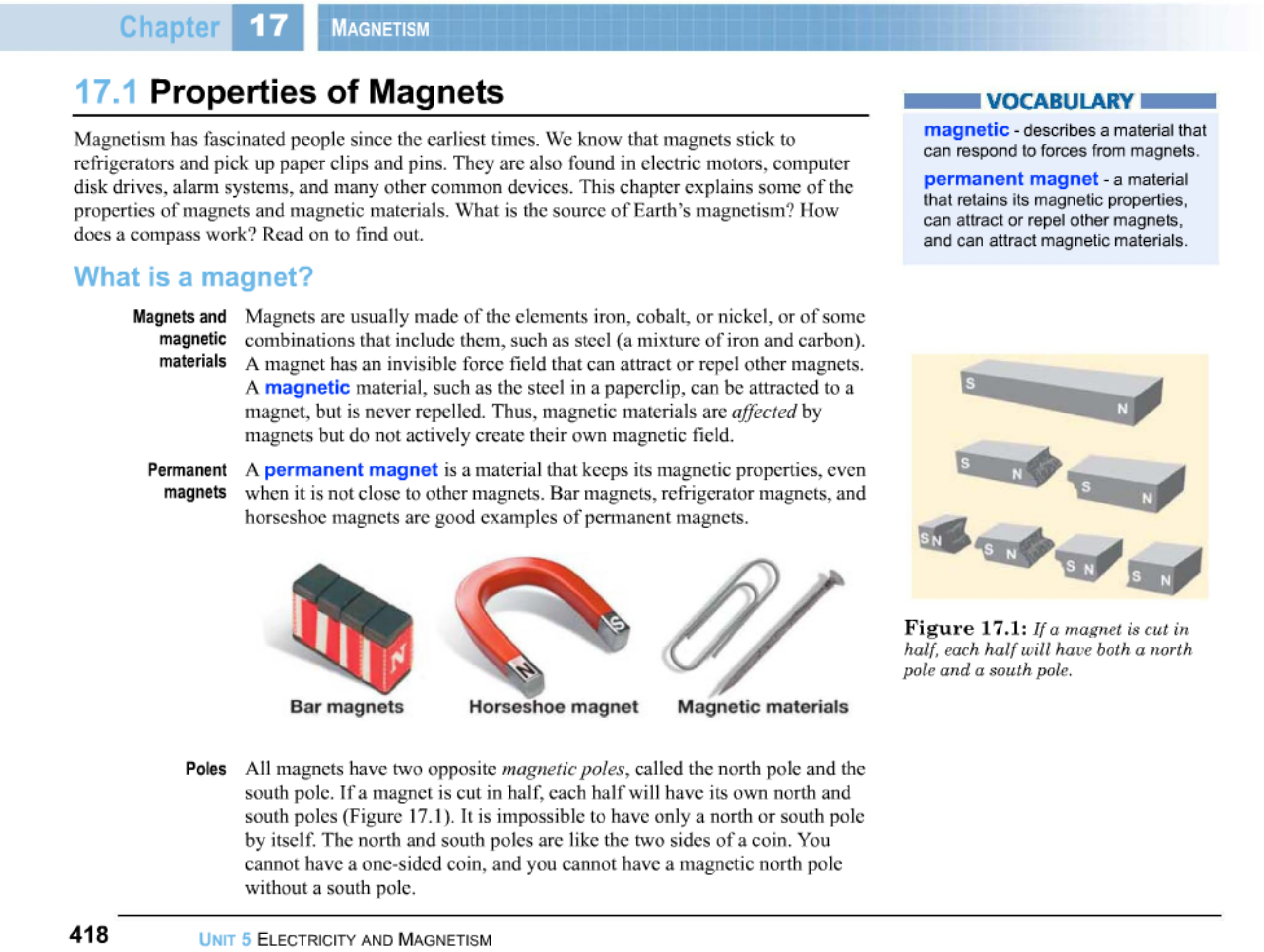
Electricity and magnetism may not seem very similar. You don't get a shock from picking up a magnet. However, you can create magnetism with electric current in an electromagnet. Why does electric current create magnetism?

In 1819, a teacher named Hans Christian Øersted tried an experiment in front of his students for the first time. He passed electric current through a wire near a compass. To his surprise, the compass needle moved! A few years later, Michael Faraday built the first electric motor. Today, we know electricity and magnetism are two faces of the same basic force: the force between charges. In this chapter, you will see how our knowledge of electricity and magnetism allows us to build both electric motors, and also electric generators. It would be hard to imagine today's world without either of these important inventions.

