SIXTH EDITION

AIRCRAFT

ELECTRICITY AND ELECTRONICS

Thomas K. Eismin

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Electricity and Electronics

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About the Author

Thomas K. Eismin is a professor of aviation technology and has been teaching at Purdue University since 1977. He has held several Federal Aviation Administration certifications, including Inspection Authorization, Airframe and Powerplant Mechanic, Designated Mechanic Examiner, and Private Pilot with instrument and lighter-than-air ratings. Professor Eismin is author of previous editions of *Aircraft Electricity and Electronics*.

Preface

Modern aircraft and aerospace vehicles are today more reliant on electrical and electronic systems than ever before. The "more electric airplane" is a design concept that enhances the use of electric power to replace traditional hydraulic, pneumatic, and other systems found on traditional planes. Aircraft such as the Boeing B-787 and Airbus A-380 embraced this concept in order to improve aircraft efficiencies and increase performance. The more electric airplane design concepts have also found their way into light business jets and single-engine trainer/personnel aircraft. Today, there are more electrical and electronic systems found on aircraft than ever before; for this reason all design, engineering, and technical personnel employed in the aerospace industry must have a solid understanding of the materials discussed in this text.

The integration of digital electronics and microprocessor technologies has allowed aircraft manufacturers to improve performance and safety while at the same time save weight compared to conventional systems. Electronic circuits are found in virtually every system of a modern aircraft. Large transport category aircraft are now fly-by-wire and utilize a variety of computers for navigation, flight management, and systems operation. Today, an aircraft technician must possess a thorough understanding of both basic electrical theory and advanced electronic systems. *Aircraft Electricity and Electronics* provides the reader with practical knowledge that can be used by students, engineers, and technicians alike.

In this sixth edition of *Aircraft Electricity and Electronics* several new technologies are introduced to the reader. As with modern aircraft, digital concepts are now integrated throughout the text. Digital data transfer systems, such as ARINC 664, AFDX, ARINC 429, and RS-232, are all presented in detail along with other data bus systems and concepts. Modern fly-by-wire aircraft are presented along with fiber optic technologies. New flight deck instrumentation systems, such as electronic flight bags, synthetic vision systems, and heads-up displays, are included in this edition.

The sixth edition has also improved some of the basic information necessary to build a proper foundation for understanding aircraft electrical systems. The current Federal Aviation Regulations concerning the certification of Airframe and Powerplant (A&P) Mechanics remain a vital component of this text. The text also presents information well beyond these basic requirements, thus providing the student with a thorough understanding of the theory, design, and maintenance of current aircraft electrical and electronic systems.

The book is written with the assumption that the reader possesses no prior knowledge of electricity and electronics, yet the text can also be used by experienced personnel to gain a better understanding of advanced systems. In Chaps. 1 through 5 basic electrical theory and concepts are discussed. These chapters include the fundamentals necessary for a strong understanding of the FAA's regulations as they pertain to aircraft electrical systems. Chapters 6 through 12 contain vital information on the design and maintenance of specific systems. This section begins with the basics on test equipment and electrical troubleshooting theory, and eventually presents an in-depth look at digital and microprocessor circuits as they apply to aircraft, computerized power systems, and the test equipment used for systems troubleshooting and repair. Chapters 13 through 17 introduce the reader to the advanced electronics found on modern aircraft. Integrated communication and navigation systems, autoflight and autoland systems, flat panel display systems, and fly-by-wire components are all presented to the reader in an easy-to-understand practical fashion.

The sixth edition of *Aircraft Electricity and Electronics* is the type of book you may acquire as a student and keep as a reference throughout your career.

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Aircraft
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Fundamentals of Electricity 1

INTRODUCTION

This current period in history is often called the "information age" because electricity and electronic circuits can collect, store, and analyze vast quantities of information. Through the use of computer systems, 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 neither state-of-the-art aircraft nor space vehicles could fly without 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 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. Typically, this knowledge would be used during design, inspection, installation, and repair of the aircraft.

Before the previous century, little was known concerning the nature of electricity. However, modern theoretical concepts, mathematics, and basic physical laws have explained how electricity acts. We can now predict with extreme accuracy virtually all aspects of electricity, either through mathematics or by observation and documentation of electrical actions. The precise reasons why electricity acts as it does may be debated for quite some time; meanwhile, we will continue to make electricity a useful tool by predicting its actions.

