8.3 Properties of Magnets

Magnetism has fascinated people since the earliest times. We know that magnets stick to refrigerators and pick up paper clips or pins. They are also found in electric motors, computer disk drives, burglar alarm systems, and many other common devices.

What is a magnet?

Magnets and magnetic materials

If a material is **magnetic**, it has the ability to exert forces on magnets or other magnetic materials. A magnet on a refrigerator is attracted to the steel in the refrigerator's door. A *magnet* is a material that can create magnetic effects by itself. *Magnetic materials* are affected by magnets but do not actively create their own magnetism. Iron and steel are magnetic materials that can also be magnets.

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.

Poles

All magnets have two magnetic poles (north and south). If a magnet is cut, each part will have its own north and south poles (Figure 8.15). 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 can't have a one-sided coin, and you can't have a single magnetic pole either.

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 8.16). Plastics, wood, and most insulating materials are transparent to (have no effect on) magnetic forces.

VOCABULARY

magnetic - the property of creating or responding to forces from magnets.

permanent magnet - a material that remains magnetic without outside energy being supplied.

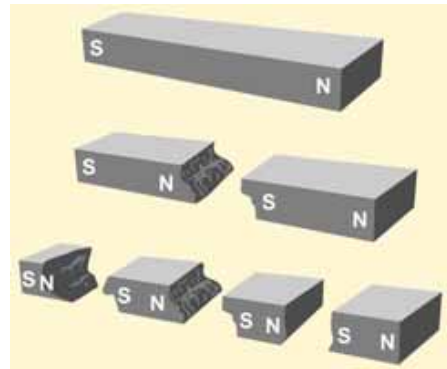


Figure 8.15: *If a magnet is cut, each piece has both a north and a south pole.*

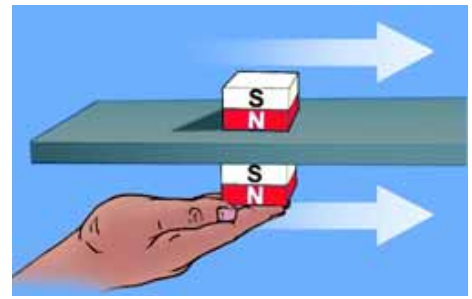


Figure 8.16: *The force between two magnets can pass through many solid materials.*

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 the **magnetic field**. Second, the magnetic field makes forces that act on other magnets nearby (and back on the same magnet too).

The speed of magnetic forces

When you bring a magnet somewhere, the magnetic field spreads out around the magnet at the speed of light. The speed of light is 300 million kilometers *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. Sensitive instruments can measure this small amount of time.

Magnetic forces get weaker with distance

The force from a magnet gets weaker as it gets farther away. You can feel this by comparing the force when you hold two magnets close together compared to holding them far apart (Figure 8.17). 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 8 times or more.

Drawing the magnetic field

A special kind of diagram is used to show the magnetic field. The diagram shows an arrow in the direction of the force on the north pole of an imaginary test magnet. Since the test magnet is imaginary, we can allow it to have only a north pole. Figure 8.18 shows a drawing of the magnetic field around a small magnet. The force points away from the north pole because a north pole would be repelled from another north pole. The force points toward the south pole because a north pole magnet would be attracted to the south pole. You can actually see the pattern of the magnetic field by sprinkling magnetic iron filings on cardboard with a magnet underneath (shown left).

