SECTION 3

Electricity from Magnetism

When you use an electrical appliance or turn on a light in your home, you probably don't think about where the electrical energy comes from.

For most people, an electric power company supplies their home with electrical energy. In this section, you'll learn how a magnetic field can induce an electric current and how power companies use this process to supply electrical energy.

What You Will Learn

- Explain how a magnetic field can make an electric current.
- Explain how electromagnetic induction is used in a generator.
- Compare step-up and step-down transformers.

Vocabulary

electromagnetic induction
electric generator
transformer

READING STRATEGY

Paired Summarizing Read this section silently. In pairs, take turns summarizing the material. Stop to discuss ideas that seem confusing.

Electric Current from a Changing Magnetic Field

Hans Christian Oersted discovered that an electric current could make a magnetic field. Soon after, scientists wondered if a magnetic field could make an electric current. In 1831, two scientists each solved this problem. Joseph Henry, of the United States, made the discovery first. But Michael Faraday, from Great Britain, published his results first. Faraday also reported them in great detail, so his results are better known.

Faraday's Experiment

Faraday used a setup like the one shown in **Figure 1.** Faraday hoped that the magnetic field of the electromagnet would make—or induce—an electric current in the second wire. But no matter how strong the electromagnet was, he could not make an electric current in the second wire.

Reading Check **What was Faraday trying to do in his experiment?** (*See the Appendix for answers to Reading Checks.*)

Figure 1 **Faraday's Experiment with Magnets and Induction**

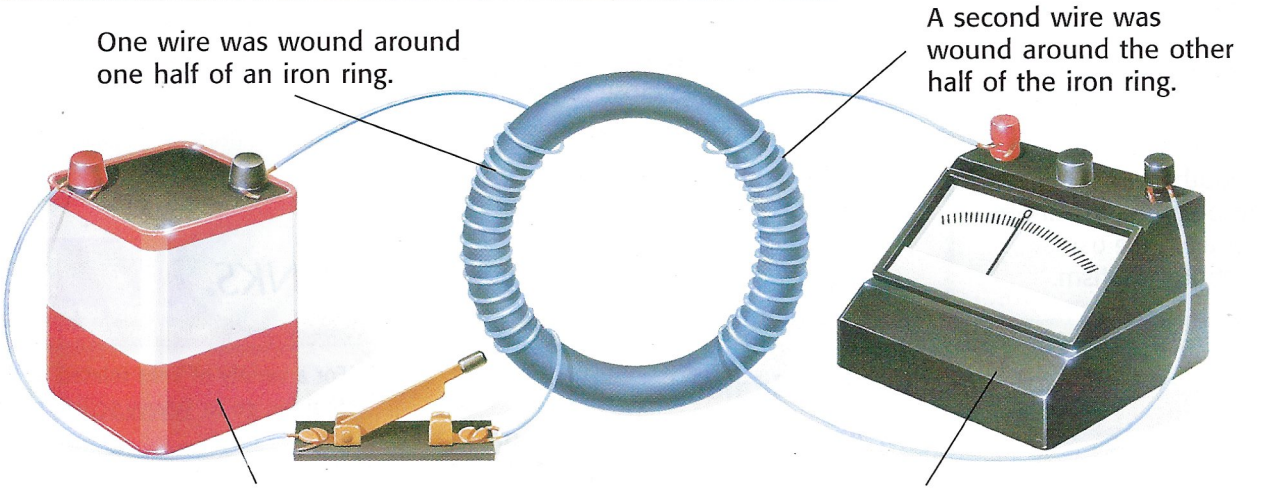
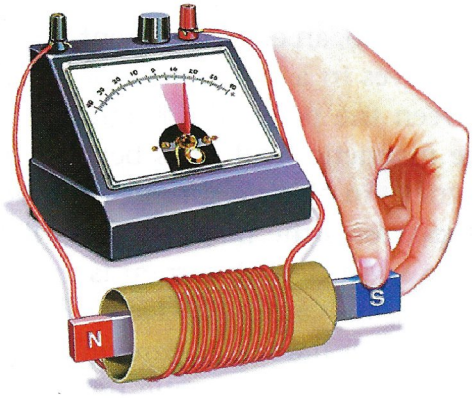
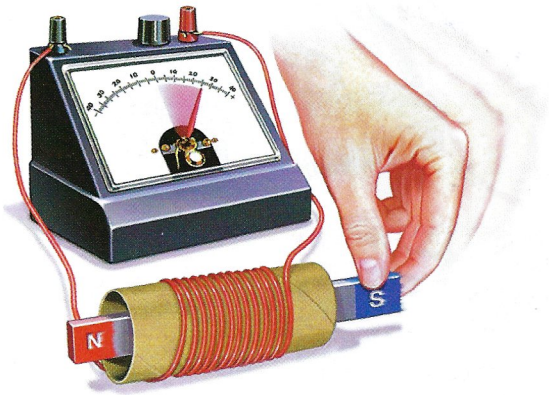


