Fifth Edition

Electronics Fundamentals

Circuits, Devices, and Applications

Floyd

ELECTRONICS FUNDAMENTALS

Circuits, Devices, and Applications

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Prentice Hall

Upper Saddle River, New Jersey
Columbus, Ohio

Library of Congress Cataloging in Publication Data

Floyd, Thomas L.
Electronics fundamentals : circuits, devices, and applications / Thomas L. Floyd.–5th ed.
p. cm.
Includes index.
ISBN 0-13-085236-8 (alk. paper)
1. Electronics. 2. Electronic circuits. 3. Electronic apparatus and appliances. I. Title.

TK7816.F57 2001
621.381—dc21

00-029849

Vice President and Publisher: Dave Garza
Editor in Chief: Stephen Helba
Acquisitions Editor: Scott J. Sambucci
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Design Coordinator: Karrie Converse-Jones
Text Design: Seventeenth Street Studios
Cover Designer: Allen Bumpus
Cover Art: Marjory Dressler
Illustrations: Jane Lopez and Steve Botts
Photographs: Part-opening and chapter-opening photographs by EyeWire, Inc.
Copyeditor: Lois Porter
Production Manager: Pat Tonneman
Marketing Manager: Ben Leonard

This book was set in Times Roman and Highlander by The Clarinda Company. It was printed and bound by R. R. Donnelley & Sons Company. The cover was printed by Phoenix Color Corp.

Prentice Hall

10 9 8 7 6 5 4 3 2
ISBN: 0-13-085236-8

Preface

This fifth edition of *Electronics Fundamentals: Circuits, Devices, and Applications* provides a comprehensive coverage of basic electrical and electronic concepts, practical applications, and troubleshooting. The organization has been improved for a smoother and more logical flow of the material in certain areas. In this edition, many topics have been strengthened and improved, and some new topics and features have been added. Also, a completely new text design and layout enhance the text's appearance and useability.

This textbook is divided into three parts: DC Circuits in Chapters 1 through 7, AC Circuits in Chapters 8 through 15, and Devices in Chapters 16 through 21.

NEW FEATURES AND IMPROVEMENTS

Engineering Notation Chapter 1 includes an expanded coverage of engineering notation and the use of the calculator (TI-86) in scientific and engineering notation.

Electrical Safety Chapter 2 introduces electrical safety. It is supplemented by a feature called *Safety Point* found throughout portions of the text. Safety Points are identified by a special logo and design treatment.

Troubleshooting An expanded coverage of troubleshooting begins in Section 3-8 with an introduction to troubleshooting. A systematic approach called the APM (analysis, planning, and measurement) method is introduced and used in many of the troubleshooting sections and examples. A new logo identifies troubleshooting features.

Circuit Simulation Tutorials A website tutorial associated with most chapters can be downloaded for student use. These tutorials introduce students to elements of Electronics Workbench™, as needed, on a chapter-by-chapter basis. These tutorials may be found at **http://www.prenhall.com/floyd.**

Circuit Simulation Problems A new set of problems at the end of most chapters reference circuits simulated with both Electronics Workbench and CircuitMaker® on the CD-ROM that accompanies the text. Many of these circuits have hidden faults that the student must locate using troubleshooting skills. Results are provided in a password-protected file on the CD-ROM. Circuit simulation problems and exercises on the CD-ROM are indicated by a special logo.

Hands-On Tips Called HOTips for short, this feature provides useful and practical information interspersed throughout the book. They generally relate to the text coverage but can be skipped over without affecting an understanding of chapter material. HOTips are identified by a special logo and design treatment.

Biographies Brief biographies of those after whom major electrical and magnetic units have been named are located near the point where the unit is introduced. Each biography is indentified by a special design treatment.

Key Terms Terms identified as the most important in each chapter are listed as key terms on the chapter opener. Within the chapter, key terms are highlighted in color and with a special icon. Each Key Term is also defined in the Glossary.

Chapter Reorganization Several chapters in the AC part of the text have been rearranged to provide a smoother and more logical flow of topics. The new chapter sequence is as follows: Chapter 9: Capacitors, Chapter 10: *RC* Circuits, Chapter 11: Inductors, Chapter 12: *RL* Circuits, Chapter 13: *RLC* Circuits and Resonance, and Chapter 14: Transformers.

ADDITIONAL FEATURES

- Full-color format
- A two-page chapter opener for each chapter with an introduction, chapter outline, chapter objectives, key terms, and application assignment preview
- An introduction and list of objectives at the beginning of each section within a chapter keyed to the chapter objectives
- An Application Assignment at the end of each chapter (except Chapter 1)
- Many high-quality illustrations
- Numerous worked examples
- A Related Problem in each worked example with answers at the end of the chapter
- An Electronics Workbench/CircuitMaker simulation on CD-ROM for selected worked examples
- An Electronics Workbench/CircuitMaker exercise in selected Application Assignments
- Section Reviews with answers at the end of the chapter
- Troubleshooting section in many of the chapters
- Self-test in each chapter with answers at the end of the chapter
- Problem set at the end of each chapter divided by chapter sections and organized into basic and advanced categories. Answers to odd-numbered problems are provided at the end of the book.
- A comprehensive Glossary at the end of the book. Terms that appear boldface or in color in the text are defined in the glossary.
- Standard resistor and capacitor values are used throughout.

ACCOMPANYING STUDENT RESOURCES

New—*Student Workbook* by James K. Gee. Features step-by-step explanations of textbook material, additional examples with solutions, explanatory tables, reminders, and a Problem Set for every textbook section. Odd-numbered answers to Problem Set questions are included at the end of the Student Workbook. Gee's Student Workbook is tied section by section to the Floyd text, thus enabling students to easily locate specific sections with which they are having difficulty or would like additional practice. (ISBN 0–13–019392–5)

New—StudyWizard e-tutorial CD-ROM. Students can enhance their understanding of each chapter by answering the review questions and testing their knowledge of the terminology with StudyWizard. This program is available separately from the text. Contact your local bookstore for more information.

New—Electronics Workbench/CircuitMaker CD-ROM. Packaged with each text, this software includes simulation circuits for selected examples and end-of-chapter problems and a Student Version of CircuitMaker. Electronics Workbench software can be obtained through your local bookstore, or by contacting Electronics Workbench at 800-263-5552, or through their website at www.electronicsworkbench.com.

Experiments in Electronics Fundamentals and Electric Circuits Fundamentals Fifth Edition, by David Buchla. (ISBN 0–13–017002–X)

Companion Website (www.prenhall.com/floyd). This website offers students a free online study guide that they can check for conceptual understanding of key topics. It includes simulation tutorials in Electronics Workbench.

