Aircraft
Electricity and Electronics

Seventh Edition

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INTRODUCTION

Through the use of modern computer systems, electronic sensors, and high-speed data, electronic circuits are used to control virtually every system found on modern aircraft. **Electronics** is a special application of electricity wherein precise manipulation of electrons is employed. Today's aircraft use computers, electronics, and electrical circuits more than ever before. It is safe to say that all state-of-the-art aircraft and aerospace vehicles rely heavily on the use of electricity/electronics.

Electrical systems serve two basic functions on modern aircraft: (1) to power systems, such as lights and motors and (2) to collect and analyze information, such as in computer and data collection systems. The term *electricity* is used when referring to power circuits, while the term *electronics* typically refers to transistorized and computer systems. Today's technicians and engineers must possess a thorough understanding of all facets of electronics. This knowledge would be used during design, inspection, installation, and repair of the aircraft and aerospace vehicles.

THE ELECTRON THEORY

The atomic structure of matter dictates the means for the production and transmission of electrical power. All matter contains microscopic particles made of electrons and protons. The forces that bind these particles together to create matter are the same forces that create electrical current flow and produce electrical power. Every aircraft generator, alternator, and battery, virtually all electrical components, react according to the **electron theory**. The electron theory describes specifically the internal molecular forces of matter as they pertain to electrical power. The electron theory is therefore a vital foundation upon which to build an understanding of electricity and electronics.

Molecules and Atoms

Matter is defined as anything that occupies space; hence, everything that we can see and feel constitutes matter. Matter is composed of molecules, which, in turn, are composed of atoms. If a quantity of a common substance, such as water, is divided in half, and the half is then divided, and the resulting quarter divided, and so on, a point will be reached where any further division will change the nature of the water and turn it into something else. The smallest particle into which any compound can be divided and still retain its identity is called a **molecule**.

If a molecule of a substance is divided, it will be found to consist of particles called **atoms**. An atom is the smallest possible particle of an element. An **element** is a single substance that cannot be separated into different substances.

At the time this text was written, there were 118 known elements. Although some elements are radioactive and very unstable, there are 80 stable elements which are known as common elements. There are 94 elements which occur naturally on earth. Examples of common elements are iron, copper, lead, gold, zinc, oxygen, hydrogen, and so on. Any pure element consists of one type of atom and will have properties of only that one element. For example, a copper element will consist of one or more atoms; each atom will have the specific properties of copper.

A compound is a chemical combination of two or more different elements, and the smallest possible particle of a compound is a molecule. For example, a molecule of water (H_2O) consists of two atoms of hydrogen and one atom of oxygen. A diagram representing a water molecule is shown in Fig. 1-1.

Electrons, Protons, and Neutrons

An atom consists of extremely small particles of energy known as electrons, protons, and neutrons. All matter consists of two or more of these basic components. The simplest atom is that of hydrogen, which has one electron and one proton, as represented in the diagram of Fig. 1-2*a*. The structure of an oxygen atom is indicated in Fig. 1-2*b*. This atom has eight protons, eight neutrons, and eight electrons. The protons and neutrons form the **nucleus** of the atom; electrons revolve around the nucleus in orbits varying in shape from elliptical to circular and may be compared to the planets as they move around the sun. A **positive** charge is carried by each proton, no charge is carried by the neutrons, and **negative** charge is carried by each electron. The charges carried by the electron and the proton are equal in magnitude but opposite in nature. An atom that has an equal number of protons and electrons is

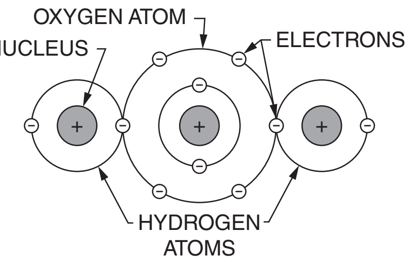

FIGURE 1-1 A water molecule.

