FIFTH EDITION

Understanding ELECTRICITY AND ELECTRONICS TECHNOLOGY

Buban • Schmitt • Carter

UNDERSTANDING ELECTRICITY AND ELECTRONICS TECHNOLOGY

Fifth Edition

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EDITOR'S FOREWORD

The McGraw-Hill Publications in Industrial Education constitute a comprehensive series of textbooks covering important areas of industrial education. *Understanding Electricity and Electronics Technology,* a volume in this series, has proved to be one of the most widely used textbooks in its field. To remain effective in such a rapidly changing and expanding field, a textbook must be updated, improved, and expanded. This fifth edition incorporates all the vital aspects of theory and practice necessary to keep pace with the latest technology and pedagogy.

This book reflects the authors' many years of teaching experience at various educational levels and their broad knowledge of the practical side of the field. Their ingenuity and resourcefulness are constantly being tested and refined in the classroom and laboratory. The result is a textbook that is a superior source of information for the junior and senior high school student, as well as for the technical student taking electricity and electronics for the first time.

A two-color format has been used throughout this book to highlight outstanding concepts. A highly readable typeface and an open, pleasing overall design sustain the student's interest. Discussion topics, learning-by-doing exercises, individual-study activities, and construction projects are all designed to challenge the theoretical and practical minds of boys and girls having a wide range of backgrounds, interests, and abilities.

The authors, editor, and publisher hope that the fifth edition of *Understanding Electricity and Electronics Technology* will stimulate the interest of students in this most important area. Perhaps the inspiration fostered by study of this fascinating field of energy and communication will result in satisfying the need for future electrical and electronics specialists. Indeed, it might stimulate the imaginations of potential electrical engineers and technicians, those who will contribute to the society of tomorrow.

Chris H. Groneman

McGraw-Hill Publications in Industrial Education
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PREFACE

Understanding Electricity and Electronics Technology is intended for a basic course in electricity and electronics. While the organization of the book has been especially designed to adapt easily to varying course lengths, more than sufficient material has been included for a full-year course.

Two publications are correlated with the text to provide a complete basic electricity and electronics learning program. They are an *Activities Manual* and a *Teacher's Resource Guide*.

The *Activities Manual* contains procedures for performing 62 experiments. Special attention has been given to the use of readily available and relatively low-cost components and materials. A unique feature of the laboratory program that this manual presents is instructions for the construction of the circuit board, the power supply, and the coils that are to be used in performing the experiments. Experiments in digital circuitry and in interfacing the computer with the real world are included. The *Activities Manual* also contains *Learning Guides*. The Learning Guides consist of objective questions that are directly related to the 50 textbook units. These guides provide a convenient way to check individual progress and to identify those topics that require further attention.

The *Teacher's Resource Guide* provides suggestions for using the student text and for conducting the correlated laboratory activities and experiments. The overall goals of the electricity-electronics program are presented as well as the performance objectives for each text unit and the student behavioral statements related to the performance objectives. The *Teacher's Resource Guide* contains a list of all components and other items needed to perform the experiments. Answer keys are provided for the *Activities Manual*, for the *Learning Guides*, and for the Self-Tests provided after each textbook unit.

Early in this text the student is introduced to the fundamental theories on which later discussions of practical applications are based. This logical development of the subject is particularly effective in relating the technological advances in electricity and electronics to basic concepts in physics, mechanics, and chemistry, to which the student is introduced. This approach is strengthened by a judicious use of basic mathematics, primarily in problem-solving situations that involve fundamental electrical relationships.

Classroom experience with the previous editions and many useful suggestions from users of the text have helped shape the general organization and content of this edition. The career and avocational opportunities in electricity and electronics open to both men and women are explored in detail. The discussions of materials, devices, and processes reflect the latest developments in their respective areas. In keeping with the objective of relating the subject to the real world, basic consumer information on electrical products and their use is included when pertinent. The unit on other sources of energy looks toward the future, touching on energy problems likely to affect the lives of everyone. This edition includes coverage of all major technological areas, including computers and peripherals, data communications, cellular radio, satellite broadcasting, digital audio, synthesized speech, and modern solid state devices.

The text consists of 10 main sections that present a total of 50 units of instruction and suggestions for the construction of several projects. End-of-unit materials include learning-by-doing exercises, self-tests, review and discussion topics, and individual-study activities. Each is designed to achieve a particular objective in motivating, evaluating, and reinforcing the student's comprehension of what has been studied. *Learning-by-doing* exercises provide practical "hands-on" experiences in the use of circuit diagrams, tools, and test equipment. They may be used as individual or group assignments or as demonstrations by the instructor. Each of the exercises has been designed to use inexpensive materials usually available in the school shop or laboratory. The *self-test* sections provide a way for students to assess their own progress through each unit in a challenging and independent fashion. The *review and discussion* topics may be used effectively by the teacher to stimulate classroom discussions of specific topics, to highlight particular points, and to develop topics more fully. In this manner the instructor can very easily expand the treatment of certain subject matter as the needs and interests of the class demand. The *individual-study* activities that are particularly suited as project assignments for those students showing special interests or aptitudes. Small groups of two, three, or four students can also be assigned these activities. The primary purpose is to encourage students to make use of school, community, and industry resources to prepare a report and then to use their oral or written skills to communicate the information to their class. The pursuit of these objectives can serve as an effective method of extending the scope of the student's learning experiences beyond the classroom.