Electronics Supersite (www.prenhall.com/electronics). Students will find additional troubleshooting exercises, links to industry sites, an interview with an electronics professional, and more.

INSTRUCTOR RESOURCES

New—PowerPoint CD-ROM. Contains slides featuring all figures from the text, of which 150 selected slides contain explanatory text to elaborate on the presented graphic. This CD-ROM also includes innovative PowerPoint slides for the lab manual by Dave Buchla. (ISBN 0–13–019386–0)

Companion Website (www.prenhall.com/floyd). For the professor, this website offers the ability to post your syllabus online with our Syllabus Builder. This is a great solution for classes taught online, self-paced, or in any computer-assisted manner.

Electronics Supersite (www.prenhall.com/electronics). Instructors will find the *Prentice Hall Electronics Technology Journal,* extra classroom resources, and all of the supplements for this text available online for easy access. Contact your local Prentice Hall sales representative for your "User Name" and "Passcode."

Online Course Support. If your program is offering your electronics course in a distance learning format, please contact your local Prentice Hall sales representative for a list of product solutions.

Instructor's Resource Manual. Includes solutions to chapter problems, solutions to Application Assignments, a section relating SCANS objectives to textbook coverage, and a CEMA skills list. (ISBN 0–13–019387–9)

Lab Solutions Manual. Includes worked-out lab results for the Lab Manual by Buchla. (ISBN 0–13–019391–7)

Test Item File. This edition of the Test Item File has been checked for accuracy and features 166 new questions. (ISBN 0–13–019388–7)

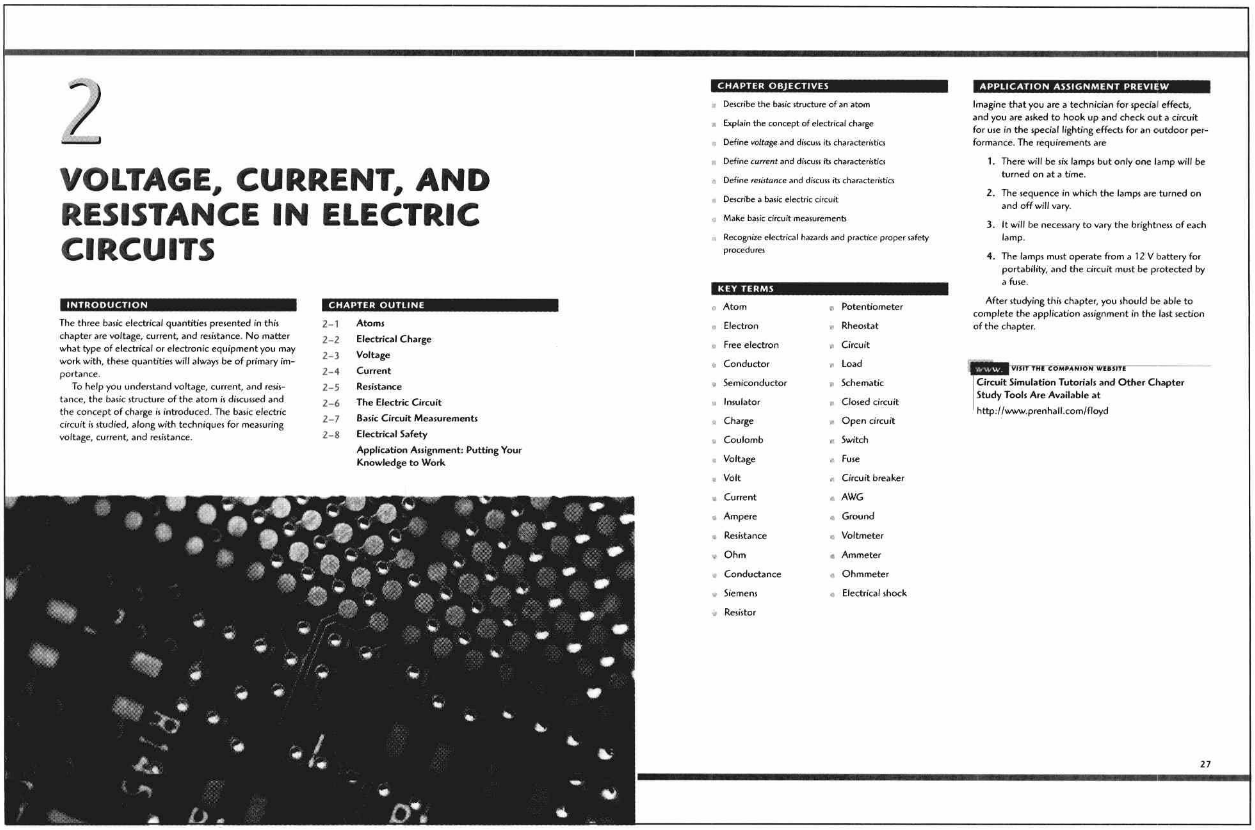
Prentice Hall Test Manager. This is a CD-ROM version of the Test Item File. (ISBN 0–13–019389–5)

ILLUSTRATION OF CHAPTER FEATURES

Chapter Opener Each chapter begins with a two-page spread, as shown in Figure P–1. The left page includes the chapter number and title, a chapter introduction, and a list of sections in the chapter. The right page has a list of chapter objectives, a list of key terms, an application assignment preview, and a website reference for circuit simulation tutorials and other helpful material.

Section Opener Each section in a chapter begins with a brief introduction that includes a general overview and section objectives as related to the chapter objectives. An example is shown in Figure P–2.

Section Review Each section in a chapter ends with a review consisting of questions or exercises that emphasize the main concepts presented in the section. This is also shown in Figure P–2. The answers to the Section Reviews are at the end of the chapter.



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VOLTAGE, CURRENT, AND RESISTANCE IN ELECTRIC CIRCUITS

INTRODUCTION

The three basic electrical quantities presented in this chapter are voltage, current, and resistance. No matter what type of electrical or electronic equipment you may work with, these quantities will always be of primary importance.

To help you understand voltage, current, and resistance, the basic structure of the atom is discussed and the concept of charge is introduced. The basic electric circuit is studied, along with techniques for measuring voltage, current, and resistance.

