Benchmarks—SC.C.2.3.1 (pp. 578–579, 581, 584–585): The student knows that many forces (e.g., gravitational, electrical, and magnetic) act at a distance (e.g., without contact).

section 3

Also covers: SC.H.1.3.2 (p. 586), SC.H.1.3.4 Annually Assessed (pp. 584–585), SC.H.1.3.5 Annually Assessed (pp. 581, 584–585), SC.H.3.3.5 (p. 586)

Magnetism

as you read

What You'll Learn

- **Describe** how magnets exert forces on each other.
- **Explain** why some materials are magnetic.
- **Describe** how objects become temporary magnets.
- **Explain** how an electric generator produces electrical energy.

Why It's Important

Magnetism helps produce the electrical energy you obtain from electrical outlets.

Review Vocabulary

✷ **magnetic:** able to exert a noncontact force that can attract iron, cobalt, nickel, and certain other materials

New Vocabulary

- ✷ **magnetic field**
- magnetic domain
- electromagnet
- electromagnetic induction

✷ FCAT Vocabulary

Magnets

Did you use a magnet today? If you've watched TV, listened to a CD, dried your hair with a hairdryer, or used a computer, the answer is yes. Magnets are a part of all these devices and many others. Magnets can exert forces on objects that are made from, or contain, magnetic materials. Magnets also exert forces on other magnets. It is the forces exerted by magnets that make them so useful.

Magnetic Poles Every magnet has two ends or sides. Each of the ends or sides is a magnetic pole. There are two types of magnetic poles. One is a north pole and the other is a south pole. Every magnet has a north pole and a south pole. For example, one end of a bar magnet is a south pole and the other end is a north pole. For a magnet in the shape of a disc or a ring, one side is a north pole and the other side is a south pole.

Reading Check *Where would the poles of a magnet shaped like a horseshoe be located?*

The Forces Between Magnetic Poles The magnetic poles of a magnet exert forces on the magnetic poles of other magnets, as shown in **Figure 18.** If two north poles or two south poles are moved toward each other, they repel. If the north pole of one magnet is brought toward the south pole of another magnet, the magnets attract each other. In other words, like poles repel and unlike poles attract. The magnetic forces between two magnets become stronger as the magnets move closer together, and weaker as they move farther apart.

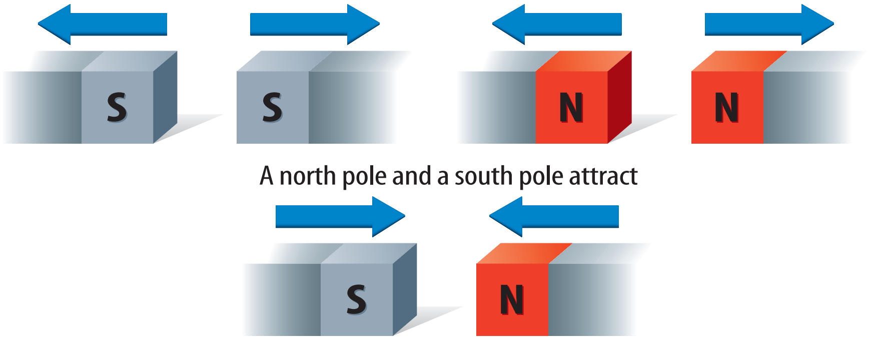


Figure 18 The magnetic forces between magnetic poles are attractive between unlike poles and repulsive between like poles.
Compare *the forces between magnetic poles to the forces between electric charges.*