As you read this chapter, you will see that our study of the atom, electricity, and magnetism has come full circle! This chapter will help you understand exactly how the electricity that we use in our homes, schools, and offices is generated. It is actually all about magnets!

Key Questions

- ✔ *How are electricity and magnetism related?*
- ✔ *Why are there magnets in an electric motor?*
- ✔ *How is the electricity that powers all of the appliances in your home generated?*



17.1 Properties of Magnets

Magnetism has fascinated people since the earliest times. We know that magnets stick to refrigerators and pick up paper clips and pins. They are also found in electric motors, computer disk drives, alarm systems, and many other common devices. This chapter explains some of the properties of magnets and magnetic materials. What is the source of Earth's magnetism? How does a compass work? Read on to find out.

What is a magnet?

Magnets and magnetic materials Magnets are usually made of the elements iron, cobalt, or nickel, or of some combinations that include them, such as steel (a mixture of iron and carbon). A magnet has an invisible force field that can attract or repel other magnets. A **magnetic** material, such as the steel in a paperclip, can be attracted to a magnet, but is never repelled. Thus, magnetic materials are *affected* by magnets but do not actively create their own magnetic field.

Permanent magnets A **permanent magnet** is a material that keeps its magnetic properties, even when it is not close to other magnets. Bar magnets, refrigerator magnets, and horseshoe magnets are good examples of permanent magnets.

Bar magnets
Horseshoe magnet
Magnetic materials

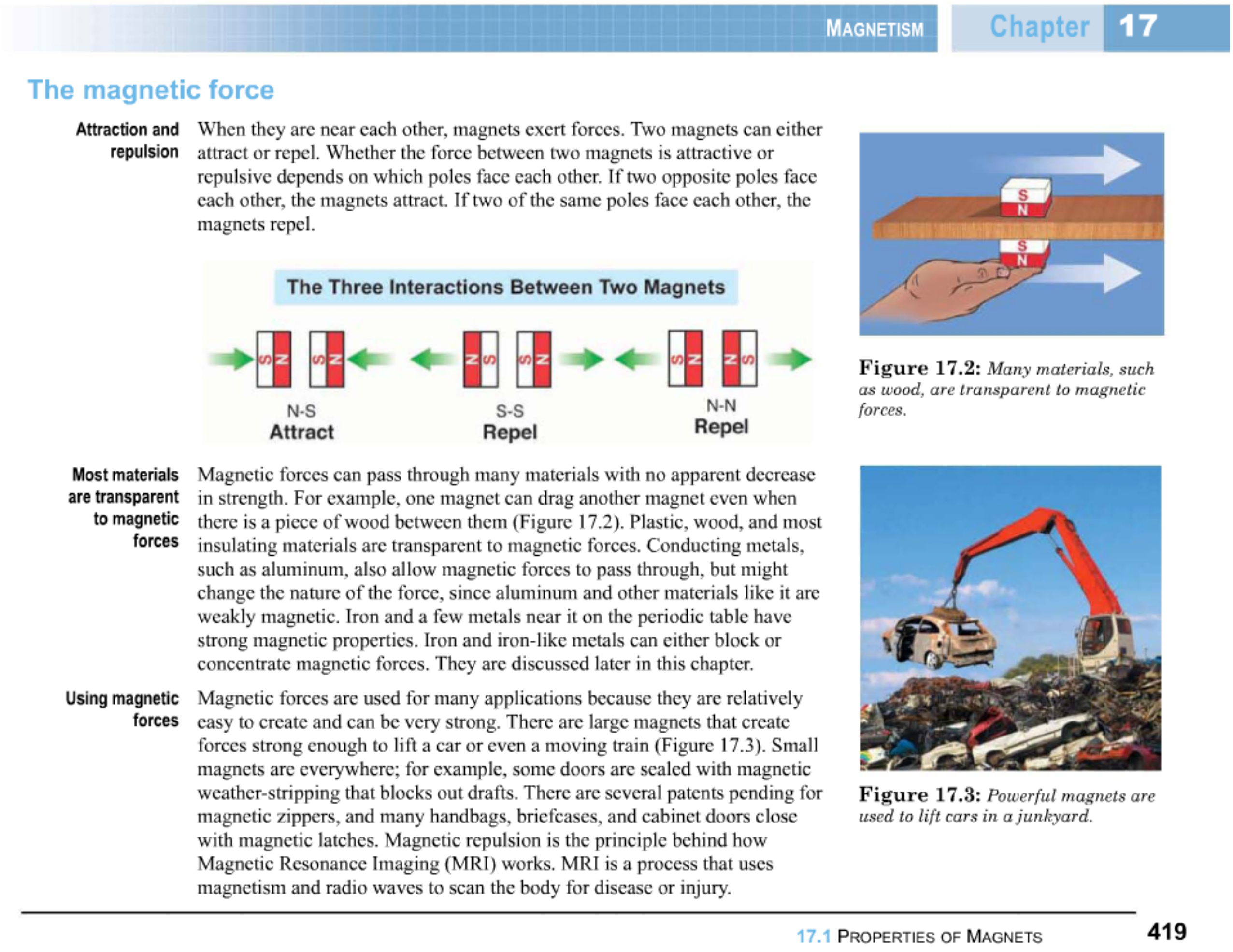
Poles All magnets have two opposite *magnetic poles*, called the north pole and the south pole. If a magnet is cut in half, each half will have its own north and south poles (Figure 17.1). It is impossible to have only a north or south pole by itself. The north and south poles are like the two sides of a coin. You cannot have a one-sided coin, and you cannot have a magnetic north pole without a south pole.

