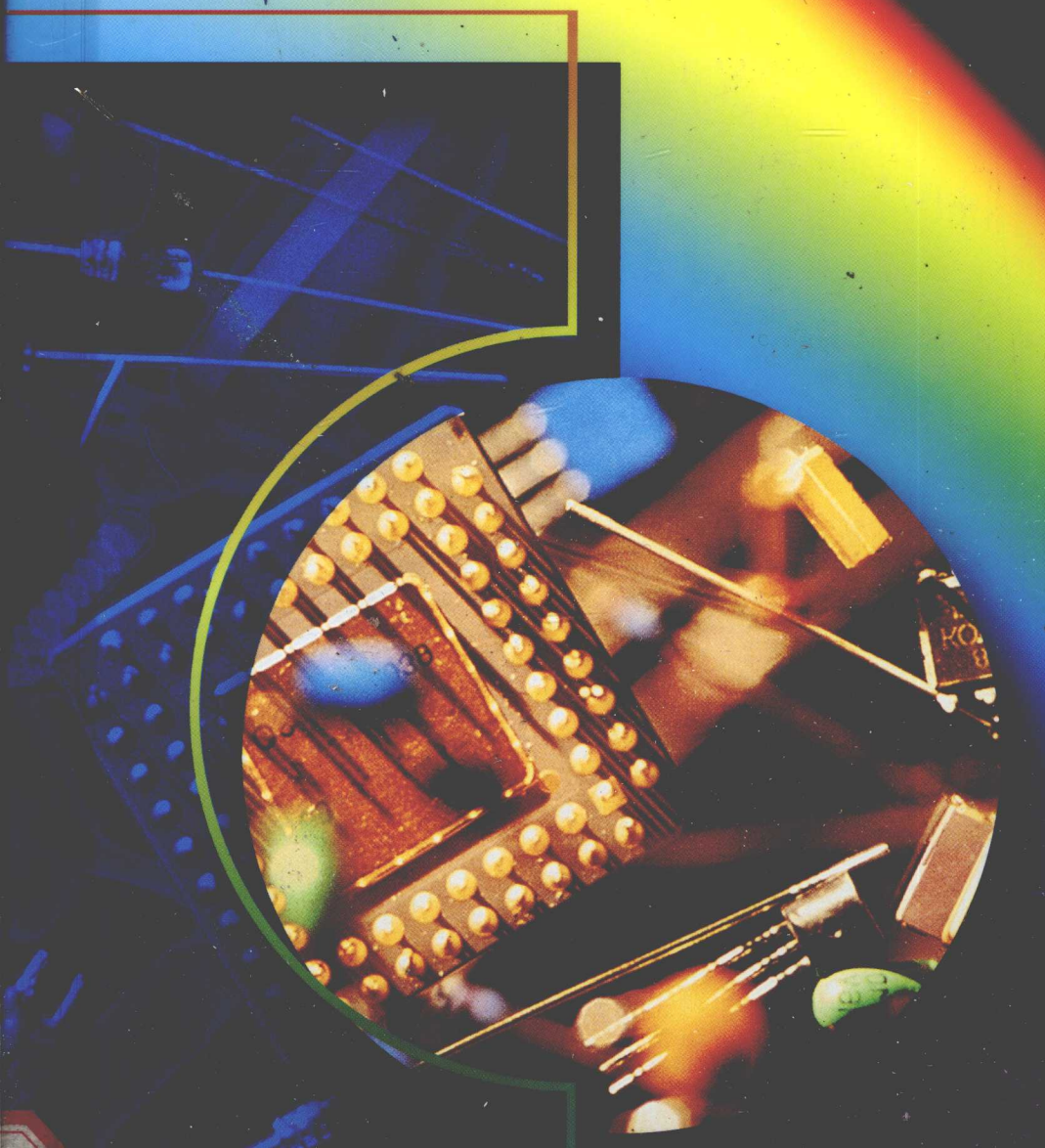
# ELECTRICITY

## Principles and Applications



Fifth Edition

Fowler

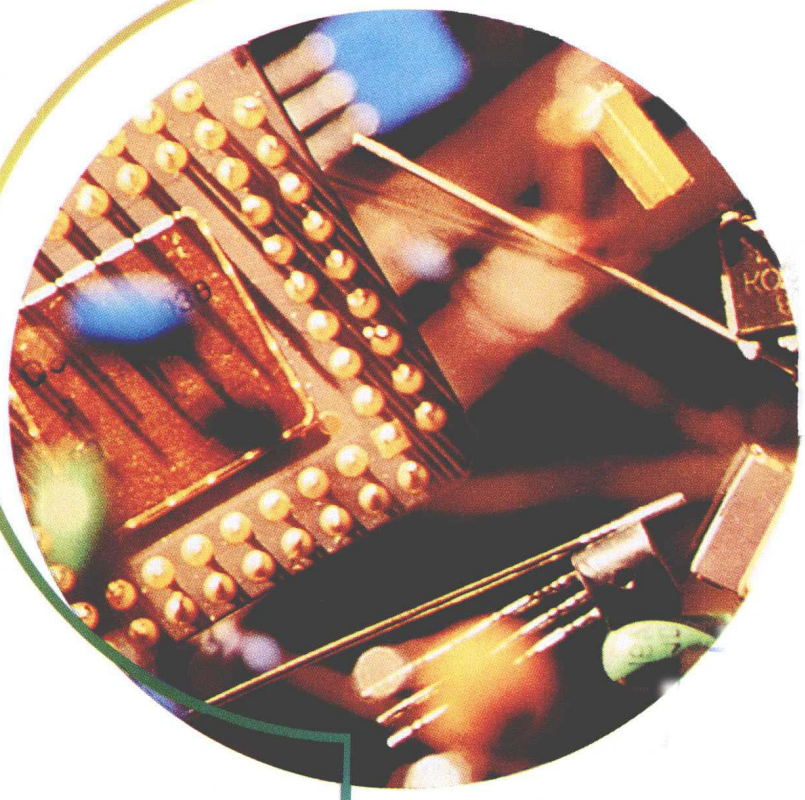
*Basic Skills in Electricity and Electronics*

