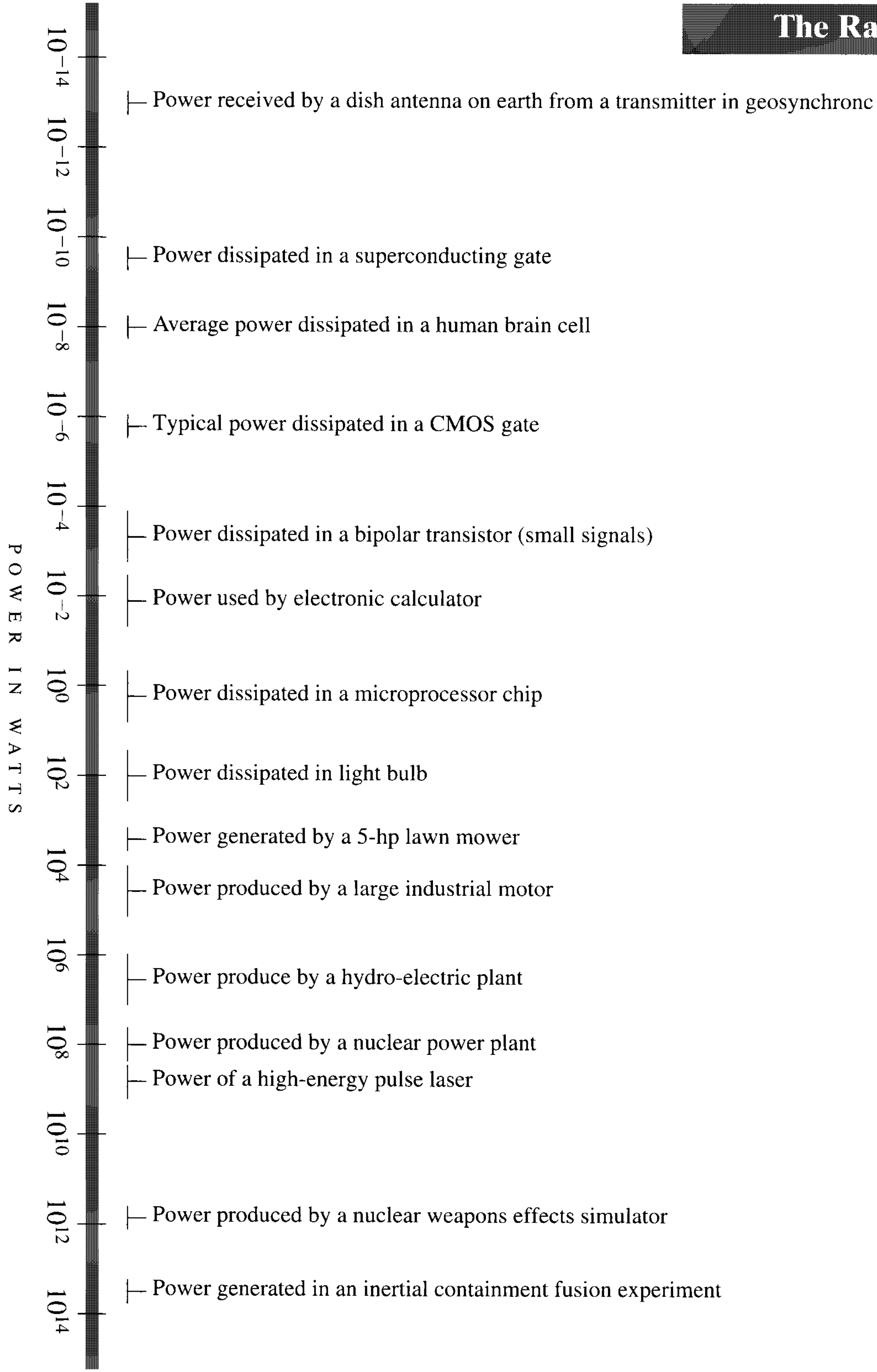
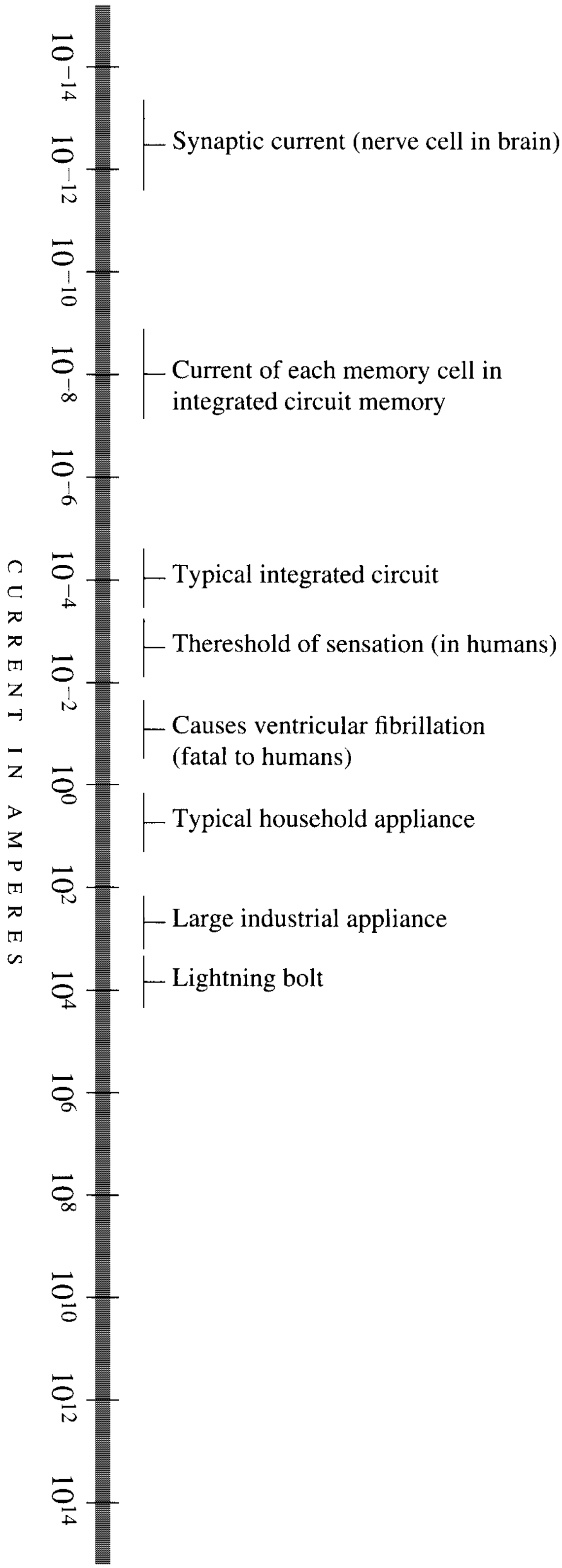
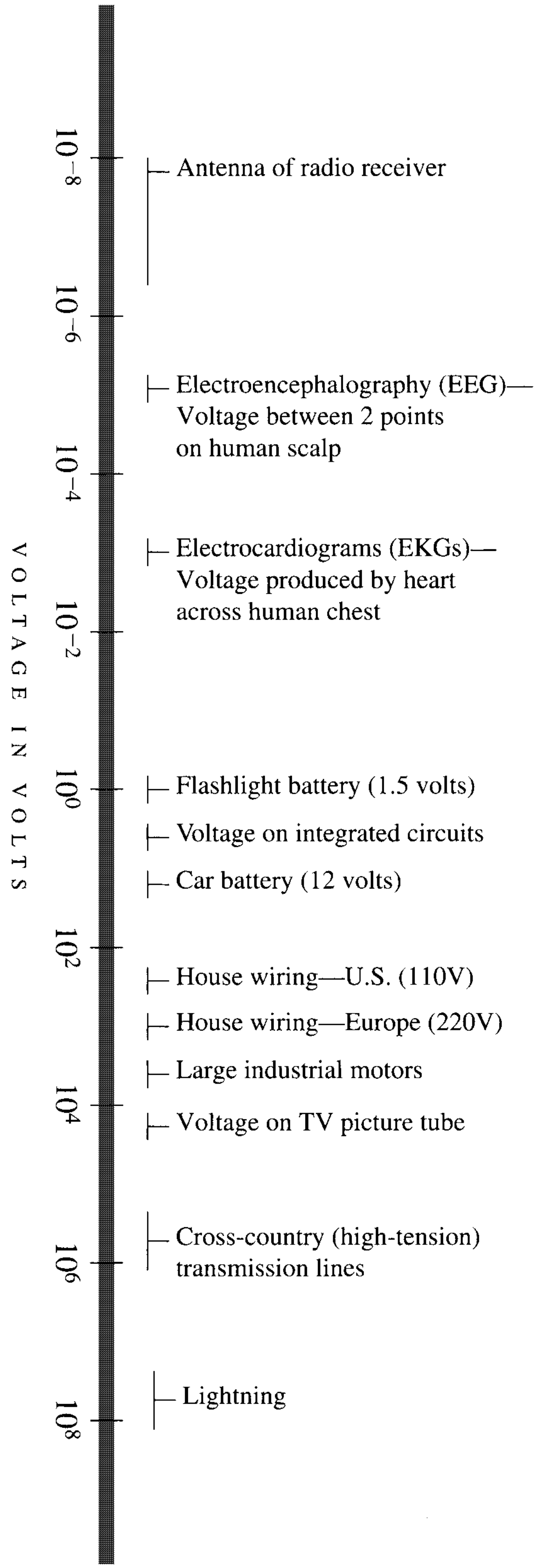
The Range of Power