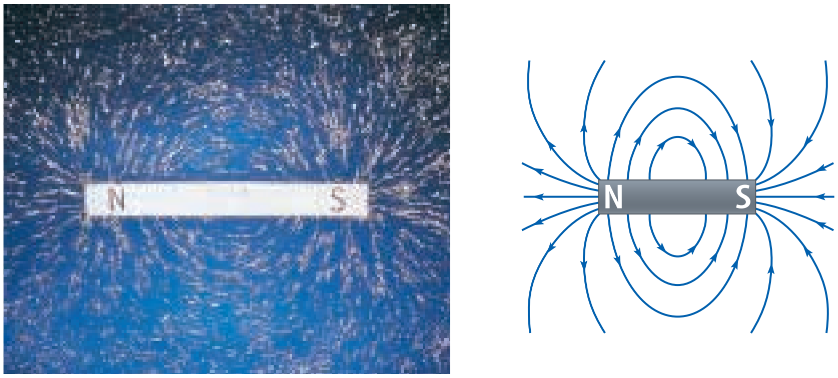


Figure 19 Iron filings sprinkled around a bar magnet show the magnetic field lines. Magnetic field lines always connect the north and south poles of a magnet.

Magnetic Field If you hold two like poles of two magnets near each other, you can feel them push each other apart, even though they are not touching. Recall that electric charges exert forces on each other even if they are not touching. This is because an electric charge is surrounded by an electric field.

In a similar way, a magnet is surrounded by a magnetic field that exerts forces on other magnets. However, not only is a magnet surrounded by a magnetic field but so is a moving electric charge. A **magnetic field** is the region of space surrounding a magnet or a moving charge where a magnetic force is exerted on other magnets and moving charges.

The magnetic field around a bar magnet is shown in **Figure 19.** Iron filings sprinkled around a bar magnet line up to form a pattern of curved lines. These lines are called magnetic field lines. Magnetic field lines help show the direction of the magnetic field around a magnet.

Magnetic Materials

A paper clip will stick to a magnet, but a piece of aluminum foil won't stick. Both the paper clip and the aluminum are metal. Why is one attracted to the magnet and the other is not?

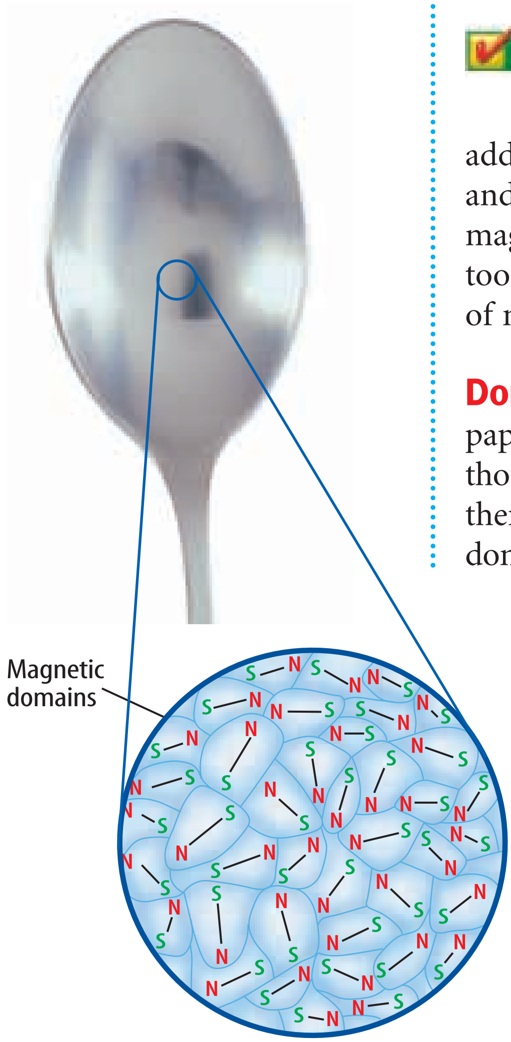
Only metals that contain the elements iron, nickel, cobalt, and a few other rare-earth elements are attracted to magnets. Materials that contain these elements are magnetic materials. Magnets also contain one or more of these metals. The steel paper clip contains iron and therefore is a magnetic material.