# ELECTRICITY

## Principles and Applications

Fifth Edition

Richard J. Fowler



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**Electricity: Principles and Applications, Fifth Edition**

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# Editors' Foreword

The Glencoe *Basic Skills in Electricity and Electronics* series has been designed to provide entry-level competencies in a wide range of occupations in the electrical and electronic fields. The series consists of coordinated instructional materials designed especially for the career-oriented student. Each major subject area covered in the series is supported by a textbook, an experiments manual, and an instructor's productivity center. All the materials focus on the theory, practices, applications, and experiences necessary for those preparing to enter technical careers.

There are two fundamental considerations in the preparation of materials for such a series: the needs of the learner and needs of the employer. The materials in this series meet these needs in an expert fashion. The authors and editors have drawn upon their broad teaching and technical experiences to accurately interpret and meet the needs of the student. The needs of business and industry have been identified through personal interviews, industry publications, government occupational trend reports, and reports by industry associations.

The processes used to produce and refine the series have been ongoing. Technological change is rapid and the content has been revised to focus on current trends. Refinements in pedagogy have been defined and implemented based on classroom testing and feedback from students and instructors using the series. Every effort has been made to offer the best possible learning materials.

The widespread acceptance of the *Basic Skills in Electricity and Electronics* series and the positive responses from users confirm the basic soundness in content and design of these materials as well as their effectiveness as learning tools. Instructors will find the texts and manuals in each of the subject areas logically structured, well-paced, and developed around a framework of modern objectives. Students will find the materials to be readable, lucidly illustrated, and interesting. They will also find a generous amount of self-study and review materials and examples to help them determine their own progress.

Both the initial and on-going success of this series are due in large part to the wisdom and vision of Gordon Rockmaker who was a magical combination of editor, writer, teacher, electrical engineer and friend. Gordon has retired but he is still our friend. The publisher and editors welcome comments and suggestions from instructors and students using the materials in this series.

***Charles A. Schuler,***
***Project Editor***
***and***
***Brian P. Mackin,***
***Editorial Director***

## Basic Skills in Electricity and Electronics

### Charles A. Schuler, Project Editor

***New Editions in This Series***
*Electricity: Principles and Applications, Fifth Edition,* Richard J. Fowler
*Electronics: Principles and Applications, Fifth Edition,* Charles A. Schuler
*Digital Electronics: Principles and Applications, Fifth Edition,* Roger L. Tokheim
***Other Series Titles Available:***
*Communication Electronics, Second Edition,* Louis E. Frenzel
*Microprocessors: Principles and Applications, Second Edition,* Charles M. Gilmore
*Industrial Electronics,* Frank D. Petruzella
*Mathematics for Electronics,* Harry Forster, Jr.

# Preface

*Electricity: Principles and Applications,* Fifth Edition, is written for students just beginning their study of electricity. No previous formal training in the subject is assumed. Only arithmetic and basic algebra are used in explaining and solving electrical problems. Although simultaneous equations are introduced in Chap. 6, they are defined and explained in some detail before actually being used. Similarly, the elements of trigonometry that relate to ac circuits are explained as needed.

This edition retains the logical, sequential order of topics found in the previous edition. The terms and concepts that are developed and discussed in Chap. 1 are needed to fully understand Chap. 2. The concepts of Chap. 2 are used in Chap. 3, and so on. The exception is Chap. 6, which can be studied out of sequence or omitted entirely without interrupting the continuity of the remaining chapters.

Chapters 1 through 6 of this text are devoted, in general, to the fundamentals of direct current, and Chaps. 8 through 13 focus on subjects usually associated with alternating current. This arrangement provides students with balanced coverage of basic concepts. The transition from direct current to alternating current through the study of magnetism and electromagnetism is distinct enough to allow use of the material in a traditional dc/ac sequence. However, all the material is structured to provide a unified introduction to the broad subject area called *electricity.*

Although no prior formal background in electricity is assumed, it is highly unlikely that a student will not have had extensive exposure to the world of electricity and electronics. For this reason, certain words associated with electricity are expected to have already entered the students' vocabulary, for example, *switch, plug, motor, computer, CPU,* and *television.* Nevertheless, strict technical definitions are used throughout to aid students to rid themselves of technical misconceptions.