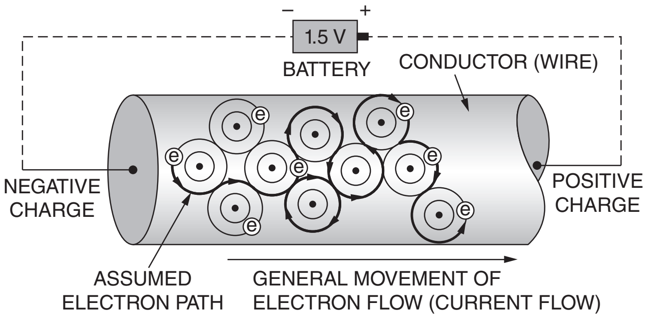

FIGURE 1-3 Electrical pressure (voltage) creates electron movement through a conductor.

electrically neutral; that is, the charge carried by the electrons is balanced by the charge carried by the protons.

It has been explained that an atom carries two opposite charges: protons in the nucleus have a positive charge, and electrons have a negative charge. When the charge of the nucleus is equal to the combined charges of the electrons, the atom is neutral; but if the atom has a shortage of electrons, it will be **positively charged.** Conversely, if the atom has an excess of electrons, it will be **negatively charged.** A positively charged atom is called a **positive ion,** and a negatively charged atom is called a **negative ion.** Charged molecules are also called ions. It should be noted that protons remain within the nucleus; only electrons are added or removed from an atom, thus creating a positive or negative ion. This movement of electrons is the basis for all electrical power.

Atomic Structure and Free Electrons

The path of an electron around the nucleus of an atom describes an imaginary sphere or shell. Hydrogen and helium atoms have only one shell, but the more complex atoms have numerous shells. Figure 1-2 illustrates this concept. When an atom has more than two electrons, it must have more than one shell, since the first shell will accommodate only two electrons. This is shown in Fig. 1-2*b*. The number of shells in an atom depends on the total number of electrons surrounding the nucleus.

The atomic structure of a substance determines how well the substance can conduct an electric current. Certain elements, chiefly metals, are known as **conductors** because an electric current will flow through them easily. The atoms of these elements give up electrons or receive electrons in the outer orbits with little difficulty. The electrons that move from one atom to another are called **free electrons.** The movement of free electrons from one atom to another is indicated by the diagram in Fig. 1-3, and it will be noted that they pass from the outer shell of one atom to the outer shell of the next. The only electrons shown in the diagram are those in the outer orbits.

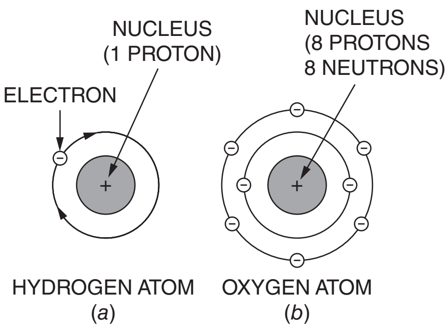

FIGURE 1-2 Structure of atoms.

The movement of free electrons does not always constitute electric current flow. There are often several free electrons randomly drifting through the atoms of any conductor. It is only when these free electrons move in the same direction that electric current exists. A power supply, such as a battery, typically creates a potential difference from one end of a conductor to another (Fig. 1-3). A strong negative charge on one end of a conductor and a positive charge on the other is the means to create a useful electron flow, commonly called "current flow."

An element is a conductor, nonconductor (insulator), or semiconductor depending on the number of electrons in the valence orbit of the material's atoms. The **valence orbit** of any atom is the outermost orbit (shell) of that atom. The electrons in this valence orbit are known as **valence electrons.** All atoms desire to have their valence orbit completely full of electrons, and the fewer valence electrons in an atom, the easier it will accept extra electrons. Therefore, atoms with fewer than half of their valence electrons tend to easily accept (carry) the moving electrons of an electric current flow. Such materials are called **conductors.** Materials that have more than half of their valence electrons are called **insulators.** Insulators will not easily accept extra electrons. Materials with exactly half of their valence electrons are **semiconductors.** Semiconductors have very high resistance to current flow in their pure state; however, when exact numbers of electrons are added or removed, the material offers very low resistance to electric current flow.

Semiconductors can act like a conductor or an insulator, depending on what external charge is placed on the material. Semiconductors are the basic materials used to produce diodes, transistors, and integrated circuits.