VOCABULARY

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

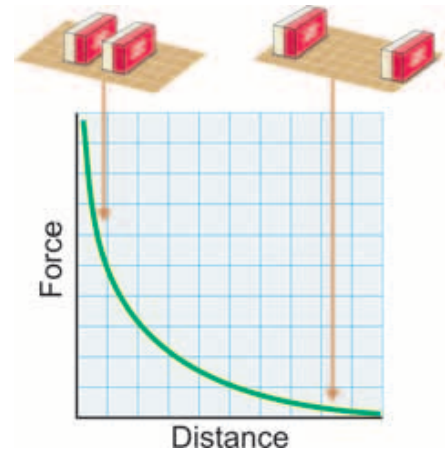


Figure 8.17: *The force between two magnets fades away quickly as the magnets are separated.*

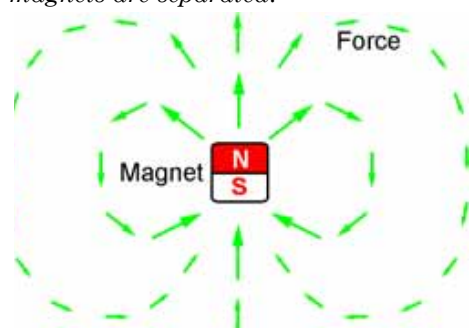


Figure 8.18: *The force on an imaginary north magnetic pole (test magnet) near a source magnet.*

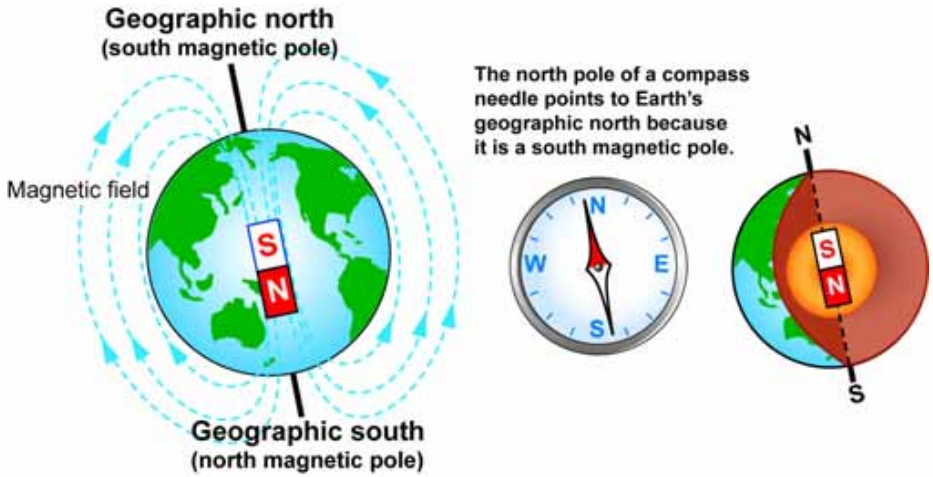
How does a compass work?

A compass is a magnet

A compass needle is a magnet that is free to spin (Figure 8.19). The north pole of a compass needle always points toward the south pole of a permanent magnet. This is in the direction of the magnetic field lines. Because the needle aligns with the local magnetic field, a compass is a great way to "see" magnetic field lines.

North and south poles

The planet Earth has a magnetic field that comes from the core of the planet itself. The terms "north pole" and "south pole" come from the direction that a magnetized compass needle points. The end of the magnet that points toward geographic north was called the magnet's north pole and the opposite pole was called south. The names were decided long before people understood how a compass needle worked.



Geographic and magnetic poles

The true *geographic* North and South Poles are where the Earth's axis of rotation intersects its surface. Earth's *magnetic* poles are defined by the planet's magnetic field. When you use a compass, the north-pointing end of the needle points toward a spot near (but not exactly at) Earth's geographic north pole. That means the *south magnetic pole* of the planet is near the geographic North Pole.

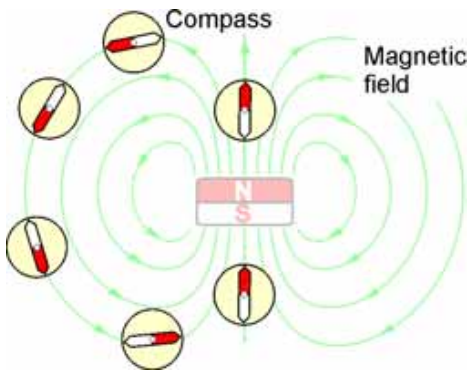


Figure 8.19: *A compass needle lines up with a magnetic field.*

Some animals have biological compasses

Many animals, 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. Samples of magnetite are common in rock collections or kits.