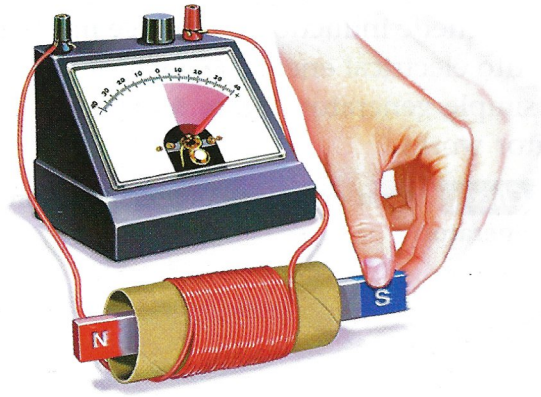
Figure 2 **Factors that Affect an Induced Current**



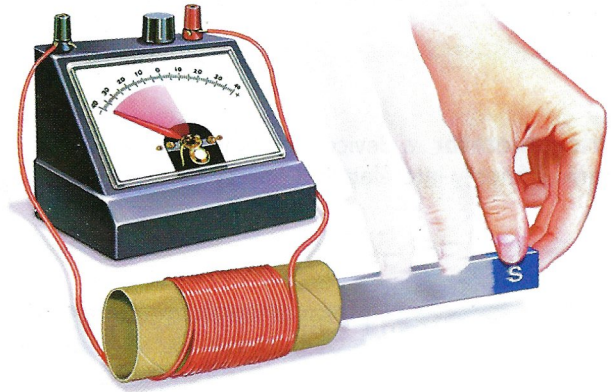
a An electric current is induced when you move a magnet through a coil of wire.



b A greater electric current is induced if you move the magnet faster through the coil because the magnetic field is changing faster.



c A greater electric current is induced if you add more loops of wire. This magnet is moving at the same speed as the magnet in **b.**



d The induced electric current reverses direction if the magnet is pulled out rather than pushed in.

Success for an Instant

As Faraday experimented with the electromagnetic ring, he noticed something interesting. At the instant he connected the wires to the battery, the galvanometer pointer moved. This movement showed that an electric current was present. The pointer moved again at the instant he disconnected the battery. But as long as the battery was fully connected, the galvanometer measured no electric current.

Faraday realized that electric current in the second wire was made only when the magnetic field was changing. The magnetic field changed as the battery was connected and disconnected. The process by which an electric current is made by changing a magnetic field is called **electromagnetic induction.** Faraday did many more experiments in this area. Some of his results are shown in **Figure 2.**

electromagnetic induction the process of creating a current in a circuit by changing a magnetic field