Three of the best conductors are silver, gold, and copper; their valence orbits are nearly empty, containing only one electron each. Silver is the best conductor of all metals, although copper and gold are used more often in electrical circuits. Gold has excellent corrosion-resistant properties and copper is the least expensive of the three. Two of the best insulators

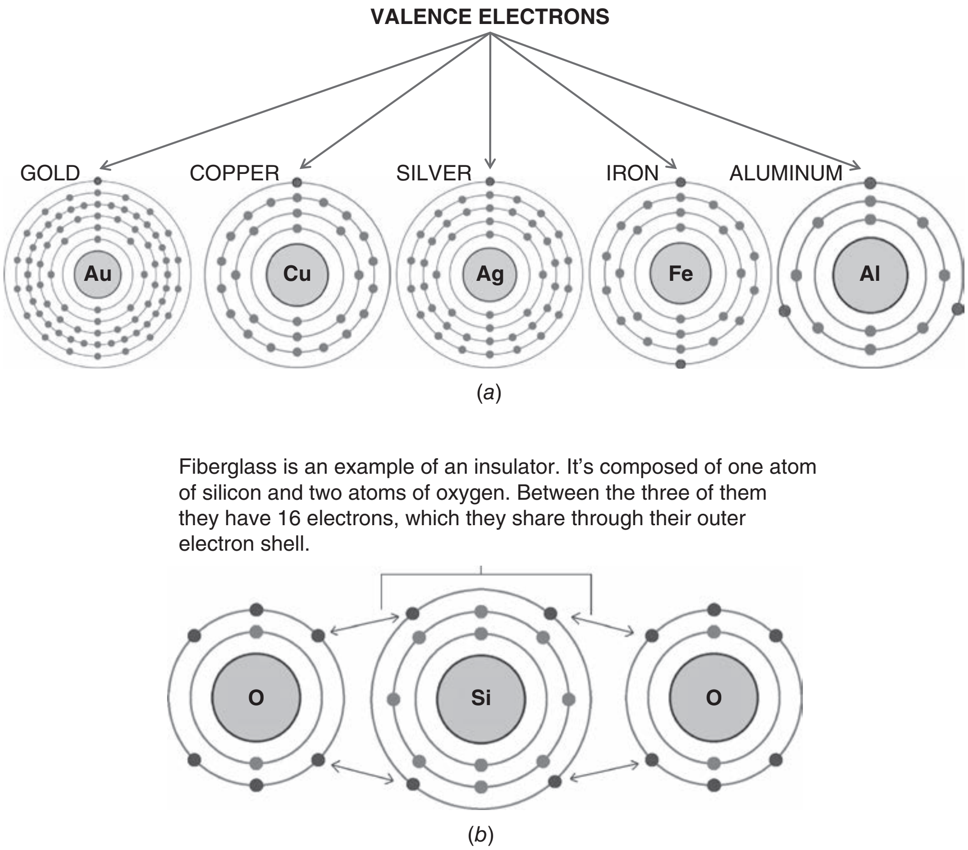

FIGURE 1-4 The number of electrons in the outer orbit of an atom determines if a material is a conductor or an insulator: (*a*) common conductors have fewer than four electrons, (*b*) insulators have more than four electrons.

are neon and helium; their atoms contain full valence orbits. We commonly substitute other "less perfect" materials for conductors and insulators to reduce costs and increase workability. Common conductors are copper and aluminum; common insulators are air, plastic, fiberglass, and rubber (Fig. 1-4). The two most common semiconductors are germanium and silicon; both of these materials have exactly four electrons in their valence orbits (Fig. 1-5). Atoms with four valence electrons are semiconductors; atoms with fewer than four valence electrons are conductors; those with more than four valence electrons are insulators.

Simply being a conductor does not create electron movement. There must be an external force in addition to the molecular forces present inside the conductor's atoms. On the aircraft the external forces are usually supplied by the battery, generator, or alternator.

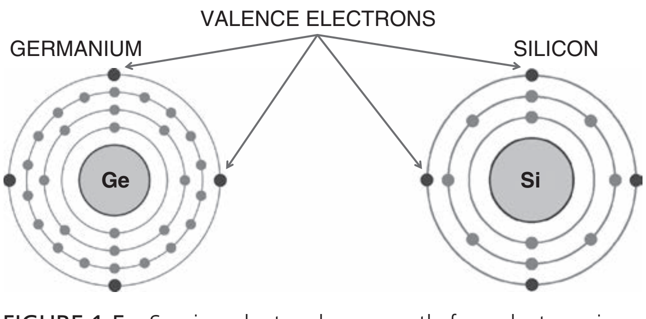

FIGURE 1-5 Semiconductors have exactly four electrons in the atom's outer orbit.