CHAPTER OUTLINE

2–1 Atoms
2–2 Electrical Charge
2–3 Voltage
2–4 Current
2–5 Resistance
2–6 The Electric Circuit
2–7 Basic Circuit Measurements
2–8 Electrical Safety
Application Assignment: Putting Your Knowledge to Work

CHAPTER OBJECTIVES

- Describe the basic structure of an atom
- Explain the concept of electrical charge
- Define *voltage* and discuss its characteristics
- Define *current* and discuss its characteristics
- Define *resistance* and discuss its characteristics
- Describe a basic electric circuit
- Make basic circuit measurements
- Recognize electrical hazards and practice proper safety procedures

KEY TERMS

- Atom
- Electron
- Free electron
- Conductor
- Semiconductor
- Insulator
- Charge
- Coulomb
- Voltage
- Volt
- Current
- Ampere
- Resistance
- Ohm
- Conductance
- Siemens
- Resistor
- Potentiometer
- Rheostat
- Circuit
- Load
- Schematic
- Closed circuit
- Open circuit
- Switch
- Fuse
- Circuit breaker
- AWG
- Ground
- Voltmeter
- Ammeter
- Ohmmeter
- Electrical shock

APPLICATION ASSIGNMENT PREVIEW

Imagine that you are a technician for special effects, and you are asked to hook up and check out a circuit for use in the special lighting effects for an outdoor performance. The requirements are

1. There will be six lamps but only one lamp will be turned on at a time.
2. The sequence in which the lamps are turned on and off will vary.
3. It will be necessary to vary the brightness of each lamp.
4. The lamps must operate from a 12 V battery for portability, and the circuit must be protected by a fuse.

After studying this chapter, you should be able to complete the application assignment in the last section of the chapter.

www. VISIT THE COMPANION WEBSITE

Circuit Simulation Tutorials and Other Chapter Study Tools Are Available at

http://www.prenhall.com/floyd

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▲ FIGURE P–1

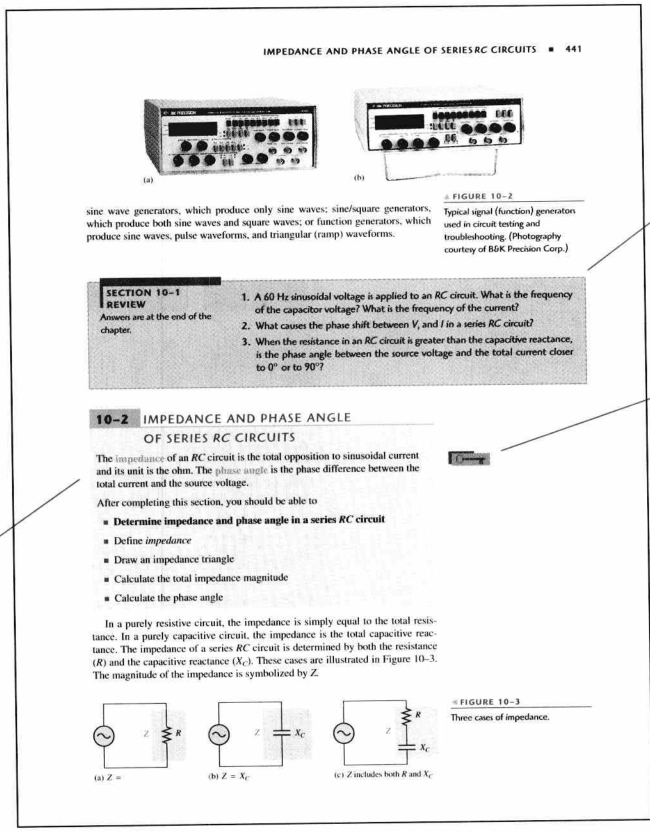
Chapter opener.

Worked Examples, Related Problems, and EWB/CircuitMaker Exercise Numerous worked examples help illustrate and clarify basic concepts or specific procedures. Each example ends with a Related Problem that reinforces or expands on the example by requiring the student to work through a problem similar to the example. Selected examples contain an EWB/CircuitMaker exercise keyed to the CD-ROM. A typical worked example with a related problem and an EWB/CircuitMaker exercise is shown in Figure P–3. Answers to Related Problems are at the end of the chapter.

Troubleshooting Sections Many chapters include a troubleshooting section that relates to the topics covered in the chapter and emphasizes logical thinking as well as a structured approach called APM (analysis, planning, and measurement). Particular troubleshooting methods such as *half-splitting* are applied.

Application Assignment: Putting Your Knowledge to Work Application Assignments are located at the end of each chapter (except Chapter 1) and are identified by a special photographic logo and colored background design. A practical application of the material covered in the chapter is presented. In a series of steps, the student is required to compare circuit layouts with a schematic, analyze circuits using concepts and theories learned in the chapter, and evaluate and/or troubleshoot circuits. A typical Application Assignment is shown in Figure P–4. The Application Assignments are optional and skipping over them does not affect any other coverage.

Although they are not intended or designed for use as laboratory projects (except the laboratory of the mind), many of the application assignments use



IMPEDANCE AND PHASE ANGLE OF SERIES *RC* CIRCUITS ■ 441

sine wave generators, which produce only sine waves; sine/square generators, which produce both sine waves and square waves; or function generators, which produce sine waves, pulse waveforms, and triangular (ramp) waveforms.

FIGURE 10–2

Typical signal (function) generators used in circuit testing and troubleshooting. (Photography courtesy of B&K Precision Corp.)

SECTION 10–1 REVIEW

Answers are at the end of the chapter.

1. A 60 Hz sinusoidal voltage is applied to an *RC* circuit. What is the frequency of the capacitor voltage? What is the frequency of the current?
2. What causes the phase shift between V_s and I in a series *RC* circuit?
3. When the resistance in an *RC* circuit is greater than the capacitive reactance, is the phase angle between the source voltage and the total current closer to 0° or to 90°?

10–2 IMPEDANCE AND PHASE ANGLE OF SERIES *RC* CIRCUITS

The impedance of an *RC* circuit is the total opposition to sinusoidal current and its unit is the ohm. The phase angle is the phase difference between the total current and the source voltage.

After completing this section, you should be able to

- **Determine impedance and phase angle in a series *RC* circuit**
- Define *impedance*
- Draw an impedance triangle
- Calculate the total impedance magnitude
- Calculate the phase angle

In a purely resistive circuit, the impedance is simply equal to the total resistance. In a purely capacitive circuit, the impedance is the total capacitive reactance. The impedance of a series *RC* circuit is determined by both the resistance (R) and the capacitive reactance (X_C). These cases are illustrated in Figure 10–3. The magnitude of the impedance is symbolized by Z.

(a) $Z =$ (b) $Z = X_C$ (c) Z includes both R and X_C

FIGURE 10–3

Three cases of impedance.