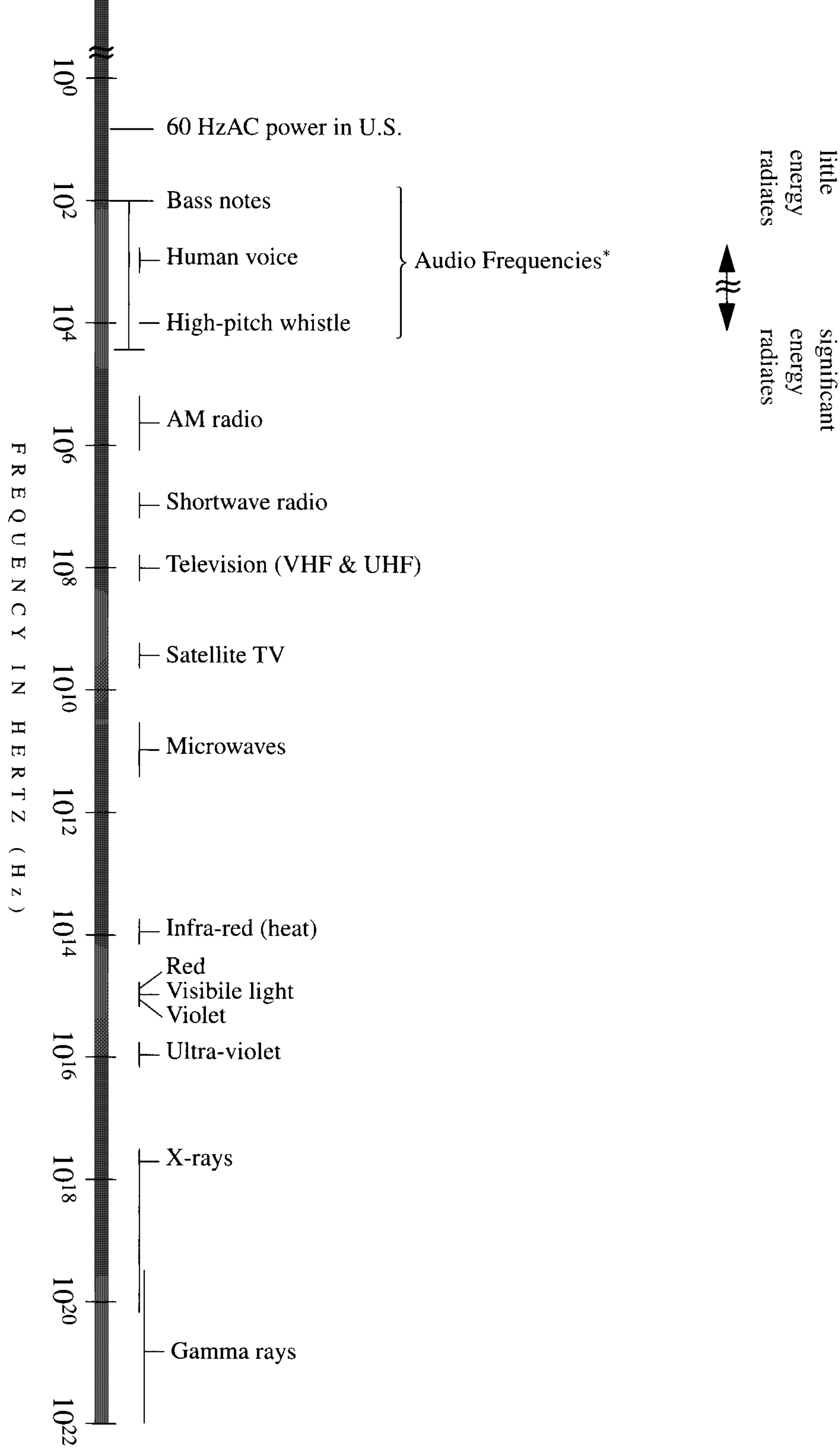
The Range of Current



The Range of Voltage



The Range of Spectrum



Brief Contents

Contents

Preface

The Circuit Analysis Course in the Engineering Curriculum

Circuit analysis is not only fundamental to the areas of electrical and computer engineering—the concepts studied also have tentacles that extend to areas far beyond the boundaries of these topics. Today, this subject may get less time in the curriculum than in the past because of constraints that range from attempts to reduce the total number of hours required for graduation to the size or even growth of the university's core requirement. Therefore, a viable book on this topic must be designed to enhance the learning process on every possible front; that is, it must (1) be easily readable, (2) contain numerous learning aids so that the material can be quickly grasped, and (3) provide ample opportunity for readers to become proficient by testing their understanding. Thus, success is dependent not only on learning the material, but also on learning it quickly. I have designed this book to match those needs.

How This Text Meets the Needs of Instructor and Student

Seven editions of *Basic Engineering Circuit Analysis* have provided readers with a thorough understanding of the fundamental concepts of circuit analysis and their applications to real-world problems. Over the almost 20-year life cycle of this text, instructors and students alike have found the book's most helpful features to be:

1. the clear and concise explanations
2. a variety of effective learning aids
3. numerous problems with varying degrees of difficulty
4. a variety of real-world examples that demonstrate the usefulness of the material under discussion.

Like the previous editions, the seventh edition is designed as a core text for students majoring in electrical and computer engineering, as well as a basic introduction to electric circuits for students in other engineering disciplines. The goal is to provide an effective and efficient environment for students to obtain a thorough understanding of the analysis of electric circuits and an introduction to their design. The material is presented at a level suitable for students who are taking or have completed the introductory courses in college calculus and physics. I have taken great care to provide complete and clear discussions, as well as an abundant supply of new learning aids.

ACCURACY The text and problems/solutions have been thoroughly checked for clarity and accuracy not only by the author, but also by more than a dozen academics and one honor student. This group consists of 11 reviewers who are well-known professors of ECE, and they are:

Robert Krueger, University of Wisconsin
Ashok Goel, Michigan Technological University

Clifford Pollock, Cornell University
Peyton Peebles, University of Florida
Marty Kaliski, Cal Poly, San Luis Obispo
Darryl Morrell, Arizona State University
Peddapullaiah Sannuti, Rutgers University
Paul Greiling, UCLA
Jorge Aravena, LSU
James Rowland, University of Kansas
Thomas H. Shumpert, Auburn University

In addition, the following individuals served as accuracy checkers for every aspect of the text:

Professor Scott Smith, Boise State University
Professor Val Tareski, North Dakota State University
Mr. Jung Young Lee, UC Berkeley

FLEXIBILITY While the organization and presentation of the material have been designed to enable students to understand and apply the fundamentals as quickly as possible, the organization also provides instructors maximum flexibility to use the text in a variety of different course settings and learning styles. Some sections or chapters can be skipped completely and still provide a coherent presentation in a natural progression from start to finish. For example, those instructors who do not wish to cover the CAD tools, that is, PSPICE, MATLAB, and Microsoft EXCEL, can skip them with no loss of continuity. On the other hand, one could make computer-generated solutions a major focus of the course. In addition, the design material permits instructors to introduce this important topic early in the curriculum.

Pedagogical Structure Designed to Reinforce Learning

Students don't all learn in the same way. Some are visual learners, while others are more kinesthetic. A "learning styles survey" appears after the preface to help each student determine his or her particular learning style and gives guidance on how to tailor his or her study habits. Pedagogical features are included to fit different learning styles.

