Nature of Electricity

INTRODUCTION TO ELECTRICITY

What Is Electricity?

Electricity is a natural force produced by the movement of electrons. The most common natural source of electrical energy is lightning. Of course, the energy produced by a burst of lightning is much too strong to be harnessed for use in homes and businesses. Therefore, the electrical energy we use every day is produced artificially in generating plants and power stations.

It's hard to overstate the importance of electricity to today's homes and industries. Electrical power is used for lighting, heating, air conditioning, and running home appliances. Manufacturing plants use electricity to run processing equipment, control systems, and computers. Millions of present-day jobs would be radically different or nonexistent without electricity. We couldn't live the way we're used to without electricity. If you doubt that, think about the panic that occurs when your lights go out or when your bank's computer shuts down!

The History of Electricity

Humans have experienced the effects of electricity since ancient times. Early men and women observed the effects of lightning, magnetism, and static electricity without understanding where these forces came from or what caused them.

The first experiments with electricity were performed about 600 B.C. in ancient Greece. The Greeks noted that when the mineral amber was rubbed against fur, the amber gained the ability to attract small objects. Today, we understand that this attraction is caused by static electricity. However, in ancient Greece, there was no real understanding of this phenomenon and no practical application for it.

By the fifteenth century, scientists had begun to examine natural forces more closely and develop theories about them. Over the next several hundred years, scientists such as Alessandro Volta, George Ohm, James Joule, and James Watt made important discoveries about electricity, magnetism, and physics. All of these men gave their names to electrical properties and units (volt, ohm, joule, watt).

In America, an important advance in electrical studies was made in 1752 when Benjamin Franklin performed his famous experiments with lightning and kites. Franklin attached a metal key to a kite string and sent the kite sailing into a lightning storm. He then observed the discharge of lightning firsthand as it struck the key. Franklin observed that the lightning was an intense electrical discharge between the negatively charged lower portion of thunderclouds and the positively charged earth. His observations provided important insights into the nature of electricity.

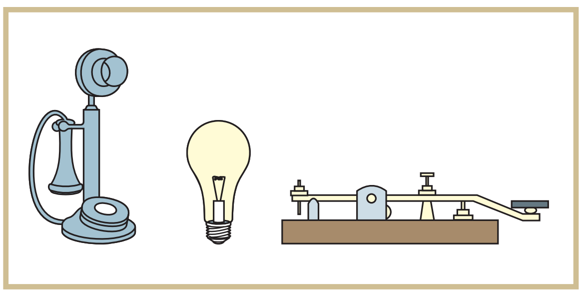

FIGURE 1—The telegraph, telephone, and electric light are three of the first practical uses of electricity.

The nineteenth century saw the practical application of electrical principles to commercial products and devices. The first truly successful application of electricity was made in 1837 with the telegraph. The telephone was invented in 1876 by Alexander Graham Bell; then came the incandescent light, invented by Thomas Edison in 1878 (Figure 1). In their day, these devices revolutionized the world, and all are still indispensable in our world today.

Now that you understand a little about the importance of electricity and its history, let's examine how electricity is used today.

A Simple Circuit

As an electrician or technician in an industrial environment, you'll need to know how electricity is generated, distributed, used, and controlled. Let's start the learning process by looking at a simple circuit. Examining the basic structure and components of a circuit will help you better understand the material we'll study later in this text.

A *circuit* is defined as a complete electrical path. A typical circuit includes a power source, conductors, a load, and a switch. The *power source* in a circuit is typically a wall outlet or a battery. The *conductors* are the wires that carry the electricity. The *load* is a device, such as a light or an appliance, that we want to run with electricity. The *switch* is the device used to turn the electricity flow on and off.

In a circuit, when the switch is turned on, electrical power from the power source flows through an unbroken path to the load. This is called a *closed circuit,* because the circuit is complete—the power flows through the entire circuit path. When the switch is turned off, the path of the circuit is broken, and power can't flow to the load. This is called an *open circuit.*

A simple flashlight circuit is shown in Figure 2. The power source in this circuit is a battery. The conductors are copper wire. The load is a standard light bulb. In Figure 2A, the switch is open (turned off). The electrical circuit is therefore open, and power can't flow through the wires to get to the light bulb. In Figure 2B, the switch is closed (turned on). The circuit is therefore complete, and electricity can flow through the wires to reach the light bulb and turn it on.