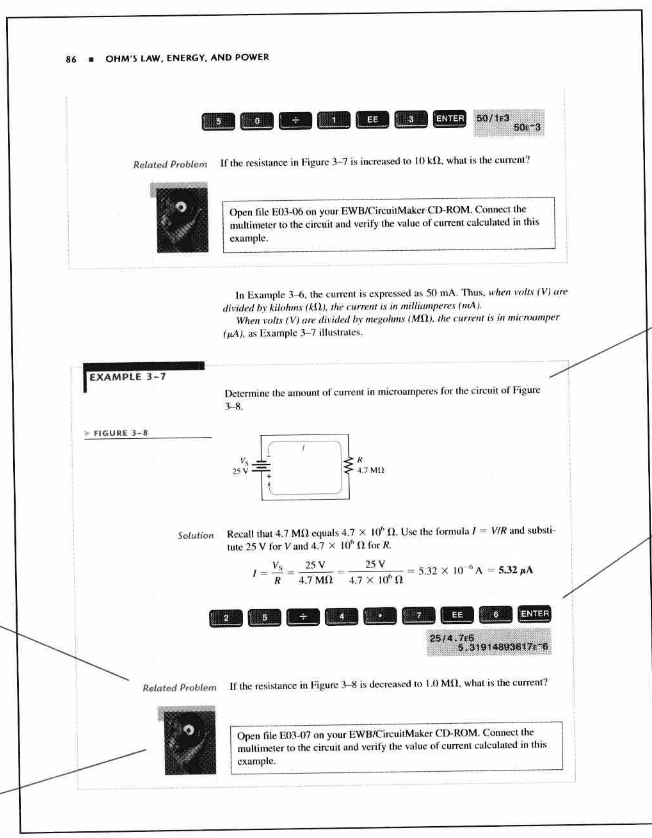
Introductory statements and a list of performance-based objectives begin each section.

Review questions end each section.

A key icon indicates a key term that is in color.

FIGURE P–2

Section review and section opener.



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5 0 ÷ 1 EE 3 ENTER 50/1E3 50E-3

Related Problem If the resistance in Figure 3–7 is increased to 10 kΩ, what is the current?

Open file E03-06 on your EWB/CircuitMaker CD-ROM. Connect the multimeter to the circuit and verify the value of current calculated in this example.

In Example 3–6, the current is expressed as 50 mA. Thus, *when volts (V) are divided by kilohms (kΩ), the current is in milliamperes (mA).*

When volts (V) are divided by megohms (MΩ), the current is in microamper (μA), as Example 3–7 illustrates.

EXAMPLE 3–7

Determine the amount of current in microamperes for the circuit of Figure 3–8.

FIGURE 3–8

Solution Recall that 4.7 MΩ equals $4.7 \times 10^6\ \Omega$. Use the formula $I = V/R$ and substitute 25 V for V and $4.7 \times 10^6\ \Omega$ for R.

$$I = \frac{V_S}{R} = \frac{25\text{ V}}{4.7\text{ M}\Omega} = \frac{25\text{ V}}{4.7 \times 10^6\ \Omega} = 5.32 \times 10^{-6}\text{ A} = \mathbf{5.32\ \mu A}$$

2 5 ÷ 4 • 7 EE 6 ENTER 25/4.7E6 5.31914893617E-6

Related Problem If the resistance in Figure 3–8 is decreased to 1.0 MΩ, what is the current?

Open file E03-07 on your EWB/CircuitMaker CD-ROM. Connect the multimeter to the circuit and verify the value of current calculated in this example.

Examples are contained within a colored box.

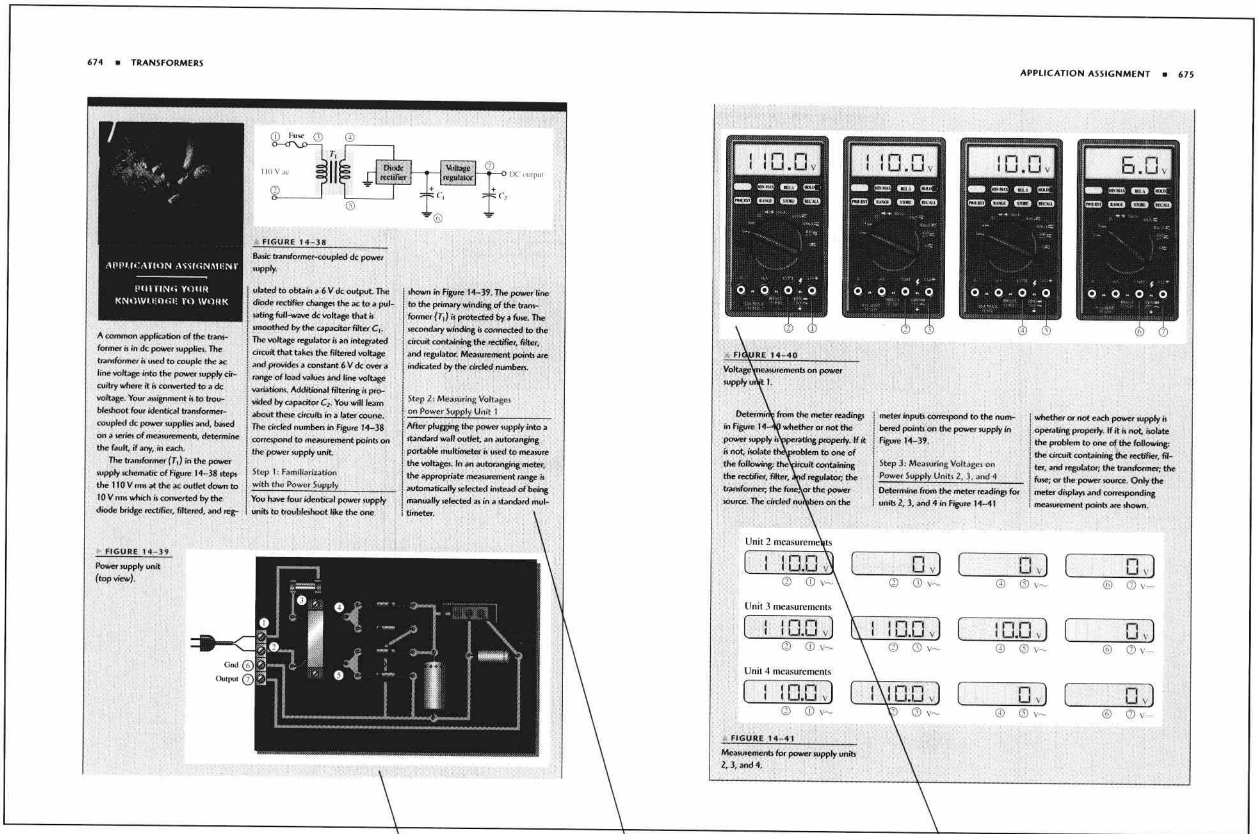
Selected examples contain calculator key sequences and display.

Each example contains a problem related to the example.

Selected examples contain an EWB/CircuitMaker exercise keyed to the CD-ROM.