- ***Learning Goals***, listed at the beginning of each chapter, provide an overview of the topics within the chapter and the skills and knowledge students should achieve.
- ***Learning Hints*** that appear on many pages of the text help shorten the learning curve. These comments in the margin provide guidance for understanding different facets of the presentation and problems of all types. Coupled with myriad examples, Learning Hints provide readers with a companion tutor. Additionally, they aid the instructor and the student by conveying some of the subtleties that are typically implicit in lecture or in traditional presentation.
- ***Learning by Example*** sections, more often than any other component, provide students with the means for acquiring and evaluating new knowledge. The numerous worked-out examples in the text are the hallmark feature.
- An expanded number of real-world examples, labeled ***Learning by Application***, appear in many sections of the text, and at the end of every applicable chapter, answer the question "Why do we study circuit theory?" Applications frequently deal with design issues ranging from very simple matters, such as finding the value of some specific component, to modeling the collapse of the Tacoma Narrows Bridge.
- ***Learning by Doing*** and ***Learning Extensions*** are assessment tools coordinated within the text. The Learning by Doing exercises are quick, simple reinforcements of the principles and provide a check of the reader's understanding of the material. Learning Extensions

provide practice for the reader in applying the basic concepts, as well as guidance in understanding the techniques needed to solve the end-of-chapter problems.

- ***Problem-Solving Strategies*** are placed to assist the student in selecting the proper solution technique, or combination of techniques applicable in a particular situation. This assistance not only helps the student understand the subtle differences among various techniques in their application to a particular problem, but also helps eliminate the psychological barrier that sometimes exists in determining a suitable method of attack.
- ***Computer-aided Design (CAD) Tools*** allow students, like all modern engineers, to apply the power of the computer to solve a variety of problems. Special icons are employed within the book to indicate sections where the CAD tools are used. The very latest version of PSPICE by Cadence is used, and this version coupled with the use of both MATLAB and Microsoft EXCEL are integrated within the text and coordinated with the Student Study Guide (discussed later) where Electronics Workbench is also introduced.
- ***Learning by Design*** sections appear at the end of each applicable chapter. This feature provides the reader with an understanding of how to apply what they have learned to the design of circuits. The use of engineering design in a curriculum is a major component of the ABET criteria. The inclusion of this material permits its introduction to the student at an early stage in the curriculum.
- ***Learning Check*** includes both the Summary and Problems, and appears at the end of every chapter. The important topics are reviewed concisely in the Summary as a quick reminder for readers. The problems are segmented by chapter subdivision and graduated in difficulty to permit users to test their understanding of the material and hone their skills in solving different types of problems. *The problem sets also include some problems specifically designed to mimic those that appear on the Fundamentals of Engineering (FE) Exam taken by students in preparation for becoming a Registered Professional Engineer.*

New to This Edition

This edition generally follows the presentation outlined in previous editions. However, I have made some important changes that are designed to meet the current needs of the course and that respond to the experience and comments of colleagues who have taught from the book. As is my custom, the problem sets are new, the presentation has been streamlined to include important new material, and a number of new and exciting real-world applications are presented throughout. Other specific improvements are outlined on a chapter-by-chapter basis as follows:

Chapter 2—Standard resistor values are presented, and their tolerances and power ratings are discussed using examples. The delta/wye and wye/delta transformations have also been inserted here.

Chapter 3—MATLAB is introduced here as a CAD tool for solving a set of linearly independent simultaneous equations for both nodal and loop analysis. The presentation of op-amps is updated to reflect the use of modern components.

Chapter 4—Microsoft EXCEL is introduced and the new version of PSPICE by Cadence is introduced and employed in the solution of dc circuits.

Chapter 5—Standard values for capacitors and inductors are given, and their tolerances and specific component ratings are discussed using examples.

Chapter 6—Both first- and second-order transient circuits are combined in this chapter. MATLAB plotting routines are used to obtain transient response plots, and PSPICE is used in the solution of transient problems.

Chapter 7—Both MATLAB and PSPICE are employed to obtain solutions to ac steady-state circuit analysis problems. PSPICE can also be used to sweep the frequency to obtain plots of magnitude and phase.

Chapter 8—The Magnetically Coupled Networks chapter has been moved forward to this location.

Chapter 11—Variable frequency network performance has moved to this chapter, and MATLAB is employed to obtain the magnitude and phase plots from a transfer function. The Operational Transconductance Amplifier (OTA) is also introduced as a viable component for wireless applications, which include high-frequency active filters and low-voltage circuitry.

Chapter 12—MATLAB is used to obtain the inverse Laplace transform and perform a convolution.

Chapter 14—Fourier analysis techniques have been moved to this location. PSPICE is used to obtain the Fourier series components of a waveform.

Chapter 15—Two-Port Networks have been moved from an appendix to a full chapter.

Chapter 16—This new chapter provides an introduction to semiconductor electronics. Diodes and transistors and some of their applications are examined.

Companion Web Site

Among other items, this site contains *Answers to Selected Problems.*

Supplements

The ***Student Study Guide*** for the seventh edition contains additional detailed examples that track the chapter presentation to aid and check the student's understanding of the problem-solving process. Many of these examples involve computer simulations with PSPICE, MATLAB, Microsoft EXCEL, and Electronics Workbench. A CD bound into the study guide includes circuit simulations and five easy-to-use video segments for demonstrating PSPICE solutions.

EGrade Anonymous Quizzing is also available to students using this text. Students are encouraged to visit our web site at *www.wiley.com/college/circuitsextra* and register to begin taking practice quizzes on eGrade to increase their circuits problem-solving skills. EGrade questions are organized by topic and are automatically scored to provide immediate feedback, so the student can either drill specifically in problem areas (focusing on topics he or she needs more work in) or just do general practice drills to prepare for a test.

Problem-Solving Companion is available for download from the text web site. This *Companion* contains over 70 additional problems with extremely detailed worked-out solutions to walk you through the problem-solving process. It also includes techniques for solving linearly independent simultaneous equations. Visit the web site at *www.wiley.com/college/elec/irwin407402* for an example from this resource.

Circuits Extra—Check out the latest offerings for users of Wiley circuits texts.

EGrade On-line Assessment is also available for this text. EGrade is a tool that allows instructors to automate the process of assigning, delivering, grading, and routing all kinds of homework, quizzes, and tests, while providing students with immediate scoring and feedback on their work. Electric circuits test banks in eGrade format are available for instructors who would like to include a web component in their course in the form of on-line homework and quizzing. Questions are arranged by topic and are in a variety of formats, including fill-in-the-blank, multiple choice, true/false, and more. For more information, and to see a demo of eGrade, visit *www.wiley.com/college/egrade.*

The ***Solutions Manual***, containing solutions to all learning extensions and end-of-chapter problems, and *PowerPoint Slides* for this text are available only to instructors who have adopted the text for classroom use. The solutions manual and PowerPoint slides are available on the web site at *www.wiley.com/college/elec/irwin407402*, under the *Instructor's Companion Site*. You must first register for a password on-line and supply your course information for confirmation before you will receive access to these resources.

Circuit Works is a simulator based on a set library of 100 circuits, with adjustable parameters and 35 parameterized signal generators. This tool helps you to succeed by learning the principles and relationships that underlie basic first- and second-order circuits having resistors, capacitors, inductors, op-amps, dependent and independent sources, and tranformers. *Circuit Works* is free to purchasers of this text. To download *Circuit Works* for free, simply go to the web site at *http://www.wiley.com/college/circuitworks* and register with the unique password included on the inside cover of this text.

Acknowledgements

Over the approximate 20-year period that this text has been employed, it is estimated that more than one thousand instructors have used my book to teach circuit analysis to hundreds of thousands of students. I am most grateful for the confidence that has been demonstrated in the educational soundness of the text. In addition, I have received numerous evaluations and suggestions from professors and their students over the years, and their feedback has helped me continuously improve the presentation. For this seventh edition, I would especially like to express my appreciation to a number of individuals and groups. I owe Bill Dillard at Auburn University a special debt of gratitude for the numerous contributions that he made to the development of new material in the text, as well as some of the supporting material. I am also most appreciative of the suggestions for improvement that were made by Professor John Choma of the University of Southern California and Professor Mark Nelms of Auburn University.