Since concepts build from chapter to chapter, and within a chapter from section to section, students are provided with a number of stopping points for test questions and problems. These tests serve two purposes: They reveal areas of weakness that require restudy, and they serve as positive reinforcement for material students know. Answers to the tests are provided as the last item of each chapter.

Each chapter concludes with a summary of the key concepts covered in the chapter. The summaries also help identify areas of weakness and reinforce areas of strength. Students should not skim through this material lightly.

In addition to the tests that are strategically located within each chapter, a comprehensive list of review questions is provided at the end of each chapter. Direct answers, or exact procedures indicating how to obtain the answers, to the Critical Thinking Questions, which follow the sections on review questions, will not be found in the chapter. These questions require students to express their own ideas and beliefs or to develop procedures for solving problems that have not been specifically illustrated in the chapter.

For this edition, the text interior was redesigned to use color more effectively, while retaining the popular marginal color strip. Students can quickly find their chapter-ending assignments with the red strip. Highlighted key terms now appear in the margin of each page close to their point of text discussion. Color strips are also used as a quick thumb reference to find the numerous illustrative examples within a chapter. The text design allows for consistent color-coding of circuit components. This edition also contains informative features called "Did You Know?", "Job Tips," and "About Electronics," which should spark interesting in-class discussions.

But the changes are much more than cosmetic. For this edition, we sought the advice of instructors who have used the book for many years and of instructors who have used it for only a short period of time. They provided precise recommendations and consistent responses with their questionnaires. Their collective information and suggestions are included in this new edition.

Every chapter has undergone modifications, ranging from subtle changes in line art or problem additions to the addition of new sections. Chapter 4 contains an introduction to surface-mount devices (SMDs) and resettable fuses. Chapter 6 includes a brief introduction to Kirchhoff's voltage law. More information is included on magnetic quantities and units in Chap. 7. Chapter 10 provides an introduction to SMD capacitors. Off-center-tapped windings are now included in



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Chap. 12. Numerous subtle changes in Chap. 14 result in improved coverage of dc motors. Throughout the book, there are numerous new questions and problems that reflect the changes within each chapter. New photographs and line drawings provide a timely updating of electrical concepts.

This truly is the age of electricity and electronics. The solid foundation in electricity provided by this text is likely to prove useful, whether a student intends to pursue a career in electricity and electronics or simply needs the material as background information for other pursuits. The content and organization of this book reflect the experience and feedback of years of classroom testing. The author welcomes comments and suggestions from students and teachers alike.

Be sure to visit our website at www.glencoe.com/ps/bsee/fowler. There you will find valuable information on subjects including careers and skills standards. You will also find resources organized by chapter, and links to equipment manufacturers and other related websites.

## Acknowledgments

The author, project editor, and publisher would like to thank the instructors (listed at right) who provided general and detailed comments, and those who responded to the survey that was sent out while the book was being revised. Their comments and suggestions pro-vided the valuable input necessary to make a good book even better.

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**Richard J. Fowler**

# Safety

Electric and electronic circuits can be dangerous. Safe practices are necessary to prevent electrical shock, fires, explosions, mechanical damage, and injuries resulting from the improper use of tools.

Perhaps the greatest hazard is electrical shock. A current through the human body in excess of 10 milliamperes can paralyze the victim and make it impossible to let go of a "live" conductor or component. Ten milliamperes is a rather small amount of electrical flow: It is only *ten one-thousandths* of an ampere. An ordinary flashlight uses more than 40 times that amount of current!

Flashlight cells and batteries are safe to handle because the resistance of human skin is normally high enough to keep the current flow very small. For example, touching an ordinary 1.5-V cell produces a current flow in the microampere range (a microampere is one-millionth of an ampere). This amount of current is too small to be noticed.

High voltage, on the other hand, can force enough current through the skin to produce a shock. If the current approaches 100 milliamperes or more, the shock can be fatal. Thus, the danger of shock increases with voltage. Those who work with high voltage must be properly trained and equipped.

When human skin is moist or cut, its resistance to the flow of electricity can drop drastically. When this happens, even moderate voltages may cause a serious shock. Experienced technicians know this, and they also know that so-called low-voltage equipment may have a high-voltage section or two. In other words, they do not practice two methods of working with circuits: one for high voltage and one for low voltage. They follow safe procedures at all times. They do not assume protective devices are working. They do not assume a circuit is off even though the switch is in the OFF position. They know the switch could be defective.

As your knowledge and experience grow, you will learn many specific safe procedures for dealing with electricity and electronics. In the meantime:

1. Always follow procedures.
2. Use service manuals as often as possible. They often contain specific safety information. Read, and comply with, all appropriate material safety data sheets.
3. Investigate before you act.
4. When in doubt, *do not act*. Ask your instructor or supervisor.