The effect of current on a compass

Finding the relationship between electricity and magnetism

For a long time, people believed electricity and magnetism were unrelated. As scientists began to understand electricity better, they searched for relationships between electricity and magnetism. In 1819, Hans Christian Øersted placed a compass needle near a wire in a circuit. When a switch in the circuit was closed, the compass needle moved just as if the wire were a magnet. We now know that magnetism is created by electric current and that electricity and magnetism are two forms of the same basic force.

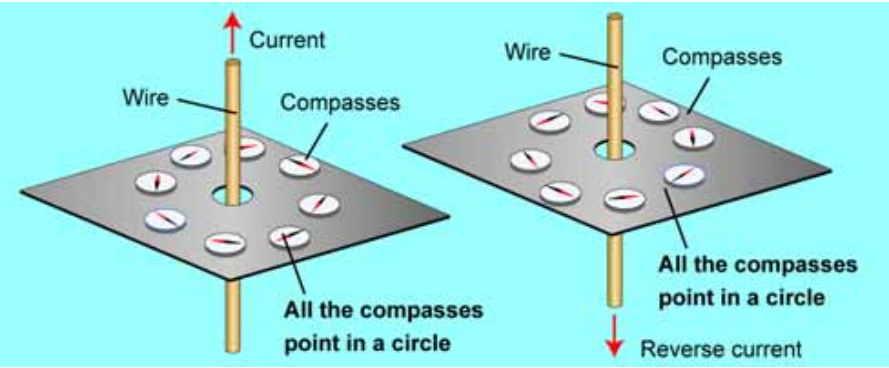
Magnetism is created by electric current.

An experiment with a wire and compasses

Imagine a variation on Øersted's experiment. A long straight wire is connected to a battery and a switch. The wire passes through a board with a hole in it. Around the hole are many compasses that can detect any magnetic field. When the switch is off, the compasses all point north (Figure 8.20)

Compasses react to electric current

As soon as the switch is closed, current flows, and the compasses point in a circle (see illustration below). The compasses stay pointed in a circle as long as there is current in the wire. If the current stops, the compasses return to pointing north again. If the current is reversed in the wire, the compasses again point in a circle, but in the opposite direction.



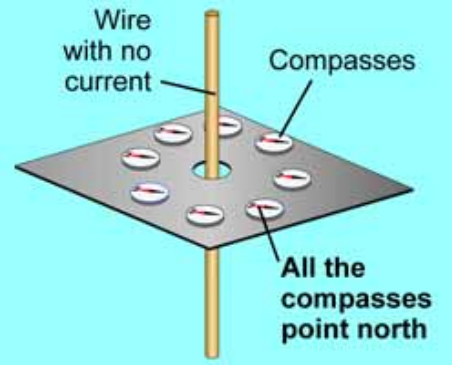
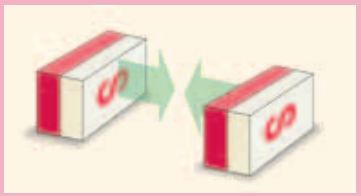


Figure 8.20: *When there is no current in a wire, all of the compasses point north.*

CHALLENGE

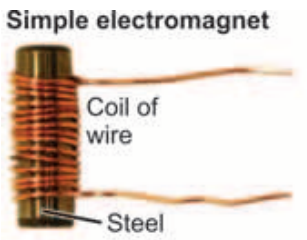
Permanent magnets



Magnetism is created by electric current. A permanent magnet stays magnetic even though there are no wires to carry current. How does a permanent magnet get its magnetism? Here's a hint: There are electric charges inside atoms and those charges have energy of motion.