Section 10 is devoted to suggestions for projects that will provide practical experiences in the design and construction of useful electrical and electronic devices. These projects are free of detailed step-by-step instructions since the authors feel such details are best left to instructors, who are familiar with the facilities available to them and the abilities of their students. Section 10 also includes selected technical problems to solve. The basic purpose is to provide situations where students will have to apply their knowledge, skills, and creativity to derive an appropriate solution.

As in the previous edition, metric units are included with the customary U.S. units. With the United States destined to join the rest of the industrial world in the adoption of the metric system of measurements, it is important that students obtain a working knowledge of these units early in their industrial education.

The authors wish to acknowledge the companies, organizations, and individuals who generously contributed material for use in this book. Specific reference to these sources is given, where appropriate, throughout the text. They gratefully acknowledge the special assistance, contributions, and information extended by the following companies and organizations: Admiral Home Appliances; American National Standards, Inc.; The American Radio Relay League; Ametek; Analog Devices; AT&T; Ball Corp.; Bell Atlantic Mobile Systems; Black Box Corp.; Burr-Brown Corp.; Electronic Industries Association; Exide Corp.; Exxon Corp.; Fayette Manufacturing Corp.; Federal Communications Commission; The Foxboro Co.; General Electric Co.; GTE Laboratories, Inc.; Hayes Microcomputer Products, Inc.; Hunter Associates; ICOM AMERICA, Inc.; ILC Data Device Corp.; Infolink Corp.; Institute of Electrical and Electronics Engineers; Lead Industries Association, Inc.; Magnetic Shield Division-Perfection Mica Co.; Mid-Atlantic Finishing, Inc.; Mostek Corp.; NEC America, Inc.; Pitney Bowes; RCA Corp.; Reference Technology, Inc.; Sencore; Siemens Opto; Sony Corporation of America; Sunbeam Appliance Co.; Tandy Corp./Radio Shack; Teletype Corp.; Toroid Corp. of Maryland; Varta Batteries, Inc.; Veeco Instruments, Inc.; Virginia Electric and Power Co.; U.S. Department of Energy; and Zenith Electronics Corp.

The authors wish to express their sincere appreciation to Doris L. Schmitt and Elizabeth G. Carter, who have provided encouragement and assistance in the preparation of this edition. A special acknowledgement is made to the late Peter Buban. He will be remembered for his dedication to his profession, his concern for students, and his many contributions to the previous editions of this text.

Comments and suggestions for the improvement of this edition are most welcome.

Marshall L. Schmitt
Charles G. Carter, Jr.

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SECTION 1

INTRODUCTION

Why study electricity and electronics? Try to imagine living today without using electricity and electronics. You would have no electric lights, no telephone, no television, and no doorbell to announce your friends. You could not buy a radio, a computer, or a flashlight. There would be no electricians, computer programmers, or electrical engineers. Electricity and electronics have made life not only easier and more interesting but also more complicated.

Because electricity has had such an impact on our lives, we need to know something about its uses, its dangers, and its potential for the future. This is true today more than ever before. For example, computers are already available to play chess, to retrieve information at lightning speed, to aid doctors in treating disease, and to control robots in manufacturing automobiles.

As you grow older, you will probably be called on as a citizen to help make many decisions. One of these decisions will, no doubt, deal with the fuels used to *generate,* or produce, electric energy. Unit 44 discusses the generating plants that change various forms of energy to electric energy. The advantages and disadvantages of the different generating methods are also presented. Studying this information will help you make informed judgments today and in the future about the fuels that produce electric energy.

In a more personal way, we live with an ever-increasing variety of electrical and electronic products. If we are to choose and use them wisely, we should know something about them. For example, we should know how they are designed, manufactured, and made more efficient. Also, we should know what their limits are and to what uses they can best be put. The study of electricity and electronics can open new avenues of interest for you. This study may suggest career or hobby opportunities you may like. Perhaps your future work station may be in your own home and your connection with fellow workers may be through a computer terminal.

Only by expanding your knowledge can you hope to deal with living in this fast-moving world of ours. Studying this text will help give you this base.