## General Safety Rules for Electricity and Electronics

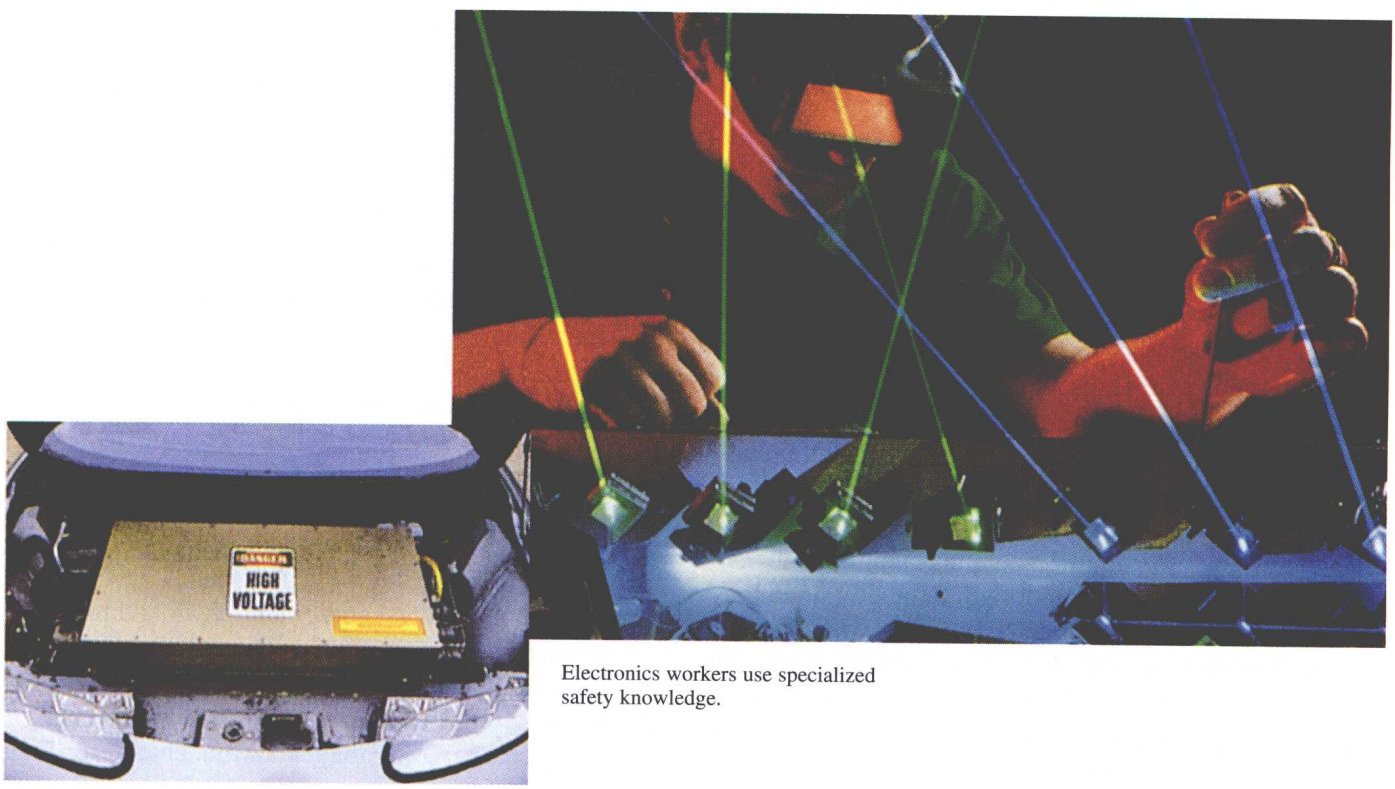
Safe practices will protect you and your fellow workers. Study the following rules. Discuss them with others, and ask your instructor about any you do not understand.

1. Do not work when you are tired or taking medicine that makes you drowsy.
2. Do not work in poor light.
3. Do not work in damp areas or with wet shoes or clothing.
4. Use approved tools, equipment, and protective devices.
5. Avoid wearing rings, bracelets, and similar metal items when working around exposed electric circuits.
6. Never assume that a circuit is off. Double-check it with an instrument that you are sure is operational.
7. Some situations require a "buddy system" to guarantee that power will not be turned on while a technician is still working on a circuit.
8. Never tamper with or try to override safety devices such as an interlock (a type of switch that automatically removes power when a door is opened or a panel removed).
9. Keep tools and test equipment clean and in good working condition. Replace insulated probes and leads at the first sign of deterioration.
10. Some devices, such as capacitors, can store a *lethal* charge. They may store this charge for long periods of time. You must be certain these devices are discharged before working around them.
11. Do not remove grounds and do not use adaptors that defeat the equipment ground.
12. Use only an approved fire extinguisher for electrical and electronic equipment. Water can conduct electricity and may severely damage equipment. Carbon dioxide ($CO_2$) or halogenated-type extinguishers are usually preferred. Foam-type extin-

guishers may also be desired in *some* cases. Commercial fire extinguishers are rated for the type of fires for which they are effective. Use only those rated for the proper working conditions.