Now you understand what a circuit is, but we still haven't explained exactly how the electrical power is created. Well, at the very beginning of this text, you learned that electricity is the movement of electrons. *Electrons* are tiny atomic particles that have a negative electrical charge. In the circuit shown in Figure 2, moving electrons come from the battery. The battery produces a flow of electrons that moves through the wires to light the flashlight bulb.

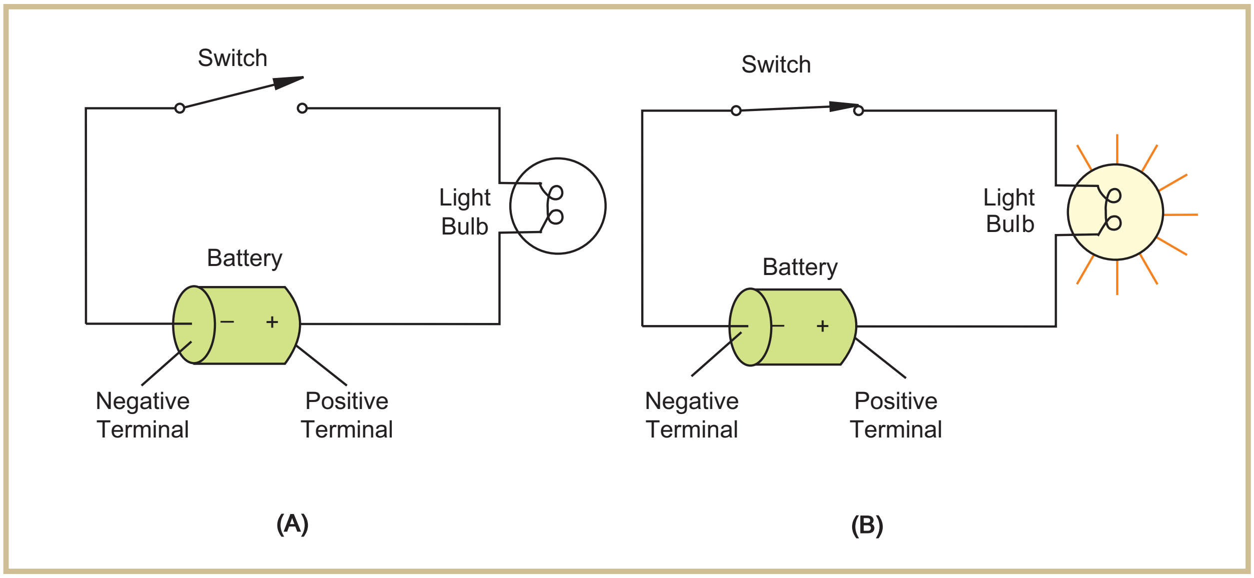

FIGURE 2—This figure illustrates a simple electrical circuit. In (A), the switch is open, so electricity can't flow to the light bulb. In (B), the switch is closed, allowing electricity to reach the light bulb and light it.

Let's take a closer look at the battery and how it produces electrical power. Note that the battery has two different ends, and each end is labeled differently. The end of the battery that's labeled with a negative sign (–) is called the *negative terminal.* The opposite end of the battery is marked with a positive sign (+) and is called the *positive terminal.* The negative terminal of the battery contains *too many* electrons. The positive terminal of the battery contains *too few* electrons.

It's a law of nature that whenever too many electrons are in one place, the electrons will move to a place where there are fewer electrons. That is, these opposite forces attract each other. So, the electrons at the negative terminal of the battery are drawn toward the positive end of the battery.

If we attach wires to the two battery terminals, we create a path for the electrons to follow from the negative end of the battery to the positive end. By attaching the conductors, we're "building a road" between the two terminals. Then, when the switch is turned on and the circuit is closed, the electrons from the negative terminal of the battery are drawn to the positive terminal. As the electrons flow through the light bulb, they cause the bulb's filament to heat up and glow, producing visible light. The flow of electrons through a circuit is called *electric current.*

Atoms and Electrons

You've just learned that electrons must flow through a simple circuit in order for the circuit to work, and we mentioned that electrons are atomic particles. What exactly does this mean? To answer that question, we'll need to look at the structure of an atom.

All matter in the universe is formed from about one hundred or so different substances called *elements*. Each different element, such as gold, silver, or oxygen, is made up of its own unique gold, silver, or oxygen atoms. An *atom* is the smallest particle of an element that still keeps the properties of the element.