UNIT 1 Atoms, Electrons, and Electric Charges

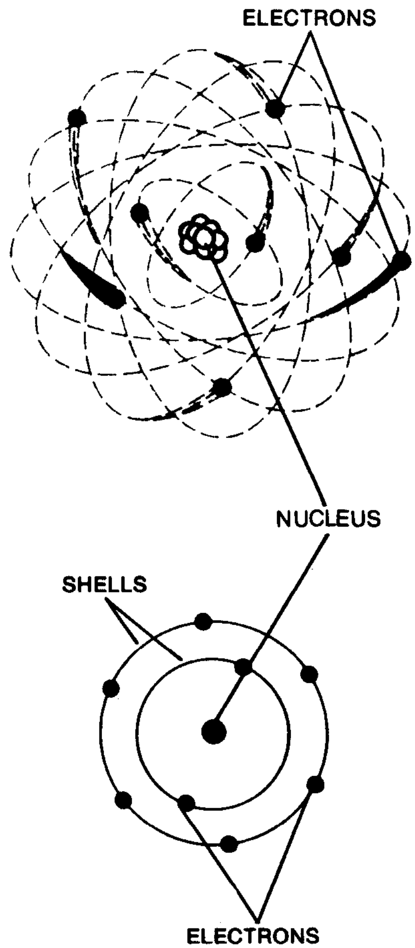

Fig. 1-1. Artist's view of the inside of an atom, containing eight electrons that move around the nucleus in two shells

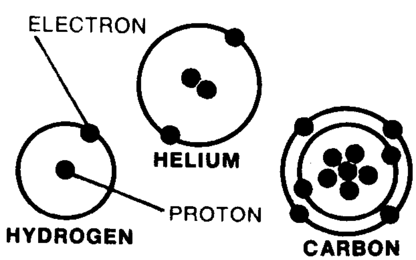

Fig. 1-2. Atoms of hydrogen, helium, and carbon

Before we discuss the basics of electricity and electronics, we need to understand what matter is. *Matter* is anything that occupies space and has *mass,* or weight. Wire, rubber, and glass are examples of matter. Scientists study the properties of matter in order to know how it works. Scientists are also concerned with the study of energy. *Energy* is the capacity for doing work. Energy has different forms, such as heat energy and electric energy. Electric energy results from the motion of tiny bits of matter called *electrons*. Energy can make changes in materials, such as putting them together, taking them apart, or simply moving them from one place to another.

The basic unit of matter is the *atom*. In studying electricity and electronics, it is important for you to understand the atom because the electron is one of its parts. In this unit, the structure of the atom and its electrical properties are discussed.

STRUCTURE OF THE ATOM

An atom is made up of tiny particles. Two of these particles, the *electron* and the *proton,* are important to our studies.

Electrons move around the center, or *nucleus,* of an atom in paths. These paths are usually called *shells* (Fig. 1-1). An atom can have several shells around its nucleus. Each of these shells can have only up to a certain number of electrons. This number is called the *quota* of a shell. When every shell of the atom contains its quota of electrons, the atom is said to be in a stable condition. The nucleus of the atom is made up of particles called *protons* and *neutrons*. These are held together tightly by a binding energy.

All electrons are alike, and all protons are alike. Thus, atoms differ from one another only in the number of electrons and protons they contain (Fig. 1-2). The number of protons in the nucleus is the *atomic number* of that atom. Neutrons weigh about the same as protons. The term *atomic weight* refers to the total number of particles (both protons and neutrons) in the nucleus of an atom.

While scientists have provided much information about the atom, the search for more information continues. For example, new theories indicate that the nucleus of the atom contains other kinds of particles that are dynamic and complex. A discussion of these subatomic particles is beyond the scope of this text. These particles, however, are being studied intensively by scientists in the field called *high-energy physics*.

ELEMENTS, COMPOUNDS, AND MOLECULES

When all the atoms in a substance are alike, the substance is called an *element*. Copper, iron, and carbon are among the more than 100 different elements known to exist. Different elements can combine to form a

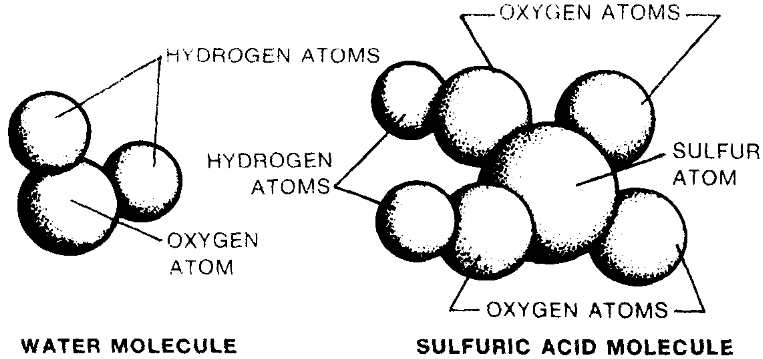

Fig. 1-3. Molecules of water and sulfuric acid. A molecule is made up of a number of atoms.

substance called a *compound*. Water, sugar, and plastic materials are examples of compounds.