When two electrons are near each other and are not acted upon by a positive charge, they repel each other with a relatively tremendous force. It is said that if two electrons could be magnified to the size of peas and were placed 100 ft apart, they would repel each other with tons of force. It is this force that causes electrons to move through a conductor. Remember, the attraction force of the protons in their nucleus to the electrons in their orbits creates stability in an atom whenever a neutral charge is present. If an extra electron enters the atom's outer orbit, the atom becomes very unstable. It is this unstable repelling force between the orbiting electrons that causes the movement of any extra electron through the conductor. When an extra electron enters the outer orbit of an atom, the repelling force immediately causes another electron to move out of the orbit of that atom and into the orbit of another. If the material is a conductor, the electrons move easily from one atom to another.

Conventional Current Flow and Electron Flow

There are two common ways to describe "the flow of electricity": (1) *conventional current flow* and (2) *electron flow*. **Conventional current flow** states that current in an electrical circuit moves from the positive connection of a power source (battery) through the circuit to the negative connection of the battery as shown in Fig. 1-6*a*. **Electron flow** is the movement of electrons through a circuit from the negative connection of a battery into the positive connection of that same battery (see Fig. 1-6*b*).

So why is there so much confusion? The answer is due to the timeline of history. The *conventional current flow* theory (also called *current flow*) was first established in the seventeenth century and made well known by Benjamin Franklin. As science advanced, it was discovered that actually electrons moved from negative to positive, known as *electron flow*. By the time the true direction of electron flow was discovered, the nomenclature of *positive* and *negative* and the direction of flow had already been so well established in the scientific community that no effort was made to change it. Today, although scientists agree on the direction of electron flow, both theories are used when describing electricity.

One of the latest theories that define the nature of electricity states that electrons flow in one direction and *holes* flow in the opposite direction. A **hole** is the space created by the absence of an electron. As electrons move from negative to positive, holes move from positive to negative. This concept is often used when studying the internal current flow of semiconductors; however, for general applications of current flow, holes need not be considered.

It is important not to let this concept of current flow direction confuse your understanding of electricity. Simply be consistent in your approach and remember while reading this text or any FAA material, *current flows from negative to positive*.

In most practical applications it is **not** important to know which direction current flows (negative to positive or positive to negative). If the battery and the load are connected correctly, there will be a current flow and the circuit should operate, see Fig. 1-6. However, if the battery becomes disconnected from the load, the circuit will not operate. So in most cases, the technician is concerned whether current flows in the circuit or not. The direction current flows in is not important.

Polarity

The specific location of the positive and negative connections of a given circuit or component is called **polarity**. For example, when replacing a battery in a simple calculator one must insert the battery in the correct direction. The positive side of the battery must be placed on the positive connection, and the negative side of the battery must be placed on the negative connection. This ensures the battery will be installed with the correct polarity. The calculator is said to be polarity sensitive and will only operate with the battery installed correctly. For most aircraft electrical installations observing the correct polarity is very important. This is because most electrical components contain semiconductor devices, such as transistors, diodes, and integrated circuits, which are all polarity sensitive.

Some electrical devices tolerate electron flow in either direction with no difference in operation (these devices are