All atoms are made up of tiny atomic particles called *protons, neutrons,* and *electrons*. The electron is a very lightweight particle that has a negative electrical charge. Protons are much heavier than electrons (about 1,840 times heavier) and have a positive charge. Neutrons have no electrical charge at all—they're neutral. Electrons are the smallest type of atomic particle; they're much smaller than the atom as a whole.

Now, let's look at an atom. Figure 3 shows a drawing of a hydrogen atom, the simplest atom known. A hydrogen atom contains one electron and one proton. The proton is located at the *nucleus* (the center) of the atom. The electron orbits around the nucleus in a circle, just like the moon orbits around the earth. All atoms are constructed in the same general way as the hydrogen atom, but the number of protons, neutrons, and electrons varies with each different substance.

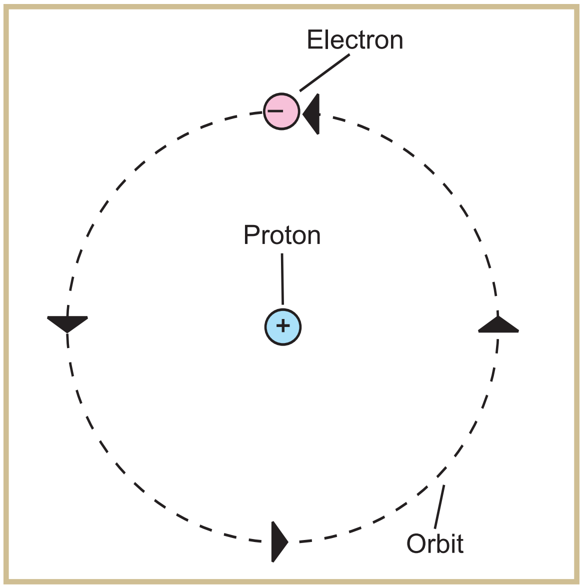

FIGURE 3—A single atom of hydrogen contains one proton and one electron. The proton is represented by the circle with the plus sign (+) inside. The electron is represented by the circle with the minus sign (−) inside.

The hydrogen atom is perfectly balanced electrically. The atom contains one positively charged proton and one negatively charged electron; the proton and electron balance each other out. Because of this balance, the electron in a hydrogen atom is tightly attached to the proton. The electron can't easily be removed from the atom.

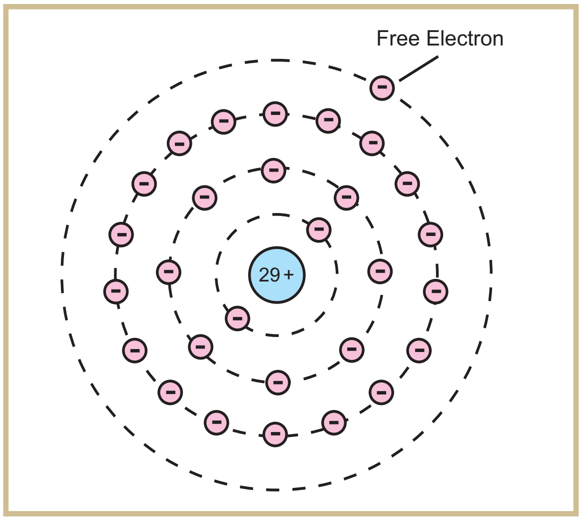

FIGURE 4—A copper atom contains a single electron in its outermost orbit. This free electron can easily be dislodged from its orbit.

Now, in comparison, let's look at an atom of copper (Figure 4). The copper atom contains 29 electrons and 29 protons. The electrons orbit the nucleus of the copper atom in several layers called *shells*. The outermost shell contains only one electron called a *free electron*. Since the free electron is alone and very far away from the atom's nucleus, it can easily be dislodged from its orbit.

In general, protons and neutrons can't easily be removed from an atom. However, in some atoms, *electrons* can be easily removed. You already know that electric current is produced by the movement of electrons. Well, in order to get the electrons moving, we have to remove them from atoms.

Electrons can be removed from atoms in a variety of ways. For example, when light strikes some substances, electrons may be dislodged from the substance. Another common way to remove electrons from a substance is through *friction* (rubbing).

The structure of an atom will determine how easily an electron can be removed from it. For example, you saw that the structure of the hydrogen atom makes it difficult to remove an electron from its orbit. Because of this, it's very difficult to get electrons moving in hydrogen. However, in the copper atom, the outermost electron can easily be removed from its orbit. Therefore, it's very easy to produce a flow of electric current in copper atoms. (This is why copper is used in electrical wires and cables!)