The smallest particle of a compound that has all the properties of that compound is called a *molecule*. A molecule contains atoms of each of the elements that form the compound (Fig. 1-3).

CHARGES

Electrons and protons have tiny amounts of energy known as *electric charges*. Electrons have negative (−) charges. Protons have positive (+) charges. Neutrons have no electric charge. Thus, they are neutral. The amount of the negative charge of each electron is equal to the amount of the positive charge of each proton. These opposite charges attract each other. This attraction helps hold the atom together.

Under normal conditions, the negative and the positive charges in an atom are equal in value. This is because the atom has an equal number of electrons and protons. An atom in this condition is said to be electrically neutral (Fig. 1-4).

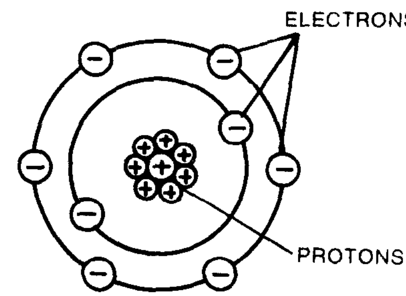

Fig. 1-4. An electrically neutral atom

VALENCE ELECTRONS

Electrons in the outermost shell of an atom are called *valence electrons*. In the study of electricity and electronics, we are concerned mostly with the behavior of valence electrons. They can, under certain conditions, leave their "parent" atoms. The number of valence electrons in atoms also determines important electrical and chemical characteristics of the substance.

ENERGY LEVELS AND FREE ELECTRONS

The electrons in any shell of an atom are said to be located at certain energy levels. These are related to the distance of the electrons from the nucleus of the atom. When outside energy such as heat, light, or electricity is applied to certain materials, the electrons within the atoms of these materials gain energy. This may cause the electrons to move to a higher energy level. Thus, they move farther from the nuclei of their atoms (Fig. 1-5A).

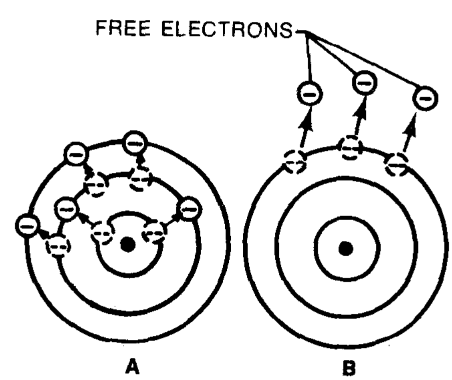

Fig. 1-5. Some electrons within an atom may move to higher energy levels within the atom or leave the atom as a result of the absorption of energy.

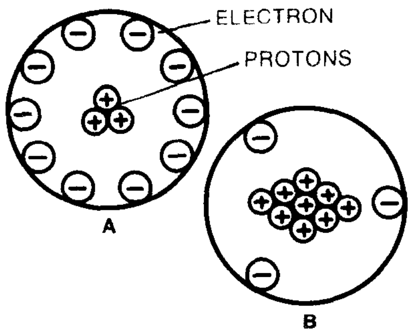

Fig. 1-6. Ions: (A) negatively charged ion; (B) positively charged ion

When an electron has moved to the highest possible energy level (or the outermost shell of its atom), it is least attracted by the positive charges of the protons within the nuclei of the atom. If enough energy is then applied to the atom, some of the outermost-shell, or valence, electrons will leave the atom. Such electrons are called *free electrons* (Fig. 1-5B).

IONS

An *ion* is a charged atom. If a neutral atom gains electrons, there are then more electrons than protons in the atom. Thus, the atom becomes a negatively charged ion (Fig. 1-6A). If a neutral atom loses electrons, protons outnumber the remaining electrons. Thus, the atom becomes a positively charged ion (Fig. 1-6B). Ions with unlike charges attract one another. Ions with like charges repel one another. The process by which atoms either gain or lose electrons is called *ionization*.

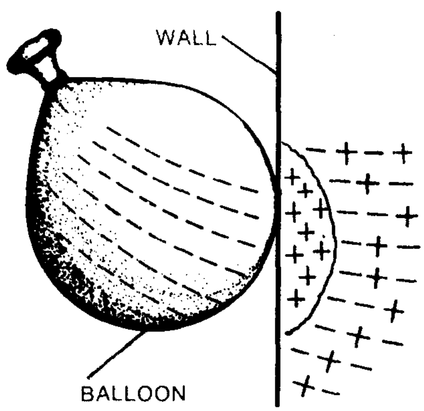

Fig. 1-7. Opposite electric charges attract each other and thus cause a rubber balloon to "stick" to a wall.