13. Follow directions when using solvents and other chemicals. They may be toxic, flammable, or may damage certain materials such as plastics. Always read and follow the appropriate material safety data sheets.
14. A few materials used in electronic equipment are toxic. Examples include tantalum capacitors and beryllium oxide transistor cases. These devices should not be crushed or abraded, and you should wash your hands thoroughly after handling them. Other materials (such as heat shrink tubing) may produce irritating fumes if overheated. Always read and follow the appropriate material safety data sheets.
15. Certain circuit components affect the safe performance of equipment and systems. Use only exact or approved replacement parts.
16. Use protective clothing and safety glasses when handling high-vacuum devices such as picture tubes and cathode-ray tubes.
17. Don't work on equipment before you know proper procedures and are aware of any potential safety hazards.
18. Many accidents have been caused by people rushing and cutting corners. Take the time required to protect yourself and others. Running, horseplay, and practical jokes are strictly forbidden in shops and laboratories.

Circuits and equipment must be treated with respect. Learn how they work and the proper way of working on them. Always practice safety: your health and life depend on it.




Electronics workers use specialized safety knowledge.

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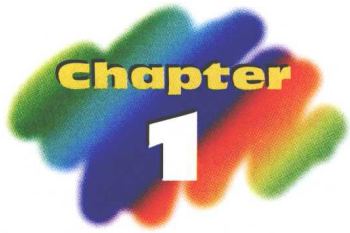



# Basic Concepts

## Chapter Objectives

*This chapter will help you to:*

1. *Use* base units for specifying and calculating energy and work.
2. *Understand* energy conversion and conversion efficiency.
3. *List and explain* the characteristics of the major particles of an atom.
4. *Explain* the nature of electric charge.
5. *Discuss* several industrial applications of static electricity.

Electricity is a form of energy. The study of electricity is concerned primarily with learning how to control electric energy. When properly controlled, electricity can do much of the work required to keep our society going. However, uncontrolled electric energy, such as lightning, can be very destructive.

Electric energy is so much a part of our daily lives that we tend to take it for granted. Yet without it our lives would be quite different, and much harder. Electric energy lights our homes and industries, operates our computers, radios, and television sets, and turns the many motors used in clocks, washing machines, clothes dryers, vacuum cleaners, and so forth.

## 1-1 Work and Energy

*Work* consists of a force moving through a distance. *Energy* is the ability, or capacity, to do work. In other words, it takes energy to do work. For example, it requires energy to pull a boat out of the water onto the beach, and work is done in pulling the boat out of the water.

The energy required to pull the boat from the water comes from the human body. A force is required to overcome the friction of the boat on the sand. A force is also required to overcome the gravitational pull on the boat as it is raised out of the water. The work then consists of the force required to move the boat some distance as it is pulled onto the shore.

The symbol (or abbreviation) for either work or energy is *W*. The same symbol is used for work and energy because the two terms are so closely related to each other.

## 1-2 Unit of Energy

**Work (*W*)**

**Energy (*W*)**

**Base units**

**Joule (J)**

*Base units* are the terms used to indicate the amount of something. The *joule* is the base unit of energy and work. The symbol for the joule is J. Specifying energy in joules is the same as specifying butter in pounds or money in dollars. All are base units used to specify amount. Base units are important because nearly all relationships in electricity are expressed in base units.

A joule of energy (or work) is very small compared with the amount of energy you use each day. For example, an electric toaster uses approximately 100,000 joules of energy to make two slices of toast. It requires 360,000 joules to operate a small (100-watt) table lamp for 1 hour.

The work or energy involved in a mechanical system (such as pulling a boat) can be

determined by the following relationship:

$$\text{Work} = \text{force} \times \text{distance}$$

Newton

Meter

In the metric system, the base unit for force is the *newton* (approximately 0.2248 pounds). The base unit for distance is the *meter* (approximately 39.4 inches), and the base unit for work (energy) is the joule. The joule is equal to the newton-meter, which is a convenient unit for mechanical energy.

Let us return to the problem of pulling a boat out of the water and calculate how much work is done in performing the task.

### Example 1-1

If it requires a steady force of 150 newtons to pull a boat, how much work is required to pull a boat 8 meters?

**Given:** Force = 150 newtons
Distance = 8 meters

**Find:** Work

**Known:** Work ($W$) = force × distance
1 newton-meter = 1 joule (J)

**Solution:** Work = 150 newtons × 8 meters
= 1200 newton-meters
= 1200 joules

**Answer:** Work = 1200 joules
$W$ = 1200 J

Note the procedure used in solving the problem given in the above example. First, the information (values) *given* in the problem is listed. Next, the information you are required to *find* is recorded. Finally, the relationship (formula) between the two is written. For simple problems this formal procedure may seem unnecessary, but solving more complex problems will be easier if you establish the habit of using this formal procedure.

So far, the calculation of specific amounts of work or energy has been limited to mechanical examples. Once we learn some new terms, like *voltage, current,* and *power,* we will be able to solve problems involving electric energy.

Converted energy

In example 1-1, we found that the work done in moving the boat was 1200 joules (J). The amount of energy required to move the boat is also 1200 J. Work and energy have the same base unit. They are basically the same thing. Work is the use of energy to perform some task. For example, a car battery has energy stored in it. When the car engine is started, energy from the battery is used to do the work of cranking the engine. The *work done* and the *energy used* are two ways of saying the same thing.

### Example 1-2

It requires 500 joules of energy and 100 newtons of force to move an object from point A to point B. What is the distance between point A and point B?