The number of electrons that an atom contains, and how easily those electrons can be dislodged from their orbits, is very important in our study of electricity. Any substance in which electrons can move freely is called a *conductor*. Atoms that are tightly bonded are very poor conductors of electricity, while atoms that contain free electrons in their outer shells (like copper) are excellent conductors of electricity. We'll discuss conductors in more detail a little later.

The Flow of Electrons in a Circuit

Now that you understand more about how atoms are constructed, let's examine how electrons flow within an electrical circuit. Figure 5 shows a simple circuit in which a copper wire is attached to a battery. One section of the copper wire is enlarged so that you can see the individual copper atoms that make up the wire. The battery in this figure has a negative terminal (–) and a positive terminal (+). There are too many electrons at the negative end and too few electrons at the positive end. In the figure, the circuit is closed, and the electrons from the negative battery terminal are drawn to the positive terminal.

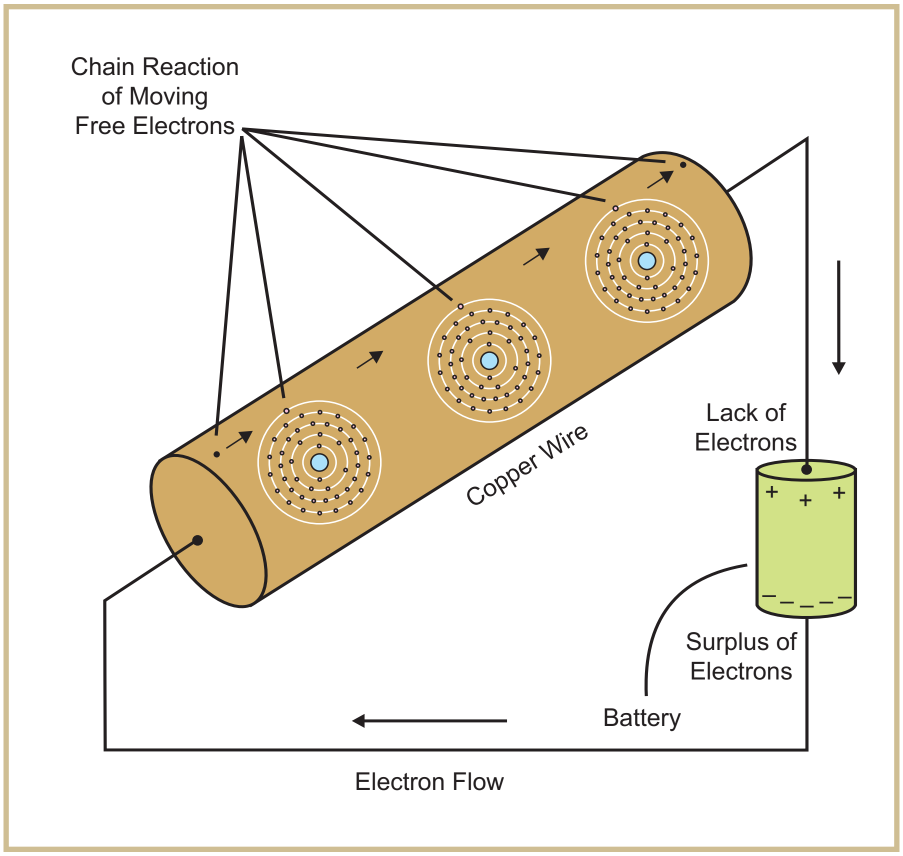

FIGURE 5—In this magnified view of a simple circuit, a free electron from the battery enters the copper conductor wire. As the battery electron enters the wire, it displaces free electrons from the copper atoms in the wire, creating a "chain reaction" of moving electrons.

So, an electron is drawn from the negative terminal of the battery into the copper conductor wire. This electron then collides with a free electron in a copper atom, bumping the copper electron out of orbit and taking its place. The displaced copper electron moves to a neighboring copper atom, bumps another free electron out of orbit, and takes its place. As this "chain reaction" continues, each free electron bumps its neighbor out of orbit and takes its place. The electrons keep pushing each other along until a free electron reaches the end of the conductor wire and moves into the positive terminal of the battery. This chain reaction of moving electrons is electric current.

In reality, we can't follow the movement of just one electron through a wire. Many millions of tiny copper atoms make up a wire. When a circuit is closed, millions of electrons move through the wire at the same time, and at a very, very high rate of speed.

Conductors, Resistors, and Insulators

One of the first scientists to observe the flow of electrical current through various materials was George Ohm. In the early 1800s, Ohm performed experiments with electric current. He found that when current was applied to different materials, some materials carried the current readily, and others didn't. He found that different materials put up different degrees of resistance to the flow of electricity.