VOCABULARY

magnetic - describes a material that can respond to forces from magnets.

permanent magnet - a material that retains its magnetic properties, can attract or repel other magnets, and can attract magnetic materials.

Figure 17.1: *If a magnet is cut in half, each half will have both a north pole and a south pole.*



MAGNETISM Chapter 17

The magnetic force

Attraction and repulsion When they are near each other, magnets exert forces. Two magnets can either attract or repel. Whether the force between two magnets is attractive or repulsive depends on which poles face each other. If two opposite poles face each other, the magnets attract. If two of the same poles face each other, the magnets repel.

The Three Interactions Between Two Magnets

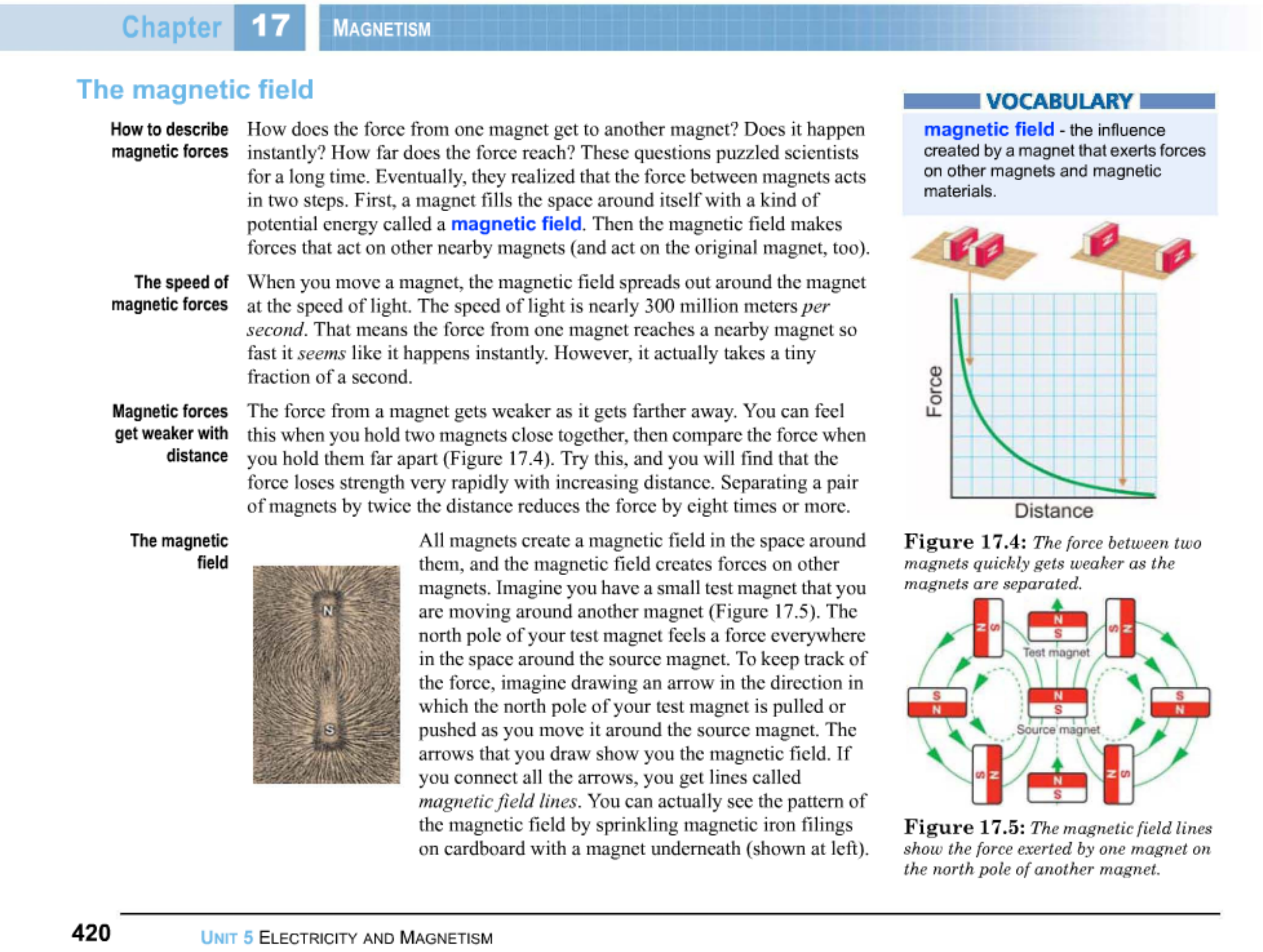
Most materials are transparent to magnetic forces Magnetic forces can pass through many materials with no apparent decrease in strength. For example, one magnet can drag another magnet even when there is a piece of wood between them (Figure 17.2). Plastic, wood, and most insulating materials are transparent to magnetic forces. Conducting metals, such as aluminum, also allow magnetic forces to pass through, but might change the nature of the force, since aluminum and other materials like it are weakly magnetic. Iron and a few metals near it on the periodic table have strong magnetic properties. Iron and iron-like metals can either block or concentrate magnetic forces. They are discussed later in this chapter.