Why are some materials magnetic? All atoms contain moving electrons. These moving charges are surrounded by magnetic fields. In the atoms of most elements these magnetic fields cancel. As a result, atoms of these elements are not surrounded by a magnetic field and are not magnets. However, in atoms of magnetic materials, such as iron, cobalt, and nickel, these magnetic fields do not cancel. The atoms of these elements are tiny magnets with a north pole and a south pole.

INTEGRATE Earth Science

Earth's Magnetic Field Earth is surrounded by a magnetic field that is similar to the magnetic field around a bar magnet. Earth's magnetic poles are located near the geographic north pole and south pole. A compass uses Earth's magnetic field to help determine direction. Because a compass needle is a magnet, it rotates so it points toward Earth's magnetic poles. As a result, the north end of a compass needle points north.

Figure 20 This spoon is made of a magnetic alloy. The spoon is not a magnet because the magnetic poles of the magnetic domains point in random directions.
Explain *why the spoon is not surrounded by a magnetic field.*



Magnetic Domains In a magnetic material, forces that atoms exert on each other cause the magnetic fields surrounding atoms to point in the same direction. As a result, large numbers of atoms have their like magnetic poles pointing in the same direction. A group of atoms that have their like magnetic poles pointing in the same direction is called a **magnetic domain. Figure 20** shows how the atoms in a magnetic material form magnetic domains.

Reading Check *What are magnetic domains?*

The magnetic fields of all the atoms in a magnetic domain add together. As a result, each magnetic domain has a north pole and a south pole and is surrounded by a magnetic field. A single magnetic domain may contain trillions of atoms, but it is still too small to see. Even a small piece of iron may contain billions of magnetic domains.

Domains Line Up in Permanent Magnets Why do the paper clips stick to a bar magnet but not to each other? Even though they both are made of magnetic material, iron, they neither attract nor repel each other. In a paper clip the magnetic domains are oriented in random directions, as shown in **Figure 21.** Because the magnetic fields around the domains are in random directions, they cancel out. As a result, the paper clip is not surrounded by a magnetic field.

Figure 21 shows that in a permanent magnet, such as a bar magnet, most of the domains are oriented in a single direction. As a result, the magnetic fields around the domains don't cancel out. Instead, these magnetic fields add together to form a stronger magnetic field. The magnetic field that surrounds the magnet is the combination of the magnetic fields around the magnetic domains.

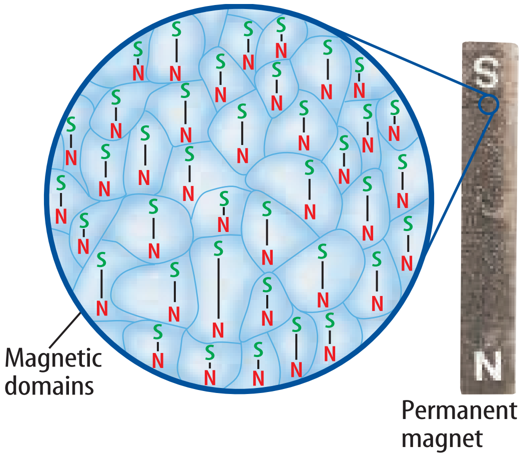


Figure 21 In a permanent magnet, most of the like poles of the magnetic domains point in the same direction.
Explain *why the magnet is surrounded by a magnetic field.*

PhotoDisc

The poles of the magnetic domains in the paper clip point in random directions when there is no magnet nearby.

The force exerted by the magnet on the domains causes them to point toward the nearby magnetic pole.