ELECTRIC CHARGES IN ACTION

A simple way of generating an electric charge is to create friction. For example, if you rub a rubber balloon briskly with a wool cloth, electrons will move from the cloth to the balloon, causing the balloon to become negatively charged. If you then put the balloon against a wall, the balloon's negative charge will repel electrons from the surface of the wall (Fig. 1-7). This will, in turn, cause the surface of the wall to become positively charged. The attraction between the opposite charges of the balloon and a small surface area of the wall is strong enough to hold the balloon in place. Other substances, such as glass, when rubbed briskly with a silk cloth, lose their electrons and therefore have a positive charge.

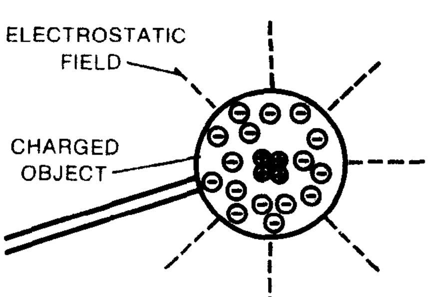

Fig. 1-8. An invisible electrostatic field is present around every charged body.

STATIC ELECTRICITY

The attraction between the charged balloon and wall represents work done by *electrostatic energy*, which is often called *static electricity*. An *electrostatic field* is the energy that surrounds every charged object (Fig. 1-8). In this kind of electricity, there is no movement of electrons between the balloon and the wall. Thus, the electricity is said to be *static*, or at rest.

Static electricity is sometimes thought of as a nuisance. However, devices such as capacitors and air cleaners and industrial processes such as the manufacture of abrasive paper make use of it.

USEFUL APPLICATIONS OF STATIC ELECTRICITY

Figure 1-9 shows how static charges are used in making abrasive paper. *Sandpaper* is a common term for abrasive paper. Such paper is used to smooth the surfaces of wood or metal. A conveyor belt carries the abrasive particles over a negatively charged plate. The abrasive particles are negatively charged by contact. At the same time, the paper, which is tacky from an adhesive coating, is moving under a positively

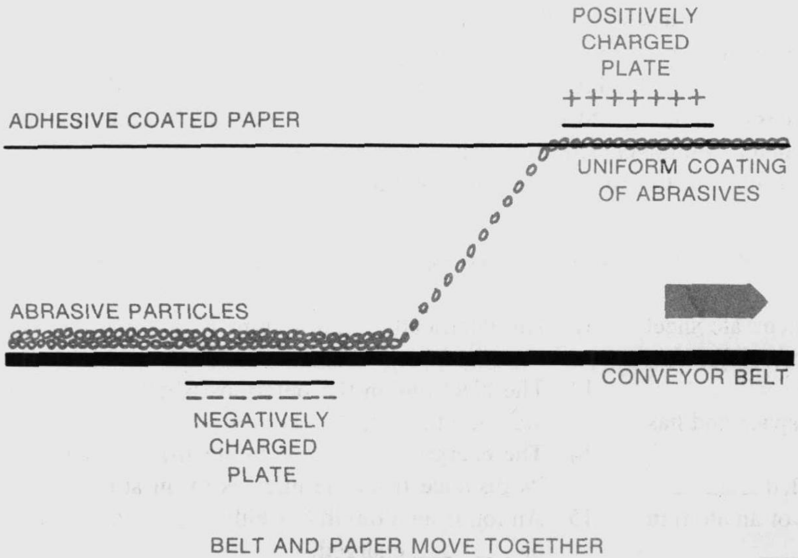

Fig. 1-9. Electrostatic charges used in making abrasive paper

charged plate. This makes the paper positive. Since opposite charges attract, the abrasive particles are attracted to the paper. These particles form a very uniform and dense abrasive surface on the paper.

Static electricity can also be used in an air cleaner (Fig. 1-10). This device can be used in home heating systems to clean the air as it circulates through the furnace. A similar device can be used by industry to reduce air pollution. Electrostatic air filters are much more efficient than simple cloth or paper filters. Those remove only large particles from the air. An electronic filter can remove tiny particles. As shown in Fig. 1-10, the dirty air passes through a paper prefilter that removes large pieces of dirt and lint. The air then moves through a series of plates that give a positive charge to the dirt and dust particles. Finally the air moves through a negatively charged filter. The positive particles are attracted to the negative filter. They become trapped there. After the filters become very dirty, the system must be shut down and cleaned.

Another practical use of static electricity is shown in Fig. 1-11. Spray painting is a common way of producing beautifully finished surfaces.