For example, he noticed that silver and copper readily permitted the passage of almost all of the applied electricity; therefore, he called these metals *conductors*. Some materials carried almost no electricity, even when a very high voltage was applied. Ohm called these materials *insulators*. Examples of insulators are glass, mica, porcelain, paper, plastic, and rubber. Other materials passed some (but not all) of the current, so these were called *resistors*. Carbon is an example of a resistor.

Using your knowledge about the structure of atoms, you can now explain the results of Ohm's experiments. You learned that some atoms are constructed with free electrons in their outermost orbits. A material in which electrons can easily be moved from one atom to another by an outside force is a good conductor of electricity.

In comparison, other materials are made of atoms in which the electrons are very tightly bound to their orbits. In these atoms, it's very difficult to remove electrons from their orbits, so the material is a poor conductor of electricity. If the electrons in an atom can't be moved from their orbits at all, the material is an insulator. If at least some of the electrons can be moved, the material is a resistor.

Two of the best-known conductors of electricity are silver and copper. The atomic structures of the silver and copper atom are compared in Figure 6. Note that both atoms have only one electron in the outermost orbit. This makes silver and copper excellent conductors of electricity.

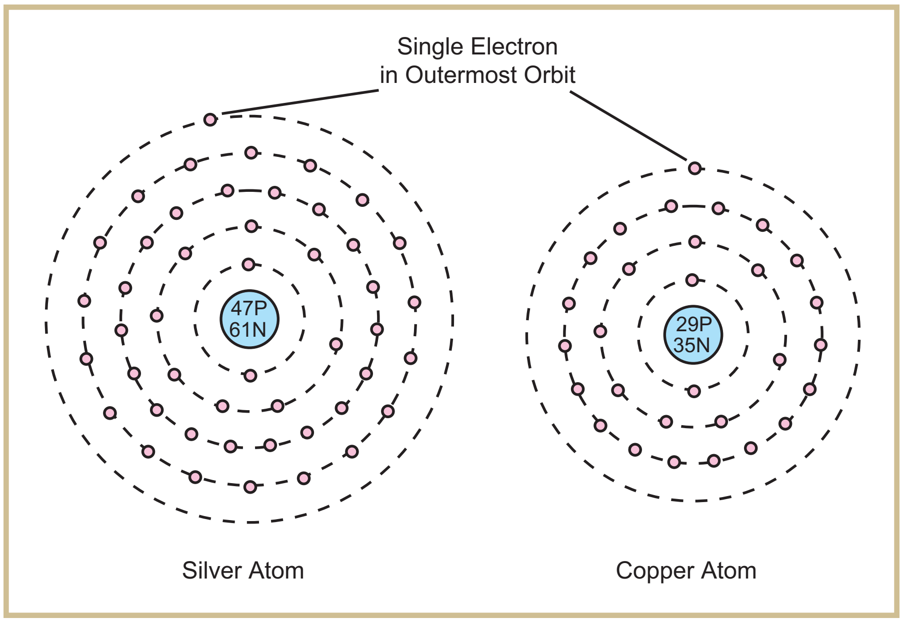

FIGURE 6—This illustration compares the atomic structures of a silver atom and a copper atom. Both atoms have a free electron in their outermost orbits, and both are good electrical conductors. However, the free electron in the silver atom is farther away from the nucleus than the free electron in the copper atom. This means that the silver electron can more easily be dislodged from its orbit than the copper electron. Thus, silver is an even better electrical conductor than copper.

Silver is actually an even better conductor than copper. Why? Well, even though both silver and copper atoms have free electrons, the free electron in silver is farther away from the nucleus than is the free electron in copper. The farther the free electron is away from the nucleus, the more loosely bound the electron will be to the nucleus. This explains why silver, which has five electron orbits, is a better conductor than copper, which has four orbits. Silver is often used as a coating on electrical conductors to keep the resistance as low as possible.

Now, let's look at an atom of carbon (Figure 7). The nucleus of the carbon atom contains six protons and six neutrons. Six electrons orbit the nucleus. Now, look more closely at the electrons. Note that the electrons orbit the nucleus in two rings, or shells. The inner shell contains two orbiting electrons, and the outer shell contains four orbiting electrons. The inner two electrons are tightly bonded to the nucleus. The outer four electrons are more loosely bonded to the nucleus and can be dislodged from their orbit.