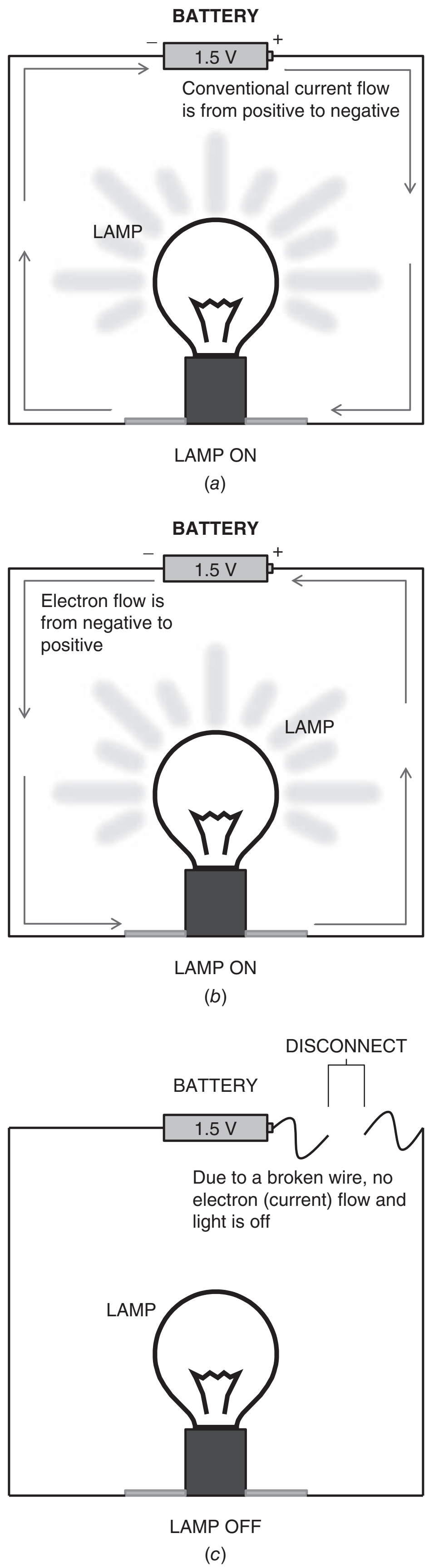

FIGURE 1-6 A complete circuit illuminates the light: (*a*) conventional current flow—from positive to negative, (*b*) electron flow—from negative to positive, (*c*) circuit disconnected—no electron/current flow.

not polarity sensitive). Incandescent lamps (the type utilizing a thin metal filament that glows white-hot with sufficient current), for example, produce light with equal efficiency regardless of current direction. Conductors and switches operate irrespective of current direction as well. The technical term for this irrelevance of flow is *nonpolarization*. We could say, then, that incandescent lamps, switches, and wires are *nonpolarized* components. Conversely, any component that will not function if the positive and negative connections are reversed is a *polarized* device.

STATIC ELECTRICITY

Electrostatics

The study of the behavior of static electricity is called **electrostatics.** The word **static** means stationary or at rest, and electric charges that are at rest are called **static electricity.**

A material with atoms containing equal numbers of electrons and protons is electrically neutral. If the number of electrons in that material should increase or decrease, the material is left with a static charge. An excess of electrons creates a negatively charged body; a deficiency of electrons creates a positively charged body. This excess or deficiency of electrons can be caused by the friction between two dissimilar substances or by contact between a neutral body and a charged body. If friction produces the static charge, the nature of that charge is determined by the types of substances. The following list of substances is called the **electric series,** and the list is so arranged that each substance is positive in relation to any one that follows it when the two are in contact.

1. Fur	6. Cotton	11. Metals
2. Flannel	7. Silk	12. Sealing wax
3. Ivory	8. Leather	13. Resins
4. Crystals	9. The body	14. Gutta percha
5. Glass	10. Wood	15. Guncotton

If, for example, a glass rod is rubbed with fur, the rod becomes negatively charged, but if it is rubbed with silk, it becomes positively charged.

When a nonconductor is charged by rubbing it with a dissimilar material, the charge remains at the points where the friction occurs because the electrons cannot move through the nonconductor material. When a conductor is charged, it can discharge easily since electrons travel freely through conductors.

An electric charge may be produced in a conductor by induction if the conductor is properly insulated. During flight metal aircraft are insulated from ground and may accumulate a static charge. This charge forms on the aluminum skin of the aircraft and will try to distribute evenly throughout the aircraft. The charge may even create a spark when moving from one component to the next. In some cases, this movement of the static charge can be a hazard to safety and is therefore kept to a minimum.