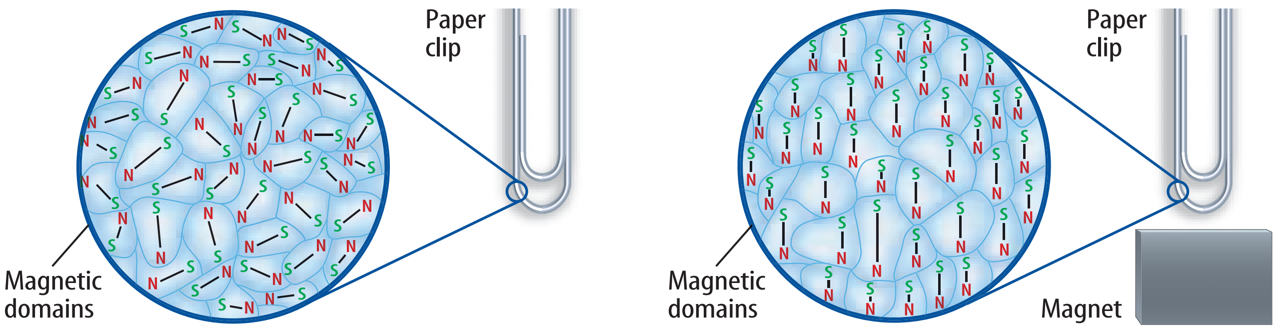


Figure 22 A paper clip that contains iron becomes a temporary magnet when a permanent magnet is nearby.

Why are magnetic materials attracted to a magnet?

A paper clip is not a magnet, but it contains magnetic domains that are small magnets. Usually, these domains point in all directions. However, when a permanent magnet comes close to the paper clip, the magnetic field of the magnet exerts forces on the magnetic domains of the paper clip. These forces cause the magnetic poles of the domains to line up and point in a single direction when a permanent magnet is nearby, as shown in **Figure 22.** The nearby pole of the permanent magnet is always next to the opposite poles of the magnetic domains. This causes the paper clip to be attracted to the magnet.

Because the domains are lined up, their magnetic fields no longer cancel out. As long as the domains in the paper clip are lined up, the paper clip is a temporary magnet with a north pole and a south pole.

Electromagnetism

Even though they might seem to be different, electricity and magnetism are related. Recall that a moving electric charge is surrounded by a magnetic field. As a result, magnetic fields are produced by electric charges in motion. This connection between electricity and magnetism often is called electromagnetism. Electrons are flowing in a current-carrying wire, and this produces a magnetic field around the wire.

Electromagnets The magnetic field produced by a current-carrying wire can be made much stronger by wrapping the wire around an iron core. A current-carrying wire wrapped around an iron core is an **electromagnet.** Just like a bar magnet, one end of an electromagnet is a north magnetic pole and the other end is a south magnetic pole, as **Figure 23** shows. However, if the direction of current flow in the wire coil of an electromagnet is reversed, then the north and south poles switch places.

SC.H.1.3.5
SC.C.2.3.1

Mini LAB

Observing Magnetic Force on a Wire

Procedure

1. Complete a safety worksheet.
2. Connect one end of a **50-cm piece of 22-gauge wire** to one terminal of a **D-cell battery.**
3. Form the wire into a loop and place one pole of a **bar magnet** about 2 cm outside the loop.
4. Touch the wire's free end to the other battery terminal. Record your observations.
5. Repeat step 4 with the connections to the battery terminals reversed.

Analysis

1. Explain how your observations show that a current in the wire produces a magnetic field.
2. Infer how the magnetic field around the wire depends on the direction of current in the wire.

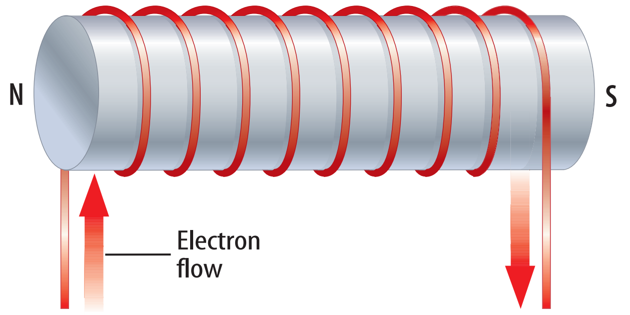


Figure 23 An electromagnet has north and south magnetic poles, and can be attracted or repelled by a permanent magnet. **Describe** *how the magnetic field around the electromagnet changes if the current in the coil is decreased.*