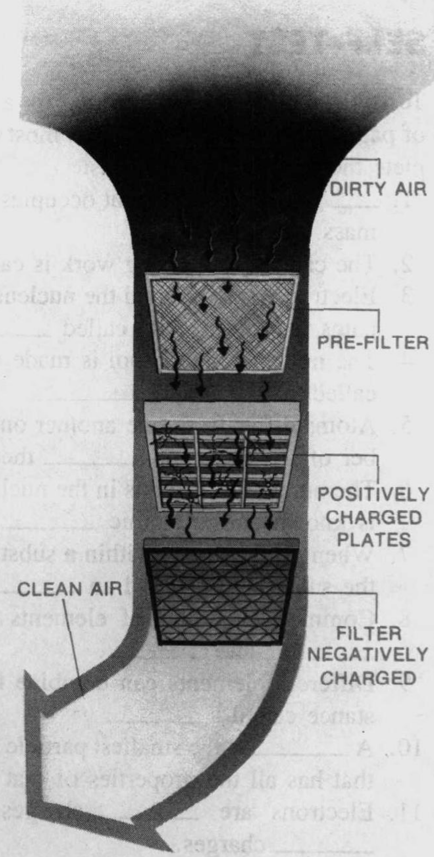

Fig. 1-10. An electrostatic air cleaner

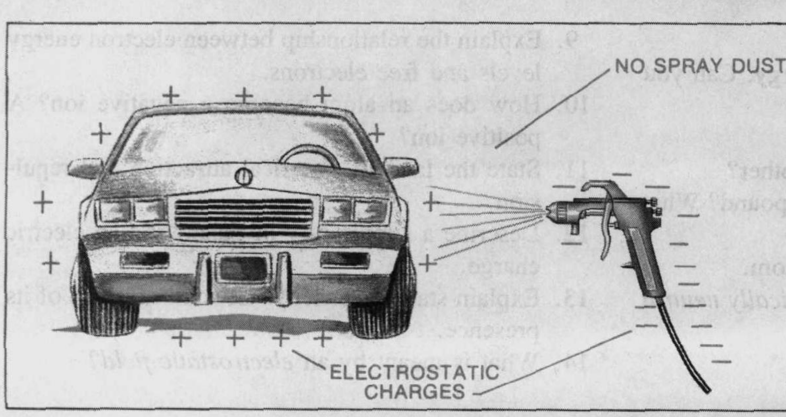

Fig. 1-11. Electrostatic spray painting

However, it is wasteful. Much of the paint never sticks to the surface. It stays in the air as *spray dust*. Spray dust is not only wasteful but also dangerous to health. Most of the spray dust can be eliminated by positively charging the object to be painted and negatively charging the paint. Moreover, since the charge decreases where the paint is applied, a uniform thickness of paint is produced.

SELF-TEST

Test your knowledge by writing, on a separate sheet of paper, the word or words that most correctly complete the following statements:

1. _______ is anything that occupies space and has mass.
2. The capacity for doing work is called _______.
3. Electrons move around the nucleus of an atom in paths that are usually called _______.
4. The nucleus of an atom is made up of particles called _______ and _______.
5. Atoms differ from one another only in the number of _______ and _______ they contain.
6. The number of protons in the nucleus of an atom is known as the atomic _______ of that atom.
7. When all the atoms within a substance are alike, the substance is called an _______.
8. Common examples of elements are _______, _______, and _______.
9. Different elements can combine to form a substance called a _______.
10. A _______ is the smallest particle of a compound that has all the properties of that compound.
11. Electrons are _______ charges. Protons are _______ charges.
12. An electrically neutral atom is one that has the same number of _______ and _______.
13. The electrons in the outermost shell of an atom are called _______ electrons.
14. The energy _______ of an electron is related to its distance from the nucleus of an atom.
15. An ion is an atom that is either _______ charged or _______ charged.
16. If a neutral atom gains electrons, it becomes a _______ ion.
17. If a neutral atom loses electrons, it becomes a _______ ion.
18. Ions with unlike electric charges _______ each other. Ions with like electric charges _______ each other.
19. The process by which atoms either gain or lose electrons is called _______.
20. A simple way of generating an electric charge is by _______.
21. The attraction between two opposite electric charges is an example of _______ electricity.
22. A charged object is surrounded by an _______ field.

FOR REVIEW AND DISCUSSION

1. Define the term *energy*.
2. Identify two different forms of energy. Can you list more?
3. Describe the makeup of an atom.
4. How do atoms differ from one another?
5. What is an element? What is a compound? What is a molecule?
6. Define the atomic number of an atom.
7. Explain what is meant by an *electrically neutral atom*.
8. What are valence electrons?
9. Explain the relationship between electron energy levels and free electrons.
10. How does an atom become a negative ion? A positive ion?
11. State the laws of electrical attraction and repulsion.
12. Describe a simple way of generating an electric charge.
13. Explain static electricity. Give an example of its presence.
14. What is meant by an *electrostatic field*?

INDIVIDUAL-STUDY ACTIVITY

1. Prepare a written or an oral report on the electron theory as it relates to the study of electricity.
2. Prepare a written or an oral report on the field of high-energy physics. Include in your report the function of an accelerator as it pertains to this field of inquiry.

