UNIT 1

Atomic Structure

Why You Need to Know

Atoms are the building blocks of the universe, and all matter is composed of them. One component of an atom is the electron, and all electrical quantities, such as voltage, current, and watts, are based on other electrical units that are derived from the measurement of electrons. A basic understanding of electron flow will remove the "mystery" of electricity and will start you on a path to a further understanding of electrical theory. This unit explains

- how electricity is produced and how those sources are divided in alternating current (AC) and direct current (DC) for utilization.
- why some materials are conductors and others are insulators.
- why a conductor becomes warm as a current flows through it.

Key Terms

Alternating current (AC)
Atom
Atomic number
Attraction
Bidirectional
Conductor
Direct current (DC)
Electron
Electron orbit
Element
Insulators
Matter
Molecules
Negative
Neutron
Nucleus
Positive
Proton
Repulsion
Semiconductors
Unidirectional
Valence electrons

Outline

1–1 Early History of Electricity
1–2 Atoms
1–3 The Law of Charges
1–4 Structure of the Atom
1–5 Electron Orbits
1–6 Valence Electrons
1–7 The Bump Theory
1–8 Power Sources
1–9 Insulators
1–10 Semiconductors
1–11 Molecules
1–12 Methods of Producing Electricity
1–13 Electrical Effects

Objectives

After studying this unit, you should be able to

- list the three principal parts of an atom.
- state the law of charges.
- discuss centripetal force.
- discuss the differences between conductors and insulators.

Preview

Electricity is the driving force that provides most of the power for the industrialized world. It is used to light homes, cook meals, heat and cool buildings, drive motors, and supply the ignition for most automobiles. The technician who understands electricity can seek employment in almost any part of the world.

Electric sources are divided into two basic types, **direct current** (DC) and **alternating current** (AC). Direct current is **unidirectional,** which means that it flows in only one direction. The first part of this text is mainly devoted to the study of direct current. Alternating current is **bidirectional,** which means that it reverses its direction of flow at regular intervals. The latter part of this text is devoted mainly to the study of alternating current. ■

1–1 Early History of Electricity

Although the practical use of electricity has become common only within the last hundred years, it has been known as a force for much longer. The Greeks were the first to discover electricity about 2500 years ago. They noticed that when amber was rubbed with other materials, it became charged with an unknown force that had the power to attract objects such as dried leaves, feathers, bits of cloth, or other lightweight materials. The Greeks called amber *elektron*. The word *electric* was derived from it and meant "to be like amber," or to have the ability to attract other objects.

This mysterious force remained little more than a curious phenomenon until about 2000 years later, when other people began to conduct experiments. In the early 1600s, William Gilbert discovered that amber was not the only material that could be charged to attract other objects. He called materials that could be charged *electriks* and materials that could not be charged *nonelektriks*.

About 300 years ago, a few men began to study the behavior of various charged objects. In 1733, a Frenchman named Charles DuFay found that a piece of charged glass would repel some charged objects and attract others. These men soon learned that the force of **repulsion** was just as important as the force of **attraction.** From these experiments, two lists were developed *(Figure 1–1)*. It was determined that any material in list A would attract any material in list B, that all materials in list A would repel each other, and that all materials in list B would repel each other *(Figure 1–2)*. Various names were suggested for the materials in lists A and B. Any opposite-sounding names could have been chosen, such as east and west, north and south, male and female. Benjamin Franklin named the materials in list A **positive** and the materials in list B **negative.** These names are still used today. The first item in each list was used as a standard for determining whether a charged object was positive or negative. Any object repelled by a piece of glass rubbed on silk would have a positive charge, and any item repelled by a hard rubber rod rubbed on wool would have a negative charge.

LIST A	LIST B
Glass (Rubbed on Silk)	Hard Rubber (Rubbed on Wool)
Glass (Rubbed on Wool or Cotton)	Block of Sulfur (Rubbed on Wool or Fur)
Mica (Rubbed on Cloth)	Most Kinds of Rubber (Rubbed on Cloth)
Asbestos (Rubbed on Cloth or Paper)	Sealing Wax (Rubbed on Silk, Wool, or Fur)
Stick of Sealing Wax (Rubbed on Wool)	Mica (Rubbed on Dry Wool)
	Amber (Rubbed on Cloth)

FIGURE 1–1 List of charged materials.

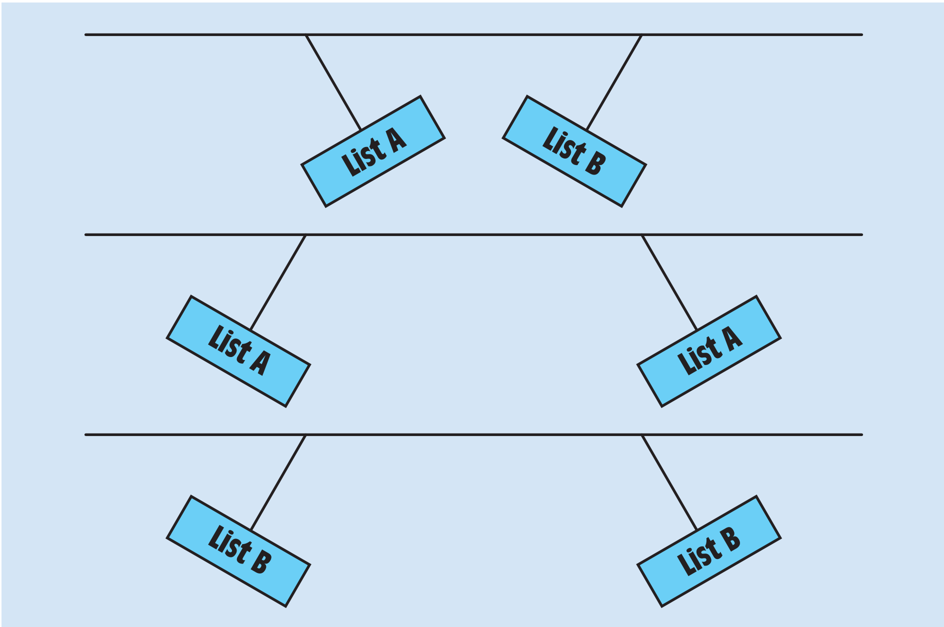

FIGURE 1–2 Unlike charges attract and like charges repel.

1–2 Atoms

Understanding electricity necessitates starting with the study of atoms. The **atom** is the basic building block of the universe. All **matter** is made from a combination of atoms. Matter is any substance that has mass and occupies space. Matter can exist in any of three states: solid, liquid, or gas. Water, for example, can exist as a solid in the form of ice, as a liquid, or as a gas in the form of steam *(Figure 1–3)*. An **element** is a substance that cannot be chemically divided into two or more simpler substances. A table listing both natural and artificial elements is shown in *Figure 1–4*. An atom is the smallest part of an element. The

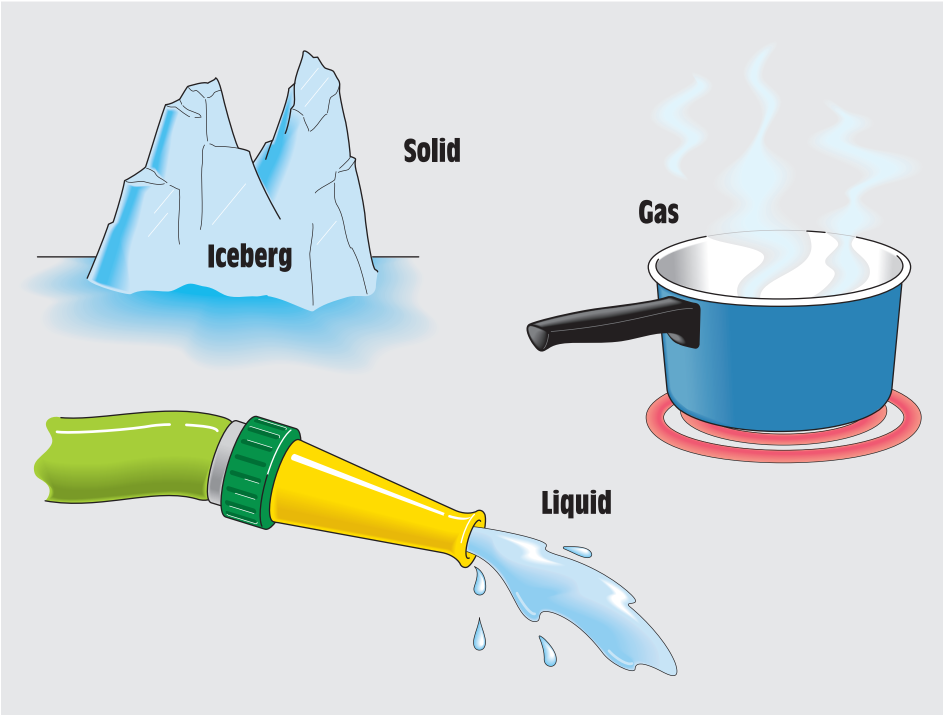

FIGURE 1–3 Water can exist in three states, depending on temperature and pressure.

ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL	ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL	ATOMIC NUMBER	NAME	VALENCE ELECTRONS	SYMBOL
1	Hydrogen	1	H	37	Rubidium	1	Rb	73	Tantalum	2	Ta
2	Helium	2	He	38	Strontium	2	Sr	74	Tungsten	2	W
3	Lithium	1	Li	39	Yttrium	2	Y	75	Rhenium	2	Re
4	Beryllum	2	Be	40	Zirconium	2	Zr	76	Osmium	2	Os
5	Boron	3	B	41	Niobium	1	Nb	77	Iridium	2	Ir
6	Carbon	4	C	42	Molybdenum	1	Mo	78	Platinum	1	Pt
7	Nitrogen	5	N	43	Technetium	2	Tc	79	Gold	1	Au
8	Oxygen	6	O	44	Ruthenium	1	Ru	80	Mercury	2	Hg
9	Fluorine	7	F	45	Rhodium	1	Rh	81	Thallium	3	Tl
10	Neon	8	Ne	46	Palladium	–	Pd	82	Lead	4	Pb
11	Sodium	1	Na	47	Silver	1	Ag	83	Bismuth	5	Bl
12	Magnesium	2	Ma	48	Cadmium	2	Cd	84	Polonium	6	Po
13	Aluminum	3	Al	49	Indium	3	In	85	Astatine	7	At
14	Silicon	4	Si	50	Tin	4	Sn	86	Radon	8	Rd
15	Phosphorus	5	P	51	Antimony	5	Sb	87	Francium	1	Fr
16	Sulfur	6	S	52	Tellurium	6	Te	88	Radium	2	Ra
17	Chlorine	7	Cl	53	Iodine	7	I	89	Actinium	2	Ac
18	Argon	8	A	54	Xenon	8	Xe	90	Thorium	2	Th
19	Potassium	1	K	55	Cesium	1	Cs	91	Protactinium	2	Pa
20	Calcium	2	Ca	56	Barium	2	Ba	92	Uranium	2	U
21	Scandium	2	Sc	57	Lanthanum	2	La				
22	Titanium	2	Ti	58	Cerium	2	Ce		Artificial Elements		
23	Vanadium	2	V	59	Praseodymium	2	Pr				
24	Chromium	1	Cr	60	Neodymium	2	Nd	93	Neptunium	2	Np
25	Manganese	2	Mn	61	Promethium	2	Pm	94	Plutonium	2	Pu
26	Iron	2	Fe	62	Samarium	2	Sm	95	Americium	2	Am
27	Cobalt	2	Co	63	Europium	2	Eu	96	Curium	2	Cm
28	Nickel	2	Ni	64	Gadolinium	2	Gd	97	Berkelium	2	Bk
29	Copper	1	Cu	65	Terbium	2	Tb	98	Californium	2	Cf
30	Zinc	2	Zn	66	Dysprosium	2	Dy	99	Einsteinium	2	E
31	Gallium	3	Ga	67	Holmium	2	Ho	100	Fermium	2	Fm
32	Germanium	4	Ge	68	Erbium	2	Er	101	Mendelevium	2	Mv
33	Arsenic	5	As	69	Thulium	2	Tm	102	Nobelium	2	No
34	Selenium	6	Se	70	Ytterbium	2	Yb	103	Lawrencium	2	Lw
35	Bromine	7	Br	71	Lutetium	2	Lu				
36	Krypton	8	Kr	72	Hafnium	2	Hf				

FIGURE 1–4 Table of elements.

three principal parts of an atom are the **electron,** the **neutron,** and the **proton.** Although most atoms contain these three principal parts, the smallest atom, hydrogen, does not contain a neutron (*Figure 1–5*). Hydrogen contains one proton and one electron. The smallest atom that contains neutrons is helium (*Figure 1–6*). Helium contains two protons, two neutrons, and two electrons. It is theorized that protons and neutrons are actually made of smaller particles called *quarks*.

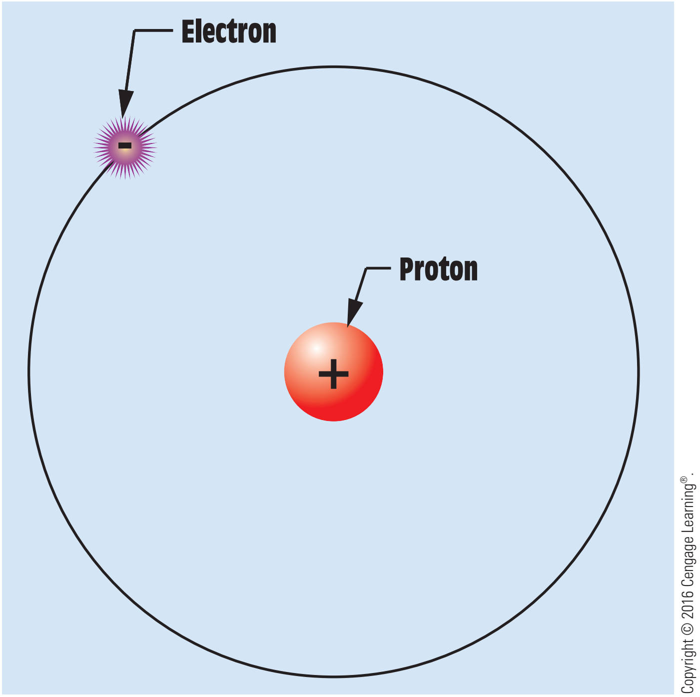

FIGURE 1–5 Hydrogen contains one proton and one electron.

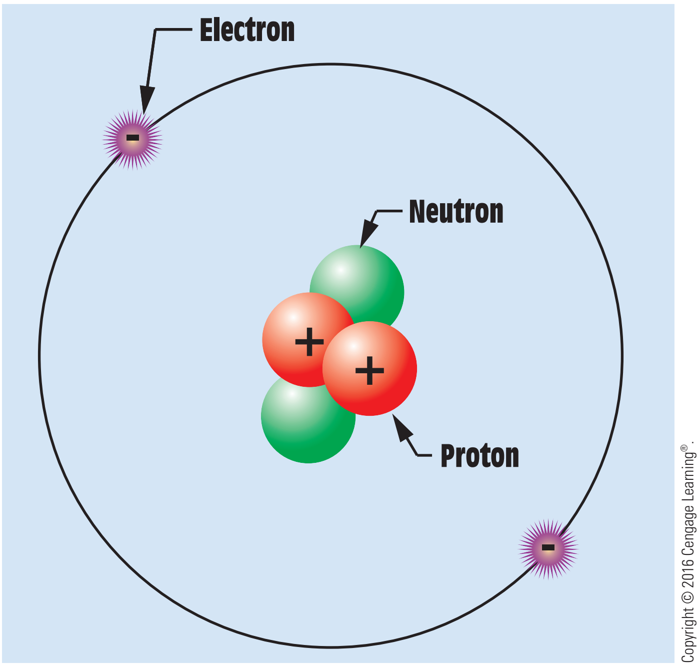

FIGURE 1–6 Helium contains two protons, two neutrons, and two electrons.

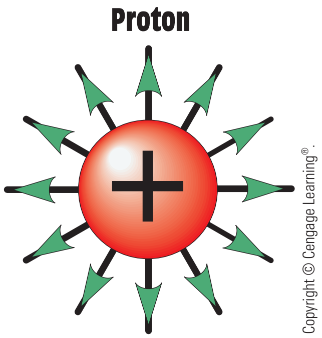

FIGURE 1–7 The lines of force extend outward.

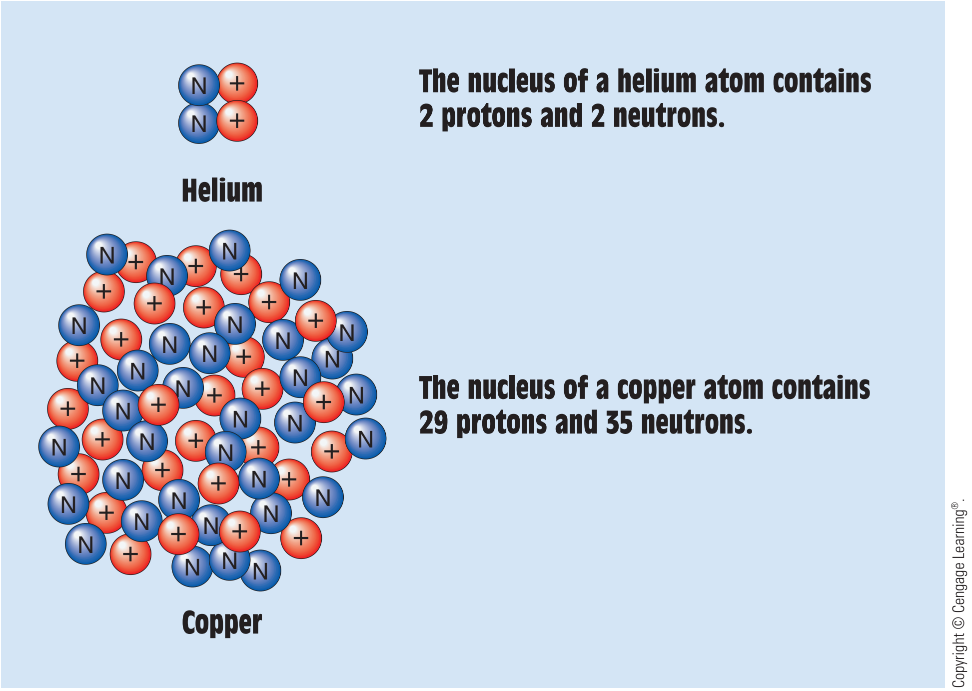

FIGURE 1–8 The nucleus may or may not contain the same number of protons and neutrons.

Notice that the proton has a positive charge, the electron a negative charge, and the neutron no charge. The neutrons and the protons combine to form the **nucleus** of the atom. Because the neutron has no charge, the nucleus has a net positive charge. The number of protons in the nucleus determines what kind of element an atom is. Oxygen, for example, contains 8 protons in its nucleus, and gold contains 79. The **atomic number** of an element is the same as the number of protons in the nucleus. The lines of force produced by the positive charge of the proton extend outward in all directions (*Figure 1–7*). The nucleus may or may not contain as many neutrons as protons. For example, an atom of helium contains 2 protons and 2 neutrons in its nucleus, whereas an atom of copper contains 29 protons and 35 neutrons (*Figure 1–8*).

The electron orbits the outside of the nucleus. The latest scientific measurements suggest protons and neutrons weigh about 1838 times more than the electron and that the electron is approximately 1000 times smaller than a proton (*Figure 1–5*). Previously, it was believed that the electron was about three times larger than the proton. Many scientists believe that it is almost impossible to accurately measure the size of these particles and that the actual size is of no real importance. It is the characteristics of the particles that is of importance. Because the electron exhibits a negative charge, the lines of force come in from all directions (*Figure 1–9*).

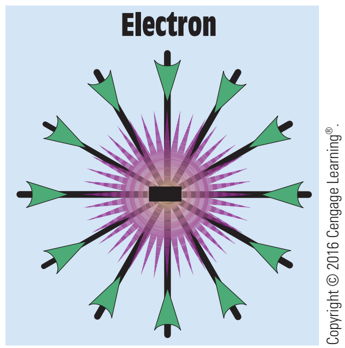

FIGURE 1–9 The lines of force come inward.