Using magnetic forces Magnetic forces are used for many applications because they are relatively easy to create and can be very strong. There are large magnets that create forces strong enough to lift a car or even a moving train (Figure 17.3). Small magnets are everywhere; for example, some doors are sealed with magnetic weather-stripping that blocks out drafts. There are several patents pending for magnetic zippers, and many handbags, briefcases, and cabinet doors close with magnetic latches. Magnetic repulsion is the principle behind how Magnetic Resonance Imaging (MRI) works. MRI is a process that uses magnetism and radio waves to scan the body for disease or injury.

Figure 17.2: *Many materials, such as wood, are transparent to magnetic forces.*

Figure 17.3: *Powerful magnets are used to lift cars in a junkyard.*

17.1 PROPERTIES OF MAGNETS 419



The magnetic field

How to describe magnetic forces How does the force from one magnet get to another magnet? Does it happen instantly? How far does the force reach? These questions puzzled scientists for a long time. Eventually, they realized that the force between magnets acts in two steps. First, a magnet fills the space around itself with a kind of potential energy called a **magnetic field**. Then the magnetic field makes forces that act on other nearby magnets (and act on the original magnet, too).

The speed of magnetic forces When you move a magnet, the magnetic field spreads out around the magnet at the speed of light. The speed of light is nearly 300 million meters *per second*. That means the force from one magnet reaches a nearby magnet so fast it *seems* like it happens instantly. However, it actually takes a tiny fraction of a second.

Magnetic forces get weaker with distance The force from a magnet gets weaker as it gets farther away. You can feel this when you hold two magnets close together, then compare the force when you hold them far apart (Figure 17.4). Try this, and you will find that the force loses strength very rapidly with increasing distance. Separating a pair of magnets by twice the distance reduces the force by eight times or more.

The magnetic field All magnets create a magnetic field in the space around them, and the magnetic field creates forces on other magnets. Imagine you have a small test magnet that you are moving around another magnet (Figure 17.5). The north pole of your test magnet feels a force everywhere in the space around the source magnet. To keep track of the force, imagine drawing an arrow in the direction in which the north pole of your test magnet is pulled or pushed as you move it around the source magnet. The arrows that you draw show you the magnetic field. If you connect all the arrows, you get lines called *magnetic field lines*. You can actually see the pattern of the magnetic field by sprinkling magnetic iron filings on cardboard with a magnet underneath (shown at left).

VOCABULARY

magnetic field - the influence created by a magnet that exerts forces on other magnets and magnetic materials.

Figure 17.4: *The force between two magnets quickly gets weaker as the magnets are separated.*

Figure 17.5: *The magnetic field lines show the force exerted by one magnet on the north pole of another magnet.*

Earth's magnetic field and compasses

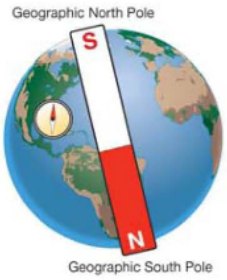
A compass needle is a magnet

A compass needle is a freely spinning magnet. If you bring the south pole of a permanent magnet near the compass needle, the needle's north pole (identified by a red-painted tip) will spin around and point toward the south pole of the permanent magnet (Figure 17.6). This is because opposite poles attract.