FIGURE P–3

An example with a related problem and an EWB/CircuitMaker exercise.



▲ **FIGURE P–4**

A typical Application Assignment.

Some application assignments use realistic circuit board art.

Steps instruct students to perform specific tasks.

Application art provides visual information related to the assignment.

representations based on realistic printed circuit boards and instruments. Results and answers for the steps in the Application Assignments are provided in the Instructor's Resource Manual.

Chapter End Matter The following pedagogical features are found at the end of each chapter:

- Summary
- Equations
- Self-Test
- Basic Problems
- Advanced Problems
- Electronics Workbench/CircuitMaker Troubleshooting Problems (keyed to CD-ROM)
- Answers to Section Reviews
- Answers to Related Problems for Examples
- Answers to Self-Test

SUGGESTIONS FOR USING THIS TEXTBOOK

As mentioned before, this book is divided into three parts: DC Circuits, AC Circuits, and Devices. The text can be used to accommodate a variety of scheduling and program requirements. Some suggestions follow:

Option 1 A three-term dc/ac/devices sequence should allow sufficient time to cover all or most of the topics in the book. Chapters 1 through 7 can be covered in the first term, Chapters 8 through 15 in the second term, and Chapters 16 through 21 in the third term.

Option 2 A modification of Option 1 is to add the coverage of capacitors through Section 9-5 and inductors through Section 11-5 to the first term dc course.

Option 3 Yet another modification to Option 1 for those who prefer to cover reactive components before covering reactive circuits is to cover Chapter 11 on inductors immediately after Chapter 9 on capacitors. Then follow with Chapter 10, Chapter 12, and so on.

Option 4 A two-term dc/ac/devices sequence in which ac is introduced in the first term by covering Part 1 and Chapter 8. Then, in the second term, cover the remaining chapters in Part 2 and Part 3. Obviously, this approach will require selective and faster-paced coverage of much of the material. Since program requirements vary greatly, it is difficult to make specific suggestions for selective coverage.

Option 5 A two-term dc/ac sequence which omits the devices coverage in Part 3. If this is the option you prefer, it is recommended that the companion text *Electric Circuits Fundamentals* be used because it is identical to *Electronics Fundamentals: Circuits, Devices, and Applications* except that it does not include Part 3.

TO THE STUDENT

Any career training requires hard work, and electronics is no exception. The best way to learn new material is by reading, thinking, and doing. This text is designed to help you along the way by providing an overview and objectives for each section, numerous worked-out examples, practice exercises, and review questions with answers.

Don't expect every concept to be crystal clear after a single reading. Read each section of the text carefully and think about what you have read. Work through the example problems step-by-step before trying the related problem that goes with the example. Sometimes more than one reading of a section will be necessary. After each section, check your understanding by answering the section review questions.

Review the chapter summary and equation list. Take the multiple-choice self-test. Finally, work the problems at the end of the chapter. Check your answers to the self-test at the end of the chapter and the odd-numbered problems against those provided at the end of the book. Working problems is the most important way to check your comprehension and solidify concepts.

CAREERS IN ELECTRONICS

The field of electronics is very diverse, and career opportunities are available in many areas. Because electronics is currently found in so many different applications and new technology is being developed at a fast rate, its future appears limitless. There is hardly an area of our lives that is not enhanced to some degree by electronics technology. Those who acquire a sound, basic knowledge of electrical and electronic principles and are willing to continue learning will always be in demand.

The importance of obtaining a thorough understanding of the basic principles contained in this text cannot be overemphasized. Most employers prefer to hire people who have both a thorough grounding in the basics and the ability and eagerness to grasp new concepts and techniques. If you have a good training in the basics, an employer will train you in the specifics of the job to which you are assigned.

There are many types of job classifications for which a person with training in electronics technology may qualify. A few of the most common job functions are discussed briefly in the following paragraphs.

Service Shop Technician Technical personnel in this category are involved in the repair or adjustment of both commercial and consumer electronic equipment that is returned to the dealer or manufacturer for service. Specific areas include TVs, VCRs, CD players, stereo equipment, CB radios, and computer hardware. This area also offers opportunities for self-employment.

Industrial Manufacturing Technician Manufacturing personnel are involved in the testing of electronic products at the assembly-line level or in the maintenance and troubleshooting of electronic and electromechanical systems used in the testing and manufacturing of products. Virtually every type of manufacturing plant, regardless of its product, uses automated equipment that is electronically controlled.

Laboratory Technician These technicians are involved in breadboarding, prototyping, and testing new or modified electronic systems in research and development laboratories. They generally work closely with engineers during the development phase of a product.

Field Service Technician Field service personnel service and repair electronic equipment—for example, computer systems, radar installations, automatic banking equipment, and security systems—at the user's location.

Engineering Assistant/Associate Engineer Personnel in this category work closely with engineers in the implementation of a concept and in the basic design and development of electronic systems. Engineering assistants are frequently involved in a project from its initial design through the early manufacturing stages.

Technical Writer Technical writers compile technical information and then use the information to write and produce manuals and audiovisual materials. A broad knowledge of a particular system and the ability to clearly explain its principles and operation are essential.

Technical Sales Technically trained people are in demand as sales representatives for high-technology products. The ability both to understand technical concepts and to communicate the technical aspects of a product to a potential customer is very valuable. In this area, as in technical writing, competency in expressing yourself orally and in writing is essential. Actually, being able to communicate well is very important in any technical job category because you must be able to record data clearly and explain procedures, conclusions, and actions taken so that others can readily understand what you are doing.

MILESTONES IN ELECTRONICS

Before you begin your study of electronics fundamentals, let's briefly look at some of the important developments that led to the electronics technology we have today. The names of many of the early pioneers in electricity and electromagnetics still live on in terms of familiar units and quantities. Names such as Ohm, Ampere, Volta, Farad, Henry, Coulomb, Oersted, and Hertz are some of the better known examples. More widely known names such as Franklin and Edison are also significant in the history of electricity and electronics because of their tremendous contributions. Short biographies of some of these pioneers, like shown here, are located throughout the text.

BIOGRAPHY

James Prescott Joule 1818–1889 Joule, a British physicist, is known for his research in electricity and thermodynamics. He formulated the relationship that states that the amount of heat energy produced by an electrical current in a conductor is proportional to the conductor's resistance and the time. The unit of energy is named in his honor. (Photo credit: Library of Congress.)

The Beginning of Electronics Early experiments with electronics involved electric currents in vacuum tubes. Heinrich Geissler (1814–1879) removed most of the air from a glass tube and found that the tube glowed when there was current through it. Later, Sir William Crookes (1832–1919) found the current in vacuum tubes seemed to consist of particles. Thomas Edison (1847–1931) experimented with carbon filament bulbs with plates and discovered that there was a current from the hot filament to a positively charged plate. He patented the idea but never used it.