1–3 The Law of Charges

Understanding atoms necessitates first understanding a basic law of physics that states that ***opposite charges attract and like charges repel.*** In *Figure 1–10*, which illustrates this principle, charged balls are suspended from strings. Notice that the two balls that contain

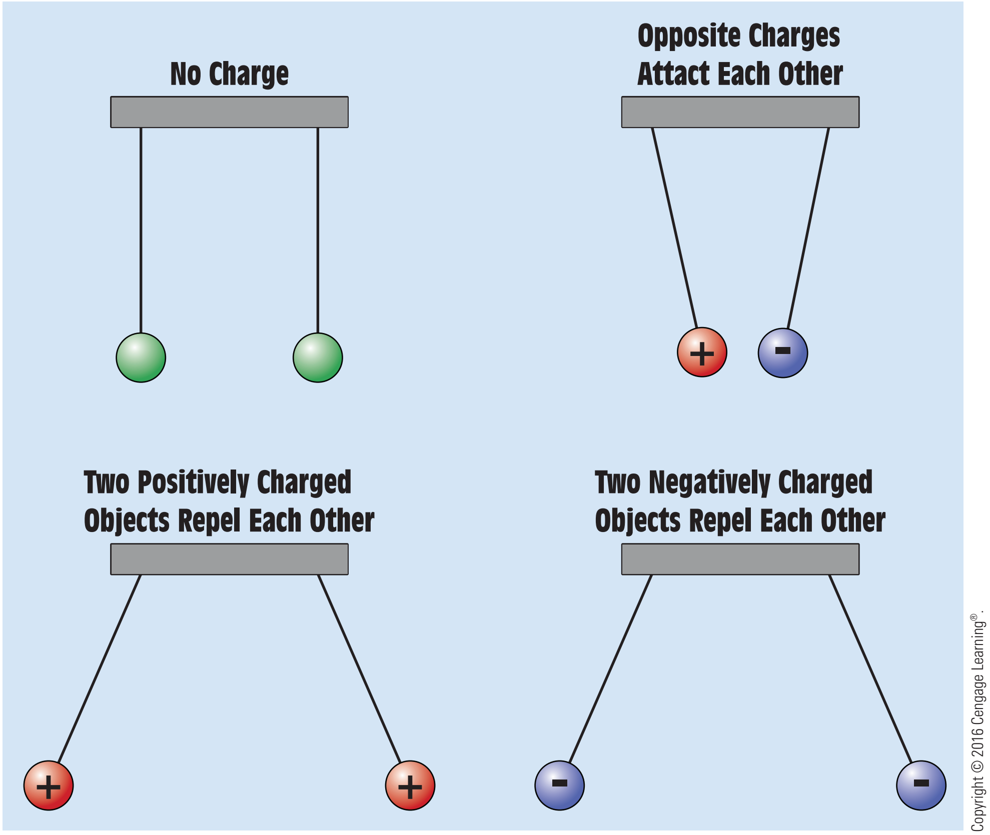

FIGURE 1–10 Unlike charges attract and like charges repel.

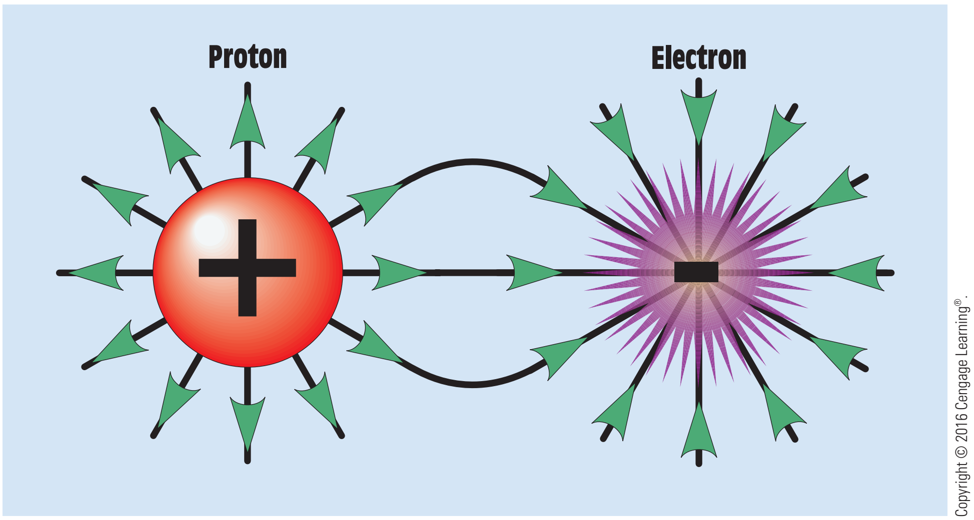

FIGURE 1–11 Unlike charges attract each other.

opposite charges are attracted to each other. The two positively charged balls and the two negatively charged balls repel each other. The reason for this is that lines of force can never cross each other. The outward-going lines of force of a positively charged object combine with the inward-going lines of force of a negatively charged object *(Figure 1–11)*. This combining produces an attraction between the two objects. If two objects with like charges

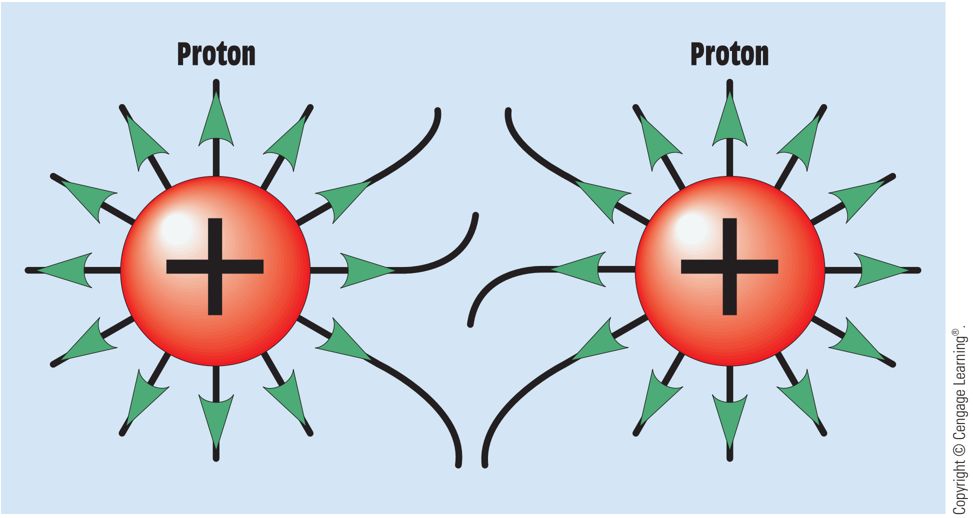

FIGURE 1–12 Like charges repel each other.

come close to each other, the lines of force repel *(Figure 1–12)*. Because the nucleus has a net positive charge and the electron has a negative charge, the electron is attracted to the nucleus.

Because the nucleus of an atom is formed from the combination of protons and neutrons, one may ask why the protons of the nucleus do not repel each other because they all have the same charge. Two theories attempt to explain this. The first theory asserted that the force of gravity held the nucleus together. Neutrons, like protons, are extremely massive particles. It was first theorized that the gravitational attraction caused by their mass overcame the repelling force of the positive charges. By the mid-1930s, however, it was known that the force of gravity could not hold the nucleus together. According to Coulomb's law, the electromagnetic force in helium is about 1.1×10^{36} times greater than the gravitational force as determined by Newton's law. In 1947, the Japanese physicist Hideki Yukawa identified a subatomic particle that acts as a mediator to hold the nucleus together. The particle is a quark known as a *gluon*. The force of the gluon is about 10^2 times stronger than the electromagnetic force.

1–4 Structure of the Atom

In 1808, a scientist named John Dalton proposed that all matter was composed of atoms. Although the assumptions that Dalton used to prove his theory were later found to be factually incorrect, the idea that all matter is composed of atoms was adopted by most of the scientific world. Then in 1897, J.J. Thomson discovered the electron. Thomson determined that electrons have a negative charge and that they have very little mass compared to the atom. He proposed that atoms have a large positively charged massive body with negatively charged electrons scattered throughout it. Thomson also proposed that the negative charge of the electrons exactly balanced the positive charge of the large mass, causing the atom to have a net charge of zero. Thomson's model of the atom proposed that electrons existed in a random manner within the atom, much like firing BBs from a BB gun into a slab of cheese. This was referred to as the plum pudding model of the atom.

In 1913, a Danish scientist named Neils Bohr presented the most accepted theory concerning the structure of an atom. In the Bohr model, electrons exist in specific

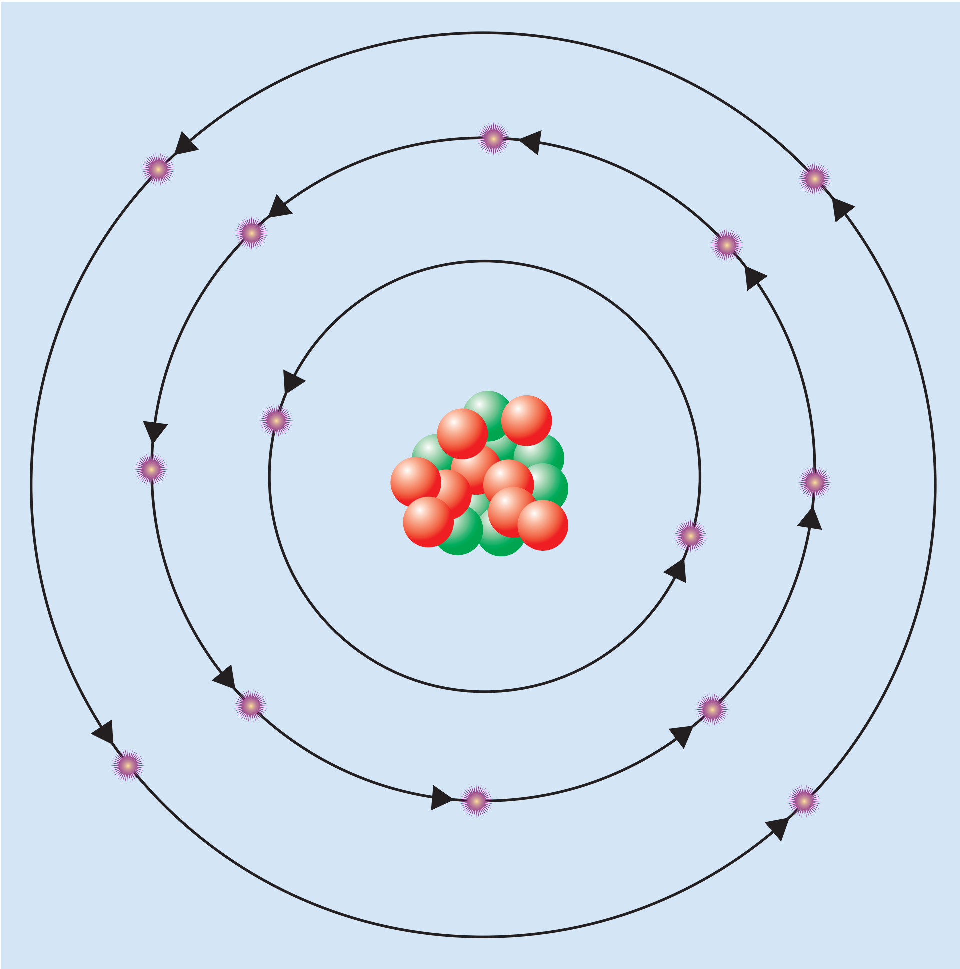

FIGURE 1–13 Bohr's model of the atom proposed that electrons orbit the nucleus in much the same way that planets orbit the Sun.