North and south poles

The planet Earth *itself* has a magnetic field that comes from the core of the planet. A compass needle spins around until the north-seeking pole of the needle points toward Earth's North Pole. This action has been helpful to explorers for centuries. But doesn't this contradict Figure 17.6? Yes, it is contradictory to say that the north end of the compass needle points north, when you know that, scientifically, the north pole of the needle is always attracted (and points toward) a south magnetic pole. This is an example of an old naming convention that was decided long before people understood how a compass needle really worked. It is customary to say that the north pole of a compass needle points to Earth's North Pole, but technically, it does this because it is attracted to a south magnetic pole.

Geographic and magnetic poles



The true *geographic* North and South Poles are where the Earth's axis of rotation intersects its surface. The North Pole is the northernmost point on Earth's surface. However, as you can see in the illustration at the left, Earth's internal magnetic field poles are actually the opposite of the geographic poles. Now, here is one more interesting point of confusion. Scientists still stick to the old naming convention, and refer to the magnetic pole that is near the geographic North Pole as the magnetic north pole (even though, technically, it's a south pole). Read on to find out *why* we make a distinction between Earth's geographic and magnetic poles.

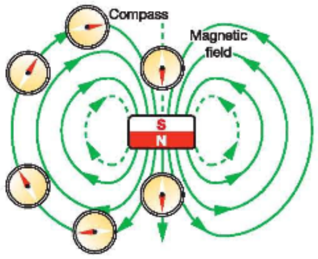
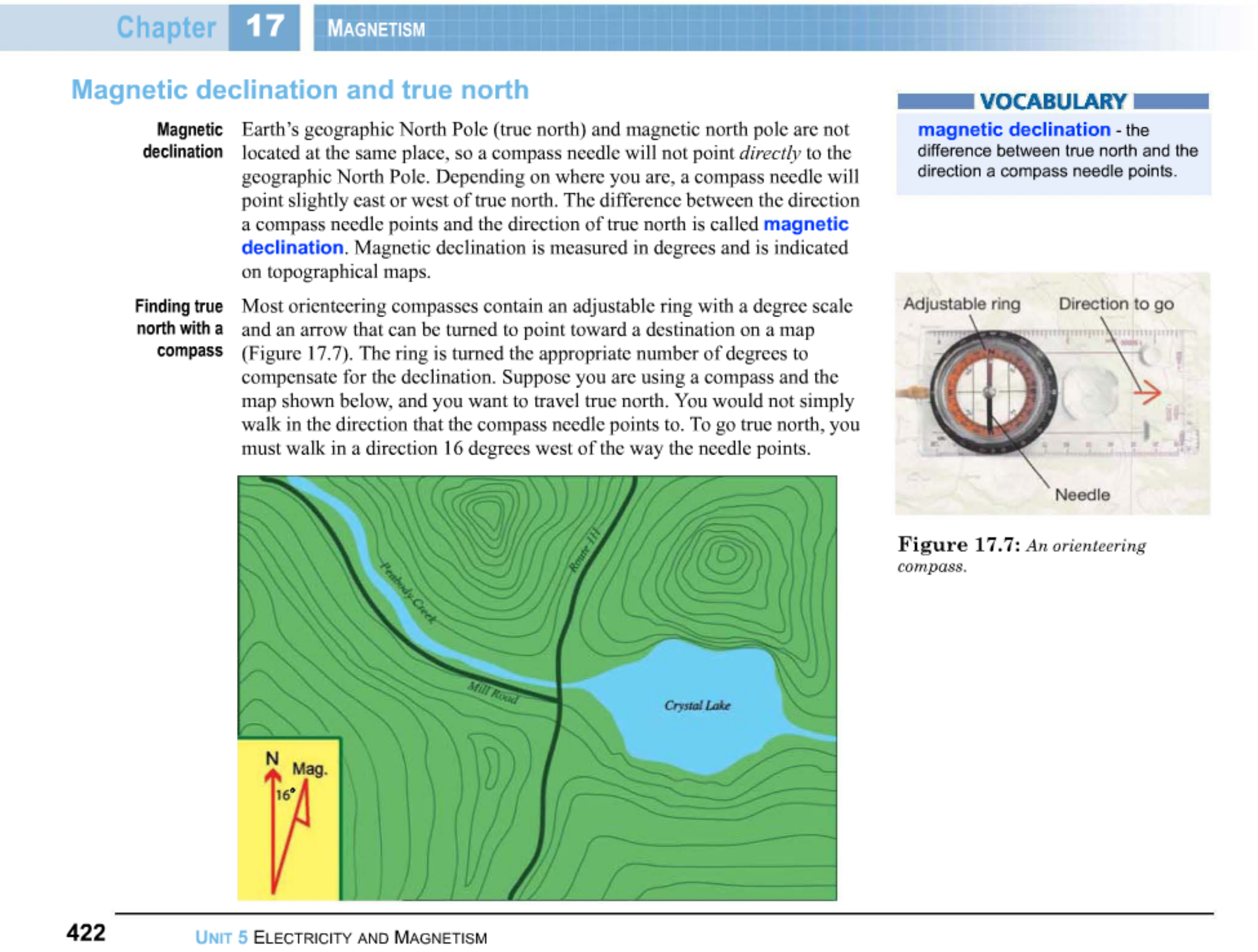