Other early experimenters measured the properties of the particles that flowed in vacuum tubes. Sir Joseph Thompson (1856–1940) measured properties of these particles, later called *electrons*.

Although wireless telegraphic communication dates back to 1844, electronics is basically a 20th century concept that began with the invention of the vacuum tube amplifier. An early vacuum tube that allowed current in only one direction was constructed by John A. Fleming in 1904. Called the Fleming valve, it was the forerunner of vacuum tube diodes. In 1907, Lee deForest added a grid to the vacuum tube. The new device, called the audiotron, could amplify a weak signal. By adding the control element, deForest ushered in the electronics revolution. It was with an improved version of his device that made transcontinental telephone service and radios possible. In 1912, a radio amateur in San Jose, California, was regularly broadcasting music!

In 1921, the secretary of commerce, Herbert Hoover, issued the first license to a broadcast radio station; within two years over 600 licenses were issued. By the end of the 1920s radios were in many homes. A new type of radio, the superheterodyne radio, invented by Edwin Armstrong, solved problems with high-frequency communication. In 1923, Vladimir Zworykin, an American researcher, invented the first television picture tube, and in 1927 Philo T. Farnsworth applied for a patent for a complete television system.

The 1930s saw many developments in radio, including metal tubes, automatic gain control, "midgit sets," directional antennas, and more. Also started in this decade was the development of the first electronic computers. Modern computers trace their origins to the work of John Atanasoff at Iowa State University. Beginning in 1937, he envisioned a binary machine that could do complex mathematical work. By 1939, he and graduate student Clifford Berry had constructed a binary machine called ABC, (for Atanasoff-Berry Computer) that used vacuum tubes for logic and condensers (capacitors) for memory. In 1939, the magnetron, a microwave oscillator, was invented in Britain by Henry Boot and John Randall. In the same year, the klystron microwave tube was invented in America by Russell and Sigurd Varian.

During World War II, electronics developed rapidly. Radar and very high-frequency communication were made possible by the magnetron and klystron. Cathode ray tubes were improved for use in radar. Computer work continued during the war. By 1946, John von Neumann had developed the first stored program computer, the Eniac, at the University of Pennsylvania. The decade ended with one of the most important inventions ever, the transistor.

Solid-State Electronics The crystal detectors used in early radios were the forerunners of modern solid-state devices. However, the era of solid-state electronics began with the invention of the transistor in 1947 at Bell Labs. The inventors were Walter Brattain, John Bardeen, and William Shockley. PC (printed circuit) boards were introduced in 1947, the year the transistor was invented. Commercial manufacturing of transistors began in Allentown, Pennsylvania, in 1951.

The most important invention of the 1950s was the integrated circuit. On September 12, 1958, Jack Kilby, at Texas Instruments, made the first integrated circuit. This invention literally created the modern computer age and brought about sweeping changes in medicine, communication, manufacturing, and the entertainment industry. Many billions of "chips"—as integrated circuits came to be called—have since been manufactured.

The 1960s saw the space race begin and spurred work on miniaturization and computers. The space race was the driving force behind the rapid changes in electronics that followed. The first successful "op-amp" was designed by Bob Widlar at Fairchild Semiconductor in 1965. Called the μA709, it was very successful but suffered from "latch-up" and other problems. Later, the most popular op-amp ever, the 741, was taking shape at Fairchild. This op-amp became the industry standard and influenced design of op-amps for years to come.

By 1971, a new company that had been formed by a group from Fairchild introduced the first microprocessor. The company was Intel and the product was the 4004 chip, which had the same processing power as the Eniac computer. Later in the same year, Intel announced the first 8-bit processor, the 8008. In 1975, the first personal computer was introduced by Altair, and Popular Science magazine featured it on the cover of the January, 1975, issue. The 1970s also saw the introduction of the pocket calculator and new developments in optical integrated circuits.

By the 1980s, half of all U.S. homes were using cable hookups instead of television antennas. The reliability, speed, and miniaturization of electronics continued throughout the 1980s, including automated testing and calibrating of PC boards. The computer became a part of instrumentation and the virtual instrument was created. Computers became a standard tool on the workbench.

The 1990s saw a widespread application of the Internet. In 1993, there were 130 websites, and now there are millions. Companies scrambled to establish a home page and many of the early developments of radio broadcasting had parallels with the Internet. In 1995, the FCC allocated spectrum space for a new service called Digital Audio Radio Service. Digital television standards were adopted in 1996 by the FCC for the nation's next generation of broadcast television.

ACKNOWLEDGMENTS

Many capable people have been part of this revision for the fifth edition of *Electronics Fundamentals: Circuits, Devices, and Applications*. It has been thoroughly reviewed and checked for both content and accuracy. Those at Prentice Hall who have contributed greatly to this project throughout the many phases of development and production include Rex Davidson, Katie Bradford, and Scott Sambucci. Lois Porter, whose attention to details is unbelievable, has once again done an outstanding job editing the manuscript. Jane Lopez has again provided the excellent illustrations and beautiful graphics work used in the text. As with the previous edition, Gary Snyder has checked the manuscript for accuracy. Also, Gary created the circuit files for the Electronics Workbench features in this edition and Karen Dickson at Protel Technology created the CircuitMaker files. A thorough line-by-line review was done by my colleague Dave Buchla and many of the improvements and changes found in this edition were a result of his recommendations.

I wish to express my appreciation to those already mentioned as well as the reviewers who provided many valuable suggestions and constructive criticism that greatly influenced this edition. These reviewers are Jerry L. Wilson, Lamar Institute of Technology; James K. Gee, ITT Technical Institute; William R. Kist, New England Institute of Technology; Peter Westray, Los Angeles Valley College; and Carl Jensen, DeVry Institute of Technology.

