ELECTRICAL ENERGY

Electrical energy is the ability to do work by virtue of the forces of the attraction and repulsion between electric charges. *Static electricity* involves forces exerted on matter because of an imbalance of electric charge. *Current electricity* refers to the flow of electric charge through matter.

STATIC ELECTRICITY

Electric charge is a fundamental property of matter, like mass or volume. The word "electric" comes from *elektron*, the Greek word for "amber," a substance used in the earliest studies of electricity. Two simple experiments show us that there are two types of electric charge. First, we suspend a pith ball from a thread and touch it with a hard rubber rod. Nothing happens. Then we rub the rubber rod with a piece of fur and touch the ball again. After the touch, the ball flies away from the rod. See Figure 14.7*a*. Whatever it is that the rubber rod gets by being rubbed with fur is called a ***negative electric charge***. If we do this to a second pith ball and bring it near the first one, the two push apart, or repel. The rubber rod also repels both pith balls. From this we conclude that the negative electric charge flowed to the pith ball when it was touched. The fact that the pith ball then flew away from the rod suggests that negative charges repel one another. The fact that the two charged pith balls repelled one another further supports this idea.

In the second experiment, we touch a suspended pith ball with a glass rod. Nothing happens. Then we rub the glass rod with a piece of silk and touch the ball again. After the touch, the ball flies away from the glass rod. See Figure 14.7*b*. Whatever it is that the glass rod gets by being rubbed with silk is called a ***positive electric charge***. We get the same results when we touch a second pith ball. If the two pith balls are brought close together, they repel. From this we conclude that positive electric charges repel one another.

If the pith balls charged by the glass rod repelled and the pith balls charged by the rubber rod repelled, why do we assume that the electric charge on the glass rod is different from the electric charge on the rubber rod? Because if we bring a pith ball charged by a rubber rod and a pith ball charged by a glass rod close to one another, they *attract*! See Figure 14.7*c*. The attraction of the two pith balls means that their charges must be different, because we already showed that like charges repel. It also means that unlike charges attract. The *law of electric charges* summarizes these results:

Like charges repel, unlike charges attract.

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Another interesting observation is that once a material has been electrically charged, it attracts uncharged materials and may either attract or repel charged materials *without touching them!* The forces of attraction and repulsion due to electric charge extend beyond the object! The region of space around a charged object in which these forces exist is called an *electric field*. Although an electric field is invisible, we know it exists because we can see its effects. The field itself can exert forces of attraction or repulsion