or "allowed" orbits around the nucleus in much the same way that planets orbit the Sun *(Figure 1–13)*. The orbit in which the electron exists is determined by the electron's mass times its speed times the radius of the orbit. These factors must equal the positive force of the nucleus. In theory there can be an infinite number of allowed orbits. Because the number of protons in the atom is equal to the number of electrons in the atom, the overall net charge of the atom is zero. This is the stable condition of the atom.

When an electron receives enough energy from some other source, it "quantum jumps" into a higher allowed orbit. Electrons, however, tend to return to a lower allowed orbit. When this occurs, the electron emits the excess energy as a single photon of electromagnetic energy. This movement of electrons caused by the external energy source is the basis of electric current flow. This will be described further in Section 1–6 as it relates to valence electrons.

1–5 Electron Orbits

Each **electron orbit** of an atom contains a set number of electrons *(Figure 1–14)*. The number of electrons that can be contained in any one orbit, or shell, is found by the formula ($2N^2$).

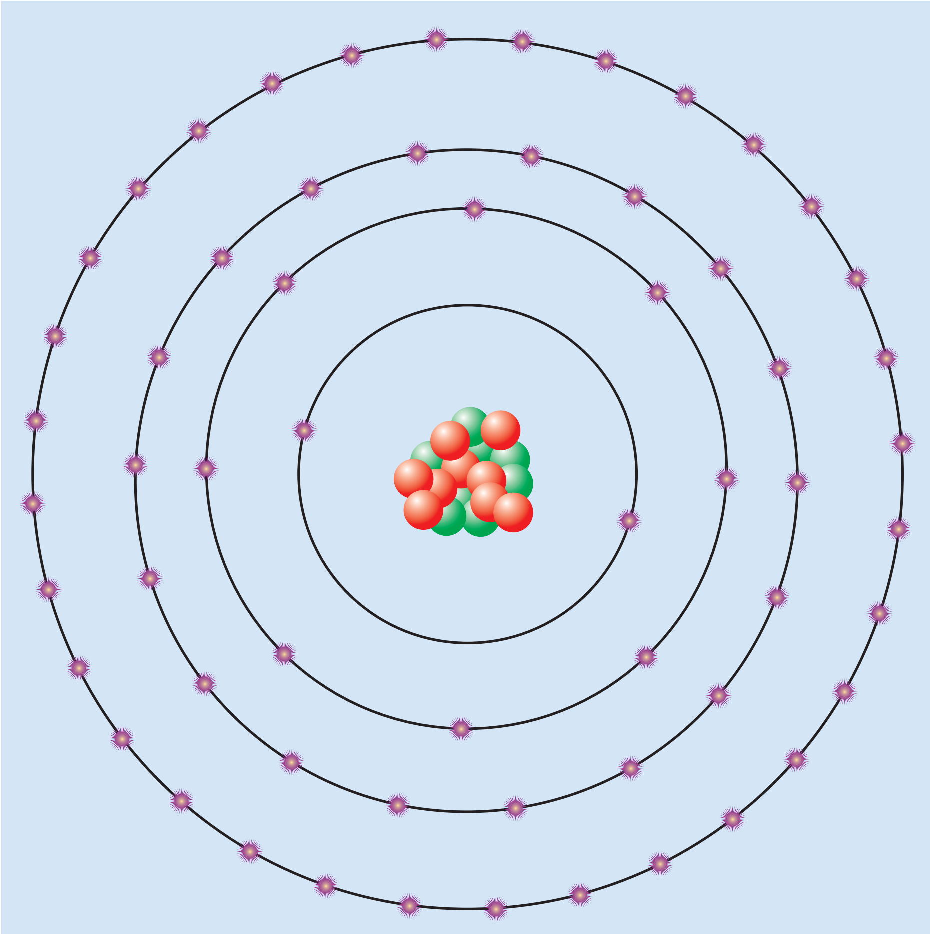

FIGURE 1–14 Electron orbits.

The letter *N* represents the number of the orbit, or shell. For example, the first orbit can hold no more than 2 electrons:

$$2 \times (1)^2 \text{ or}$$
$$2 \times 1 = 2$$

The second orbit can hold no more than 8 electrons:

$$2 \times (2)^2 \text{ or}$$
$$2 \times 4 = 8$$

The third orbit can contain no more than 18 electrons:

$$2 \times (3)^2 \text{ or}$$
$$2 \times 9 = 18$$

The fourth and fifth orbits cannot hold more than 32 electrons. Thirty-two is the maximum number of electrons that can be contained in any orbit:

$$2 \times (4)^2 \text{ or}$$
$$2 \times 16 = 32$$

Although atoms are often drawn flat, as illustrated in *Figure 1–14*, electrons orbit the nucleus in a spherical fashion, as shown in *Figure 1–15*. Electrons travel at such a high rate of speed that they form a shell around the nucleus. For this reason, electron orbits are often referred to as *shells*.

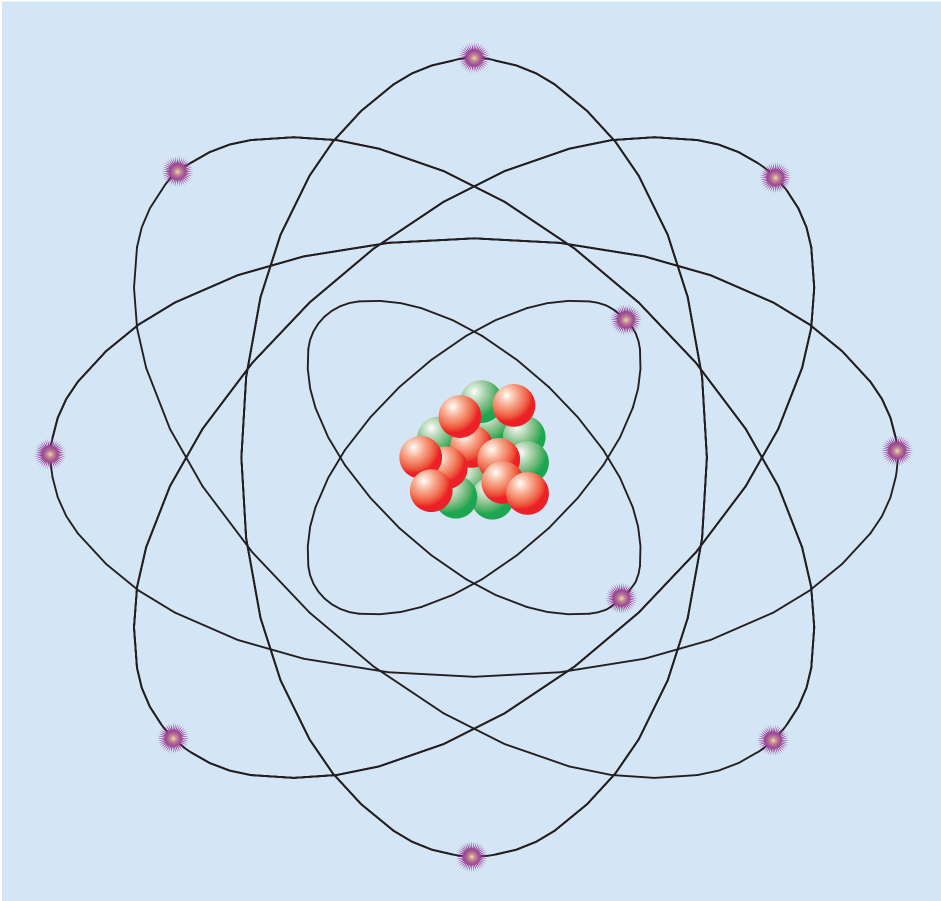

FIGURE 1–15 Electrons orbit the nucleus in a circular fashion.