The force that is created between two charged bodies is called the **electrostatic force.** This force can be either attractive or repulsive, depending on the object's charge. Like charges repel each other. Unlike charges attract each other. The electrostatic force is similar to those forces that exist inside of an atom between electrons and protons. However, the electrostatic force is considered to be on a much larger scale, dealing with entire objects, not minute atomic particles. The amount of static charge contained within a body will determine the strength of the electrostatic field. Weak charges produce weak electrostatic fields and vice versa. Precisely, the strength of an electrostatic field between two bodies is directly proportional to the strength of the charge on those two bodies. Figure 1-7*a* demonstrates this concept. The strength of the electrostatic force is also affected by the distance between the two charged bodies. If the distance between the two charged substances increases, the electrostatic force decreases; conversely, if the distance decreases, the force increases. Precisely, the electrostatic force between two charged bodies is inversely proportional to the square of the distance between those two bodies. That is, as the distance becomes twice as large between the bodies, the electrostatic force is one-fourth as great. This concept is demonstrated in Fig. 1-7*b*.

Static electrical discharge will eventually occur to all charged bodies. Any unbalance of charge strives for equilibrium. Usually contact is made with another object to neutralize the static charge. If a charged body contacts a neutral body, both objects will then share the original charge. An example of this discharge occurs when a person gets shocked while touching a common doorknob. If the person has generated a static charge (typically occurs while walking on carpet in dry air conditions), the discharge occurs as the individual makes contact with the metal knob. If the neutral body is large enough, such as the earth, virtually all the charge will become neutralized, or absorbed, by the large body.

Static discharge has become a major problem for modern microelectronics. The miniaturization of modern computerized systems has caused them to become extremely delicate. The discharge of static electricity can easily damage these components. Sensitive electronics are known as electrostatic-discharge sensitive (ESDS) components. Anyone who designs, installs, or maintains aircraft electronics must follow proper procedures to prevent damage due to static discharge. ESDS prevention techniques will be discussed later in this text.

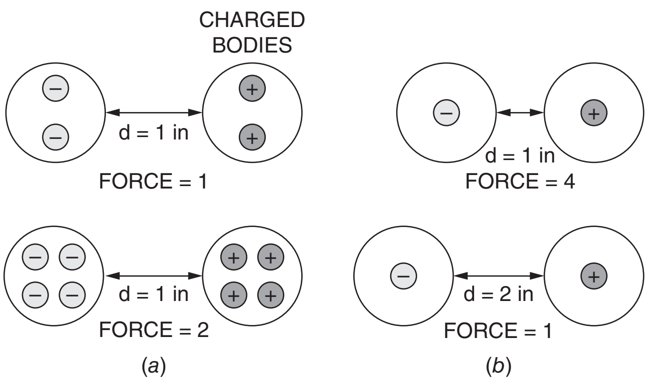

FIGURE 1-7 The strength of an electrostatic force. (*a*) Twice the static charge equals twice the static force. (*b*) Twice the distance equals one-fourth the static force.

UNITS OF ELECTRICITY

Current

An electric **current** is defined as a flow of electrons through a conductor. If the terminals of a battery are connected to the ends of a wire, the negative terminal forces electrons into the wire and the positive terminal takes electrons from the wire; hence as long as the battery is connected, there is a continuous flow of electrons (current) through the wire until the battery becomes discharged.

Because each electron has mass and inertia, electron flow is capable of doing work such as turning motors, lighting lamps, and warming heaters. Just as moving water can turn a primitive paddle wheel to grind wheat, moving electrons can do the same. Even at the speed of light, a single electron could not do much work; however, if enough electrons are set into motion, vast amounts of work can be done using electricity.

It is often hard to understand that moving electrons can do useful work; remember, electrons may be small, but they do have mass, and any moving mass can perform work.

It is said that an electric current travels at the speed of light, approximately 186,000 miles per second (mps) [299,000 km/s]. Actually, it would be more correct to say that the effect, or force, of electricity travels at this speed. Individual electrons move at a comparatively slow rate from atom to atom in a conductor, but the influence of a charge is "felt" through the entire circuit instantaneously. A simple illustration will explain this phenomenon. If we completely fill a tube with tennis balls, as shown in Fig. 1-8, and then push an additional ball into one end of the tube, one ball will fall out the other end. This is similar to the effect of electrons as they are forced into a conductor. When electrical pressure is applied to one end of the conductor, it is immediately effective at the other end. It must be remembered, however, that under most conditions, electrons must have a complete conducting path before they will enter or leave the conductor.