**Given:** Energy = 500 joules
Force = 100 newtons

**Find:** Distance

**Known:** $W$ = force × distance, and by rearranging

$$\text{Distance} = \frac{W}{\text{force}}$$

1 newton-meter = 1 joule

**Solution:**

$$\text{Distance} = \frac{500 \text{ newton-meters}}{100 \text{ newtons}}$$

= 5 meters

**Answer:** Distance = 5 meters

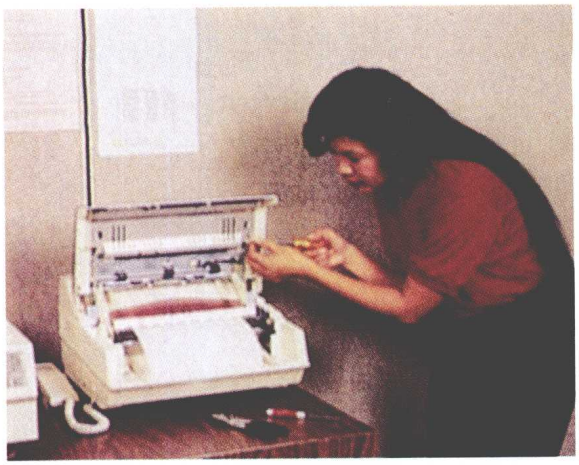
### TEST

*Answer the following questions.*

1. Define work and energy.
2. What is a base unit?
3. What is the base unit of energy?
4. How much energy does it take to push a car 130 meters with a steady force of 360 newtons?

## 1-3 Energy Conversion

One of the fundamental laws of classical physics states that, under ordinary conditions, energy can be neither created nor destroyed. The energy in the universe exists in various forms, such as heat energy, light energy, and electric energy. When we say we "use" electric energy, we do not mean that we have destroyed, or lost, the energy. We mean that we have *con-*



Technician examining a fax machine.

*verted* that electric *energy* into a more useful form of energy. For example, when we operate an electric lamp, we are converting electric energy into light energy and heat energy. We have used the electric energy in the sense that it no longer exists as electric energy, but we have not used up the energy. It still exists as heat energy and light energy.

The study of electricity deals with the study of converting energy from one form to another form. Electric energy itself is obtained by converting other forms of energy to electric energy. Batteries convert chemical energy to electric energy, solar cells convert light energy to electric energy, and generators convert mechanical (rotational) energy to electric energy.

We seldom use energy directly in the form of electric energy. Yet the electrical form of energy is very desirable because it can be easily moved from one location to another. Electric energy produced at an electric power plant many miles from your home can be easily transferred from the plant to your home. Once the electric energy is delivered to your home, it can be converted to a more useful form.

**JOB TIP**

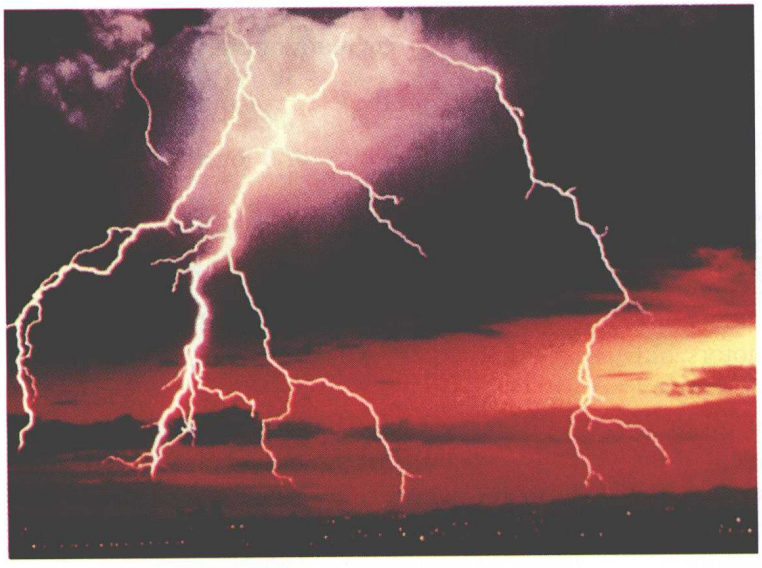
More technicians are fired for lack of people skills than for lack of technical skills.

We have already noted that a light bulb converts electric energy into light energy and heat energy. Another familiar object that converts energy is the electric stove, which converts electric energy to heat energy. Changing electric energy to mechanical (rotational) energy with an electric motor is also a common conversion.

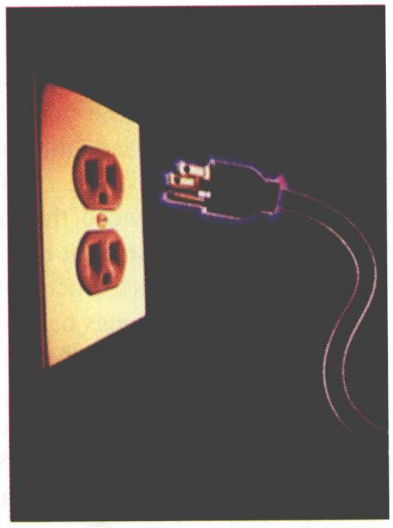
Although the process is very involved and complex, radio receivers convert electric energy into sound energy. A very small amount of the electric energy comes from electric signals sent through the air. The rest of the electric energy comes from a battery or an electric outlet. The sound energy radiates from the speaker. In a similar fashion, television receivers convert electric energy into sound energy and light energy.