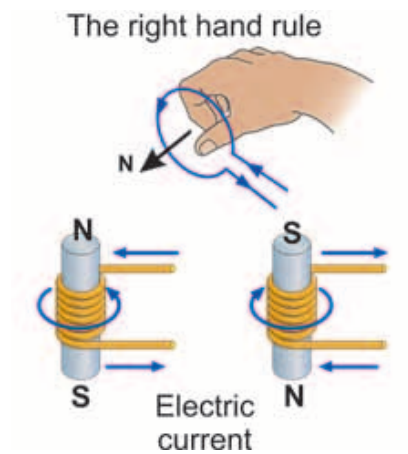
Magnetic forces and electric currents

Electromagnets



A magnet made with wires and electric current is called an **electromagnet**. A simple electromagnet is made with a coil of wire wrapped around a steel rod. The electromagnet produces a magnetic field exactly the same as a permanent magnet with its north and south poles as shown in Figure 8.21. Two coils carrying electric current exert forces on each other, just as magnets do. The forces can be attractive or repulsive depending on the direction of current in the coils. If the current is in the same direction in both coils, they attract. If the currents are in opposite directions, they repel.

The poles of an electromagnet



The north and south poles of an electromagnet are on opposite ends of the coil. Which is north depends on the direction of the electric current. When the fingers of your right hand curl in the direction of current, your thumb points toward the electromagnet's north pole. This is called the *right hand rule*. You can switch the north and south poles of an electromagnet by reversing the direction of the current in the coil. This is a great advantage over permanent magnets.

The strength of an electromagnet

The magnetic force from an electromagnet depends on the total current going around the steel core. More current creates a stronger magnet. Increasing the number of turns in the coil also increases the magnetic force even with the same current. That's because each additional turn lets the current circle the coil one more time. In effect adding turns "reuses" the same current over and over, once per turn.

VOCABULARY

electromagnet - a magnet made with wires and electric current.

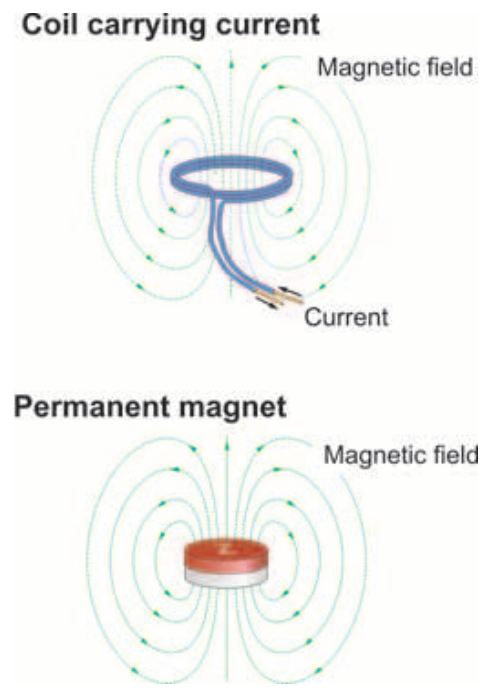


Figure 8.21: *The magnetic field from current flowing in a coil of wire and from a similar shaped permanent magnet.*

Magnetic materials

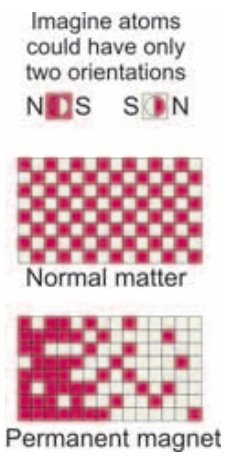
Magnetic materials

The force from a magnet doesn't affect a plastic pen cap but attracts a steel paper clip. The same magnet doesn't stick to an aluminum pot but does stick to a cast iron pot. Why do some materials have strong magnetic properties while others do not? The metals iron, nickel, and cobalt have strong magnetic properties. Steel is mostly iron, which is why a steel paper clip is attracted to a magnet. A **ferromagnetic metal** such as iron is attracted to a magnet. It doesn't usually matter whether the south or north pole is facing the iron. Iron is attracted to both magnetic poles.