I was fortunate to have an outstanding group of reviewers for the book. They are:

Robert Krueger, University of Wisconsin
Ashok Goel, Michigan Technological University
Clifford Pollock, Cornell University
Peyton Peebles, University of Florida
Marty Kaliski, Cal Poly, San Luis Obispo
Darryl Morrell, Arizona State University
Peddapullaiah Sannuti, Rutgers University
Paul Greiling, UCLA
Jorge Aravena, Louisiana State University
James Rowland, University of Kansas
Tom Shumpert, Auburn University

The book was carefully checked for accuracy by three very competent individuals: Professor Scott F. Smith, Boise State University, Professor Val Tareski, North Dakota State University, and Jung Young Lee, a honor student at UC Berkeley. I sincerely appreciate the superior job that was done by these groups. In addition, I would like to thank two professors and their students for the special group discussions that took place in Professor James Rowland's class at the University of Kansas and Professor John Durkin's class at the University of Akron.

While this is the seventh edition of this book, it is the very first edition for John Wiley & Sons, Inc. The preparation of this book and the numerous ancillary documents that support it have been handled with both enthusiasm and great care. The combined wisdom and leadership of Bill Zobrist, my Executive Editor, has resulted in a tremendous team effort that has addressed every aspect of the presentation. This team included the following individuals:

Marketing Manager, Katherine Hepburn
Senior Production Editor, Christine Cervoni
Senior Designer, Karin Kincheloe

Illustration Coordinator, Gene Aiello
Assistant Editor, Jenny Welter
Senior Market Research Analyst, Carl Kulo
Online Marketing Coordinator, Bonnie Kubat
Developmental Editor, Johnna Barto
Marketing Assistant, Cecily Iddings
Editorial Assistant, Susannah Barr

Each member of this team played a vital role in preparing the package that is the *Seventh Edition of Basic Engineering Circuit Analysis*, and I am most appreciative of their any contributions.

As in the past, I am pleased to acknowledge the support that has been provided by numerous individuals to earlier editions of this book. The Auburn personnel who have helped are:

Paula R. Marino
Thomas A. Baginski
Charles A. Gross
James L. Lowry
Zhi Ding
David C. Hill
Henry Cobb
Les Simonton
Betty Kelley
E. R. Graf
L. L. Grigsby
M. A. Honnell
R. C. Jaeger
M. S. Morse
Sung-Won Park
C. L. Rogers
Travis Blalock
Kevin Driscoll
Keith Jones
George Lindsey
David Mack
John Parr
Monty Rickles
James Trivltayakhun
Susan Williamson
Jacinda Woodward

Many of my colleagues throughout the United States, some of whom are now retired, have also made numerous suggestions for improving the book:

M. E. Shafeei, Penn State University at Harrisburg
Leonard J. Tung, Florida A&M University/ Florida State University
Darrell Vines, Texas Tech University
David Anderson, University of Iowa
Richard Baker, UCLA
James L. Dodd, Mississippi State University
Earl D. Eyman, University of Iowa
Arvin Grabel, Northeastern University
Paul Gray, University of Wisconsin, Platteville
Mohammad Habli, University of New Orleans
John Hadjilogiou, Florida Institute of Technology
Ralph Kinney, LSU
K. S. P. Kumar, University of Minnesota
James Luster, Snow College
Ian McCausland, University of Toronto
Arthur C. Moeller, Marquette University
M. Paul Murray, Mississippi State University
Burks Oakley, II, University of Illinois at Champaign-Urbana
John O'Malley, University of Florida
William R. Parkhurst, Wichita State University
George Prans, Manhattan College
James Rowland, University of Kansas
Robert N. Sackett, Normandale Community College
Richard Sanford, Clarkson University
Ronald Schultz, Cleveland State University
Karen M. St. Germaine, University of Nebraska
Janusz Strazyk, Ohio University
Saad Tabet, Florida State University
Seth Wolpert, University of Maine

Finally, I wish to express my deep appreciation to my wife, Edie, who has been most supportive of my efforts with this book.

J. David Irwin

How Do I Learn Best?

This questionnaire aims to find out something about your preferences for the way you work with information. You will have a preferred learning style, and one part of that learning style is your preference for the intake and the output of ideas and information.

Circle the letter of the answer that best explains your preference. Circle more than one if a single answer does not match your perception. Leave blank any question that does not apply.

1. You are about to give directions to a person who is standing with you. She is staying in a hotel in town and wants to visit your house later. She has a rental car. Would you
- **a.** draw a map on paper?
- **b.** tell her the directions?
- **c.** write down the directions (without a map)?
- **d.** pick her up at the hotel in your car?

2. You are not sure whether a word should be spelled "dependent" or "dependant." Do you
- **c.** look it up in the dictionary?
- **a.** see the word in your mind and choose by the way it looks?
- **b.** sound it out in your mind?
- **d.** write both versions down on paper and choose one?

3. You have just received a copy of your itinerary for a world trip. This is of interest to a friend. Would you
- **b.** call her immediately and tell her about it?
- **c.** send her a copy of the printed itinerary?
- **a.** show her on a map of the world?
- **d.** share what you plan to do at each place you visit?

4. You are going to cook something as a special treat for your family. Do you
- **d.** cook something familiar without the need for instructions?
- **a.** thumb through the cookbook looking for ideas from the pictures?
- **c.** refer to a specific cookbook where there is a good recipe?

5. A group of tourists has been assigned to you to find out about wildlife reserves or parks. Would you
- **d.** drive them to a wildlife reserve or park?
- **a.** show them slides and photographs?
- **c.** give them pamphlets or a book on wildlife reserves or parks?
- **b.** give them a talk on wildlife reserves or parks?

6. You are about to purchase a new CD player. Other than price, what would most influence your decision?
- **b.** The salesperson telling you what you want to know.
- **c.** Reading the details about it.
- **d.** Playing with the controls and listening to it.
- **a.** Its fashionable and upscale appearance.

7. Recall a time in your life when you learned how to do something like playing a new board game. Try to avoid choosing a very physical skill, e.g., riding a bike. How did you learn best? By
- **a.** visual clues—pictures, diagrams, charts?
- **c.** written instructions?
- **b.** listening to somebody explaining it?
- **d.** doing it or trying it?

8. You have an eye problem. Would you prefer that the doctor
- **b.** tell you what is wrong?
- **a.** show you a diagram of what is wrong?
- **d.** use a model to show what is wrong?

9. You are about to learn to use a new program on a computer. Would you
- **d.** sit down at the keyboard and begin to experiment with the program's features?
- **c.** read the manual that comes with the program?
- **b.** call a friend and ask questions about it?

10. You are staying in a hotel and have a rental car. You would like to visit friends whose address/location you do not know. Would you like them to
- **a.** draw you a map on paper?
- **b.** tell you the directions?
- **c.** write down the directions (without a map)?
- **d.** pick you up at the hotel in their car?

11. Apart from price, what would most influence your decision to buy a particular book?
- **d.** You have used a copy before.
- **b.** A friend talking about it.
- **c.** Quickly reading parts of it.
- **a.** The appealing way it looks.

12. A new movie has arrived in town. What would most influence your decision to go (or not go)?
- **b.** You heard a radio review about it.
- **c.** You read a review about it.
- **a.** You saw a preview of it.

13. Do you prefer a lecturer or teacher who likes to use
- **c.** a textbook, handouts, readings?
- **a.** flow diagrams, charts, graphs?
- **d.** field trips, labs, practical sessions?
- **b.** discussion, guest speakers?

	a.	b.	c.	d.
Count Your Choices:	❑	❑	❑	❑
	V	A	R	K

Now match the letter or letters you have recorded most to the same letter or letters in the learning styles chart. You may have more than one learning style preference—many people do. Next to each letter in the chart are suggestions that will refer you to different learning aids throughout this text.

Learning Styles Chart

Visual

INTAKE: TO TAKE IN THE INFORMATION	TO MAKE A STUDY PACKAGE	TEXT FEATURES THAT MAY HELP YOU THE MOST	OUTPUT: TO DO WELL ON EXAMS
• Pay close attention to charts, drawings, and handouts your instructor uses. • Underline. • Use different colors. • Use symbols, flow charts, graphs, different arrangements on the page, white space.	Convert your lecture notes into "page pictures." To do this: • Use the "Intake" strategies. • Reconstruct images in different ways. • Redraw pages from memory. • Replace words with symbols and initials. • Look at your pages.	**Learning Goals** **Charts of real-world values** **Endpaper charts** **Photos of circuit components** **Learning by Example** **Learning by Application** **Problem-Solving Strategies** **Learning by Design** **Learning Check (Problems)** **Tools for Learning (MATLAB and PSPICE)** ***Answers to Selected Problems*** ***Problem-Solving Companion*** ***Student Study Guide***	• Recall your "page pictures." • Draw diagrams where appropriate. • Practice turning your visuals back into words.