Tom Floyd

A: Table of Standard Resistor Values

Resistance Tolerance (±%)

0.1% 0.25% 0.5%	1%	2% 5%	10%	0.1% 0.25% 0.5%	1%	2% 5%	10%	0.1% 0.25% 0.5%	1%	2% 5%	10%	0.1% 0.25% 0.5%	1%	2% 5%	10%	0.1% 0.25% 0.5%	1%	2% 5%	10%	0.1% 0.25% 0.5%	1%	2% 5%	10%
10.0	10.0	10	10	14.7	14.7	—	—	21.5	21.5	—	—	31.6	31.6	—	—	46.4	46.4	—	—	68.1	68.1	68	68
10.1	—	—	—	14.9	—	—	—	21.8	—	—	—	32.0	—	—	—	47.0	—	47	47	69.0	—	—	—
10.2	10.2	—	—	15.0	15.0	15	15	22.1	22.1	22	22	32.4	32.4	—	—	47.5	47.5	—	—	69.8	69.8	—	—
10.4	—	—	—	15.2	—	—	—	22.3	—	—	—	32.8	—	—	—	48.1	—	—	—	70.6	—	—	
10.5	10.5	—	—	15.4	15.4	—	—	22.6	22.6	—	—	33.2	33.2	33	33	48.7	48.7	—	—	71.5	71.5	—	—
10.6	—	—	—	15.6	—	—	—	22.9	—	—	—	33.6	—	—	—	49.3	—	—	—	72.3	—	—	—
10.7	10.7	—	—	15.8	15.8	—	—	23.2	23.2	—	—	34.0	34.0	—	—	49.9	49.9	—	—	73.2	73.2	—	—
10.9	—	—	—	16.0	—	16	—	23.4	—	—	—	34.4	—	—	—	50.5	—	—	—	74.1	—	—	—
11.0	11.0	11	—	16.2	16.2	—	—	23.7	23.7	—	—	34.8	34.8	—	—	51.1	51.1	51	—	75.0	75.0	75	—
11.1	—	—	—	16.4	—	—	—	24.0	—	24	—	35.2	—	—	—	51.7	—	—	—	75.9	—	—	—
11.3	11.3	—	—	16.5	16.5	—	—	24.3	24.3	—	—	35.7	35.7	—	—	52.3	52.3	—	—	76.8	76.8	—	—
11.4	—	—	—	16.7	—	—	—	24.6	—	—	—	36.1	—	36	—	53.0	—	—	—	77.7	—	—	—
11.5	11.5	—	—	16.9	16.9	—	—	24.9	24.9	—	—	36.5	36.5	—	—	53.6	53.6	—	—	78.7	78.7	—	—
11.7	—	—	—	17.2	—	—	—	25.2	—	—	—	37.0	—	—	—	54.2	—	—	—	79.6	—	—	—
11.8	11.8	—	—	17.4	17.4	—	—	25.5	25.5	—	—	37.4	37.4	—	—	54.9	54.9	—	—	80.6	80.6	—	—
12.0	—	12	12	17.6	—	—	—	25.8	—	—	—	37.9	—	—	—	56.2	—	—	—	81.6	—	—	—
12.1	12.1	—	—	17.8	17.8	—	—	26.1	26.1	—	—	38.3	38.3	—	—	56.6	56.6	56	56	82.5	82.5	82	82
12.3	—	—	—	18.0	—	18	18	26.4	—	—	—	38.8	—	—	—	56.9	—	—	—	83.5	—	—	—
12.4	12.4	—	—	18.2	18.2	—	—	26.7	26.7	—	—	39.2	39.2	39	39	57.6	57.6	—	—	84.5	84.5	—	—
12.6	—	—	—	18.4	—	—	—	27.1	—	27	27	39.7	—	—	—	58.3	—	—	—	85.6	—	—	—
12.7	12.7	—	—	18.7	18.7	—	—	27.4	27.4	—	—	40.2	40.2	—	—	59.0	59.0	—	—	86.6	86.6	—	—
12.9	—	—	—	18.9	—	—	—	27.7	—	—	—	40.7	—	—	—	59.7	—	—	—	87.6	—	—	—
13.0	13.0	13	—	19.1	19.1	—	—	28.0	28.0	—	—	41.2	41.2	—	—	60.4	60.4	—	—	88.7	88.7	—	—
13.2	—	—	—	19.3	—	—	—	28.4	—	—	—	41.7	—	—	—	61.2	—	—	—	89.8	—	—	—
13.3	13.3	—	—	19.6	19.6	—	—	28.7	28.7	—	—	42.2	42.2	—	—	61.9	61.9	62	—	90.9	90.9	91	—
13.5	—	—	—	19.8	—	—	—	29.1	—	—	—	42.7	—	—	—	62.6	—	—	—	92.0	—	—	—
13.7	13.7	—	—	20.0	20.0	20	—	29.4	29.4	—	—	43.2	43.2	43	—	63.4	63.4	—	—	93.1	93.1	—	—
13.8	—	—	—	20.3	—	—	—	29.8	—	—	—	43.7	—	—	—	64.2	—	—	—	94.2	—	—	—
14.0	14.0	—	—	20.5	20.5	—	—	30.1	30.1	30	—	44.2	44.2	—	—	64.9	64.9	—	—	95.3	95.3	—	—
14.2	—	—	—	20.8	—	—	—	30.5	—	—	—	44.8	—	—	—	65.7	—	—	—	96.5	—	—	—
14.3	14.3	—	—	21.0	21.0	—	—	30.9	30.9	—	—	45.3	45.3	—	—	66.5	66.5	—	—	97.6	97.6	—	—
14.5	—	—	—	21.3	—	—	—	31.2	—	—	—	45.9	—	—	—	67.3	—	—	—	98.8	—	—	—

NOTE: These values are generally available in multiples of 0.1, 1, 10, 100, 1 k, and 1 M.

B: Batteries

Batteries are an important source of dc voltage. They are available in two basic categories: the wet cell and the dry cell. A battery generally is made up of several individual cells.

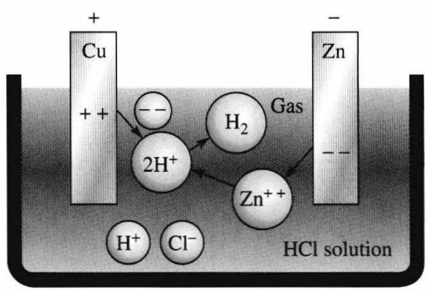
A cell consists basically of two electrodes immersed in an electrolyte. A voltage is developed between the electrodes as a result of the chemical action between the electrodes and the electrolyte. The electrodes typically are two dissimilar metals, and the electrolyte is a chemical solution.

Simple Wet Cell

Figure B–1 shows a simple copper-zinc (Cu-Zn) chemical cell. One electrode is made of copper, the other of zinc. These electrodes are immersed in a solution of water and hydrochloric acid (HCl), which is the electrolyte.

FIGURE B–1

Simple chemical cell.



Positive hydrogen ions (H^+) and negative chlorine ions (Cl^-) are formed when the HCl ionizes in the water. Since zinc is more active than hydrogen, zinc atoms leave the zinc electrode and form zinc ions (Zn^{++}) in the solution. When a zinc ion is formed, two excess electrons are left on the zinc electrode, and two hydrogen ions are displaced from the solution. These two hydrogen ions will migrate to the copper electrode, take two electrons from the copper, and form a molecule of hydrogen gas (H_2). As a result of this reaction, a negative charge develops on the zinc electrode, and a positive charge develops on the copper electrode, creating a potential difference or voltage between the two electrodes.