Figure 17.6: *This diagram illustrates how a compass needle interacts with a magnet. Remember, the compass needle is a magnet itself, and the red-painted end of the needle is a north pole.*

SCIENCE FACT

Some Animals Have Biological Compasses

Many organisms, including some species of birds, frogs, fish, turtles, and bacteria, can sense the planet's magnetic field. Migratory birds are the best known examples. Magnetite, a magnetic mineral made of iron oxide, has been found in bacteria and in the brains of birds. Tiny crystals of magnetite may act like compasses and allow these organisms to sense the small magnetic field of Earth. You can find more information about this topic by using your favorite search engine and the keywords "magnetite in birds."



Magnetic declination and true north

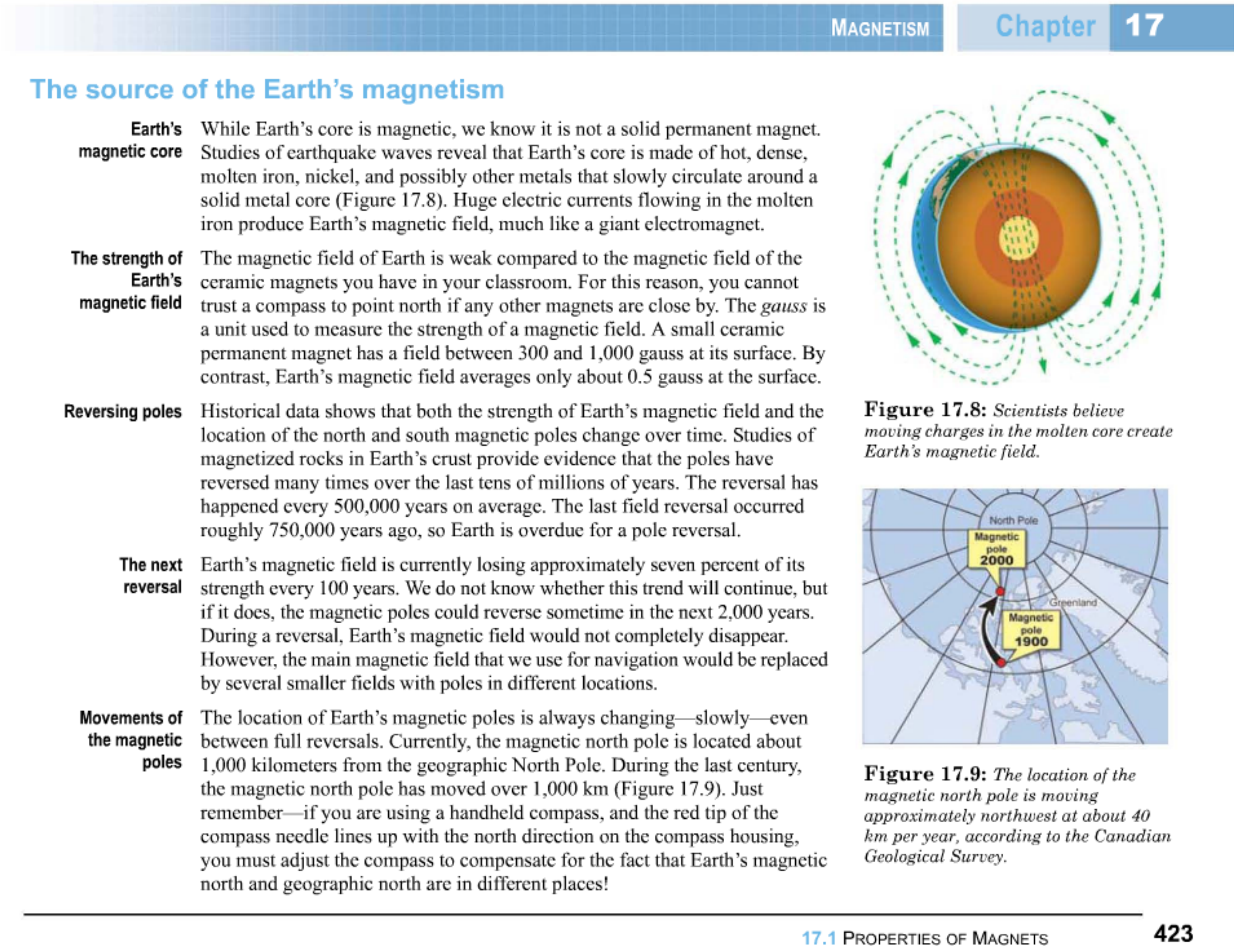
Magnetic declination Earth's geographic North Pole (true north) and magnetic north pole are not located at the same place, so a compass needle will not point *directly* to the geographic North Pole. Depending on where you are, a compass needle will point slightly east or west of true north. The difference between the direction a compass needle points and the direction of true north is called **magnetic declination**. Magnetic declination is measured in degrees and is indicated on topographical maps.