Aural

INTAKE: TO TAKE IN THE INFORMATION	TO MAKE A STUDY PACKAGE	TEXT FEATURES THAT MAY HELP YOU THE MOST	OUTPUT: TO DO WELL ON EXAMS
• Attend lectures and tutorials. • Discuss topics with students and instructors. • Explain new ideas to other people. • Use a tape recorder. • Leave spaces in your lecture notes for later recall. • Describe overheads, pictures, and visuals to somebody who was not in class.	You may take poor notes because you prefer to listen. Therefore: • Expand your notes by talking with others and with information from your textbook. • Tape record summarized notes and listen. • Read summarized notes out loud. • Explain your notes to another "aural" person.	**Learning Goals** **Learning Hints** **Learning by Example** **Problem-Solving Strategies** **Learning by Application** **Learning Check (Summary & Problems)**	• Talk with the instructor. • Spend time in quiet places recalling the ideas. • Practice writing answers to old exam questions. • Say your answers out loud.

Reading/Writing

INTAKE: TO TAKE IN THE INFORMATION	TO MAKE A STUDY PACKAGE	TEXT FEATURES THAT MAY HELP YOU THE MOST	OUTPUT: TO DO WELL ON EXAMS
• Use lists and headings. • Use dictionaries, glossaries, and definitions. • Read handouts, textbooks, and supplementary library readings. • Use lecture notes.	• Write out words again and again. • Reread notes silently. • Rewrite ideas and principles into other words. • Turn charts, diagrams, and other illustrations into statements.	**Learning Goals** **Learning Hints** **Endpaper charts** **Learning by Example** **Learning by Application** **Problem-Solving Strategies** **Learning by Design** **Learning Check (Summary & Problems)** **Tools for Learning (MATLAB and PSPICE)** ***Answers to Selected Problems*** ***Problem-Solving Companion*** ***Student Study Guide***	• Write exam answers. • Practice with multiple-choice questions. • Write paragraphs, beginnings and endings. • Write your lists in outline form. • Arrange your words into hierarchies and points.

Kinesthetic

INTAKE: TO TAKE IN THE INFORMATION	TO MAKE A STUDY PACKAGE	TEXT FEATURES THAT MAY HELP YOU THE MOST	OUTPUT: TO DO WELL ON EXAMS
• Use all your senses. • Go to labs, take field trips. • Listen to real-life examples. • Pay attention to applications. • Use hands-on approaches. • Use trial-and-error methods.	You may take poor notes because topics do not seem concrete or relevant. Therefore: • Put examples in your summaries. • Use case studies and applications to help with principles and abstract concepts. • Talk about your notes with another "kinesthetic" person. • Use pictures and photographs that illustrate an idea.	**Learning by Doing** **Learning Hints** **Learning by Example** **Learning Applications** **Extending Your Learning** **Learning by Design** **Learning Check (Problems)** **Tools for Learning (MATLAB and PSPICE)** ***Answers to Selected Problems*** ***Problem-Solving Companion*** ***Student Study Guide***	• Write practice answers. • Role-play the exam situation.

Basic Concepts

1

LEARNING Goals

Today we live in a predominantly electrical world. Although this statement may sound strange at first, a moment's reflection will indicate its inherent truth. The two primary areas of electrotechnology that permeate essentially every aspect of our lives are power and information. Without them, life as we know it would undergo stupendous changes. We have learned to generate, convert, transmit, and utilize these technologies for the enhancement of the whole human race.

Electrotechnology is a driving force in the changes that are occurring in every engineering discipline. For example, surveying is now done with lasers and electronic range finders, and automobiles employ electronic dashboards and electronic ignition systems. Industrial processes that range from chemical refineries and metal foundries to wastewater treatment plants use (1) electronic sensors to obtain information about the process, (2) instrumentation systems to gather the information, and (3) computer control systems to process the information and generate electronic commands to actuators, which correct and control the process.

Fundamental to electrotechnology is the area of circuit analysis. A thorough knowledge of this subject provides an understanding of such things as cause and effect, amplification and attenuation, feedback and control, and stability and oscillation. Of critical importance is the fact that the same principles applied to engineering systems can also be applied to economic and social systems. Thus, the ramifications of circuit analysis are immense, and a solid understanding of this subject is well worth the effort expended to obtain it.

In this chapter we will introduce some of the basic quantities that will be used throughout the text. Specifically, we will define electric current, voltage, power and energy, as well as the difference between direct current and alternating current. In addition, we will classify electric elements as either passive or active, the latter of which can be further subdivided into both independent and dependent. This basic introduction will lay the groundwork for our further study of a wide variety of electric circuits.

1.1 System of Units

The system of units we employ is the international system of units, the Système International des Unités, which is normally referred to as the SI standard system. This system, which is composed of the basic units meter (m), kilogram (kg), second (s), ampere (A), degree kelvin (°K), and candela (cd), is defined in all modern physics texts and therefore will not be defined here. However, we will discuss the units in some detail as we encounter them in our subsequent analyses.

The standard prefixes that are employed in SI are shown in Fig. 1.1. Note the decimal relationship between these prefixes. These standard prefixes are employed throughout our study of electric circuits.

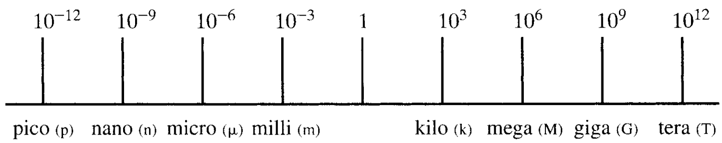


Figure 1.1
Standard SI prefixes.

Circuit technology has changed drastically over the years. For example, in the early 1960s the space on a circuit board occupied by the base of a single vacuum tube was about the size of a quarter (25-cent coin). Today that same space could be occupied by an Intel Pentium integrated circuit chip containing 3.1 million transistors. These chips are the engine for a host of electronic equipment.

1.2 Basic Quantities

Before we begin our analysis of electronic circuits, we must define terms that we will employ. However, in this chapter and throughout the book our definitions and explanations will be as simple as possible to foster an understanding of the use of the material. No attempt will be made to give complete definitions of many of the quantities because such definitions are not only unnecessary at this level but are often confusing. Although most of us have an intuitive concept of what is meant by a circuit, we will simply refer to an *electric circuit* as an interconnection of electrical components, each of which we will describe with a mathematical model.

The most elementary quantity in an analysis of electric circuits is the electric *charge*. Our interest in electric charge is centered around its motion, since charge in motion results in an energy transfer. Of particular interest to us are those situations in which the motion is confined to a definite closed path.

An electric circuit is essentially a pipeline that facilitates the transfer of charge from one point to another. The time rate of change of charge constitutes an electric *current*. Mathematically, the relationship is expressed as

$$i(t) = \frac{dq(t)}{dt} \quad \text{or} \quad q(t) = \int_{-\infty}^{t} i(x)\,dx \qquad \textbf{1.1}$$

where i and q represent current and charge, respectively (lowercase letters represent time dependency and capital letters are reserved for constant quantities). The basic unit of current is the ampere (A) and 1 ampere is 1 coulomb per second.

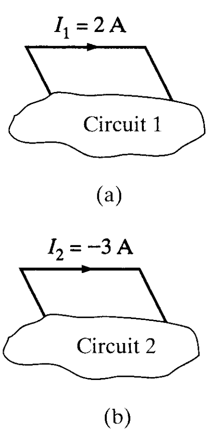
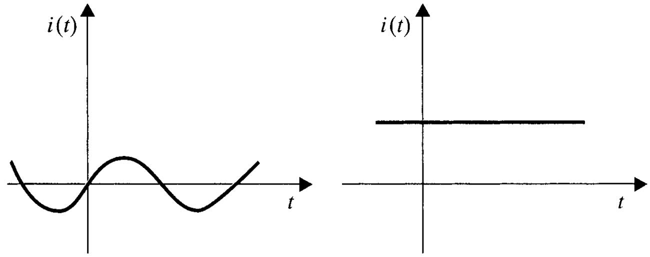


Figure 1.2
Conventional current flow: (a) positive current flow; (b) negative current flow.

Although we know that current flow in metallic conductors results from electron motion, the conventional current flow, which is universally adopted, represents the movement of positive charges. It is important that the reader think of current flow as the movement of positive charge regardless of the physical phenomena that take place. The symbolism that will be used to represent current flow is shown in Fig. 1.2. $I_1 = 2$ A in Fig. 1.2a indicates that at any point in the wire shown,



(a) (b)

Figure 1.3
Two common types of current: (a) alternating current (ac); (b) direct current (dc).