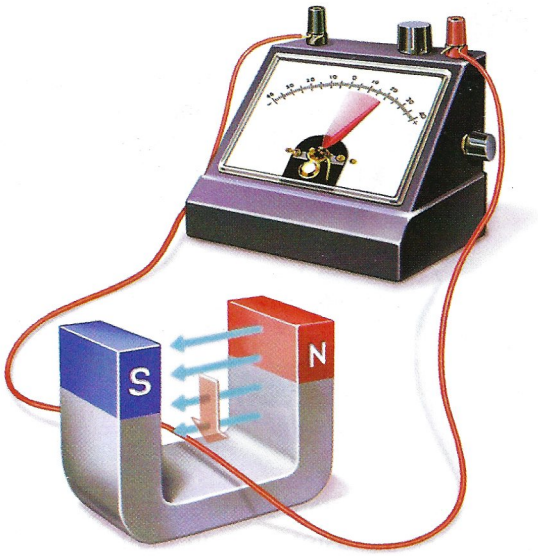


Figure 3 *As the wire moves between the poles of the magnet, it cuts through magnetic field lines, and an electric current is induced.*

Inducing Electric Current

Faraday's experiments also showed that moving either the magnet or the wire changes the magnetic field around the wire. So, an electric current is made when a magnet moves in a coil of wire or when a wire moves between the poles of a magnet.

Consider the magnetic field lines between the poles of the magnet. An electric current is induced only when a wire crosses the magnetic field lines, as shown in **Figure 3.** An electric current is induced because a magnetic force can cause electric charges to move. But the charges move in a wire only when the wire moves through the magnetic field.