## 1-4 Efficiency

No conversion process is 100 percent efficient. That is, not all the energy put into a device or a system is converted into the form of energy we desire. When 1000 joules of electric energy



Lightning—an example of uncontrolled electric energy.



Electric energy is converted for use in the home.

is put into a light bulb, only about 200 joules of light energy is produced. The other 800 joules is converted into heat energy. We could say that the *efficiency* of the light bulb is low.

**Efficiency**

The efficiency of a system is usually expressed as a percentage. It is calculated by the formula

$$\text{Percent efficiency} = \frac{\text{useful energy out}}{\text{total energy in}} \times 100$$

By abbreviating percent efficiency to % eff. and using the symbol $W$ for energy, we can write this formula as

$$\%\ \text{eff.} = \frac{W_{\text{out}}}{W_{\text{in}}} \times 100$$

Let us determine the efficiency of the light bulb mentioned earlier.

## Example 1-3

What is the efficiency of a light bulb that uses 1000 joules of electric energy to produce 200 joules of light energy?

**Given:** Energy in = 1000 joules
Energy out = 200 joules

**Find:** Percent efficiency

**Known:** $\%\ \text{eff.} = \dfrac{W_{\text{out}}}{W_{\text{in}}} \times 100$

**Solution:**
$$\%\ \text{eff.} = \frac{200\ \text{joules}}{1000\ \text{joules}} \times 100$$
$$= 0.2 \times 100$$
$$= 20$$

**Answer:** Efficiency = 20 percent

Notice that in the efficiency formula both the denominator and the numerator have base units of joules. The base units therefore cancel, and the answer is a pure number (it has no units). We could reword the answer to read, "The efficiency of the light bulb is 20 percent" or, "The light bulb is 20 percent efficient."

Not all electric devices have such a low efficiency as the light bulb. Electric motors like those used in washing machines, clothes dryers, and refrigerators have efficiencies of 50 to 75 percent. This means that 50 to 75 percent of the electric energy put into the motor is converted to mechanical (rotational) energy. The other 25 to 50 percent is converted into heat energy.

Converting electric energy to light and heat energy.

## Example 1-4

How much energy is required to produce 460 joules of light energy from a light bulb that is 25 percent efficient?

**Given:** % eff. = 25
Energy out = 460 joules

**Find:** Energy in

**Known:** $\%\ \text{eff.} = \dfrac{W_{\text{out}}}{W_{\text{in}}} \times 100$
by rearranging:
$$W_{\text{in}} = \frac{W_{\text{out}}}{\%\ \text{eff.}} \times 100$$

**Solution:**
$$W_{\text{in}} = \frac{460\ \text{joules}}{25} \times 100$$
$$= 18.4\ \text{joules} \times 100$$
$$= 1840\ \text{joules}$$

**Answer:** Energy in = 1840 joules

So far, we have illustrated the efficiency of converting electric energy into other desired forms of energy. Of course, we are just as interested in the efficiency of converting other forms of energy into electric energy.

## Example 1-5

What is the efficiency of an electric generator that produces 5000 joules of electric energy from the 7000 joules of mechanical energy used to rotate the generator?

**Given:** Energy in = 7000 joules
Energy out = 5000 joules

**Find:** Percent efficiency

**Known:** $$\% \text{ eff.} = \frac{W_{out}}{W_{in}} \times 100$$

**Solution:** $$\% \text{ eff.} = \frac{5000 \text{ joules}}{7000 \text{ joules}} \times 100$$
$$= 0.714 \times 100$$
$$= 71.4$$

**Answer:** Efficiency = 71.4 percent

### TEST

*Answer the following questions.*

5. List the forms of energy into which the electric energy from a car battery is converted.
6. What is the undesirable form of energy produced by both light bulbs and electric motors?
7. What happens to the temperature of an electric battery when the battery is discharging? Why?
8. An electric motor requires 1760 joules of electric energy to produce 1086 joules of mechanical energy. What is the efficiency of the motor?
9. A flashlight battery uses 110 joules of chemical energy to supply 100 joules of electric energy to the flashlight bulb. What is the efficiency of the battery?
10. How much mechanical energy will be provided by a motor that is 70 percent efficient and requires 1960 joules of electric energy?

## 1-5 Structure of Matter

All matter is composed of *atoms*. Atoms are the basic building blocks of nature. Regardless of their physical characteristics, glass, chalk, rock, and wood are all made from atoms. Rock is different from wood because of the type of atoms of which it is composed.

There are more than 100 different types of atoms. Matter composed of a single type of atom is called an *element*. Thus, there are as many elements as there are types of atoms. Some common elements are gold, silver, and copper.

**Element**

**JOB TIP**

Ohm's law and Kirchhoff's laws are the foundations of circuit troubleshooting. Electronic technicians use them on the jobs, sometimes without even realizing it.