2 C of charge pass from left to right each second. $I_2 = -3$ A in Fig. 1.2b indicates that at any point in the wire shown, 3 C of charge pass from right to left each second. Therefore, it is important to specify not only the magnitude of the variable representing the current, but also its direction.

There are two types of current that we encounter often in our daily lives, alternating current (ac) and direct current (dc), which are shown as a function of time in Fig. 1.3. *Alternating current* is the common current found in every household and is used to run the refrigerator, stove, washing machine, and so on. Batteries, which are used in automobiles or flashlights, are one source of *direct current*. In addition to these two types of currents, which have a wide variety of uses, we can generate many other types of currents. We will examine some of these other types later in the book. In the meantime, it is interesting to note that the magnitude of currents in elements familiar to us ranges from soup to nuts, as shown in Fig. 1.4.

We have indicated that charges in motion yield an energy transfer. Now we define the *voltage* (also called the *electromotive force* or *potential*) between two points in a circuit as the difference in energy level of a unit charge located at each of the two points. Work or energy, $w(t)$ or W, is measured in joules (J); 1 joule is 1 newton meter (N · m). Hence, voltage [$v(t)$ or V] is measured in volts (V) and 1 volt is 1 joule per coulomb; that is, 1 volt = 1 joule per coulomb = 1 newton meter per coulomb.

If a unit positive charge is moved between two points, the energy required to move it is the difference in energy level between the two points and is the defined voltage. It is extremely important that the variables that are used to represent voltage between two points be defined in such a way that the solution will let us interpret which point is at the higher potential with respect to the other.

LEARNING by Doing

D 1.1 Determine the amount of time required for 100 C of charge to pass through the circuit in Fig. 1.2a.

ANSWER *50 s*

LEARNING Hint

$$V = \frac{W}{q}$$

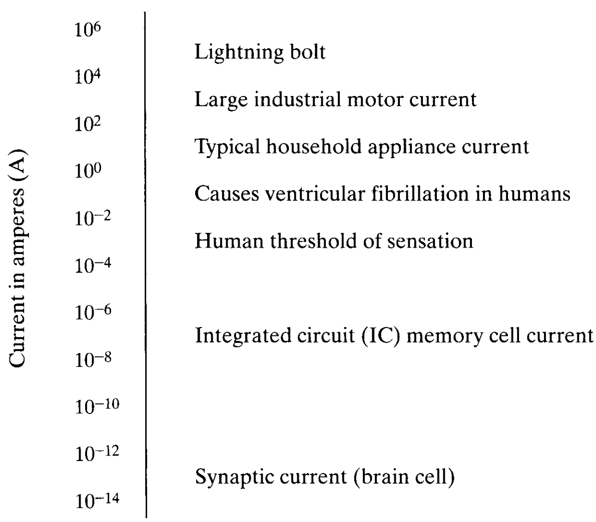


Figure 1.4
Typical current magnitudes.

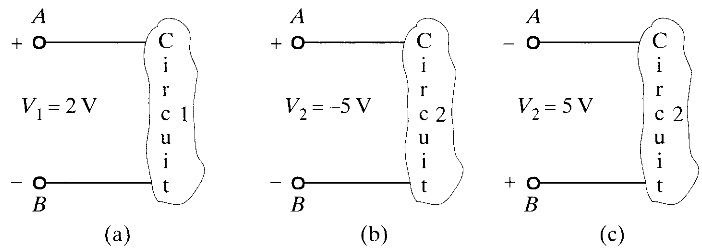


Figure 1.5
Voltage representations.

LEARNING by Doing

D 1.2 Determine the energy required to move 120 C of charge from point B to point A in the network in Fig. 1.5a.

ANSWER *240 J*

In Fig. 1.5a the variable that represents the voltage between points A and B has been defined as V_1, and it is assumed that point A is at a higher potential than point B, as indicated by the + and − signs associated with the variable and defined in the figure. The + and − signs define a reference direction for V_1. If $V_1 = 2$ V, then the difference in potential of points A and B is 2 V and point A is at the higher potential. If a unit positive charge is moved from point A through the circuit to point B, it will give up energy to the circuit and have 2 J less energy when it reaches point B. If a unit positive charge is moved from point B to point A, extra energy must be added to the charge by the circuit, and hence the charge will end up with 2 J more energy at point A than it started with at point B.

For the circuit in Fig. 1.5b, $V_2 = -5$ V means that the potential between points A and B is 5 V and point B is at the higher potential. The voltage in Fig. 1.5b can be expressed as shown in Fig. 1.5c. In this equivalent case, the difference in potential between points A and B is $V_2 = 5$ V, and point B is at the higher potential.

Note that it is important to define a variable with a reference direction so that the answer can be interpreted to give the physical condition in the circuit. We will find that it is not possible in many cases to define the variable so that the answer is positive, and we will also find that it is not necessary to do so. A negative number for a given variable gives exactly the same information as a positive number for a new variable that is the same as the old variable, except that it has an opposite reference direction. Hence, when we define either current or voltage, it is absolutely necessary that we specify both magnitude and direction. Therefore, it is incomplete to say that the voltage between two points is 10 V or the current in a line is 2 A, since only the magnitude and not the direction for the variables has been defined.

The range of magnitudes for voltage, equivalent to that for currents in Fig. 1.4, is shown in Fig. 1.6. Once again, note that this range spans many orders of magnitude.

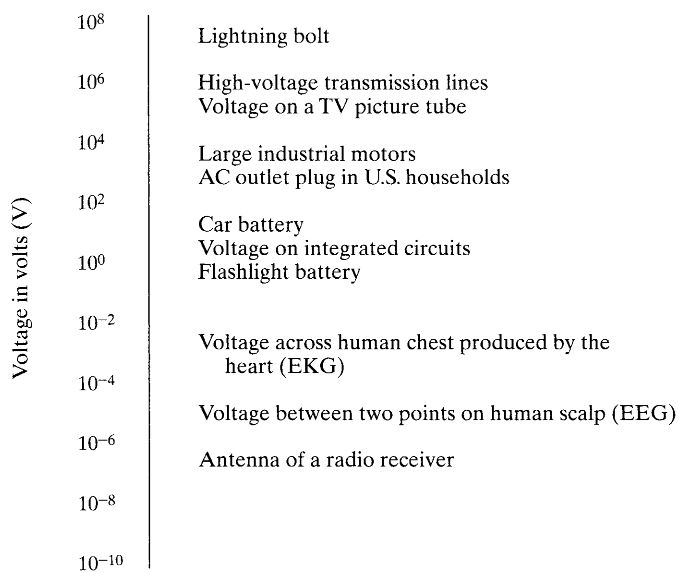


Figure 1.6
Typical voltage magnitudes.

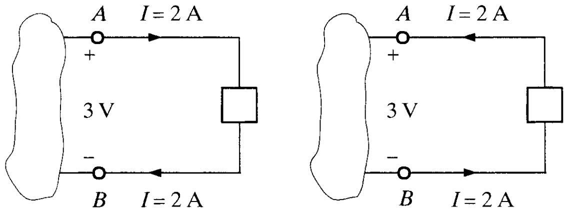
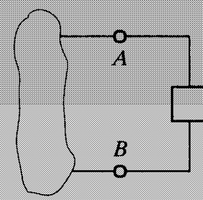


Figure 1.7 *Voltage–current relationships for (a) energy absorbed and (b) energy supplied.*

LEARNING by Doing

D 1.3 Five joules of energy are absorbed by 1 C of charge when moved from point *B* to point *A*. Find the voltage between points *A* and *B*.



ANSWER *5 V, B is +*

At this point we have presented the conventions that we employ in our discussions of current and voltage. *Energy* is yet another important term of basic significance. Figure 1.7 illustrates the voltage–current relationships for energy transfer. In this figure, the block representing a circuit element has been extracted from a larger circuit for examination. In Fig. 1.7a, energy is being supplied *to* the element by whatever is attached to the terminals. Note that 2 A, that is, 2 C, of charge are moving from point *A* to point *B* through the element each second. Each coulomb loses 3 J of energy as it passes through the element from point *A* to point *B*. Therefore, the element is absorbing 6 J of energy per second. Note that when the element is *absorbing* energy, a positive current enters the positive terminal. In Fig. 1.7b energy is being supplied *by* the element to whatever is connected to terminals *A*-*B*. In this case, note that when the element is *supplying* energy, a positive current enters the negative terminal and leaves via the positive terminal. In this convention a negative current in one direction is equivalent to a positive current in the opposite direction, and vice versa. Similarly, a negative voltage in one direction is equivalent to a positive voltage in the opposite direction.