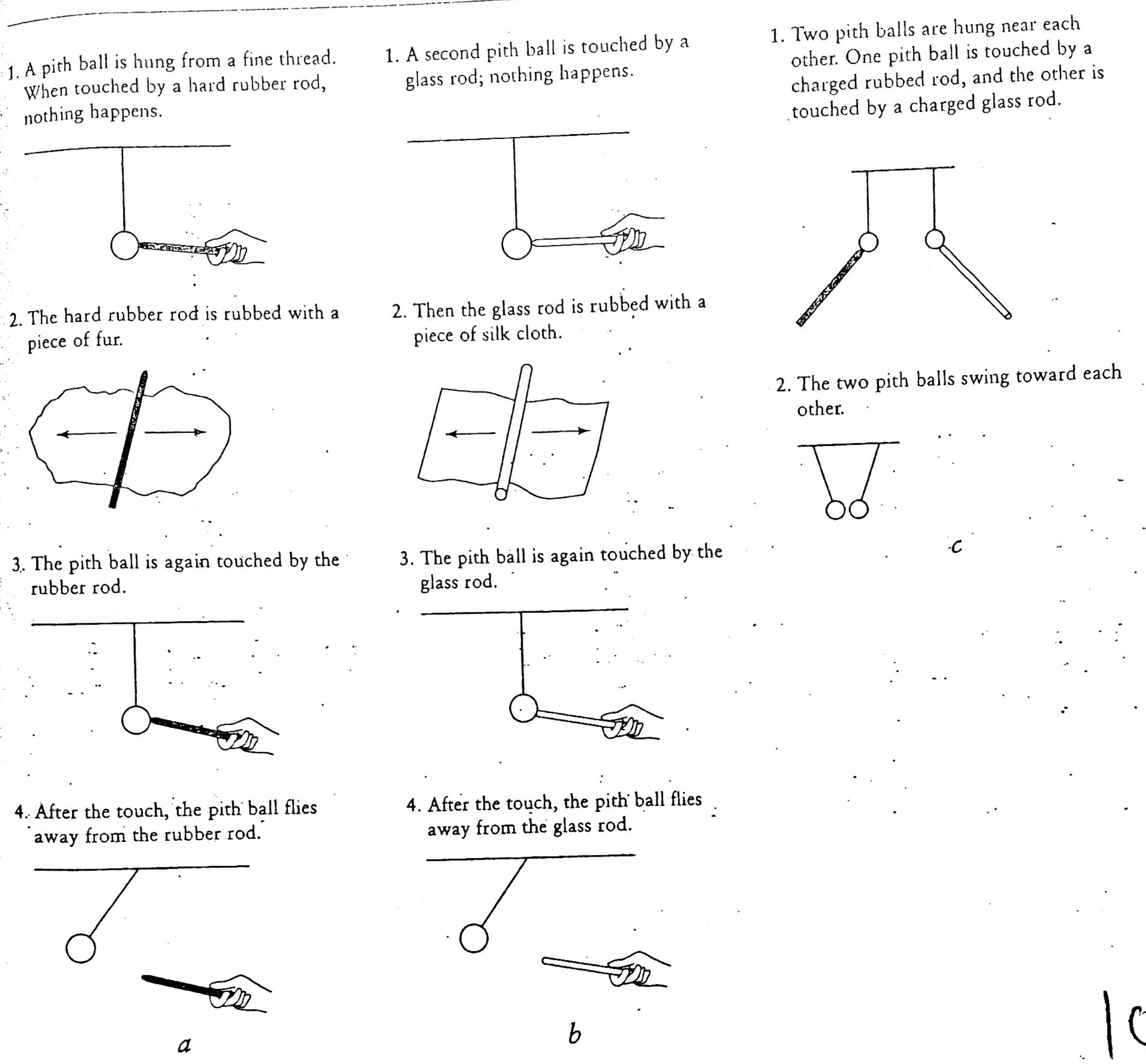


Figure 14.7
Several simple experiments show the existence of two types of electric charges and how they interact.

on matter, even if the charged object does not come into contact with the matter. See Figure 14.8.

Where do the charges come from when one substance is rubbed with another? Further experiments show that while the rubber rod gets a negative charge when rubbed with a piece of fur, the piece of fur gets a positive charge. A similar thing happens with the glass rod and silk. Matter seems to have both negative and positive electric charges. The rubbing serves only to separate the charges from one another. Numerous experiments have shown that there are only two kinds of electric charge—positive and negative. They have also shown that uncharged, or ***neutral***, matter actually has equal amounts of positive and negative charges. Unlike charges attract strongly, so separating neutral matter into portions that are positive and negative is hard. Since like charges repel strongly, adding more charge to an already charged object becomes harder and harder. So what exactly is charge? We can say only that it is charge, just as mass is, well, mass.

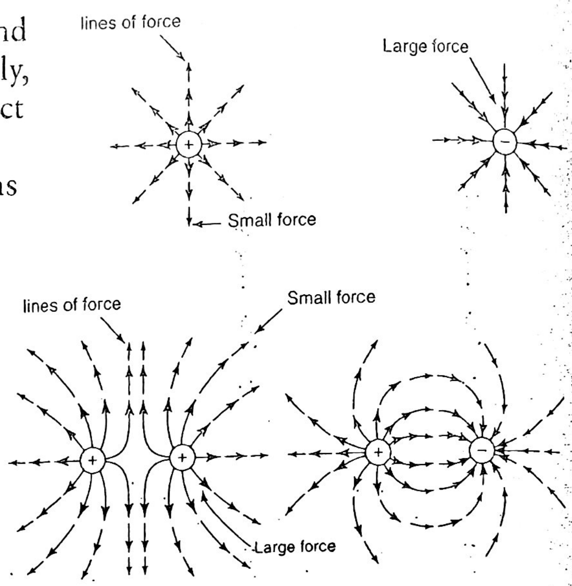


Figure 14.8
(*a*) Electric fields around some charged particles. Arrows indicate the direction in which force is exerted. (*b*) Electric fields when like and unlike charges are brought close to one another.