Finding true north with a compass Most orienteering compasses contain an adjustable ring with a degree scale and an arrow that can be turned to point toward a destination on a map (Figure 17.7). The ring is turned the appropriate number of degrees to compensate for the declination. Suppose you are using a compass and the map shown below, and you want to travel true north. You would not simply walk in the direction that the compass needle points to. To go true north, you must walk in a direction 16 degrees west of the way the needle points.

VOCABULARY

magnetic declination - the difference between true north and the direction a compass needle points.

Figure 17.7: *An orienteering compass.*



The source of the Earth's magnetism

Earth's magnetic core While Earth's core is magnetic, we know it is not a solid permanent magnet. Studies of earthquake waves reveal that Earth's core is made of hot, dense, molten iron, nickel, and possibly other metals that slowly circulate around a solid metal core (Figure 17.8). Huge electric currents flowing in the molten iron produce Earth's magnetic field, much like a giant electromagnet.

The strength of Earth's magnetic field The magnetic field of Earth is weak compared to the magnetic field of the ceramic magnets you have in your classroom. For this reason, you cannot trust a compass to point north if any other magnets are close by. The *gauss* is a unit used to measure the strength of a magnetic field. A small ceramic permanent magnet has a field between 300 and 1,000 gauss at its surface. By contrast, Earth's magnetic field averages only about 0.5 gauss at the surface.

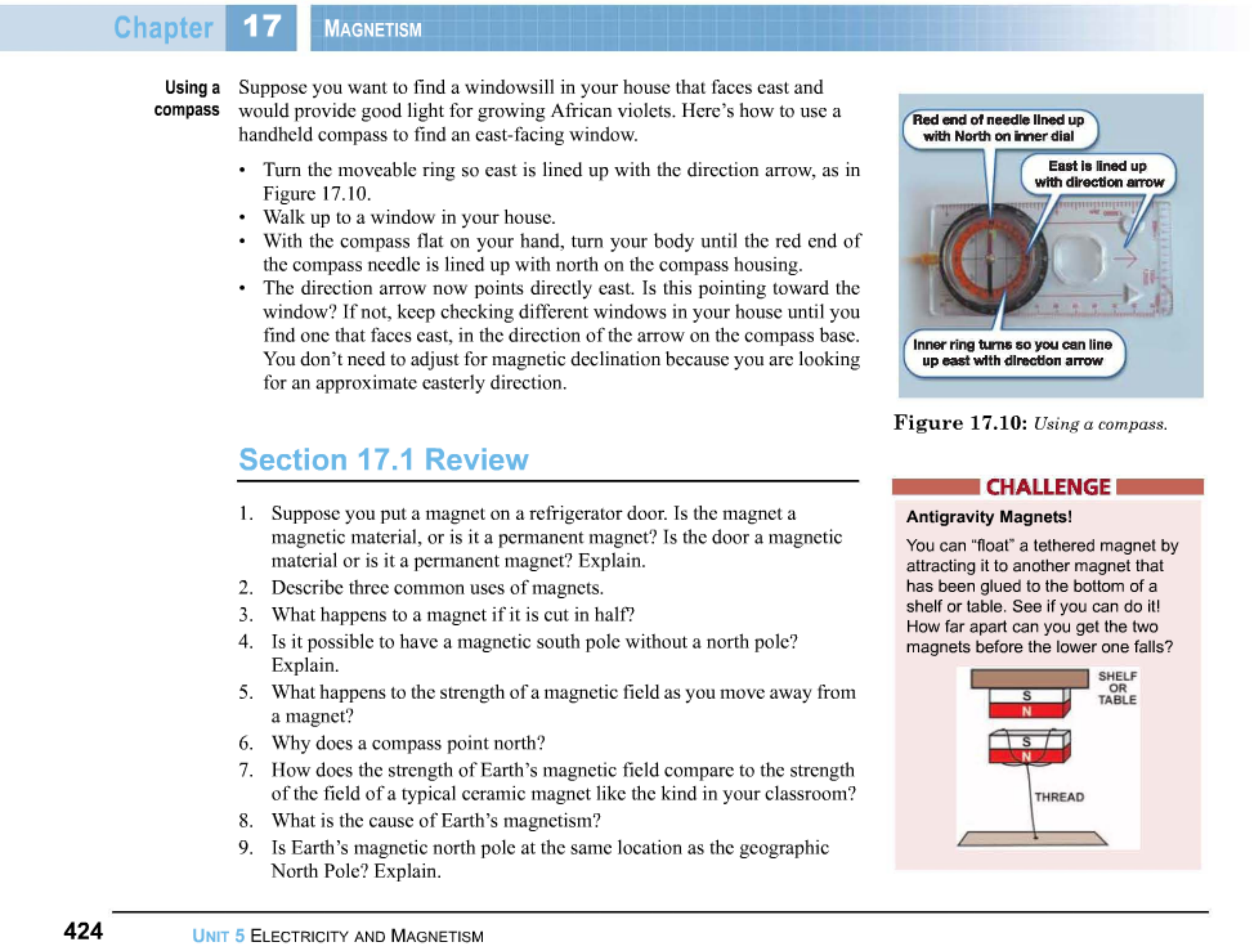
Reversing poles Historical data shows that both the strength of Earth's magnetic field and the location of the north and south magnetic poles change over time. Studies of magnetized rocks in Earth's crust provide evidence that the poles have reversed many times over the last tens of millions of years. The reversal has happened every 500,000 years on average. The last field reversal occurred roughly 750,000 years ago, so Earth is overdue for a pole reversal.

