## 17.2 Electromagnets

In the last section, you learned about permanent magnets and magnetism. There is another type of magnet, one that is created by electric current. This type of magnet is called an electromagnet. What is an electromagnet? Why do magnets and electromagnets act the same way? In this section, you'll learn about electromagnets and how they helped scientists explain how magnetism works.

### What is an electromagnet?

**Searching for a connection** For a long time, people thought about electricity and magnetism as different and unrelated topics. Around the beginning of the nineteenth century, scientists started to suspect that the two were related. As scientists began to understand electricity better, they searched for relationships between electricity and magnetism.

**The principle of an electromagnet** In 1819, Hans Christian Øersted, a Danish physicist and chemist, noticed that a current in a wire caused a compass needle to deflect. He had discovered that moving electric charges create a magnetic field! A dedicated teacher, he made this discovery while teaching his students at the University of Copenhagen. He suspected there might be an effect and did the experiment for the very first time in front of his class. With his discovery, Øersted was the first to identify the principle of an electromagnet.

**How to make an electromagnet** **Electromagnets** are magnets that are created when there is electric current flowing in a wire. The simplest electromagnet uses a coil of wire, often wrapped around a piece of iron (Figure 17.11). Because iron is magnetic, it concentrates the magnetic field created by the current in the coil.

**The north and south poles of an electromagnet** The north and south poles of an electromagnet are located at the ends of the coil (Figure 17.11). Which end is the north pole depends on the direction of the electric current. If you curl the fingers of your right hand in the direction of the current, your thumb will point toward the magnet's north pole. This method of finding the magnetic poles is called the *right-hand rule*. You can switch the north and south poles of an electromagnet by reversing the direction of the current. This is a great advantage over permanent magnets. You can't easily change the poles of a permanent magnet.

**VOCABULARY**

**electromagnet** - a magnet created by a wire carrying electric current.

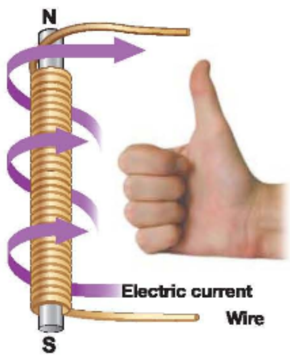



**Figure 17.11:** *A simple electromagnet uses a coil of wire, often wrapped around a piece of iron or steel. If you curl the fingers of your right hand in the direction of the current, your thumb will point toward the north pole of the electromagnet.*

## Applications of electromagnets

**Current controls electromagnets** By changing the amount of current, you can easily change the strength of an electromagnet or even turn its magnetism on and off. Electromagnets can also be much stronger than permanent magnets because the electric current can be large. For these reasons, electromagnets are preferable to permanent magnets in many applications.

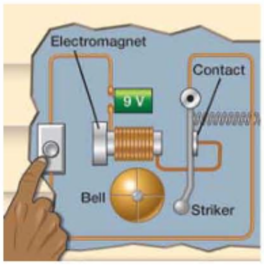
**Magnetically levitated trains** Magnetically levitated (maglev) train technology uses electromagnetic force to lift a train a few inches above its track (Figure 17.12). By "floating" the train on a powerful magnetic field, the friction between wheels and rails is eliminated. Maglev trains can achieve high speeds using less power than normal trains. In 2003, in Japan, a three-car maglev train carrying 12 passengers reached a world-record speed of 581 kilometers (360 miles) per hour. Maglev trains are now being developed and tested in Germany, Japan, and the United States.

**Figure 17.12:** *A maglev train track has electromagnets in it that both lift the train and pull it forward.*

**Electromagnets and toasters** The sliding switch on a toaster does several things. First, it turns the heating circuit on. Second, it activates an electromagnet that then attracts a spring-loaded metal tray to the bottom of the toaster (Figure 17.13). When a timing device signals that the bread has been toasting long enough, current to the electromagnet is cut off. This releases the spring-loaded tray that then pushes up on the bread so that it pops out of the toaster.


**Figure 17.13:** *A toaster tray is pulled down by an electromagnet while bread is toasting. When the toast is done, current is cut off and the tray pops up. The cutaway shows the heating element—nichrome wires wrapped around a sheet of mica.*

**Electromagnets and doorbells**




A doorbell contains an electromagnet. When the button of the doorbell is pushed, current is sent through the electromagnet. The electromagnet attracts a piece of metal called the striker. The striker moves towards the electromagnet but hits a bell that is in the way. The movement of the striker away from the contact breaks the circuit after it hits the bell. A spring pulls the striker back and reconnects the circuit. If a finger is still pressing on the button, the cycle starts over again and the bell keeps ringing.

## Building an electromagnet

**Making an electromagnet from wire and a nail** You can easily build an electromagnet from wire and a piece of iron, such as a nail. Wrap the wire in many turns around the nail and connect a battery as shown in Figure 17.14. When current flows in the wire, the nail becomes a magnet. Use the right-hand rule to figure out which end of the nail is the north pole and which is the south pole. To reverse north and south, reverse the connection to the battery, making the current flow the opposite way.

**Increasing the strength of an electromagnet** As you read on the previous page, increasing the current makes an electromagnet stronger. There are two ways to increase the current:

1. apply more voltage by adding a second battery; or
2. add more turns of wire around the nail.

**Why adding turns works** The second method works because the magnetism in your electromagnet comes from the *total* amount of current flowing *around* the nail. If there is 1 amp of current in the wire, each loop of wire adds 1 amp to the total amount that flows around the nail. Ten loops of 1 amp each make 10 total amps flowing around. By adding more turns, you use the same current over and over to get stronger magnetism (Figure 17.15).