LEARNING Example 1.1

Suppose that your car will not start. To determine whether the battery is faulty, you turn on the light switch and find that the lights are very dim, indicating a weak battery. You borrow a friend's car and a set of jumper cables. However, how do you connect his car's battery to yours? What do you want his battery to do?

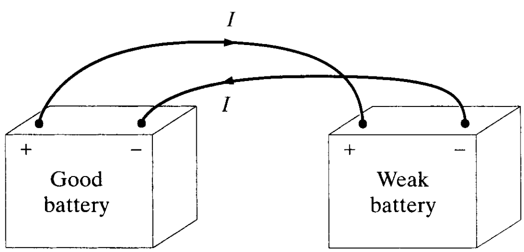


Figure 1.8 *Diagram for Example 1.1.*

SOLUTION Essentially, his car's battery must supply energy to yours, and therefore it should be connected in the manner shown in Fig. 1.8. Note that the positive current leaves the positive terminal of the good battery (supplying energy) and enters the positive terminal of the weak battery (absorbing energy). Note that the same connections are used when charging a battery.

In practical applications there are often considerations other than simply the electrical relations (e.g., safety). Such is the case with jump-starting an automobile. Automobile batteries produce explosive gases that can be ignited accidentally, causing severe physical injury. Be safe—follow the procedure described in your auto owner's manual.

We have defined voltage in joules per coulomb as the energy required to move a positive charge of 1 C through an element. If we assume that we are dealing with a differential amount of charge and energy, then

$$v = \frac{dw}{dq} \qquad \textbf{1.2}$$

Multiplying this quantity by the current in the element yields

$$vi = \frac{dw}{dq}\left(\frac{dq}{dt}\right) = \frac{dw}{dt} = p \quad \textbf{1.3}$$

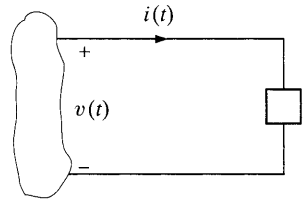


Figure 1.9
Sign convention for power.

which is the time rate of change of energy or power measured in joules per second, or watts (W). Since, in general, both v and i are functions of time, p is also a time-varying quantity. Therefore, the change in energy from time t_1 to time t_2 can be found by integrating Eq. (1.3); that is,

$$\Delta w = \int_{t_1}^{t_2} p\,dt = \int_{t_1}^{t_2} vi\,dt \quad \textbf{1.4}$$

LEARNING Hint

The passive sign convention is used to determine whether power is being absorbed or supplied.

At this point, let us summarize our sign convention for power. To determine the sign of any of the quantities involved, the variables for the current and voltage should be arranged as shown in Fig. 1.9. The variable for the voltage $v(t)$ is defined as the voltage across the element with the positive reference at the same terminal that the current variable $i(t)$ is entering. This convention is called the *passive sign convention* and will be so noted in the remainder of this book. The product of v and i, with their attendant signs, will determine the magnitude and sign of the power. If the sign of the power is positive, power is being absorbed by the element; if the sign is negative, power is being supplied by the element.

LEARNING Example 1.2

Given the two diagrams shown in Fig. 1.10, determine whether the element is absorbing or supplying power and how much.

SOLUTION In Fig. 1.10a the power is $P = (2\text{ V})(-4\text{ A}) = -8\text{ W}$. Therefore, the element is supplying power. In Fig. 1.10b, the power is $P = (2\text{ V})(2\text{ A}) = 4\text{W}$. Therefore, the element is absorbing power.

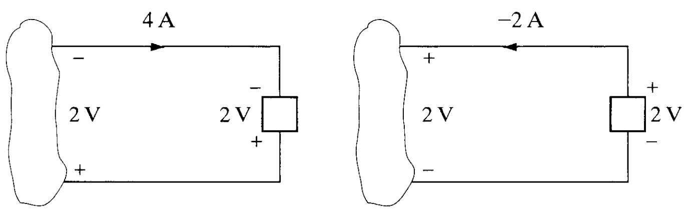


Figure 1.10
Elements for Example 1.2.

(a) (b)

LEARNING EXTENSION

E1.1 Determine the amount of power absorbed or supplied by the elements in Fig. E1.1.

ANSWER (a) $P = -48$ W; (b) $P = 8$ W.

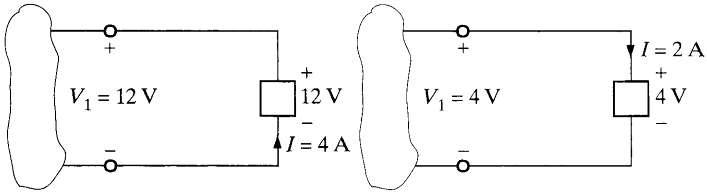


Figure E1.1

(a) (b)

LEARNING Example 1.3

We wish to determine the unknown voltage or current in Fig. 1.11.

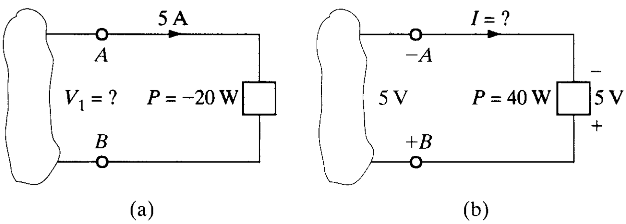


Figure 1.11 Elements for Example 1.3.

SOLUTION In Fig. 1.11a, a power of −20 W indicates that the element is delivering power. Therefore, the current enters the negative terminal (terminal A), and from Eq. (1.3) the voltage is 4 V. Thus B is the positive terminal, A is the negative terminal, and the voltage between them is 4 V.

In Fig 1.11b, a power of +40 W indicates that the element is absorbing power and, therefore, the current should enter the positive terminal B. The current thus has a value of −8 A, as shown in the figure.

LEARNING EXTENSION

E1.2 Determine the unknown variables in Fig. E1.2.

ANSWER (a) $V_1 = -20$ V; (b) $I = -5$ A.

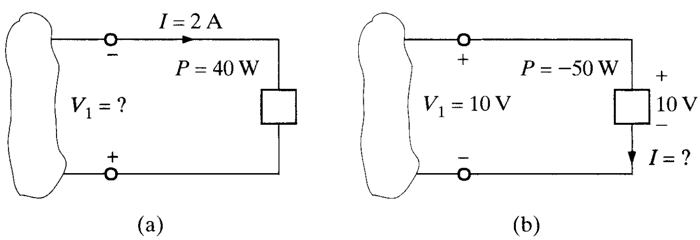


Figure E1.2

Finally, it is important to note that these electrical networks satisfy the principle of conservation of energy. For our present purposes this means that the power supplied in a network is exactly equal to the power absorbed.

1.3 Circuit Elements

Thus far we have defined voltage, current, and power. In the remainder of this chapter we will define both independent and dependent current and voltage sources. Although we will assume ideal elements, we will try to indicate the shortcomings of these assumptions as we proceed with the discussion.

In general, the elements we will define are terminal devices that are completely characterized by the current through the element and/or the voltage across it. These elements, which we will employ in constructing electric circuits, will be broadly classified as being either active or passive. The distinction between these two classifications depends essentially on one thing—whether they supply or absorb energy. As the words themselves imply, an *active* element is capable of generating energy and a *passive* element cannot generate energy.

However, we will show later that some passive elements are capable of storing energy. Typical active elements are batteries, generators, and transistor models. The three common passive elements are resistors, capacitors, and inductors.

In Chapter 2 we will launch an examination of passive elements by discussing the resistor in detail. However, before proceeding with that element, we first present some very important active elements.

1. Independent voltage source
2. Independent current source
3. Two dependent voltage sources
4. Two dependent current sources

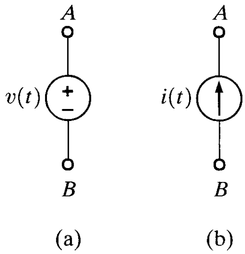


Figure 1.12 *Symbols for (a) independent voltage source, (b) independent current source.*

INDEPENDENT SOURCES An *independent voltage source* is a two-terminal element that maintains a specified voltage between its terminals *regardless of the current through it*. The general symbol for an independent source, a circle, is shown in Fig. 1.12a. As the figure indicates, terminal A is $v(t)$ volts positive with respect to terminal B.

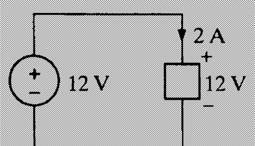
In contrast to the independent voltage source, the *independent current source* is a two-terminal element that maintains a specified current *regardless of the voltage across its terminals*. The general symbol for an independent current source is shown in Fig. 1.12b, where $i(t)$ is the specified current and the arrow indicates the positive direction of current flow.