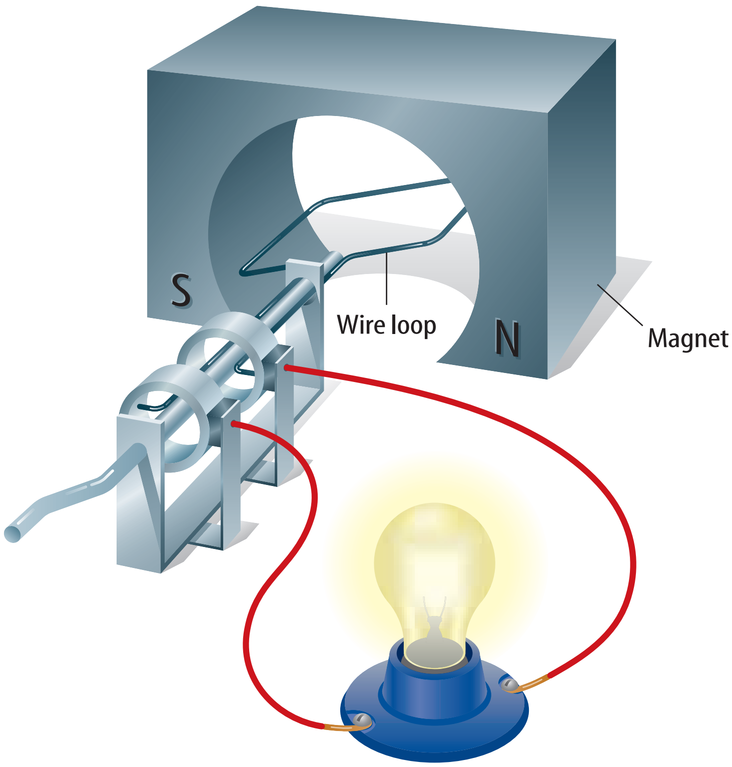
Using Electromagnets The strength of the magnetic field produced by an electromagnet depends on the amount of current flowing in the wire coil. Increasing the amount of current increases the magnetic field strength. However, the magnetic field disappears if no current flows in the coil. As a result, an electromagnet is a temporary magnet whose magnetic properties can be controlled. Because of this, electromagnets are used in many devices, including doorbells, telephones, CD players, and computers.

Generating Electric Current

If an electric current produces a magnetic field, can a magnetic field be used to produce an electric current? The answer is yes. If a magnet is moved through a wire loop that is part of a circuit, an electric current flows in the circuit. The current flows only as long as the magnet is moving. A current also flows in the circuit if it is the wire loop that moves and the magnet that is at rest. The production of an electric current by moving a magnet and a loop relative to each other is called **electromagnetic induction.**

Remember that a battery produces an electric field in a circuit that causes electrons to flow. Electromagnetic induction also produces an electric field in a circuit that causes electrons to flow.

Figure 24 When the wire loop rotates in the magnetic field of the permanent magnet, an electric current flows in the lightbulb.



Electric Generators You plug a lamp into an electrical outlet and turn the switch on. Immediately, an electric current flows in the lamp, causing the lightbulb to glow. Electrical energy is supplied to the lamp through the electric field created in the lamp. However, when you plug a device into an electrical outlet, the electrical energy used is produced by an electric generator instead of a battery.

Figure 24 shows a simple electrical generator. A loop of wire is rotated within a magnetic field. The motion of the wire loop with respect to the magnetic field produces an electrical field in the wire. This electrical field causes a current to flow. Current continues to flow as long as the wire loop is kept rotating. To keep the wire loop rotating, mechanical energy must be continually supplied to the generator. As a result, a generator converts mechanical energy into electrical energy.