UNIT 2 Electric Circuits

An *electric circuit* is a combination of parts connected to form a complete path through which electrons can move. The purpose of a circuit is to make use of the energy of moving electrons. Therefore, a circuit is also a system of parts, or components, by which electric energy can be changed into other forms of energy, such as heat, light, or magnetism.

PARTS OF A CIRCUIT

A basic complete circuit has four parts: (1) the energy source, (2) the conductors, (3) the load, and (4) the control device (Fig. 2-1).

Energy Source. The *energy source* in a circuit produces the force that causes electrons to move. It is like a pump that forces water through a pipe. In electricity, this force is called *voltage,* or *electromotive force.* The basic unit of force is the *volt*. The flow of electrons is called *current*. The most common energy sources used in electric circuits are chemical cells and electromechanical generators. These devices do the work needed to move electrons through the parts of the circuit.

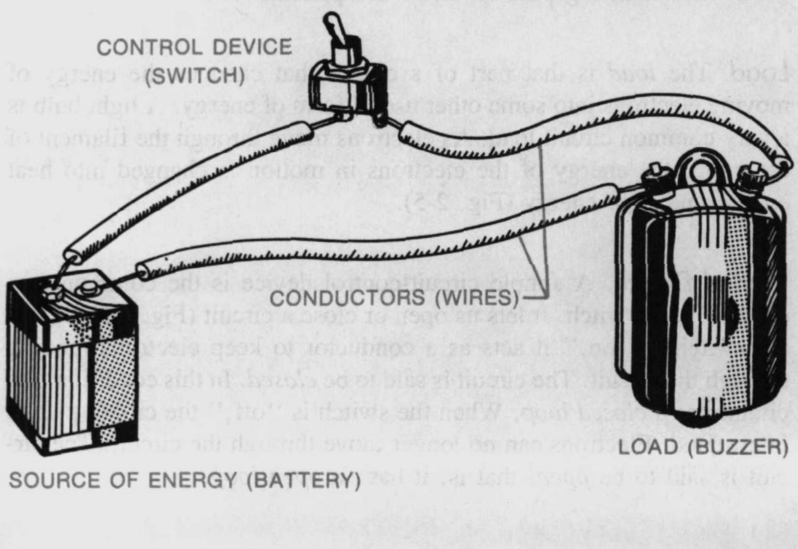

Fig. 2-1. A basic electric circuit

Conductors. The *conductors* in a circuit provide an easy path through which electrons can move through the circuit. Copper is the most commonly used conductor material. It is formed into wire, bars, or channels (Fig. 2-2). Copper wire may be bare or covered with some kind of insulating material. The insulation prevents electrons from moving outside the wire (Fig. 2-3).

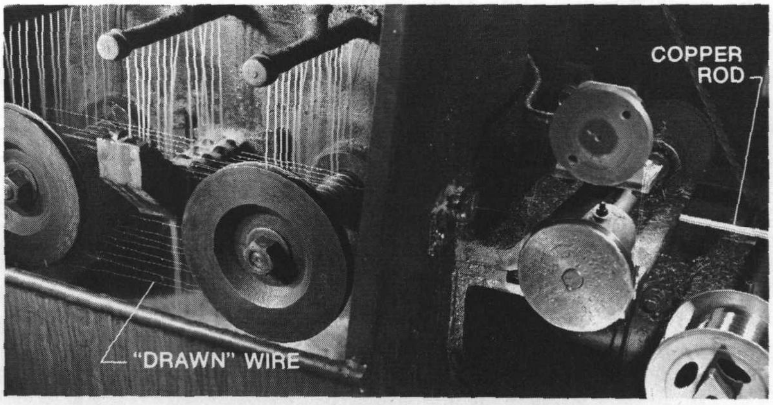

Fig. 2-2. Wire is manufactured by pulling copper rods through dies (Rome Cable Corporation)

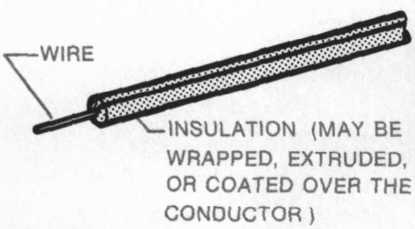

Fig. 2-3. Insulated wire. Some common insulating materials are neoprene, rubber, nylon, polyethylene, Teflon, vinyl, cotton, asbestos, paper, and enamel.

In some circuits, metal objects other than copper conductors form the conducting paths. In an automobile, for example, the entire car frame serves as a conductor. It completes a number of circuits that connect the voltage source (the car battery) to various electrical and electronic devices (the loads). The metal *chassis,* or frame, that supports the components of electrical devices is also used as a common conductor for the electric circuit. Figure 2-4 shows an experimental circuit that uses a novel method to achieve a common conducting path. Many of the component leads of this circuit are soldered directly to the copper-clad surface of the laminated circuit board. The copper-clad surface forms a common conducting path for these components.