1–6 Valence Electrons

The outer shell of an atom is known as the *valence shell*. Any electrons located in the outer shell of an atom are known as **valence electrons** (*Figure 1–16*). The valence shell of an atom cannot hold more than 8 electrons. Atoms with 8 electrons in the valence shell are very stable. Elements, such as neon, argon, krypton, xeon, and radon all contain 8 valence electrons. These elements are called noble gases and are inert. Atoms with less than 8 electrons in the valence shell can join with other atoms to share valence electrons to form stable molecules or compounds when the shared valence electrons effectively add up to the desired 8 outer electrons. The joining of different atoms to form molecules and compounds is described later in Section 1–10. Atoms with less than 8 electrons are less stable, and an external energy force can cause these valence electrons to escape the attraction of the nucleus. When an electron escapes the hold of the nucleus, it becomes a free electron, and the atom ends up with a net positive charge. This is called ionization, and the positive atom is called a positive ion. In a similar manner, the free electron may lose energy and fall into orbit around a neutral atom, causing that atom to have a net negative charge. That atom is called a negative ion. This explains why some materials can be made to have a positive charge, while others have a negative charge. Atoms with one, two, or three valence electrons

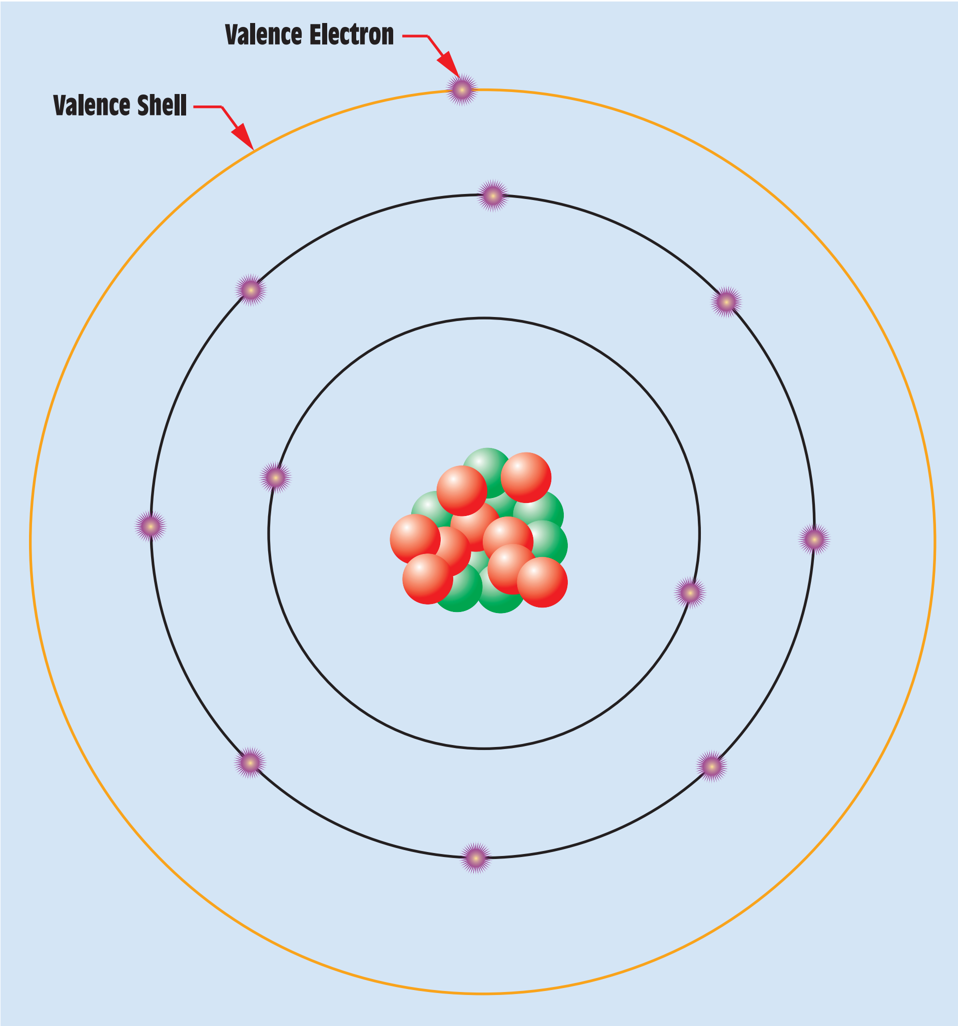

FIGURE 1–16 The electrons located in the outer orbit of an atom are valence electrons.

are the least stable, and they can be made to give up these valence electrons with less energy applied. The valence electrons are of primary concern in the study of electricity because these electrons explain much of electrical theory. A **conductor,** for instance, is made from a material that contains between one and three valence electrons. Conductors are materials that permit electrons to flow through them easily. When an atom has only one or two valence electrons, these electrons are loosely held by the atom and are easily given up for current flow. Silver, copper, and gold all contain one valence electron and are excellent conductors of electricity. Silver is the best natural conductor of electricity, followed by copper, gold, and aluminum. An atom of copper is shown in *Figure 1–17*. Although it is known that atoms containing few valence electrons are the best conductors, it is not known why some of these materials are better conductors than others. Copper, gold, platinum, and silver all contain only one valence electron. Silver, however, conducts electricity more readily than any of the others. Aluminum, which contains three valence electrons, is a better conductor than platinum, which contains only one valence electron.

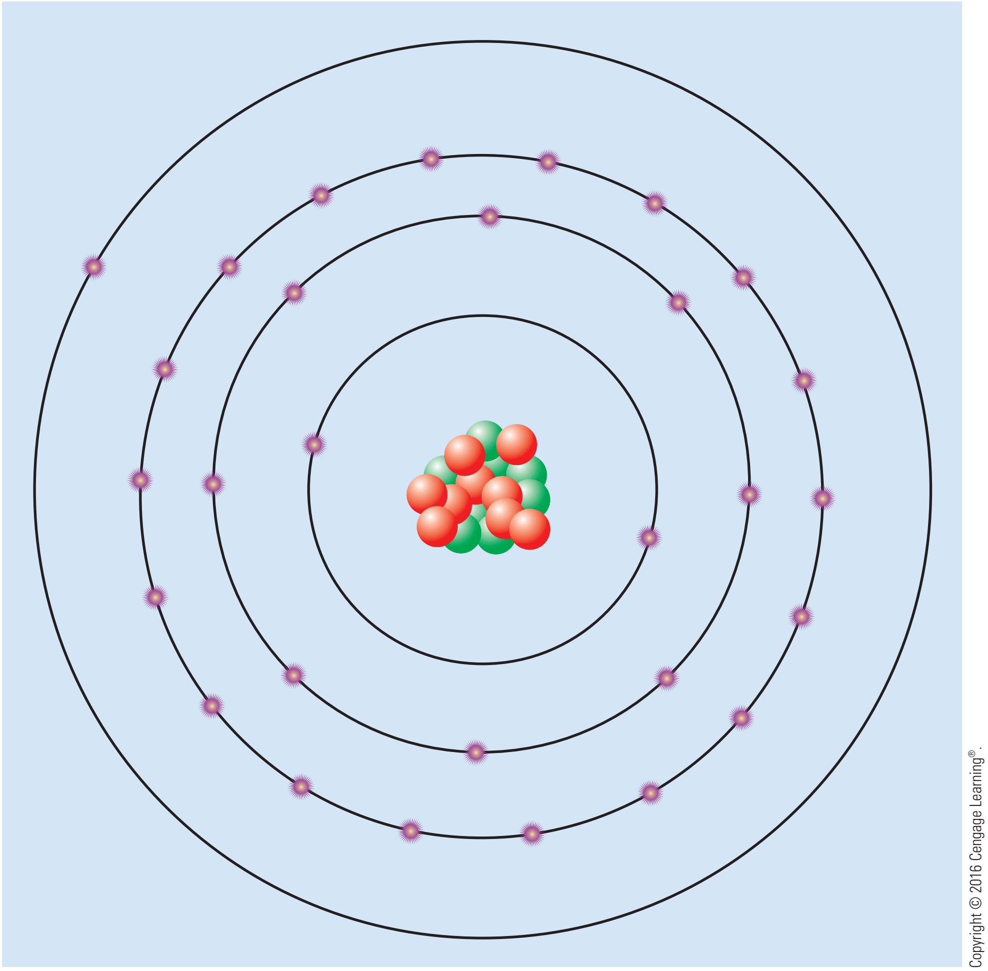

FIGURE 1–17 A copper atom contains 29 electrons and has 1 valence electron.

1–7 The Bump Theory

Electrical current is the flow of electrons. There are several theories concerning how electrons are made to flow through a conductor. One theory is generally referred to as the *bump theory*. It states that current flow is produced when an electron from one atom knocks electrons of another atom out of orbit. *Figure 1–18* illustrates this action. When an atom contains only one valence electron, that electron is easily given up when struck by another electron. The striking electron gives its energy to the electron being struck. The striking electron may settle into orbit around the atom, and the electron that was struck moves off to strike another electron. This same effect can be seen in the game of pool. If the moving cue ball strikes a stationary ball exactly right, the energy of the cue ball is given to the stationary ball. The stationary ball then moves off with the cue ball's energy, and the cue ball stops moving (*Figure 1–19*). The additional energy causes the electron to move out of orbit and become a free electron. After traveling a short distance, the electron enters the valence orbit of a different atom. When it returns to orbit, some or all of the gained energy is released in the form of heat, which is why conductors become warm when current flows through them. If too much current flows in a conductor, it may become hot enough to cause a fire.