CURRENT ELECTRICITY

An *electric current* is a flow of charge from one place to another. Almost all substances fall into one of two categories: conductors and insulators. *Conductors* are substances through which charge flows easily. *Insulators* are substances through which charge can flow only with great difficulty. Metals and many liquids and gases whose particles are charged are good conductors. Nonmetals, liquids, and gases whose particles are electrically neutral are insulators. Some substances, called *semiconductors*, have an ability to conduct charge at a level between that of conductors and insulators.

In order to produce a flow of electric charge, you must have a separation of positive and negative charges. *Electric cells*, such as the D cells in a flashlight, use chemical reactions to separate positive and negative charges. Electric power plants use complex systems to make charge flow through the wires that connect to your home. The two prongs on the plugs of all your household appliances connect to the positively and negatively charged conductors in the power outlet. Electric charge will flow through a conductor if it forms a continuous pathway, or *closed circuit*, from matter that is positively charged to matter that is negatively charged. However, if a break occurs in the conducting pathway, it is called an *open circuit*, and electric charge will not flow. Never touch both conductors in a power outlet at the same time, or *you* could become part of the circuit. Electric charge could then flow through your body and give you a severe shock, which could be fatal.

A *switch* is a device that allows one to control the flow of charge through a circuit by opening and closing the circuit. A device that uses flowing electric charge to do work is called a *load*. Lightbulbs, televisions, CD players, and the like are all loads. In a lightbulb, charge is made to flow through a thin wire, called a filament. The moving charges exert forces onto the molecules in the wire that cause them to vibrate more rapidly, and the wire gets so hot that it glows. If too much electricity flows through the wires in your house, they too can heat up and cause a fire. Therefore, household circuits are protected by *fuses* or *circuit breakers* that open the circuit if the wires get too hot.

A load can be connected to an electric circuit in several ways. In a ***series circuit***, electric charge can travel along only one pathway through the circuit. See Figure 14.9*a*. Some Christmas lights are wired in a series circuit. If one of the lights burns out, the conducting pathway is broken and electric charge stops flowing. Then all of the lights go out at once. In a ***parallel circuit***, the electric charge can flow through the circuit along more than one pathway. See Figure 14.9*b*. Christmas lights wired in a parallel circuit do not all go out at once. If one light burns out, electric charge can flow along one of the other paths that is still unbroken. See Figure 14.9*c*.

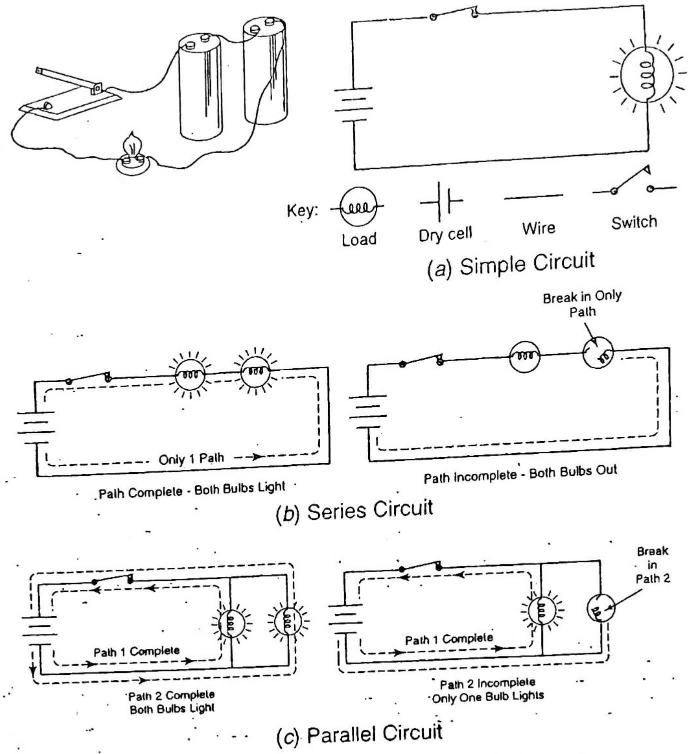
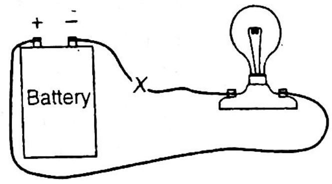


Figure 14.9
Electric circuits. (*a*) A picture of a simple circuit and the same circuit shown using symbols. (*b*) A series circuit. (*c*) A parallel circuit.