**More turns also mean more resistance** Of course, nothing comes for free. By adding more turns, you also increase the resistance of your coil. Increasing the resistance makes the current a little lower and generates more heat. A good electromagnet has enough turns to get a strong enough magnet without too much resistance.

**Factors affecting the force** The magnetic force exerted by a simple electromagnet depends on three factors:

1. the amount of electric current in the wire;
2. the amount of iron or steel in the electromagnet's core; and,
3. the number of turns in the coil.

In more sophisticated electromagnets, the shape, size, material in the core, and winding pattern of the coil also have an effect on the strength of the magnetic field produced.

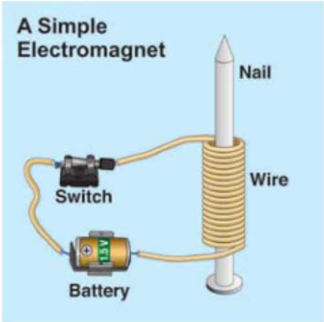



**Figure 17.14:** *Making an electromagnet from a nail and wire.*

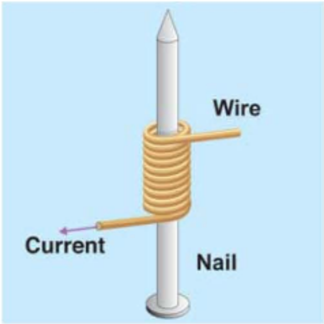



**Figure 17.15:** *Adding turns of wire increases the total current flowing around the electromagnet. The total current in all the turns is what determines the strength of the electromagnet.*

## Similarities between permanent magnets and electromagnets

**Electric currents cause all magnetism**

Why do permanent magnets and electromagnets act the same way? The discovery of electromagnets helped scientists to determine why magnetism exists. Electric current through loops of wire creates an electromagnet. Atomic-scale electric currents create a permanent magnet.

**Electrons move, creating small loops of current**

Atoms contain two types of charged particles, protons (positive) and electrons (negative). The charged electrons in atoms behave like small loops of current. These small loops of current mean that atoms themselves act like tiny electromagnets with north and south poles! We don't usually notice the magnetism from atoms for the following two reasons.

1. Atoms are very tiny, and the magnetism from a single atom is far too small to detect without very sensitive instruments.
2. The alignment of the atomic north and south poles changes from one atom to the next. On average, the atomic magnets cancel each other out .

**How permanent magnets work**

If all the atomic magnets are lined up in a similar direction, the magnetism of each atom adds to that of its neighbors, and we observe magnetic properties on a large scale. This is what makes a permanent magnet. Permanent magnets have the magnetic fields of individual atoms aligned in the same direction (Figure 17.16).

**Why iron always attracts magnets and never repels them**

In magnetic materials (such as iron), the atoms are free to rotate and align their individual north and south poles. If you bring the north pole of a magnet near iron, the south poles of all the iron atoms are attracted. Because they are free to move, the iron near your magnet becomes a south pole and it attracts your magnet. If you bring a south pole near iron, the opposite happens. The iron atoms nearest your magnet align themselves to make a north pole, which also attracts your magnet. This is why magnetic materials such as iron always attract your magnet, and never repel, regardless of whether your test magnet approaches with its north or south pole.

**Nonmagnetic materials**

The atoms in nonmagnetic materials, such as plastic, are not free to move and change their magnetic orientation. This is why most objects are not affected by magnets.

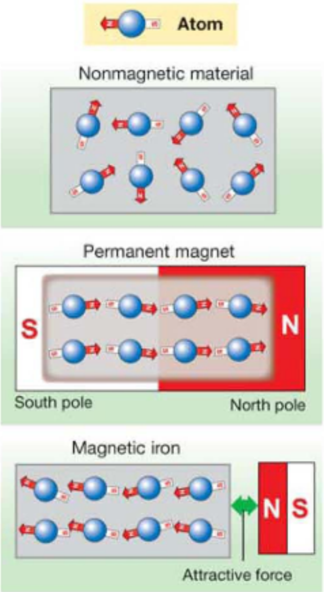
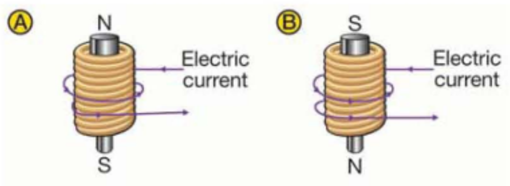



**Figure 17.16:** *Atoms act like tiny magnets. Permanent magnets have their atoms partially aligned, creating the magnetic forces we observe. The magnetic properties of iron occur because iron atoms can easily adjust their orientation in response to an outside magnetic field.*

## Section 17.2 Review

1. Which of the following will NOT increase the strength of an electromagnet made by wrapping a wire around an iron nail?
   a. increasing the number of turns of the wire
   b. increasing the current in the electromagnet
   c. removing the nail from the center of the electromagnet
2. Explain why an electromagnet usually has a core of iron or steel.
3. Name two devices that use electromagnets. Explain the purpose of the electromagnet in each device.
4. In your own words, explain how atoms give rise to magnetic properties in certain materials.
5. Which picture shows the correct location of the north and south poles of the electromagnet? Choose A or B and explain how you arrived at your choice.




6. The north pole of a magnet is brought near a refrigerator door, and the magnet sticks. If the magnet is removed and the south pole is brought near the door instead, will it also stick? Explain.
7. What would happen if you placed a compass near an electromagnet when there is an electric current in the coil of the electromagnet? Why would this happen? What if you flipped the electromagnet around so the end that was closest to the compass is now farthest away?

### KEYWORDS

**Magnetism in Materials**

Materials can have different magnetic classifications based on their atomic structure. Do a keyword search on the following classifications. Explain how the atoms of each type of material behave, and give examples of each.

- diamagnetic
- paramagnetic
- ferromagnetic