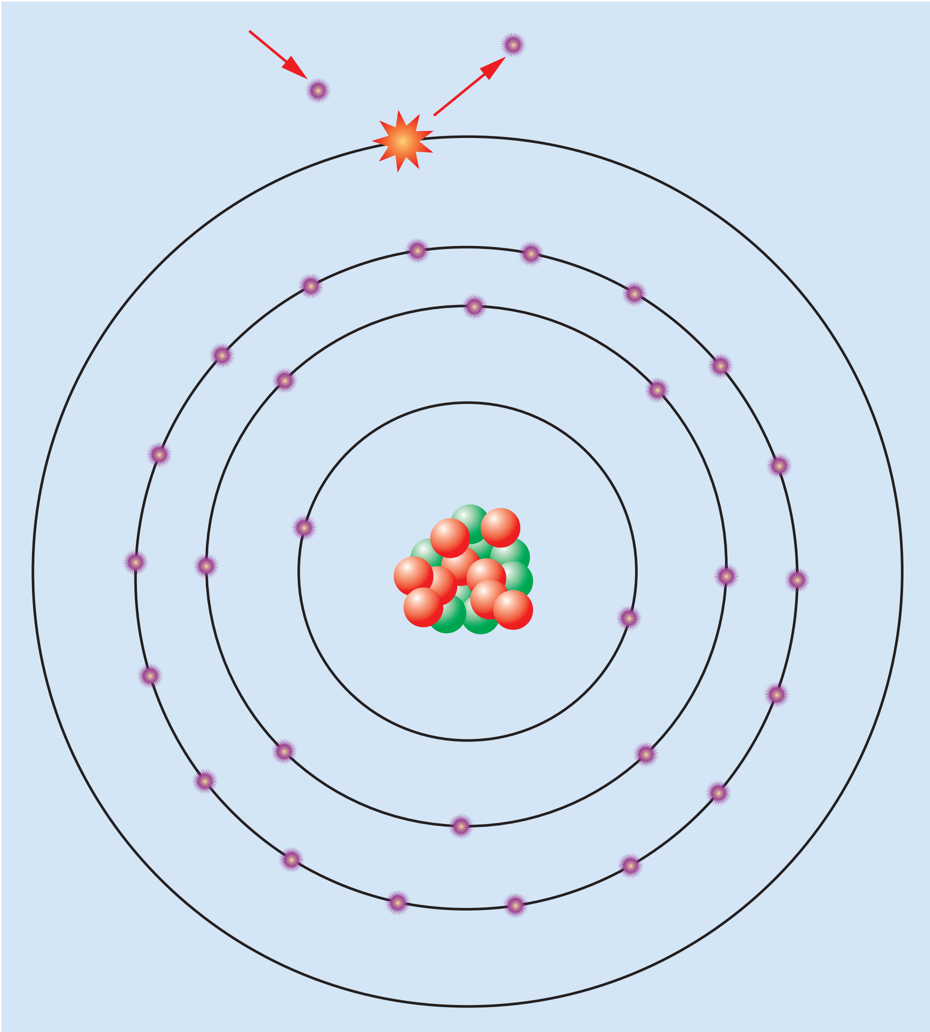

FIGURE 1–18 An electron of one atom knocks an electron of another atom out of orbit.

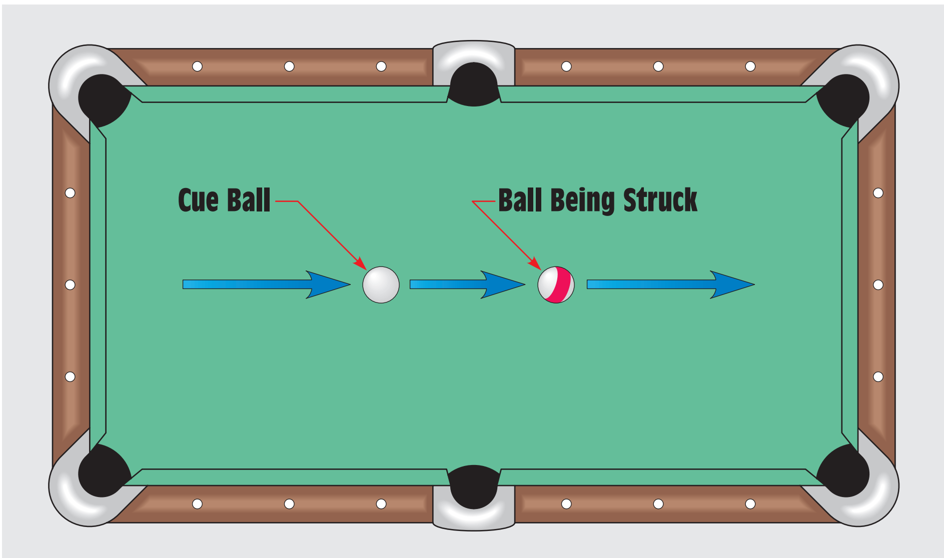

FIGURE 1–19 The energy of the cue ball is given to the ball being struck.

If an atom containing two valence electrons is struck by a moving electron, the energy of the striking electron is divided between the two valence electrons *(Figure 1–20)*. If the valence electrons are knocked out of orbit, they contain only half the energy of the striking electron. This effect can also be seen in the game of pool *(Figure 1–21)*. If a moving cue ball strikes two stationary balls at the same time, the energy of the cue ball is divided between the two stationary balls. Both stationary balls will move but with only half the energy of the cue ball.

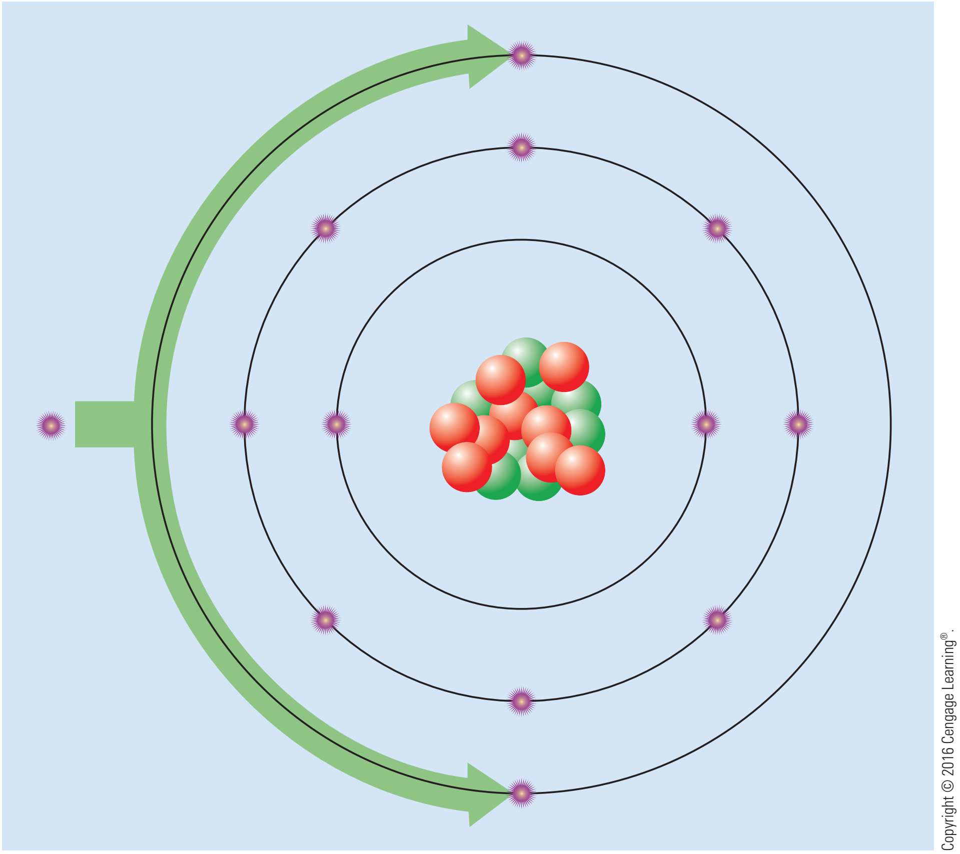

FIGURE 1–20 The energy of the striking electron is divided.

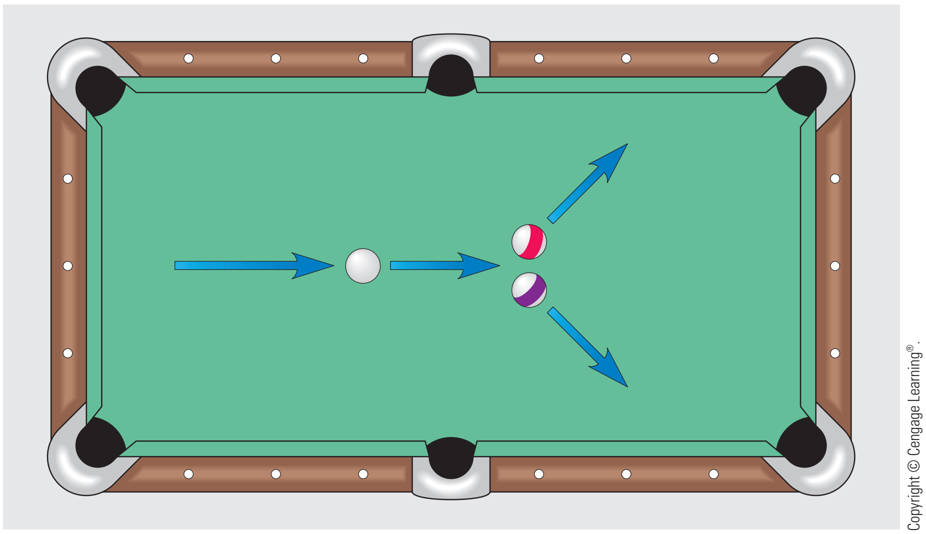

FIGURE 1–21 The energy of the cue ball is divided between the two other balls.

1–8 Power Sources

Other theories deal with the fact that all electric power sources produce a positive terminal and a negative terminal. The negative terminal is created by causing an excess of electrons to form at that terminal, and the positive terminal is created by removing a large number of electrons from that terminal (*Figure 1–22*). Different methods can be employed to produce the excess of electrons at one terminal and deficiency of electrons at the other, but when a circuit is completed between the two terminals, negative electrons are repelled away from the negative terminal and attracted to the positive (*Figure 1–23*). The greater the difference

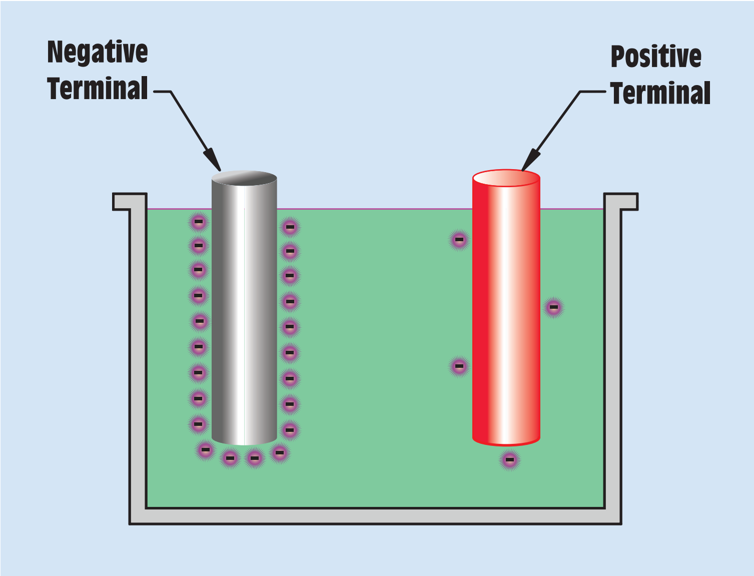

FIGURE 1–22 All electrical power sources produce a positive and a negative terminal.