In their normal mode of operation, independent sources supply power to the remainder of the circuit. However, they may also be connected into a circuit in such a way that they absorb power. A simple example of this latter case is a battery-charging circuit such as that shown in Example 1.1.

It is important that we pause here to interject a comment concerning a shortcoming of the models. In general, mathematical models approximate actual physical systems only under a certain range of conditions. Rarely does a model accurately represent a physical system under every set of conditions. To illustrate this point, consider the model for the voltage source in Fig. 1.12a. We assume that the voltage source delivers v volts regardless of what is connected to its terminals. Theoretically, we could adjust the external circuit so that an infinite amount of current would flow, and therefore the voltage source would deliver an infinite amount of power. This is, of course, physically impossible. A similar argument could be made for the independent current source. Hence, the reader is cautioned to keep in mind that models have limitations and thus are valid representations of physical systems only under certain conditions.

LEARNING by Doing

D 1.4 Determine the power supplied by the 12-V source.



ANSWER *24 W*

LEARNING Example 1.4

Determine the power absorbed or supplied by the elements in the network in Fig. 1.13.

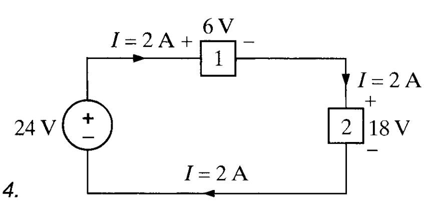


Figure 1.13 *Network for Example 1.4.*

SOLUTION The current flow is out of the positive terminal of the 24-V source, and therefore this element is supplying $(2)(24) = 48$ W of power. The current is into the positive terminals of elements 1 and 2, and therefore elements 1 and 2 are absorbing $(2)(6) = 12$ W and $(2)(18) = 36$ W, respectively. Note that the power supplied is equal to the power absorbed.

LEARNING Hint

Elements that are connected in series have the same current.

LEARNING EXTENSION

E1.3 Find the power that is absorbed or supplied by the elements in Fig. E1.3.

ANSWER Current source supplies 36 W, element 1 absorbs 54 W, and element 2 supplies 18 W.

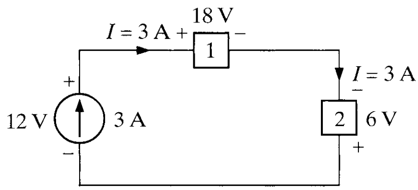


Figure E1.3

DEPENDENT SOURCES In contrast to the independent sources, which produce a particular voltage or current completely unaffected by what is happening in the remainder of the circuit, dependent sources generate a voltage or current that is determined by a voltage or current at a specified location in the circuit. These sources are very important because they are an integral part of the mathematical models used to describe the behavior of many electronic circuit elements.

For example, metal-oxide-semiconductor field-effect transistors (MOSFETs) and bipolar transistors, both of which are commonly found in a host of electronic equipment, are modeled with dependent sources, and therefore the analysis of electronic circuits involves the use of these controlled elements.

In contrast to the circle used to represent independent sources, a diamond is used to represent a dependent or controlled source. Figure 1.14 illustrates the four types of dependent sources. The input terminals on the left represent the voltage or current that controls the dependent source, and the output terminals on the right represent the output current or voltage of the controlled source. Note that in Figs. 1.14a and d the quantities μ and β are dimensionless constants because we are transforming voltage to voltage and current to current. This is not the case in Figs. 1.14b and c; hence when we employ these elements a short time later, we must describe the units of the factors r and g.

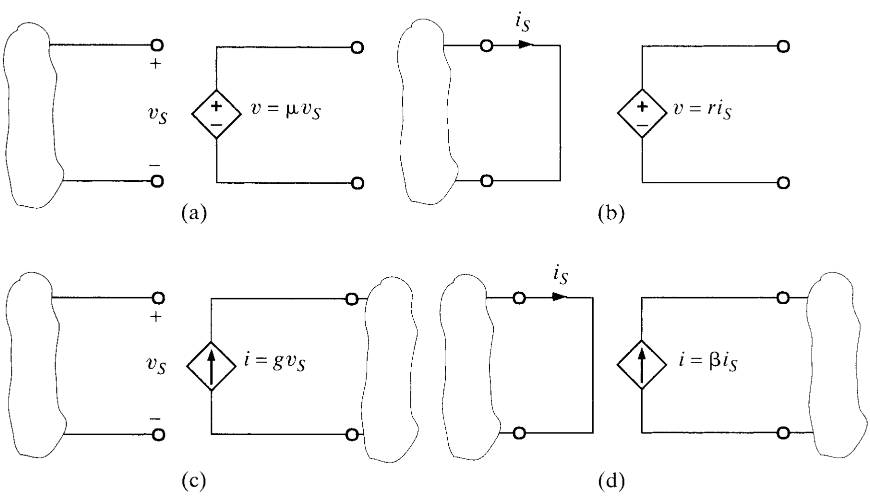


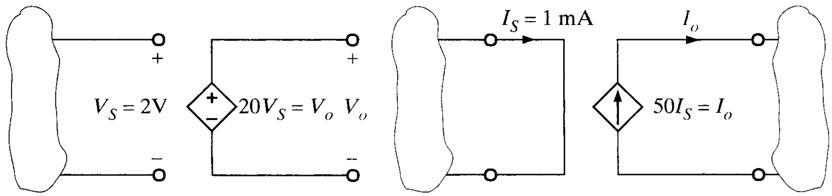
Figure 1.14
Four different types of dependent sources.

LEARNING Example 1.5

Given the two networks shown in Fig. 1.15, we wish to determine the outputs.

SOLUTION In Fig. 1.15a the output voltage is $V_o = \mu V_S$ or $V_o = 20\ V_S = (20)(2\text{ V}) = 40\text{ V}$. Note that the output voltage has been amplified from 2 V at the input terminals to 40 V at the output terminals; that is, the circuit is a voltage amplifier with an amplification factor of 20.

In Fig. 1.15b, the output current is $I_o = \beta I_S = (50)(1\text{ mA}) = 50\text{ mA}$; that is, the circuit has a current gain of 50, meaning that the output current is 50 times greater than the input current.

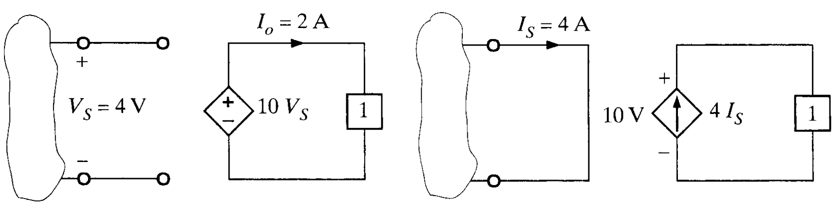


(a) (b)

Figure 1.15 Circuits for Example 1.5.

LEARNING EXTENSION

E1.4 Determine the power supplied by the dependent sources in Fig. E1.4.



(a) (b)

Figure E1.4

ANSWER (a) Power supplied = 80 W; (b) power supplied = 160 W.

LEARNING Example 1.6

Let us find the current I_o in the network in Fig. 1.16.

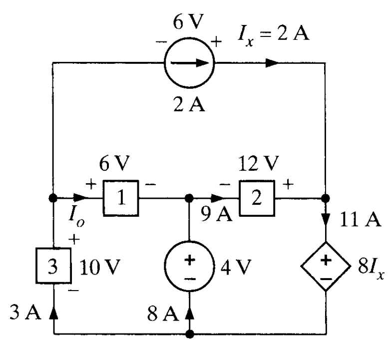


Figure 1.16 Circuit used in Example 1.6.

SOLUTION First, we must determine the power absorbed or supplied by each element in the network. Using the sign convention for power, we find

$$P_{2\text{ A}} = (6)(-2) = -12\text{ W}$$
$$P_1 = (6)(I_o) = 6I_o\text{ W}$$
$$P_2 = (12)(-9) = -108\text{ W}$$
$$P_3 = (10)(-3) = -30\text{ W}$$
$$P_{4\text{ V}} = (4)(-8) = -32\text{ W}$$
$$P_{DS} = (8I_x)(11) = (16)(11) = 176\text{ W}$$

Since energy must be conserved,

$$-12 + 6I_o - 108 - 30 - 32 + 176 = 0$$

or

$$6I_o + 176 = 12 + 108 + 30 + 32$$

Hence,

$$I_o = 1\text{A}$$