TRY THIS

The diagram below shows an incomplete electrical circuit.

1. Which object, when connected to the wires at position X, would complete the circuit and light the bulb?
   1. wooden matchstick
   2. glass test tube
   3. iron nail
   4. rubber hose
2. By using the symbols shown in Figure 14.9, draw a diagram of a circuit with two dry cells, one switch, and three lamps. In your circuit, what will happen to the lamps if one of them burns out?



MAGNETISM

Electric charges that are in motion exert forces onto one another that are very different from when they are at rest. If we put two wires through which electric charge is flowing

Waves, Currents, and Tides

Read about the ocean in motion. Then answer the questions that follow.

The ocean is full of motion. When you enjoy a day at the beach, you see it all. Big waves come crashing onto the shore. Swimmers need to be careful of small hidden currents. Big boats go by on the horizon, following the giant currents that run through the entire ocean. And every few hours the tide goes out, and then comes back in.

What causes all this motion? The wind you feel on your face at the beach causes many of the waves—anything from a small ripple to a big swell. But waves can be caused by other things. You can create a wave in a bathtub by dropping a toy, or kicking your feet, and the same is true in the ocean. Underwater earthquakes and disturbances at the shore, such as landslides, can also cause waves.

Many people know the feeling of a current tugging them at the shore. Those small currents are caused when different types of waves break on the beach. There are also giant currents that carry water all around the world and affect weather patterns. These large worldwide currents are formed in part by wind on the surface of the ocean. They're affected by the rotation of the Earth—and by the shape of the shore the water washes up against. Currents are also caused by the differences in the temperature and saltiness of water. When ice freezes at the poles of the Earth, cold, salty water is left. That water is denser than the rest of the water in the ocean, so it sinks. As it does, it displaces warmer water, and a current is created.

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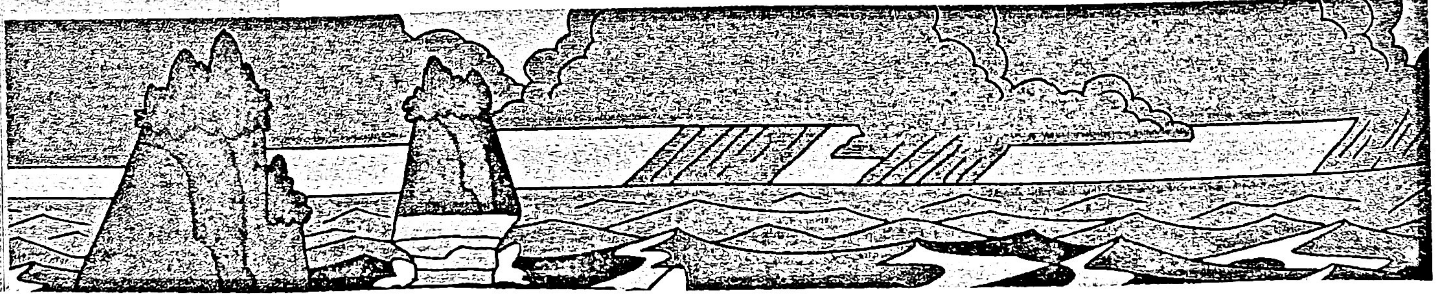

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ollow.

Through it all, the tides continue to come in and go out. They're not driven by big gusts of wind, or by temperature variations. Instead, tides respond to the gravitational pull of the sun and the moon. And because the relationship of the sun and the moon to Earth changes, tides also change.

In fact, the sun provides most of the energy that drives the motion of the ocean. It's the presence or the absence of the sun that creates the wind that drives waves. It's the heat of the sun that causes polar ice to melt or form and thus creates currents. And it's the pull of both the sun and the moon that causes tides.

So when you sit on the beach, enjoying the water and the sun, you also get a taste of the massive forces that move the whole ocean.

What five factors contribute to large and small currents?

What two things beyond Earth cause the tides?

What three factors create waves?

What is left behind after polar ice forms?

What provides most of the energy for motion in the ocean?