VOCABULARY

ferromagnetic metal - a material, like iron, which has strong magnetic properties.

How permanent magnets are made



Both permanent magnets and iron owe their magnetic properties to their atoms. The electric charge inside an atom creates a current making some atoms into tiny electromagnets. In ordinary matter the atoms are scrambled with their north and south poles pointing every different direction. On average, the magnetism of one atom cancels with the next atom so the material is not magnetic. In a permanent magnet however, the atoms have been partly locked into alignment. Their individual north and south poles stay pointing in about the same direction. That is why permanent magnets keep their magnetism.

Why iron always attracts a magnet

Iron atoms can rotate their magnetic poles to line up with neighboring atoms. When the north pole of an external magnet gets near iron, the south pole of each atom in the iron is attracted to the magnet's north pole (Figure 8.22). Many atoms group together in south-pointing clusters. The iron becomes *magnetized* and is attracted to the magnet. The south pole of an external magnet magnetizes iron the opposite way. Clusters of atoms grow that have north poles facing the external magnet.

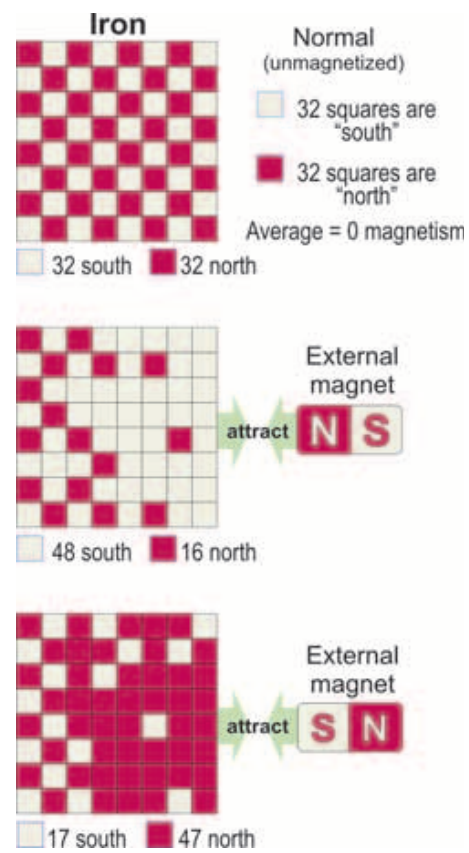


Figure 8.22: *How iron is magnetized so it always attracts an external magnet.*

Electric generators and induction

Magnetism and electricity

An electric current in a wire creates a magnetic field. The reverse is also true. If you move a magnet near a coil of wire, an electric current (or voltage) is *induced* in the coil. The word "induce" means "to cause to happen." The process of using a moving magnet to create electric current or voltage is called **electromagnetic induction**. A moving magnet *induces* electric current to flow in a circuit.

VOCABULARY

electromagnetic induction - using a moving magnet to create electric current or voltage.

Making current flow

Figure 8.23 shows an experiment demonstrating electromagnetic induction. In the experiment, a magnet can move in and out of a coil of wire. The coil is attached to a meter that measures the electric current. When the magnet moves into the coil of wire, *as the magnet is moving,* electric current is induced in the coil and the meter swings to the left. The current stops if the magnet stops moving.

Reversing the current

When the magnet is pulled back out again, *as the magnet is moving,* current is induced in the opposite direction. The meter swings to the right as the magnet moves out. Again, if the magnet stops moving, the current also stops.

Current flows only when the magnet is moving

Current is produced only if the magnet is moving, because a *changing* magnetic field is what creates current. Moving magnets induce current because they create changing magnetic fields. If the magnetic field is not changing, such as when the magnet is stationary, the current is zero.