Electric Generators

Electromagnetic induction is very important for the generation of electrical energy. An **electric generator** uses electromagnetic induction to change mechanical energy into electrical energy. **Figure 4** shows the parts of a simple generator. **Figure 5** explains how the generator works.

electric generator a device that converts mechanical energy into electrical energy

Reading Check **What energy change happens in an electric generator?**

Figure 4 **Parts of a Simple Generator**

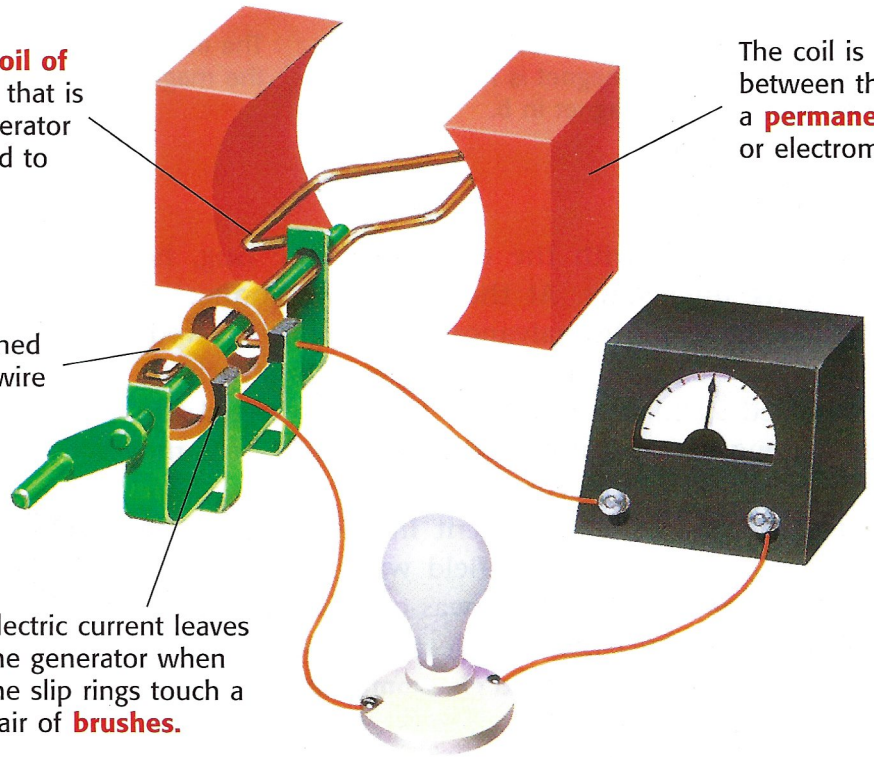
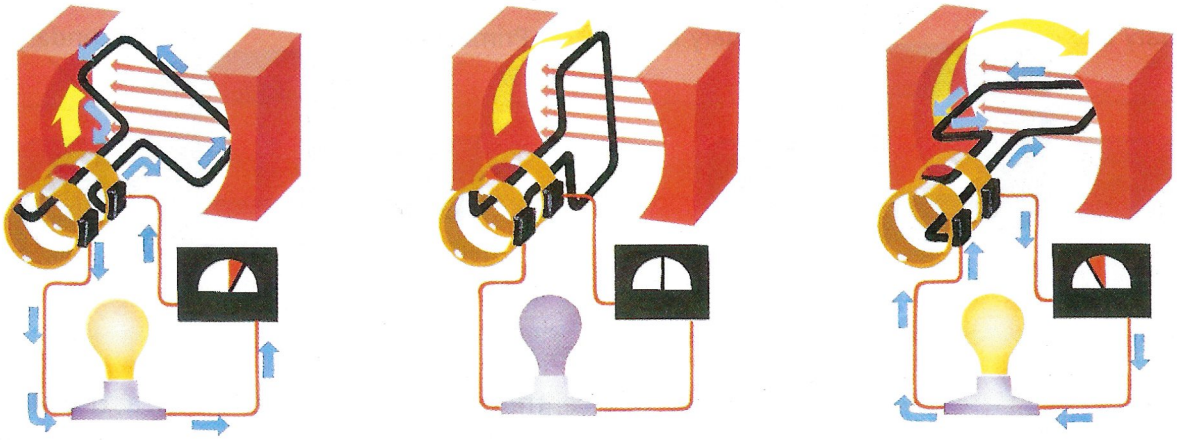