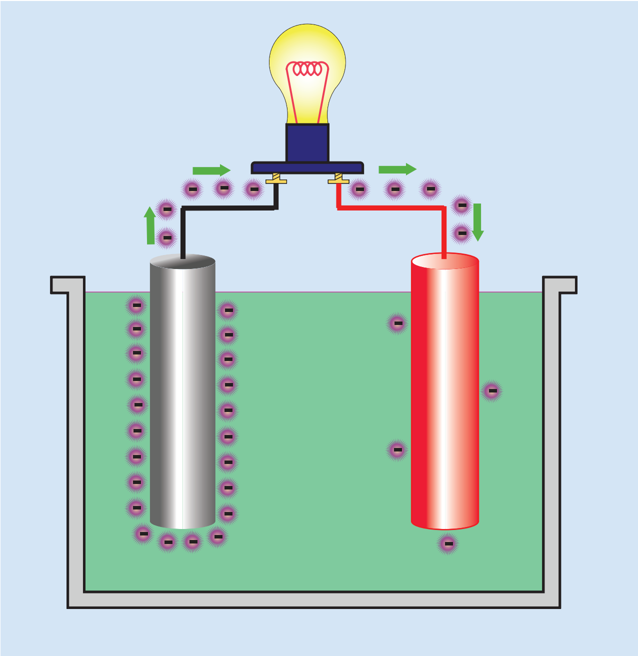

FIGURE 1–23 Completing a circuit between the positive and negative terminals causes electrons to be repelled from the negative terminal and attracted to the positive terminal.

in the number of electrons between the negative and positive terminals, the greater the force of repulsion and attraction. Different methods may be employed to cause a difference of potential. The battery, illustrated in *Figures 1–22* and *1–23*, develops a potential by chemical reaction. Generators develop a potential by cutting lines of magnetic flux with conductors.

1–9 Insulators

Materials containing seven or eight valence electrons are known as **insulators.** Insulators are materials that resist the flow of electricity. When the valence shell of an atom is full or almost full, the electrons are held tightly and are not given up easily. Some good examples of insulator materials are rubber, plastic, glass, and wood. *Figure 1–24* illustrates what happens when a moving electron strikes an atom containing eight valence electrons. The energy of the moving electron is divided so many times that it has little effect on the atom. Any atom that has seven or eight valence electrons is extremely stable and does not easily give up an electron.

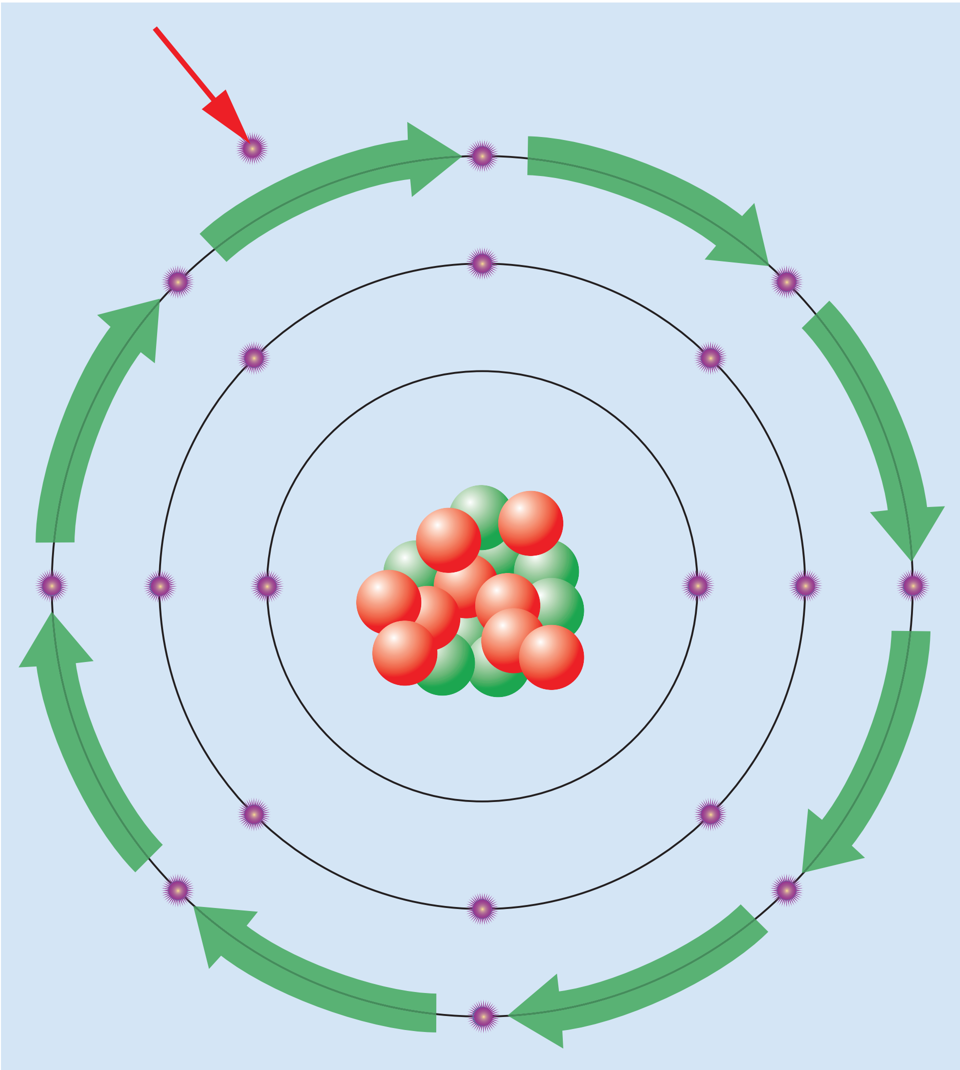

FIGURE 1–24 The energy of the striking electron is divided among the eight electrons.

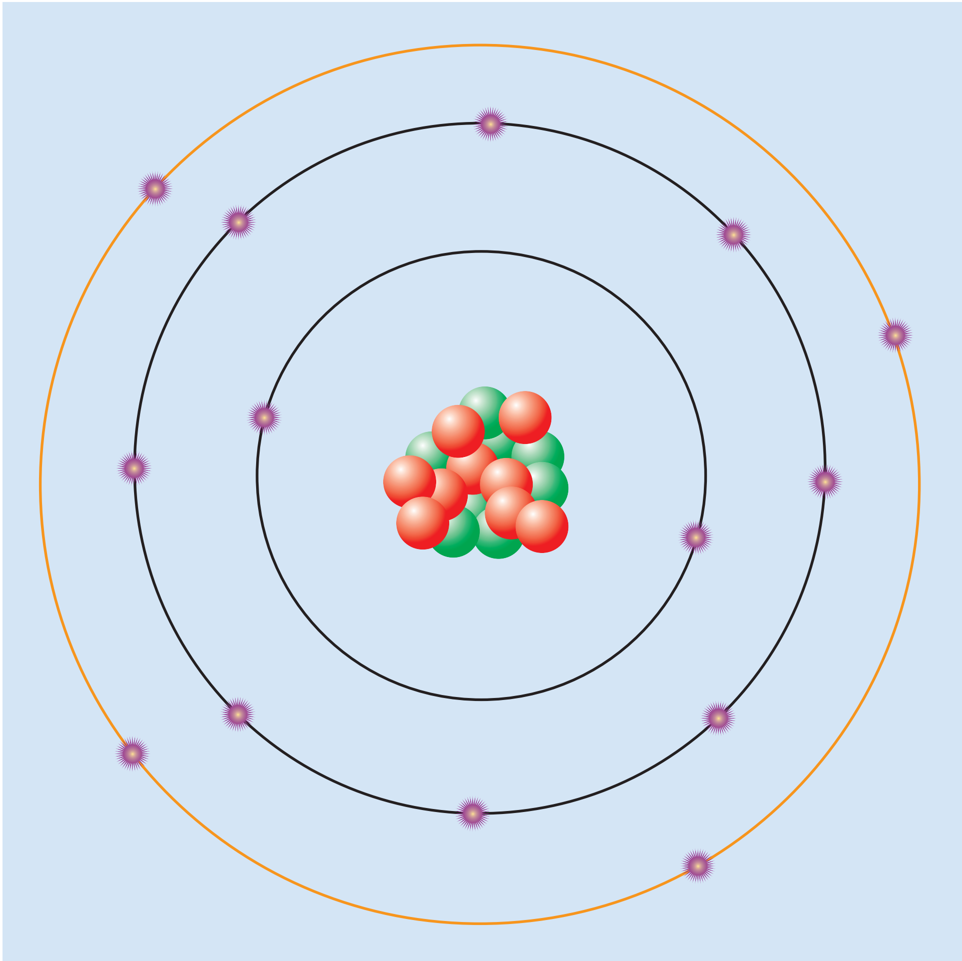

FIGURE 1–25 Semiconductors contain four valence electrons.

1–10 Semiconductors

Semiconductors are materials that are neither good conductors nor good insulators. They contain four valence electrons *(Figure 1–25)* and are characterized by the fact that as they are heated, their resistance decreases. Heat has the opposite effect on conductors, whose resistance *increases* with an increase of temperature. Semiconductors have become extremely important in the electrical industry since the invention of the transistor in 1947. All solid-state devices such as diodes, transistors, and integrated circuits are made from combinations of semiconductor materials. The two most common materials used in the production of electronic components are silicon and germanium. Of the two, silicon is used more often because of its ability to withstand heat. Before any pure semiconductor can be used to construct an electronic device, it must be mixed or "doped" with an impurity to create either a positive or negative state in the silicon.