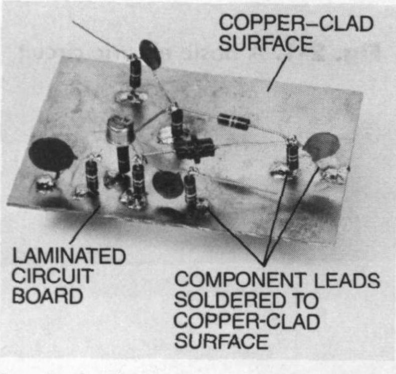

Fig. 2-4. The copper-clad surface of a circuit board provides a common conductor for the experimental circuit. (*QST, Journal of American Radio Relay League*)

Load. The *load* is that part of a circuit that changes the energy of moving electrons into some other useful form of energy. A light bulb is a very common circuit load. As electrons move through the filament of the lamp, the energy of the electrons in motion is changed into heat energy and light energy (Fig. 2-5).

Control Device. A simple circuit-control device is the common mechanical wall switch. It lets us open or close a circuit (Fig. 2-6). When the switch is "on," it acts as a conductor to keep electrons moving through the circuit. The circuit is said to be *closed*. In this condition, the circuit has a *closed loop*. When the switch is "off," the circuit path is interrupted. Electrons can no longer move through the circuit. The circuit is said to be *open,* that is, it has an *open loop*.

In addition to the familiar on-off switches, other devices can provide a switching action and control the flow of electrons in a circuit. Examples are electromagnetic relays, diodes, transistors, and logic circuits, all discussed later in this book.

KINDS OF CIRCUITS

Loads can be connected into a circuit in *series,* in *parallel,* or in *series-parallel* combinations. A series circuit provides only one path, or one loop, through which electrons can move from one terminal of the energy source to the other (Fig. 2-7A). In a parallel circuit, there may be two or more different paths, or loops, through which electrons can flow (Fig. 2-7B). A series-parallel circuit is shown in Fig. 2-7C. Note that series and parallel circuits are combined to form one circuit with several paths, or loops.

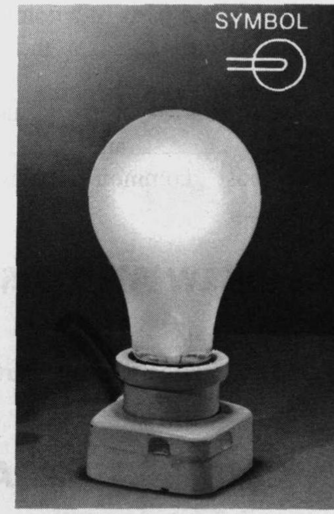

Fig. 2-5. A typical electrical load. The light bulb converts electric energy into heat and light energy. (*General Electric Company*)

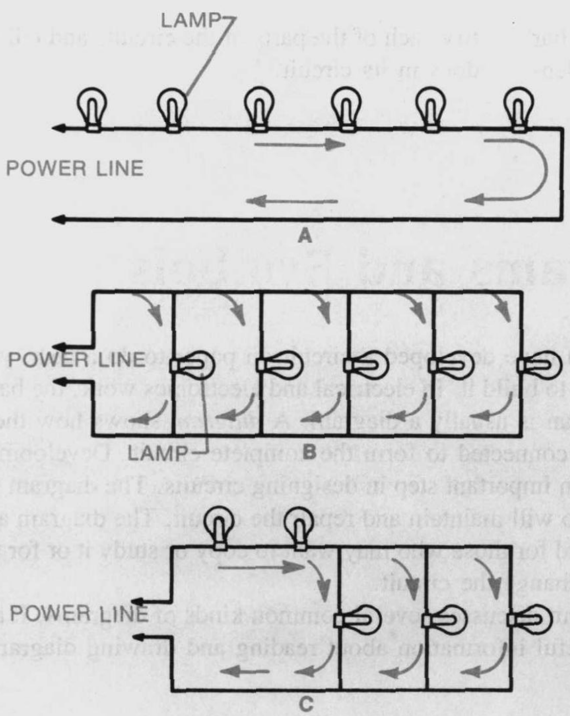

Fig. 2-7. Circuit connections: (A) series circuit; (B) parallel circuit; (C) series-parallel circuit. Arrows indicate a closed current loop.

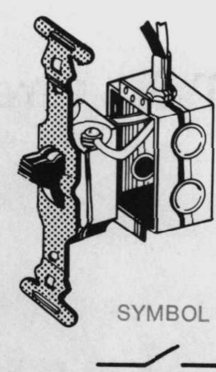

Fig. 2-6. A typical on-off switch

SELF-TEST

Test your knowledge by writing, on a separate sheet of paper, the word or words that most correctly complete the following statements:

1. An electric circuit makes it possible to use the energy of moving ______.
2. In a circuit, electric energy is changed into other forms of energy, such as ______, ______, or ______.