Figure 5 How a Generator Works

1. As the crank is turned, the rotating coil crosses the magnetic field lines of the magnet, and an electric current is induced in the wire.
2. When the coil is not crossing the magnetic field lines, no electric current is induced.
3. As the coil continues to rotate, the magnetic field lines are crossed in a different direction. An electric current is induced in the opposite direction.



Alternating Current

The electric current produced by the generator shown in **Figure 5** changes direction each time the coil makes a half turn. Because the electric current changes direction, it is an alternating current. Generators in power plants also make alternating current. But generators in power plants are very large. They have many coils of wire instead of just one. In most large generators, the magnet is turned instead of the coils.

Generating Electrical Energy

The energy that generators convert into electrical energy comes from different sources. The source in nuclear power plants is thermal energy from a nuclear reaction. The energy boils water into steam. The steam turns a turbine. The turbine turns the magnet of the generator, which induces an electric current and generates electrical energy. Other kinds of power plants burn fuel such as coal or gas to release thermal energy.

Energy from wind can also be used to turn turbines. **Figure 6** shows how the energy of falling water is converted into electrical energy in a hydroelectric power plant.

Reading Check What are three sources of energy that are used to generate electrical energy?

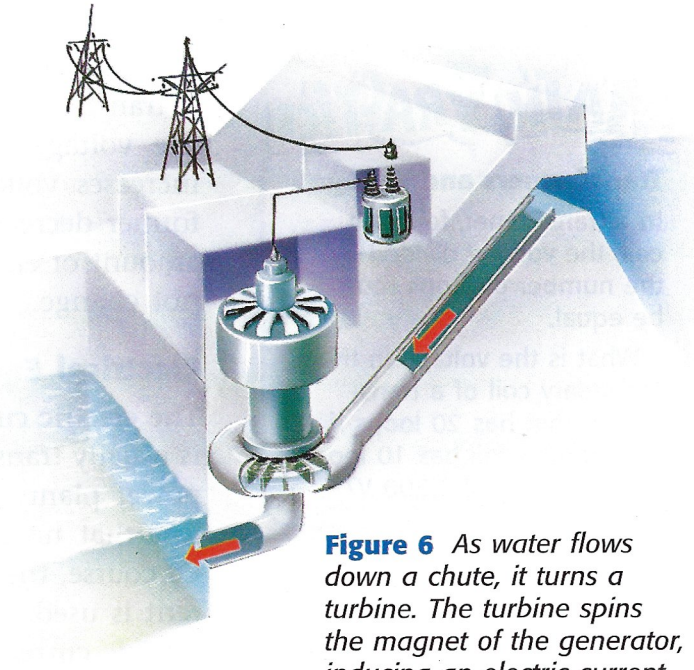
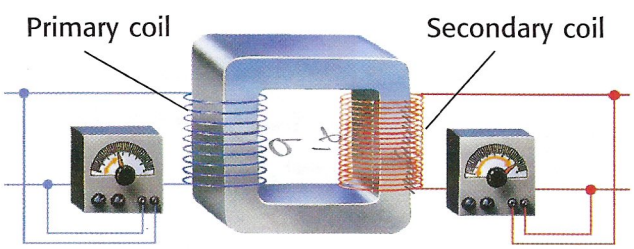


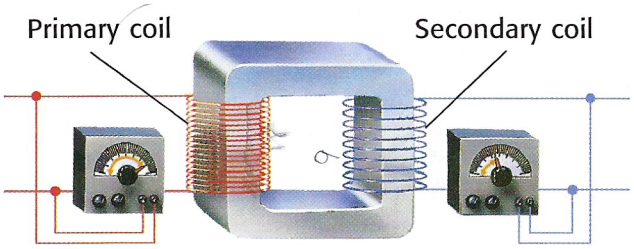
Figure 6 *As water flows down a chute, it turns a turbine. The turbine spins the magnet of the generator, inducing an electric current.*

Figure 7 How Transformers Change Voltage

The primary coil of a **step-up transformer** has fewer loops than the secondary coil. So, the voltage of the electric current in the secondary coil is higher than the voltage of the electric current in the primary coil. Therefore, voltage is increased.



The primary coil of a **step-down transformer** has more loops than the secondary coil. So, the voltage of the electric current in the secondary coil is lower than the voltage of the electric current in the primary coil. Therefore, voltage is decreased.



Transformers

transformer a device that increases or decreases the voltage of alternating current

Another device that relies on induction is a transformer. A **transformer** increases or decreases the voltage of alternating current. A simple transformer is made up of two coils of wire wrapped around an iron ring. The primary coil gets alternating current from an electrical energy source. The current makes the ring an electromagnet. But the current in the primary coil is alternating. The magnetic field of the electromagnet changes as the direction of the current changes. The changing magnetic field in the iron ring induces a current in the secondary coil.

Reading Check What does a transformer do?

Step-Up, Step-Down

The number of loops in the primary and secondary coils of a transformer determines whether it increases or decreases the voltage, as shown in **Figure 7.** A step-up transformer increases voltage and decreases current. A step-down transformer decreases voltage and increases current. However, the amount of energy going into and out of the transformer does not change.