The next reversal Earth's magnetic field is currently losing approximately seven percent of its strength every 100 years. We do not know whether this trend will continue, but if it does, the magnetic poles could reverse sometime in the next 2,000 years. During a reversal, Earth's magnetic field would not completely disappear. However, the main magnetic field that we use for navigation would be replaced by several smaller fields with poles in different locations.

Movements of the magnetic poles The location of Earth's magnetic poles is always changing—slowly—even between full reversals. Currently, the magnetic north pole is located about 1,000 kilometers from the geographic North Pole. During the last century, the magnetic north pole has moved over 1,000 km (Figure 17.9). Just remember—if you are using a handheld compass, and the red tip of the compass needle lines up with the north direction on the compass housing, you must adjust the compass to compensate for the fact that Earth's magnetic north and geographic north are in different places!

Figure 17.8: *Scientists believe moving charges in the molten core create Earth's magnetic field.*

Figure 17.9: *The location of the magnetic north pole is moving approximately northwest at about 40 km per year, according to the Canadian Geological Survey.*



Using a compass

Suppose you want to find a windowsill in your house that faces east and would provide good light for growing African violets. Here's how to use a handheld compass to find an east-facing window.

- Turn the moveable ring so east is lined up with the direction arrow, as in Figure 17.10.
- Walk up to a window in your house.
- With the compass flat on your hand, turn your body until the red end of the compass needle is lined up with north on the compass housing.
- The direction arrow now points directly east. Is this pointing toward the window? If not, keep checking different windows in your house until you find one that faces east, in the direction of the arrow on the compass base. You don't need to adjust for magnetic declination because you are looking for an approximate easterly direction.

Red end of needle lined up with North on inner dial

East is lined up with direction arrow

Inner ring turns so you can line up east with direction arrow

Figure 17.10: *Using a compass.*

Section 17.1 Review

1. Suppose you put a magnet on a refrigerator door. Is the magnet a magnetic material, or is it a permanent magnet? Is the door a magnetic material or is it a permanent magnet? Explain.
2. Describe three common uses of magnets.
3. What happens to a magnet if it is cut in half?
4. Is it possible to have a magnetic south pole without a north pole? Explain.
5. What happens to the strength of a magnetic field as you move away from a magnet?
6. Why does a compass point north?
7. How does the strength of Earth's magnetic field compare to the strength of the field of a typical ceramic magnet like the kind in your classroom?
8. What is the cause of Earth's magnetism?
9. Is Earth's magnetic north pole at the same location as the geographic North Pole? Explain.

CHALLENGE

Antigravity Magnets!

You can "float" a tethered magnet by attracting it to another magnet that has been glued to the bottom of a shelf or table. See if you can do it! How far apart can you get the two magnets before the lower one falls?

SHELF OR TABLE
S
N
S
N
THREAD