On modern aircraft, electricity performs many functions, including the ignition of fuels in piston or turbine engines, the operation of communication and navigation systems, the movement of flight controls, and analysis of system performance. Like a modern home or office, aircraft have become computerized and onboard systems communicate using data connections similar to the Ethernet. These computerized systems make air travel more comfortable, highly efficient, and safer than ever before.

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. It is now universally accepted that 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 also known as common elements. 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

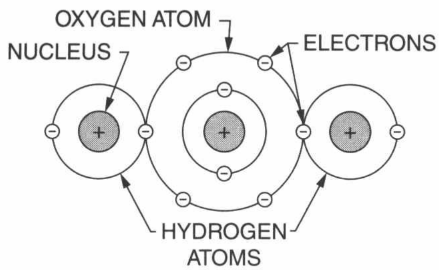

FIGURE 1-1 A water molecule.

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 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.

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

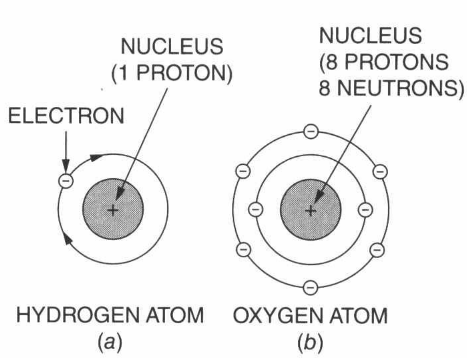

FIGURE 1-2 Structure of atoms.

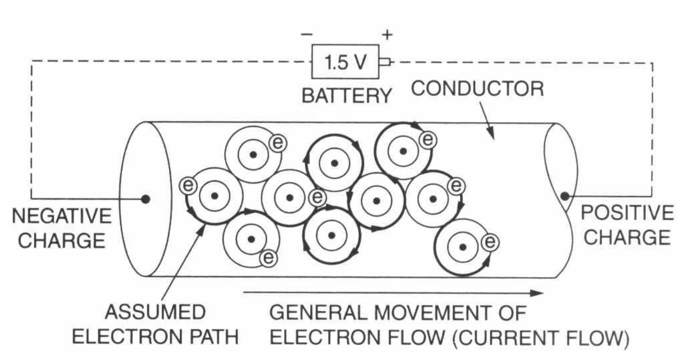

FIGURE 1-3 Electrical pressure (voltage) creates electron movement through a conductor.

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 transistors and integrated circuits.

Two of the best conductors are gold and silver; their valence orbits are nearly empty, containing only one electron each. Two of the best insulators 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. As shown in 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. The atoms' internal forces are caused by the repulsion of two similar charged bodies, such as two electrons or two protons, and the attraction of two dissimilar charged bodies, such as one electron and one proton.