When it is necessary to measure the flow of a liquid through a pipe, the rate of flow is often measured in **gallons per minute.** The gallon is a definite quantity of liquid and may be called a unit of quantity. The unit of quantity for electricity is the **coulomb** (C), named for Charles A. Coulomb (1736–1806), a French physicist who conducted many experiments with electric charges. One coulomb is the amount of electricity that, when passed through a standard silver nitrate solution, will cause 0.001118 gram (g) of silver to be deposited upon one electrode. (An electrode is a terminal, or pole, of an electric circuit.) A coulomb is also defined as 6.28×10^{18} electrons, that is, 6.28 billion billion electrons As mentioned earlier, electrons are really, really small.

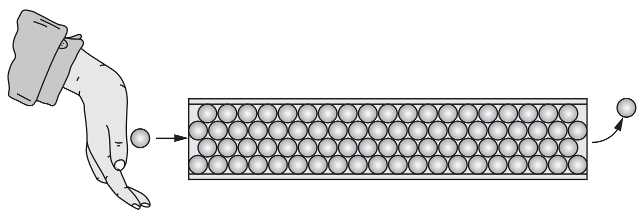

FIGURE 1-8 Demonstration of current flow. One electron into the conductor instantaneously means one electron out of the conductor.

For practical situations, electric current is measured in a unit called the *ampere.* **One ampere is the rate of flow of 1 coulomb per second.** The ampere was named in honor of the French scientist André M. Ampère (1775–1836).

The term **current** is symbolized by the letter **I.** Current is the measure of flow or movement of electrons. Current is measured in amperes, which is often abbreviated **amps.**

Voltage and Electromotive Force

Just as water flows in a pipe when there is a difference of pressure at the ends of the pipe, an electric current flows in a conductor because of a difference in electrical pressure at the ends of the conductor. If two tanks containing water at different levels are connected by a pipe with a valve, as shown in Fig. 1-9*a*, water flows from the tank with the higher level to the other tank when the valve is open. The difference in water pressure is due to the higher water level in one tank.

It may be stated that in an electric circuit, a large number of electrons at one point will cause a current to flow to another point where there is a small number of electrons if the two points are connected by a conductor (see Fig. 1-9*b*).

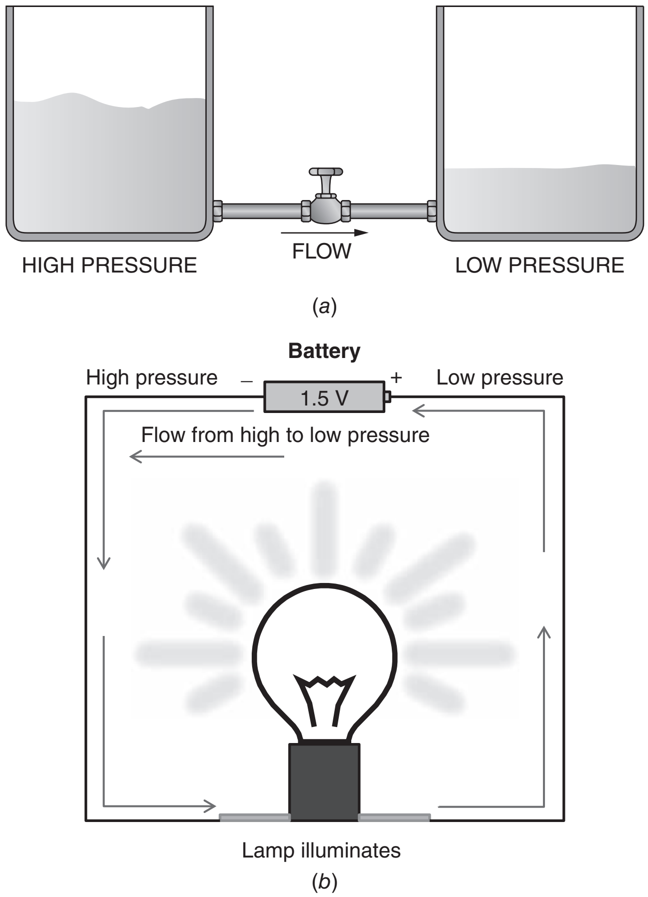

FIGURE 1-9 Pressure (force) creates movement (*a*) water flows from high to low pressure; (*b*) electrons flow from high to low pressure.