There are thousands and thousands of different materials in the world. Obviously, most materials must be composed of more than one element. When different kinds of atoms combine chemically, they form materials called *compounds*. An example of a simple compound is water, which is composed of the elements oxygen and hydrogen. Many of the materials used in electronic circuits are composed of compounds.

**Compounds**

To really understand electricity, we must "break the atom down" into still smaller particles. To understand electricity, we need to be familiar with the three major particles of the atom. These are the *electron, proton,* and *neutron.* A pictorial representation of a helium atom showing its three major particles is illustrated in Fig. 1-1. The center of the atom is called the *nucleus.* It contains the protons and neutrons. The electrons revolve around the nucleus in elliptical paths. The electron is much larger (nearly 2000 times larger) than either the proton or the neutron. Although larger, the electron is much lighter than either the proton or the neutron. (about 1/2000 as heavy). Thus, the center (nucleus) of the atom contains most of the weight, and the electrons make up most of the volume. It should also be noted that the distance between the nucleus and the electron is very great compared

**Electron**

**Proton**

**Neutron**

**Nucleus**

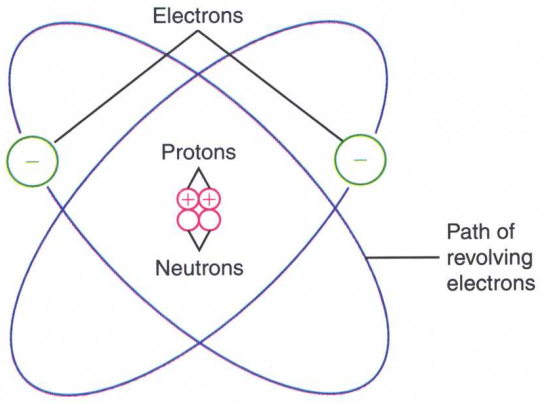
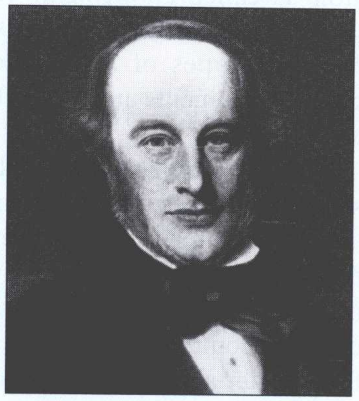



**Fig. 1-1** Structure of an atom of helium.

**Atoms**

## About Electronics

**James Prescott Joule** The SI (*Système Internationale*) unit of measure for electrical energy is the joule (J), named for James Prescott Joule (1 joule is equal to 1 volt-coulomb).



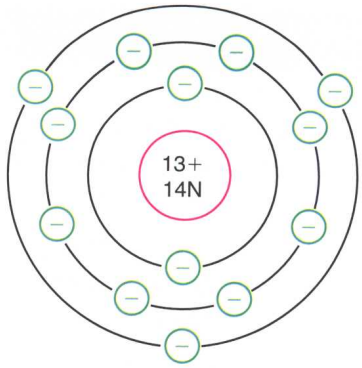



**Fig. 1-2** Simplified presentation of an aluminum atom showing its 13 electrons (−), 13 protons (+), and 14 neutrons (N).

with the size of the electron. In fact, this distance is approximately 60,000 times greater than the diameter of the electron.

An analogy may help you to visualize the relative sizes of the atomic particles and the spaces between them. The simplest atom is the hydrogen atom, which contains one proton, one electron, and no neutrons. Let the nucleus of the hydrogen atom be represented by a common marble. The electron could then be represented by a 31-meter (100-foot) sphere located 1610 kilometers (1000 miles) from the marble. Although the distance between the nucleus and the electron is very great relative to the size of either, we must remember that these sizes and distances are submicroscopic. For example, the diameter of an electron is only $4 \times 10^{-13}$ (0.0000000000004) centimeters.

**Shell**

**Orbit**

Electrons rotate, or orbit, around the nucleus of the atom in much the same manner as the earth rotates around the sun (Fig. 1-1). In atoms that contain more than one electron (that is, in all atoms except hydrogen atoms), each electron has its own orbit. With proper coordination of the orbiting electrons, it is possible for two or more atoms to share common space. Indeed, in many materials, neighboring atoms share electrons as well as space.

Figure 1-2 represents the aluminum atom in a two-dimensional form. Remember that each electron is actually orbiting around the nucleus in its own elliptical path. The two electrons closest to the nucleus do not actually follow the same orbital path. Their orbital paths are merely the same average distance from the nucleus. The two electrons closest to the nucleus are said to occupy the first *shell,* or *orbit,* of the atom. This first shell of the atom can accommodate only two electrons. Atoms that have more than two electrons, such as the aluminum atom, must have a second shell, or orbit.

The second shell of the aluminum atom contains eight electrons. This is the maximum number of electrons that the second shell of any atom can contain. The third shell can contain a maximum of 18 electrons, and the fourth shell a maximum of 32 electrons. Since the aluminum atom (Fig. 1-2) has only 13 electrons, its third shell has 3 electrons.

Technicians at work in their lab.

### TEST

*Answer the following questions.*

11. What are the major particles of an atom?
12. True or false. The diameter of the electron is small compared with the distance between the proton and the electron.



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