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

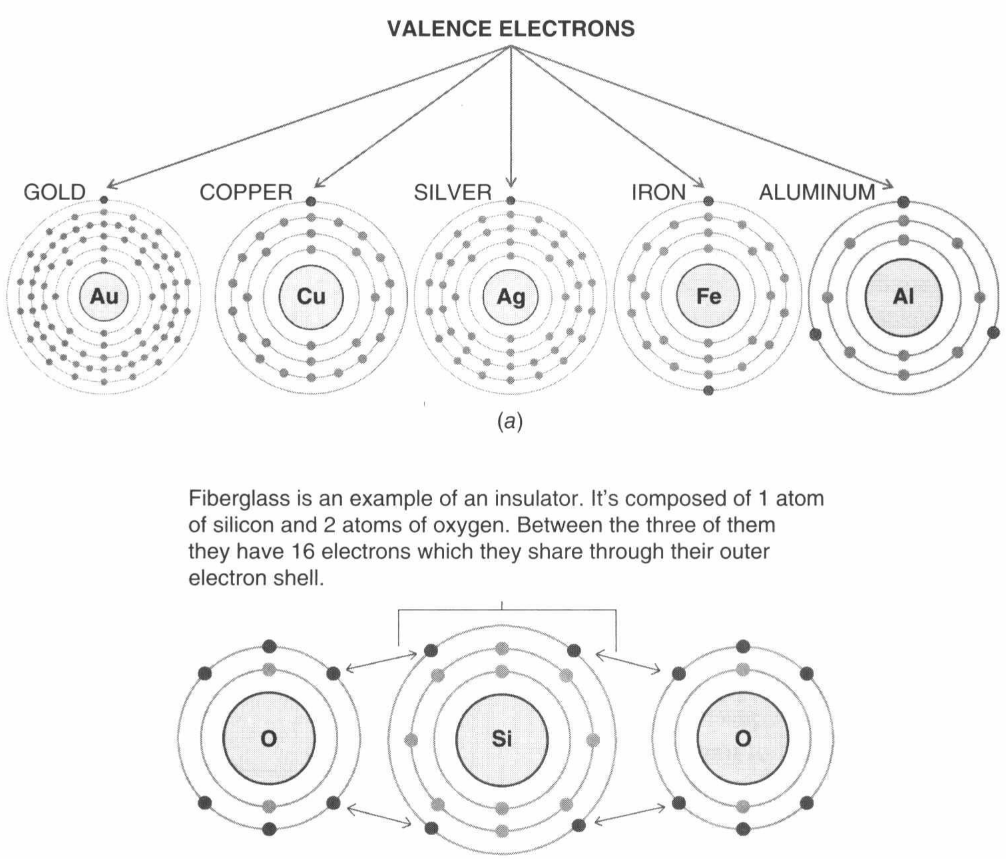

FIGURE 1-4 The number of electrons in the outer orbit of an atom determines if a material is a conductor or an insulator: (*a*) common conductors have less than 4 electrons, (*b*) insulators have more than 4 electrons.

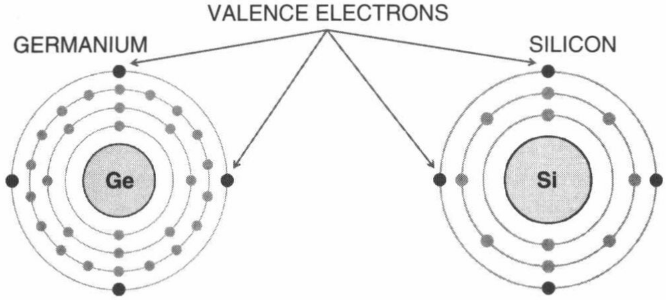

FIGURE 1-5 Semiconductors have exactly four electrons in the atom's outer orbit.

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.

Direction of Current Flow

It has been shown that an electric current is the result of the movement of electrons through a conductor. Since a negatively charged body has an excess of electrons and a positively charged body a deficiency of electrons, it is obvious that the electron flow will be **from** the negatively charged body **to** the positively charged body when the two are connected by a conductor. It can therefore be said that electricity flows from negative to positive.

In many cases it is assumed that electric current flows from positive to negative. This is often referred to as "conventional current flow." Since the polarities of electric charges were arbitrarily assigned names *(positive* and *negative),* the actual direction of current flow is difficult to distinguish without the true nature of electric current being considered. When studying the molecular nature of electricity, it is necessary to consider the true direction of electron flow, but for all ordinary electrical applications, the direction of flow can be considered to be in either direction as long as the theory is used consistently. Many texts adhere to the conventional theory that current flows from positive to negative; however, it is the purpose of this text to consider all current flow as moving from negative to positive. Electrical rules and diagrams are arranged to conform to this principle in order to prevent confusion and to give the student a true concept of electrical phenomena. The Federal Aviation Administration (FAA) adheres to the concept that current flows from negative to positive; therefore, the majority of the aviation industry also follows this convention.

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 that current flows in the circuit; not which direction current flows.