Power Plants The electrical energy you obtain from an electrical outlet is produced by generators in electric power plants. In these generators electromagnets are rotated past wire coils. To rotate the magnets, power plants use mechanical energy in the form of the kinetic energy of moving steam or moving water into electrical energy.

In some power plants fossil fuels are burned to heat water and produce steam that is used to spin generators. In hydroelectric power plants, the flow of water from behind a dam provides the mechanical energy that is transformed into electrical energy, as shown in **Figure 25.**

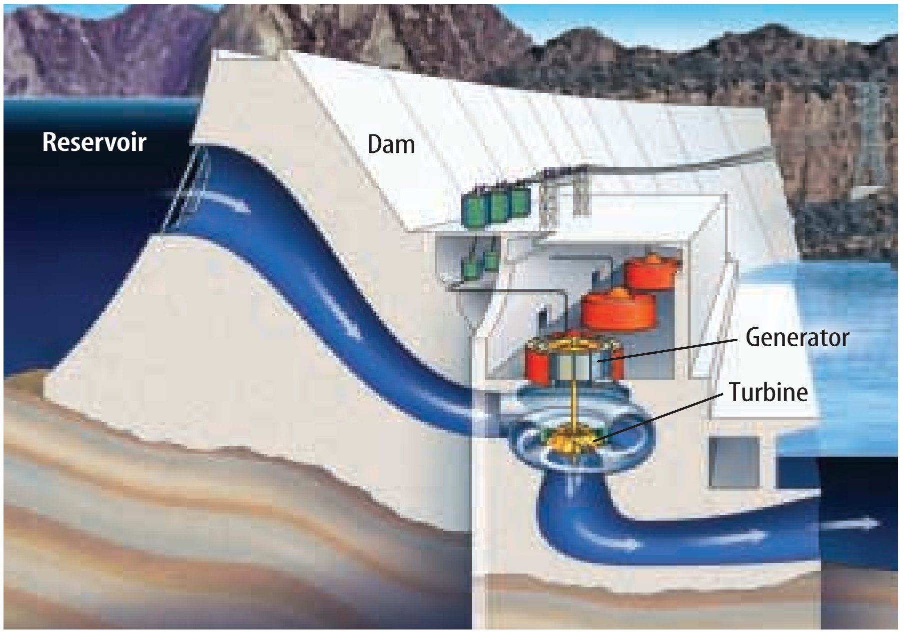


Figure 25 In a hydroelectric plant, the kinetic energy of falling water is converted into electrical energy by a generator.

section 3 review

Summary

Magnets

- All magnets have a north pole and a south pole.
- Like magnetic poles repel each other and unlike magnetic poles attract each other.
- A magnet is surrounded by a magnetic field that exerts a force on other magnets.

Magnetic Materials

- Individual atoms are magnets in magnetic materials such as iron, cobalt, and nickel.
- Magnetic domains contain atoms with their like magnetic poles pointing in the same direction.
- The magnetic domains in a permanent magnet have their magnetic poles aligned.

Electromagnetism

- An electric current is surrounded by a magnetic field.
- An electric current can be produced by the relative motion of a magnet and a wire loop.

Self Check

1. **Compare and contrast** a permanent magnet and a temporary magnet made from a magnetic material.
2. **Explain** why an object made from aluminum will not stick to a magnet.
3. **Compare and contrast** an electric generator and a battery.
4. **Identify** the circumstances that would cause an aluminum wire to be attracted or repelled by a magnet. SC.H.1.3.5
5. **Compare and contrast** an electromagnet and a permanent magnet.
6. **Think Critically** The north pole of one magnet is attracted only to the south pole of another magnet. However, a paper clip will stick to either the north pole or the south pole of a bar magnet. Explain.

Applying Math

7. **Solve a Simple Equation** A certain power plant generates enough electrical energy to supply 100,000 homes. How many of these power plants would be needed to generate enough energy for 2,000,000 homes? MA.D.2.3.1