MATH PRACTICE

Transformers and Voltage

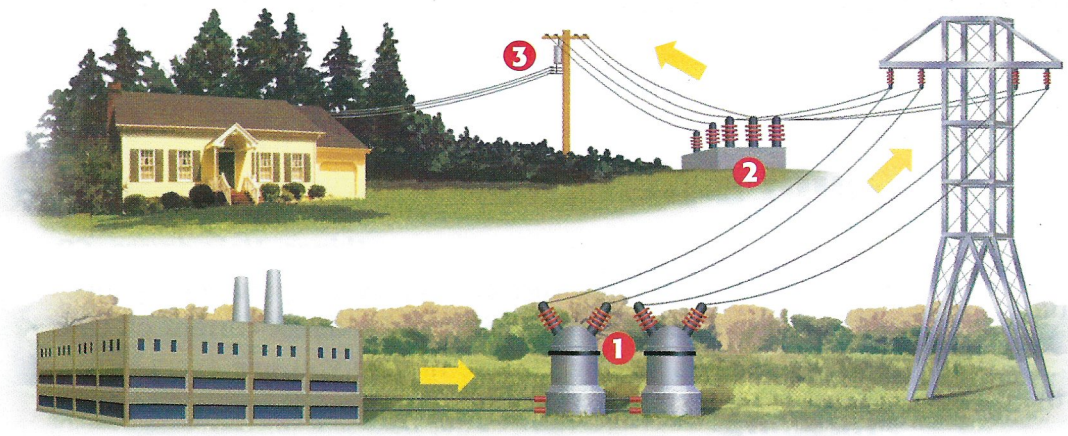
In a transformer, for each coil, the voltage divided by the number of loops must be equal.

What is the voltage in the secondary coil of a transformer that has 20 loops if the primary coil has 10 loops and a voltage of 1,200 V?

Electrical Energy for Your Home

The electric current that brings electrical energy to your home is usually transformed three times, as shown in **Figure 8.** At the power plants, the voltage is increased. This decreases power loss that happens as the energy is sent over long distances. Of course, the voltage must be decreased again before the current is used. Two step-down transformers are used before the electric current reaches your house.

Figure 8 Getting Energy to Your Home



1. The voltage is stepped up thousands of times at the power plant.
2. The voltage is stepped down at a local power distribution center.
3. The voltage is stepped down again at a transformer near your house.

SECTION Review

Summary

- Electromagnetic induction is the process of making an electric current by changing a magnetic field.
- An electric generator converts mechanical energy into electrical energy through electromagnetic induction.
- A step-up transformer increases the voltage of an alternating current. A step-down transformer decreases the voltage.
- The side of a transformer that has the greater number of loops has the higher voltage.

Using Key Terms

For each pair of terms, explain how the meanings of the terms differ.

1. *electric generator* and *transformer*

Understanding Key Ideas

2. Which of the following will induce an electric current in a wire?
   - **a.** moving a magnet into a coil of wire
   - **b.** moving a wire between the poles of a magnet
   - **c.** turning a loop of wire between the poles of a magnet
   - **d.** All of the above
3. How does a generator produce an electric current?
4. Compare a step-up transformer with a step-down transformer based on the number of loops in the primary and secondary coils.

Math Skills

5. A transformer has 500 loops in its primary coil and 5,000 loops in its secondary coil. What is the voltage in the primary coil if the voltage in the secondary coil is 20,000 V?
6. A transformer has 3,000 loops in its primary coil and 1,500 loops in its secondary coil. What is the voltage in the secondary coil if the voltage in the primary coil is 120 V?

Critical Thinking

7. **Analyzing Ideas** One reason that electric power plants do not send out electrical energy as direct current is that direct current cannot be transformed. Explain why not.
8. **Analyzing Processes** Explain why rotating either the coil or the magnet in a generator induces an electric current.

Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

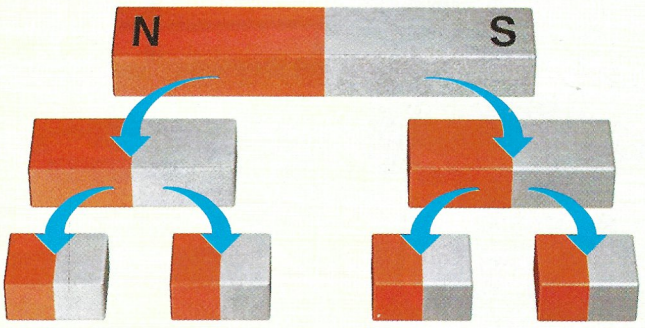
electric motor — transformer
magnetic force — electric generator
magnetic pole — electromagnetism
electromagnetic induction

1. Each end of a bar magnet is a(n) ___.
2. A(n) ___ converts mechanical energy into electrical energy.
3. ___ occurs when an electric current is made by a changing magnetic field.
4. The relationship between electricity and magnetism is called ___.