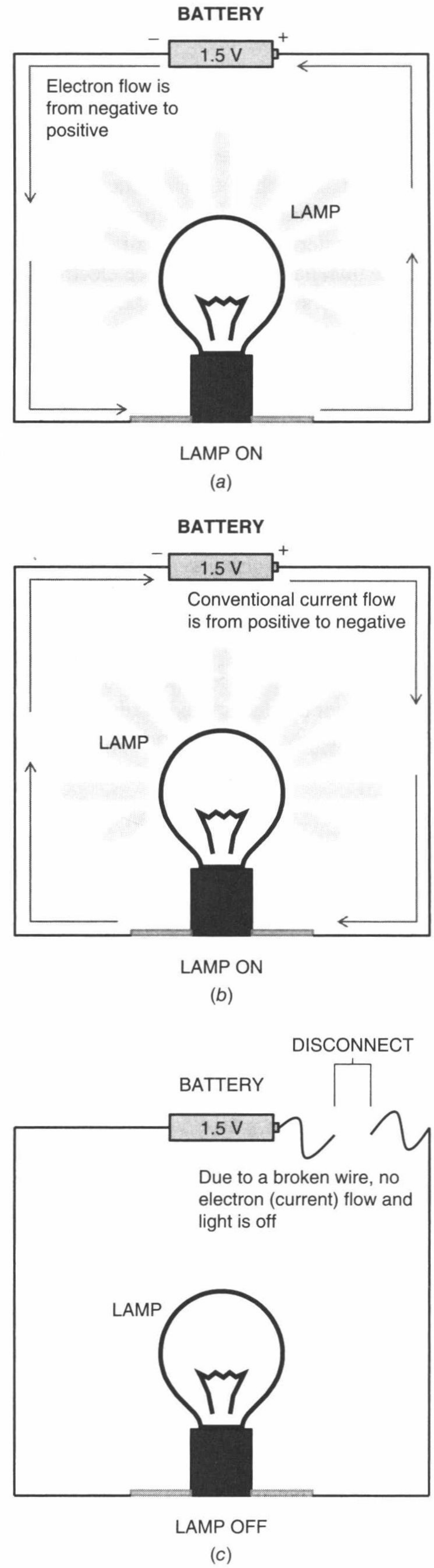

FIGURE 1-6 A complete circuit illuminates the light: (*a*) electron flow—from negative to positive, (*b*) conventional current flow—from positive to negative, (c) circuit disconnected—no electron/current flow.

The specific location of the positive and negative connections of a given circuit 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.

One of the latest theories that defines the direction of current flow 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 would move from negative to positive, holes would 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.*

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.

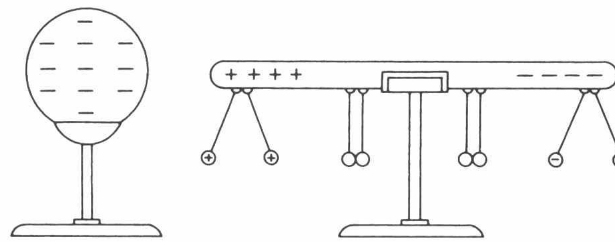

FIGURE 1-7 Charging by induction.

An electric charge may be produced in a conductor by induction if the conductor is properly insulated. Imagine that the insulated metal sphere shown in Fig. 1-7 is charged negatively and brought near one end of a metal rod that is also insulated from other conductors. The electrons constituting the negative charge in the sphere repel the electrons in the rod and drive them to the opposite site end of the rod. The rod then has a positive charge in the end nearest the charged sphere and a negative charge in the opposite end. This may be shown by suspending pith balls in pairs from the middle and ends of the rod by means of conducting threads. At the ends of the rod, the pith balls separate as the charged sphere is brought near one end; but the balls near the center do not separate because the center is neutral. As the charged sphere is moved away from the rod, the bails fall to their original positions, thus indicating that the charges in the rod have become neutralized.

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 1-8*a*

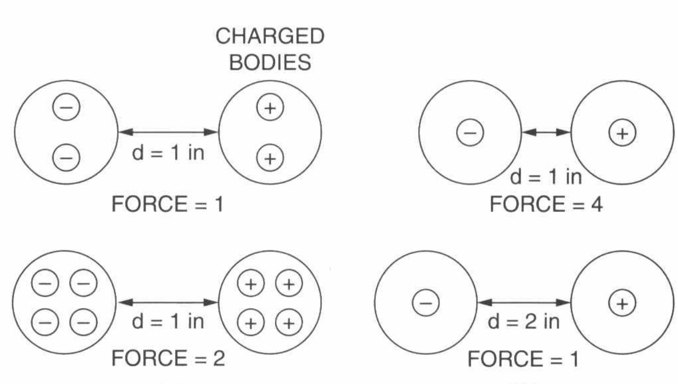

FIGURE 1-8 The strength of an electrostatic force. (*a*) Twice the static charge equals twice the static force. (*b*) Twice the distance equals one-fourth the static force.