In 1820, the Danish scientist Hans Christian Oersted (ur sted) was teaching a class at the University of Copenhagen. During his lecture, he allowed electricity to flow through a wire, just as electricity flows through wires to your electrical appliances. When electricity flowed, he noticed that the needle of a compass near the wire changed direction.

Oersted's observations surprised him. He could have assumed that something was wrong with his equipment. Instead, he investigated further. He set up several compasses around a wire. Oersted discovered that whenever he turned on the electricity, the compass needles lined up in a circle around the wire.

Oersted's discovery showed that magnetism and electricity are related. But just how are they related? To find out, you must learn about electric current.

**Electric Current**

You learned in Section 1 that all matter contains particles called electrons and protons. Electrons and protons have a property called electric charge. Electrons are negatively charged, and protons are positively charged.
When electric charges flow through a wire or similar material, they create an electric current. **Electric current** is the flow of charge through a material. The amount of charge that passes through the wire in a unit of time is the rate at which electric current flows. The unit of current is the ampere (amp or A), named for André-Marie Ampère. You will often see the name of the unit shortened to “amp.” The number of amps tells the amount of charge flowing past a given point each second.

What does all of this have to do with magnetism? **An electric current produces a magnetic field.** The lines of the magnetic field produced by a current in a straight wire are in the shape of circles with the wire at their center. You can see in Figure 17 that compasses placed around a wire line up with the magnetic field. The iron filings in Figure 18 map out the same field. The direction of the current determines the direction of the magnetic field. If the current is reversed, the magnetic field reverses as well. You can see this from the compasses in Figure 17C.

**Moving Charge and Magnetism**

Ampère carried out many experiments with electricity and magnetism. He hypothesized that all magnetism is a result of circulating charges. Atoms, for example, can become magnets because of the motion of the electrons. Based on modern knowledge of magnetism, Ampère’s hypothesis is correct. All magnetism is caused by the movement of charges.

**Checkpoint** What particles have electric charge?
Electric Circuits

An electric current will not flow automatically through every wire. Current flows only through electric circuits. An electric circuit is a complete path through which electric charges can flow. All electrical devices, from toasters to radios to electric guitars and televisions, contain electric circuits.

All circuits have the same basic features. First, a circuit has a source of electrical energy. Energy is the ability to do work. Second, circuits have devices that are run by electrical energy. A radio, a computer, a light bulb, and a refrigerator are all devices that convert electrical energy into another form of energy. A light bulb, for example, converts electrical energy to electromagnetic energy (it gives off light) and thermal energy (it gives off heat).

Third, electric circuits are connected by conducting wires and a switch. In order to describe a circuit, you can draw a circuit diagram. Exploring Electric Circuits on the next page shows a circuit diagram along with the symbols that represent the parts of the circuit. As you read, identify the parts of a circuit and their symbols.

Conductors and Insulators

Electric current flows through metal wires. Will it also flow through plastic or paper? The answer is no. Electric current does not flow through every material.

Electric currents move freely through materials called conductors. Metals, such as copper, silver, iron, and aluminum, are good conductors. In a conductor, some of the electrons are only loosely bound to their atoms. These electrons, called conduction electrons, are able to move throughout the conductor. As these electrons flow through a conductor, they form an electric current.

Did you ever wonder why a light goes on the instant you flip the switch? How do the electrons get to your lamp from the electric company so fast? The answer is that electrons are not created and sent to you when you flip a switch. They are present all along in the conductors that make up the circuit. When you flip the switch, conduction electrons at one end of the wire are pulled while those at the other end are pushed. The result is a continuous flow of electrons as soon as the circuit is completed.

Insulators are a different kind of material in which charges are not able to move freely. The electrons in an insulator are bound tightly to their atoms and do not flow easily. Examples of insulators are rubber, glass, sand, plastic, and wood.

Checkpoint What moves freely in a conductor?
EXPLORING Electric Circuits

Electric circuits are all around you. They are so common that you probably don’t think about them. An electric circuit has several basic features.

This circuit diagram represents the circuit shown in the photograph. Special symbols are used for the parts of the circuit.

Battery
A source of electrical energy makes charges move around a circuit.

Resistor
A device such as a light bulb, appliance, or computer converts electrical energy to another form. Such a device is called a resistor.

Switch
A switch is used to open and close the circuit. When the switch is closed, the electric circuit is complete. When the switch is open, the circuit is broken. Charges cannot flow through a broken path.
Electric current passes through the tungsten filament of a light bulb. As it resists the flow of charge, the filament heats up until it glows.

**Figure 20**

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**Sharpen your Skills**

**Classifying**

Gather several objects such as keys, foam, pencil lead, aluminum foil, wax paper, and paper clips. Predict which items will be conductors.

1. Obtain three 10-cm wires with the insulation removed from both ends.

2. Construct a circuit like the one shown. Use the wires, a light bulb, a D cell, and two alligator clips.

3. Insert a test object between the two clips. Observe the light bulb. Repeat the test with each of the other objects.

Which objects are conductors? Which are insulators? How do you know?

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**Electrical Resistance**

As charges flow through a circuit, they pass through resistors. A **resistor** uses electrical energy as it interferes with, or resists, the flow of charge. The opposition to the movement of charges flowing through a material is called **resistance**.

The resistance of a material depends on its atomic structure. Think about walking through a room with people in it. If the people are spread out, you can easily walk through the room without colliding with anyone. But if the people are crowded together, you will bump into people as you move through the room. In a similar way, an electron collides with particles in a material. During each collision, some of the electron's energy is converted to thermal energy (felt as heat) or electromagnetic energy (seen as light). The more collisions, the more electrical energy is converted.

**The Light Bulb**

Thomas Edison used resistance when he was developing his electric light bulb. Edison experimented with many materials. He needed one that would conduct electric current, but would offer enough resistance to make the material heat up and glow. Edison tried cotton threads, copper wires, silk fibers, shredded corn husks, and even human hair, before he settled on charcoal made from bamboo slivers. Eventually, bamboo was replaced with wire made from tungsten. Tungsten is a metal that can get hot enough to glow without melting.
**Superconductors** Scientists have discovered that some materials become superconductors at very low temperatures. A **superconductor** is a material that has no electrical resistance. A superconductor is very different from an ordinary conductor. Without resistance, a current flows through a superconductor with no loss of energy. Using superconducting wires would reduce wasted electrical energy and make electrical devices more efficient. Superconductors strongly repel magnets, as you can see in Figure 21. But their use as magnets is limited. A strong magnetic field destroys the superconductivity of a substance, turning it back into an ordinary conductor!

The greatest problem with superconductors is that very low temperatures are required. However, new materials have been found that become superconducting at higher temperatures. At the present time, researchers are working to making superconductors practical.

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**Figure 21** The magnetic field of the superconductor repels the magnetic cube. Thus the cube floats above the superconductor, much like the maglev train in Section 1.

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**Section 3 Review**

1. **Are electricity and magnetism related?** Explain.
2. **What is the difference between a conductor and an insulator?** Give an example of each.
3. **What is an electric circuit?**
4. **Thinking Critically Relating Cause and Effect** Why does a compass needle move when placed near a wire carrying an electric current? What do you think happens to the compass needle when the circuit is shut off?

**Check Your Progress**

Construct an electric circuit for your fishing rod with a D cell and a piece of insulated wire about 12 meters long. Your fishing rod will need a switch. Making a switch is a matter of closing a circuit. One way to do this is to tape one end of your wire to one end of the battery and then to touch the other end of the wire to the other end of the battery. Think of a less awkward way of controlling the fishing rod.