UNDERSTANDING KEY IDEAS

Multiple Choice

5. In the region around a magnet in which magnetic forces act exists the
   - **a.** magnetic field.
   - **b.** domain.
   - **c.** pole.
   - **d.** solenoid.
6. An electric fan has an electric motor inside to change
   - **a.** mechanical energy into electrical energy.
   - **b.** thermal energy into electrical energy.
   - **c.** electrical energy into thermal energy.
   - **d.** electrical energy into mechanical energy.
7. The marked end of a compass needle always points directly to
   - **a.** Earth's geographic South Pole.
   - **b.** Earth's geographic North Pole.
   - **c.** a magnet's south pole.
   - **d.** a magnet's north pole.
8. A device that increases the voltage of an alternating current is called a(n)
   - **a.** electric motor.
   - **b.** galvanometer.
   - **c.** step-up transformer.
   - **d.** step-down transformer.
9. The magnetic field of a solenoid can be increased by
   - **a.** adding more loops per meter.
   - **b.** increasing the current.
   - **c.** putting an iron core inside the coil to make an electromagnet.
   - **d.** All of the above
10. What do you end up with if you cut a magnet in half?
    - **a.** one north-pole piece and one south-pole piece
    - **b.** two unmagnetized pieces
    - **c.** two pieces each with a north pole and a south pole
    - **d.** two north-pole pieces



Short Answer

11 Explain why auroras are seen mostly near the North Pole and South Pole.

12 Compare the function of an electric generator with the function of an electric motor.

13 Explain why some pieces of iron are more magnetic than others are.

Math Skills

14 A step-up transformer increases voltage 20 times. If the voltage of the primary coil is 1,200 V, what is the voltage of the secondary coil?

CRITICAL THINKING

15 **Concept Mapping** Use the following terms to create a concept map: *electromagnetism, electricity, magnetism, electromagnetic induction, generators,* and *transformers*.

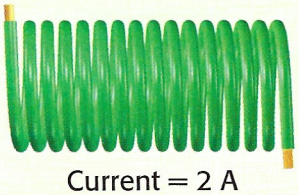
16 **Applying Concepts** You win a hand-powered flashlight as a prize in your school science fair. The flashlight has a clear plastic case, so you can look inside to see how it works. When you press the handle, a gray ring spins between two coils of wire. The ends of the wire are connected to the light bulb. So, when you press the handle, the light bulb glows. Explain how an electric current is produced to light the bulb. (Hint: Paper clips are attracted to the gray ring.)

17 **Identifying Relationships** Closed fire doors can slow the spread of fire between rooms. In some buildings, electromagnets controlled by the building's fire-alarm system hold the fire doors open. If a fire is detected, the doors automatically shut. Explain why electromagnets are used instead of permanent magnets.

INTERPRETING GRAPHICS

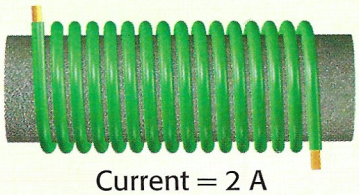
18 Look at the solenoids and electromagnets shown below. Identify which of them has the strongest magnetic field and which has the weakest magnetic field. Explain your reasoning.

a



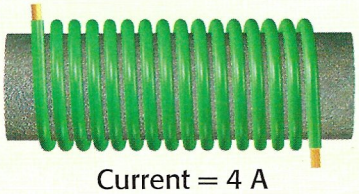
Current = 2 A

b



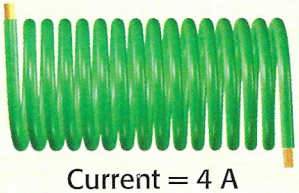
Current = 2 A

c



Current = 4 A

d



Current = 4 A