In this copper-zinc cell, the hydrogen gas given off at the copper electrode tends to form a layer of bubbles around the electrodes, insulating the copper from the electrolyte. This effect, called *polarization,* results in a reduction in the voltage produced by the cell. Polarization can be remedied by the addition of an agent to the electrolyte to remove hydrogen gas or by the use of an electrolyte that does not form hydrogen gas.

Lead-Acid Cell The positive electrode of a lead-acid cell is lead peroxide (PbO_2), and the negative electrode is spongy lead (Pb), as indicated in Figure B–2. The electrolyte is sulfuric acid (H_2SO_4) in water. Thus, the lead-acid cell is classified as a wet cell.

Two positive hydrogen ions ($2H^+$) and one negative sulfate ion (SO_4^{--}) are formed when the sulfuric acid ionizes in the water. Lead ions (Pb^{++}) from both electrodes displace the hydrogen ions in the electrolyte solution. When the lead ion from the spongy lead electrode enters the solution, it combines with a sulfate ion (SO_4^{--}) to form lead sulfate ($PbSO_4$), and it leaves two excess electrons on the electrode.

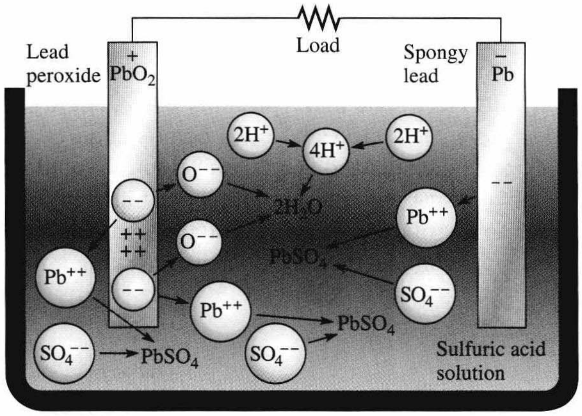


FIGURE B–2

Chemical reaction in a discharging lead-acid cell.

When a lead ion from the lead peroxide electrode enters the solution, it also leaves two excess electrons on the electrode and forms lead sulfate in the solution. However, because this electrode is lead peroxide, two free oxygen atoms are created when a lead atom leaves and enters the solution as a lead ion. These two oxygen atoms take four electrons from the lead peroxide electrode and become oxygen ions (O^{--}). This process creates a deficiency of two electrons on this electrode (there were initially two excess electrons).

The two oxygen ions ($2O^{--}$) combine in the solution with four hydrogen ions ($4H^+$) to produce two molecules of water ($2H_2O$). This process dilutes the electrolyte over a period of time. Also, there is a buildup of lead sulfate on the electrodes. These two factors result in a reduction in the voltage produced by the cell and necessitate periodic recharging.

As you have seen, for each departing lead ion, there is an excess of two electrons on the spongy lead electrode, and there is a deficiency of two electrons on the lead peroxide electrode. Therefore, the lead peroxide electrode is positive, and the spongy lead electrode is negative. This chemical reaction is pictured in Figure B–2.

As mentioned, the dilution of the electrolyte by the formation of water and lead sulfate requires that the lead-acid cell be recharged to reverse the chemical process. A chemical cell that can be recharged is called a *secondary cell.* One that cannot be recharged is called a *primary cell.*

The cell is recharged by the connection of an external voltage source to the electrodes, as shown in Figure B–3. The formula for the chemical reaction in a lead-acid cell is

$$Pb + PbO_2 + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$$

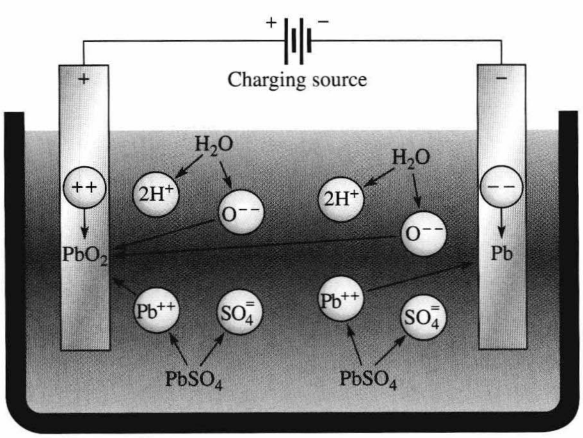


FIGURE B–3

Recharging a lead-acid cell.

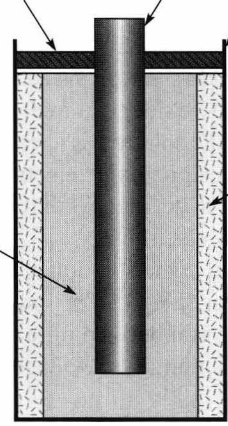
Dry Cell

In a dry cell, some of the disadvantages of a liquid electrolyte are overcome. Actually, the electrolyte in a typical dry cell is not dry but rather is in the form of a moist paste. This electrolyte is a combination of granulated carbon, powdered manganese dioxide, and ammonium chloride solution.

A typical carbon-zinc dry cell is illustrated in Figure B–4. The zinc container or can is dissolved by the electrolyte. As a result of this reaction, an excess of electrons accumulates on the container, making it the negative electrode.

FIGURE B–4

Simplified construction of a dry cell.



The hydrogen ions in the electrolyte take electrons from the carbon rod, making it the positive electrode. Hydrogen gas is formed near the carbon electrode, but this gas is eliminated by reaction with manganese dioxide (called a *depolarizing agent*). This depolarization prevents bursting of the container due to gas formation. Because the chemical reaction is not reversible, the carbon-zinc cell is a primary cell.

Types of Chemical Cells

Although only two common types of battery cells have been discussed, there are several types, listed in Table B–1.

TABLE B–1

Types of battery cells.

TYPE	+ ELECTRODE	− ELECTRODE	ELECTROLYTE	VOLTS	COMMENTS
Carbon-zinc	Carbon	Zinc	Ammonium and zinc chloride	1.5	Dry, primary
Lead-acid	Lead peroxide	Spongy lead	Sulfuric acid	2.0	Wet, secondary
Manganese-alkaline	Manganese dioxide	Zinc	Potassium hydroxide	1.5	Dry, primary or secondary
Mercury	Zinc	Mercuric oxide	Potassium hydroxide	1.3	Dry, primary
Nickel-cadmium	Nickel	Cadmium hydroxide	Potassium hydroxide	1.25	Dry, secondary
Nickel-iron (Edison cell)	Nickel oxide	Iron	Potassium hydroxide	1.36	Wet, secondary