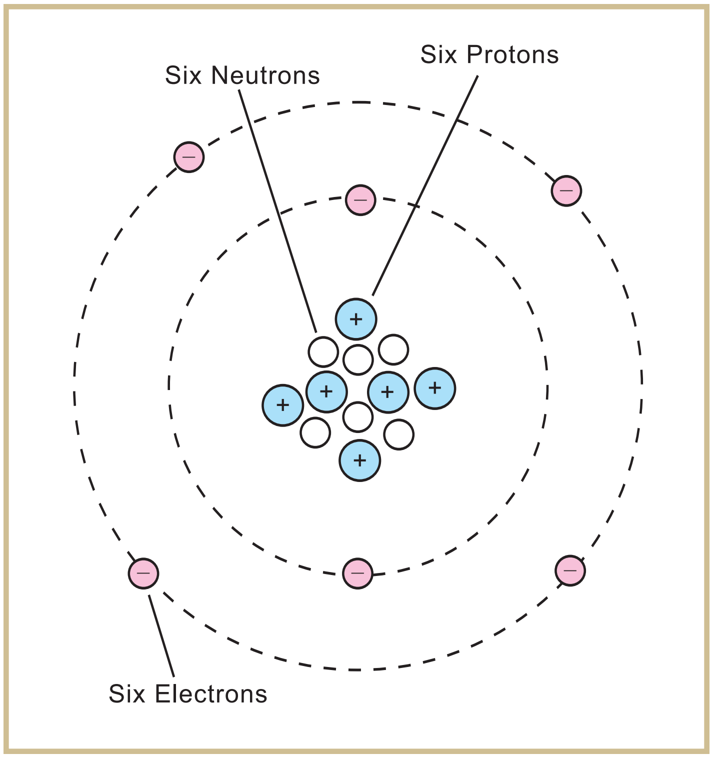

FIGURE 7—An atom of carbon has four electrons in its outer orbit. These electrons aren't easily dislodged from their orbit, so carbon is a poor conductor of electricity.

However, the four electrons in the carbon atom aren't dislodged as easily as the single free electron in a silver atom. Thus, carbon will conduct *some* electricity, but it's not as good a conductor as silver. For this reason, carbon is used to make resistors, which are devices placed in electrical circuits to reduce the flow of electricity. Resistors reduce the flow of electricity, but they don't stop it completely.

Materials such as glass and ceramic contain atoms that are very tightly bonded. These materials are therefore often used to make insulating devices. An insulator completely stops the flow of electricity in a circuit. You'll frequently see white ceramic insulators at the top of power poles.

Table 1 compares the conductivity of several metals you'll often see. *Conductivity* means how well the material carries electricity. Note that copper is used as a standard against which the conductivities of other materials are rated. For the purposes of comparison, copper is considered to be 100% conductive. The conductivity ratings of other materials are then expressed as percents, relative to copper. Note that this doesn't mean that copper has no electrical resistance; it just means that copper is used as the standard that other materials are rated against.

Silver, for example, is rated 105 percent on the table. While silver isn't a *perfect* conductor of electricity, it's the best conductor. Therefore, silver is used as the standard of measurement for the conductivity of other metals.

Table 1

RELATIVE CONDUCTIVITIES OF METALS

Metal	Conductivity Relative to Copper (%)
Silver	105
Copper	100
Gold	70
Aluminum	61
Nickel	22
Zinc	27
Brass	28
Iron	17
Tin	15
Phosphor Bronze	15
Lead	7
Steel	3 to 15

Now, before you continue your studies, take a few moments to complete *Self-Check 1* on the following page. This brief quiz will allow you to test your understanding of the material up to this point.

Self-Check 1

At the end of each section of *Nature of Electricity,* you'll be asked to pause and check your understanding of what you've just read by completing a "Self-Check" exercise. Answering these questions will help you review what you've studied so far. Please complete *Self-Check 1* now.

Indicate whether each of the following statements is True or False.

_______ 1. Atoms with free electrons in their outer orbits are poor electrical conductors.

_______ 2. Electrons are much smaller than atoms.

_______ 3. Electrons flow from the negative (–) battery terminal to the positive (+) battery terminal.

_______ 4. Aluminum is a better conductor than copper.

_______ 5. An insulator carries almost no electric current, even when a very high voltage is applied.

_______ 6. Electric current is the flow of protons through a conductor.

_______ 7. The wires that carry electric current in a circuit are called the conductors.

_______ 8. Copper is a better conductor than silver.

Check your answers with those on page 63.