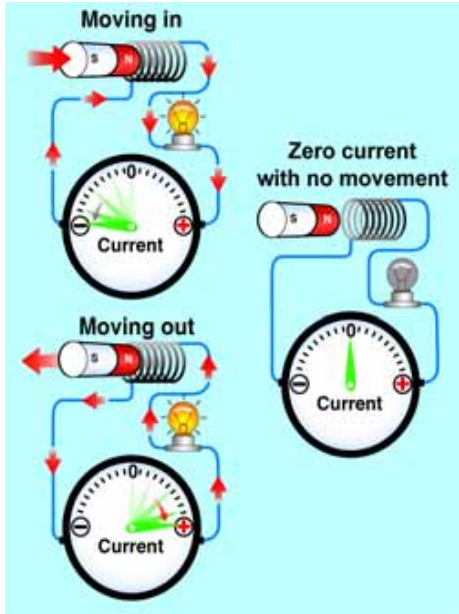
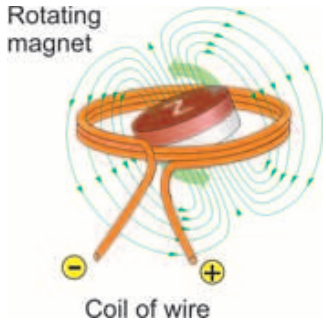


Figure 8.23: *A moving magnet produces a current in a coil of wire.*



Electric motors transform electrical energy into mechanical energy. Electric *generators* do the opposite. They transform mechanical energy into electrical energy. Generators are used to create the electricity that powers all of the appliances in your home. A simple electric generator is a magnet that spins inside a coil of wire. As the magnet spins, the changing magnetism induces electric current to flow in the coil.

Transformers

Electricity is transmitted at high voltage

It takes thick, heavy, and expensive wires to carry high current. For this reason, power companies use high voltage for transmitting electric power over long distances. The main power lines on a city street operate at 13,800 volts. Since power is current times voltage, each amp of current provides 13,800 watts of power. The problem is that you would *not* want your wall outlets to be at 13,800 volts. With a voltage this high, it would be dangerous to plug in your appliances!

Electric power transformers

A **transformer** changes the high voltage from the main power lines to the 120 volts your appliances use. Transformers can change voltage and current with very little loss of power. A series of transformers changes one amp at 13,800 volts into 115 amps at 120 volts (Figure 8.24). The total electrical power remains the same because 13,800 V × 1 A = 120 V × 115 A.

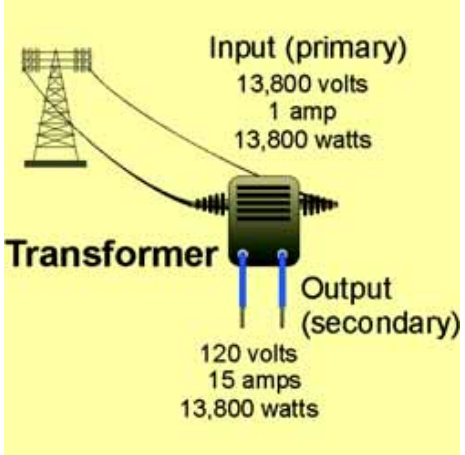


Figure 8.24: *A high-power transformer can reduce the voltage keeping the power constant.*

Transformers operate on electromagnetic induction

Figure 8.25 shows what a transformer looks like inside its protective box. You may have seen one inside a doorbell or an AC adapter. The two coils are called the *primary* and *secondary* coils. The input to the transformer is connected to the primary coil. The output of the transformer is connected to the secondary coil. The two coils have different numbers of turns to convert from one voltage to another.