1–11 Molecules

Although all matter is made from atoms, atoms should not be confused with **molecules,** which are the smallest part of a compound. Water, for example, is a compound, not an element. The smallest particle of water is a molecule made of two atoms of hydrogen and

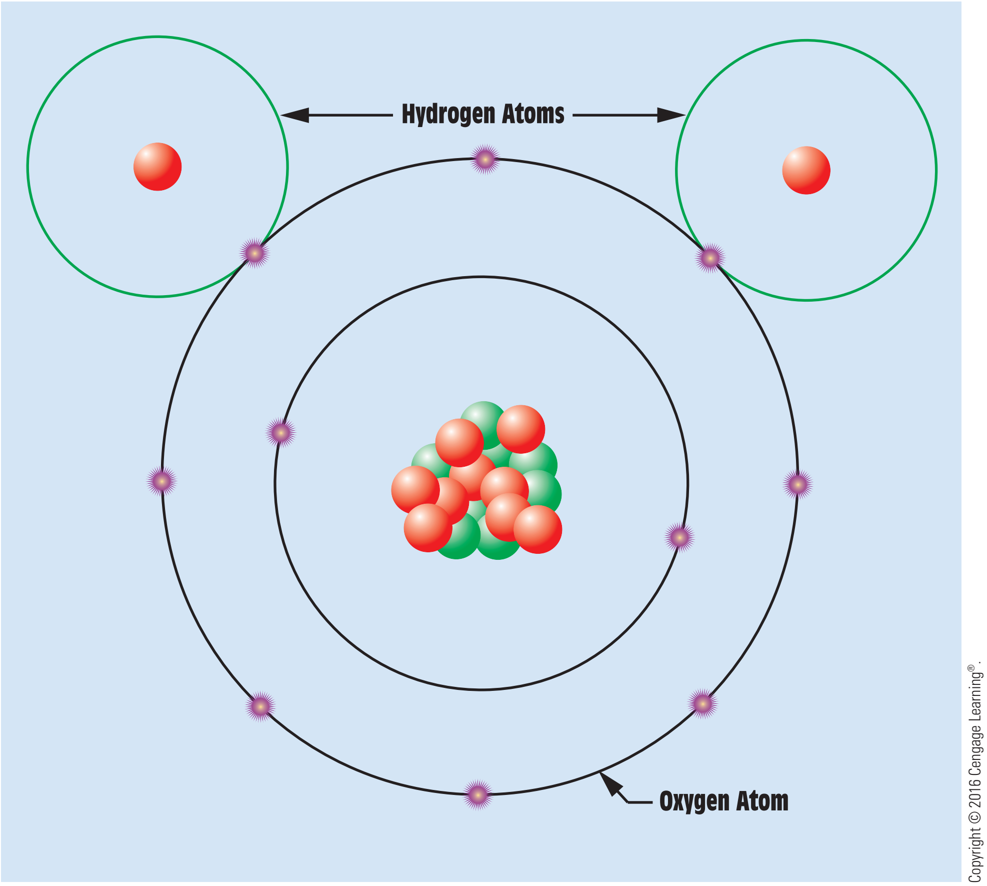

FIGURE 1–26 A water molecule.

one atom of oxygen, H_2O (*Figure 1–26*). Notice that the two hydrogen atoms share their single valence electron with the six valence electrons in the oxygen atom to effectively make a stable valence shell of eight electrons. Thus, water is a stable molecule. If the molecule of water is broken apart, it becomes two hydrogen atoms and one oxygen atom and is no longer water.

1–12 Methods of Producing Electricity

So far in this unit, it has been discussed that electricity is a flow of electrons. There are six basic methods for producing electricity:

1. Magnetism
2. Chemical action
3. Pressure
4. Heat
5. Friction
6. Light

Of the six methods listed, magnetism is the most common method used to produce electricity. Electromagnetic induction is the operating principle of all generators and alternators. These principles are covered fully later in this text.

FIGURE 1–27 Cad cell.

The second most common method of producing electricity is chemical action. The chemical production of electricity involves the movement of entire ions instead of just electrons. The principles of conduction in liquids are discussed in Unit 12 and Unit 13.

The production of electricity by pressure involves the striking, bending, or twisting of certain crystals. This effect is referred to as the *piezo* electric effect. The word *piezo* is derived from a Greek word meaning "pressure."

Producing electricity with heat is referred to as the *Seebeck* effect. The Seebeck effect is the operating principle of thermocouples. Thermocouples are discussed in Unit 13.

Static charges are probably the best example of producing electricity by friction. A static charge occurs when certain materials are rubbed together and electrons are transferred from one object to the other. Static electricity is discussed in Unit 3.

Producing electricity from light involves the use of particles called *photons*. In theory, photons are massless particles of pure energy. Photons can be produced when electrons are forced to change to a lower energy level. This is the operating principle of gas-filled lights such as sodium vapor, mercury vapor, and so on. Electricity can be produced by photons when they strike a semiconductor material. The energy of the photon is given to an electron, forcing it to move out of orbit. This is the operating principle of *photovoltaic* devices called *solar cells*. Solar cells are discussed in Unit 13. Other photo-operated devices are *photoemissive* and *photoconductive*. Photoemissive devices include photodiodes, phototransistors, photoSCRs, and so on. These devices are generally used to sense light when the speed of operation is imperative. Photoconductive devices change resistance with a change of light. The most common photoconductive device is the cad cell (*Figure 1–27*). Cad cells exhibit a resistance of about 50 ohms (Ω) in direct sunlight and several hundred thousand ohms in darkness.

1–13 Electrical Effects

With the exception of friction, electricity can be used to cause the same effects that produce it:

1. Magnetism
2. Chemical reactions
3. Pressure
4. Heat
5. Light

Anytime an electric current flows through a conductor, a magnetic field is created around the conductor. This principle is discussed in Unit 4.

Electricity can be used to produce certain chemical reactions, such as electroplating. Electroplating is accomplished by placing a base metal and a pure metal in a chemical solution. An object can be copper plated, for example, by placing a base metal object and a piece of pure copper in a solution of cuprous cyanide. The object to be plated is connected to the negative electrode, and the pure copper is connected to the positive electrode. Atoms of copper are transferred through the solution and deposited on the object to be plated.

Another example of electricity producing chemical reactions can be seen in the process of *electrolysis*. Electrolysis is the process of separating elements electrically. These principles are discussed in Unit 12.

Just as the twisting or bending of certain crystals can produce electricity, electricity can cause certain crystals to bend or twist. When electricity is applied to a certain size and shape of quartz crystal, the crystal vibrates at a certain rate. This principle has been used in crystal radios for many years. If an electric current is applied to a piece of Rochelle salt crystal, the crystal vibrates. This is the operating principle of a crystal earphone *(Figure 1–28)*.

As discussed previously in this unit, when electrons enter a valence orbit, heat is often produced. This is the reason that conductors become warm as current flows through them. This is also the operating principle of many heat-producing devices such as electric ranges, electric irons, electric heaters, and so on.

Light is produced when electrons move to a lower orbit and produce a photon. When electric current is applied to certain conductors, they not only become hot, but they also emit photons of light. Incandescent lamps use this principle of operation. When electric current is applied to the filament of an incandescent lamp, most of the electrical energy is converted into heat, but part of it produces photons of light. Incandescent lamps, however, are very inefficient. The typical 100-watt lamp produces about 95 watts of heat and 5 watts of light. Other lighting sources such as sodium vapor, mercury vapor, and fluorescent are much more efficient. Some semiconductor devices can be used to produce light without heat. Light-emitting diodes are a good example of these devices.

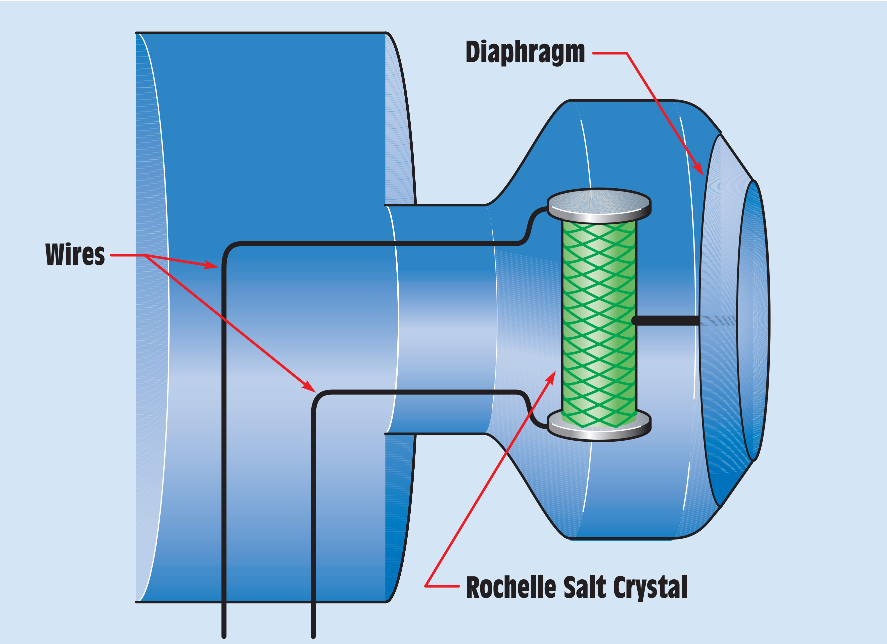

FIGURE 1–28 Producing sound with electricity.

SUMMARY

- The atom is the smallest part of an element.
- The three principal parts of an atom are the proton, the electron, and the neutron.
- Protons have a positive charge, electrons a negative charge, and neutrons no charge.
- Valence electrons are located in the outer orbit of an atom.
- Conductors are materials that provide an easy path for electron flow.
- Conductors are made from materials that contain from one to three valence electrons.
- Insulators are materials that do not provide an easy path for the flow of electrons.
- Insulators are generally made from materials containing seven or eight valence electrons.
- Semiconductors contain four valence electrons.
- Semiconductors are used in the construction of all solid-state devices such as diodes, transistors, and integrated circuits.
- A molecule is the smallest part of a compound.
- Six basic methods for producing electricity are magnetism, chemical action, light, heat, pressure, and friction.
- Five basic effects that can be caused by electricity are magnetism, chemical reactions, light, heat, and pressure.
- A photon is a massless particle of pure energy.
- Photons can be produced when electrons move from one energy level to another.

REVIEW QUESTIONS

1. What are the three principal parts of an atom, and what charge does each carry?
2. How many times smaller is an electron than a proton?
3. How many times more does a proton weigh than an electron?
4. State the law of charges.
5. How many valence electrons are generally contained in materials used for conductors?
6. How many valence electrons are generally contained in materials used for insulators?
7. What is electricity?
8. What is a gluon?
9. It is theorized that protons and neutrons are actually formed from a combination of smaller particles. What are these particles called?