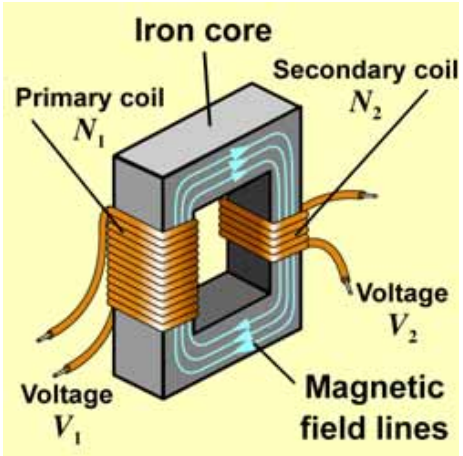
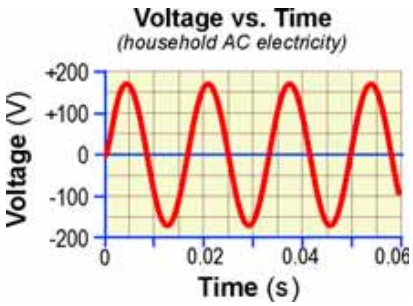


Figure 8.25: *A transformer contains coils wound around an iron core.*

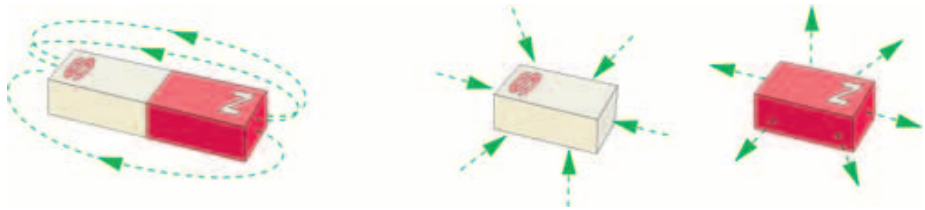
DC and AC



The current from a battery is called *direct current* or DC. In DC electricity, the positive terminal stays positive and the negative terminal stays negative. Your experiments in the lab are DC since they use batteries. *Transformers do not work with DC electricity.* For this reason, the electrical system in your house uses *alternating current* or AC. AC electricity constantly switches between positive and negative. In the electrical system used in the United States, the voltage reverses direction 60 times per second.

8.3 Section Review

1. Which magnetic pole is attracted to a south magnetic pole?
2. Why can the magnetic force be either attractive or repulsive when gravity can only be attractive?
3. Name two materials which are magnetic and two that are not magnetic.
4. What is wrong with the picture below?



5. A compass points north because
   a. Earth's gravity is strongest at the North Pole
   b. Earth's south magnetic pole is there
   c. Earth's north magnetic pole is there
6. Why does a compass change direction when it is near a current-carrying wire?
7. What is the difference between a permanent magnet and an electromagnet?
8. An electromagnet is shown in Figure 8.26. Use the right hand rule to tell whether the pointed end of the nail is a north pole or a south pole.
9. Iron attracts
   a. only the north pole of a magnet
   b. only the south pole of a magnet
   c. both north and south poles of a magnet
10. An electric generator uses changing magnetism to
   a. induce current to flow in a coil
   b. transform electrical energy into mechanical energy

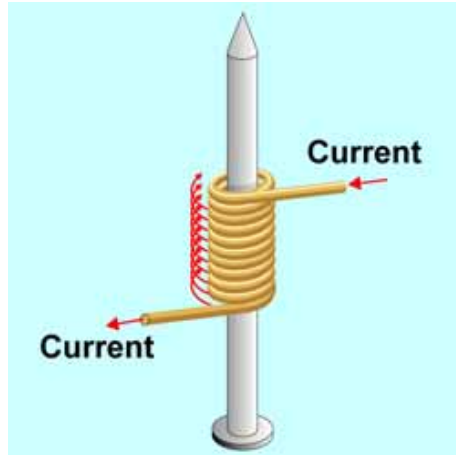


Figure 8.26: *Question 8.*

CHALLENGE

Anti-gravity magnets!

You can "float" a tethered magnet by attracting it to another magnet. See if you can do it! How far apart can you get the two magnets before the lower one falls?