Grob's Basic Electronics

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Grob's Basic Electronics

13th Edition

Mitchel E. Schultz

Western Technical College

Mc Graw Hill

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GROB'S BASIC ELECTRONICS, THIRTEENTH EDITION
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Dedication

This book is dedicated to all of the students I have had the honor of teaching over the span of my career. Your passion and level of commitment to learning has truly been inspiring.

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Preface

The thirteenth edition of ***Grob's Basic Electronics*** provides students and instructors with complete and comprehensive coverage of the fundamentals of electricity and electronics. The book is written for beginning students who have little or no experience and/or knowledge about the field of electronics. A basic understanding of algebra and trigonometry is helpful since several algebraic equations and right-angle trigonometry problems appear throughout the text.

The opening material in the book, titled **"Introduction to Powers of 10,"** prepares students to work with numbers expressed in scientific and engineering notation as well as with the most common metric prefixes encountered in electronics. Students learn how to add, subtract, multiply, divide, square, and take the square root of numbers expressed in any form of powers of 10 notation.

Chapters 1 through 12 cover the basics of atomic structure, voltage, current, resistance, the resistor color code, Ohm's law, power, series circuits, parallel circuits, series-parallel (combination) circuits, voltage and current dividers, analog and digital meters, Kirchhoff's laws, network theorems, wire resistance, switches, insulators, primary and secondary cells, battery types, internal resistance, and maximum transfer of power. The first 12 chapters are considered DC chapters because the voltages and currents used in analyzing the circuits in these chapters are strictly DC.

Chapters 13 through 27 cover the basics of magnetism, electromagnetism, relays, alternating voltage and current, capacitance, capacitor types, capacitive reactance, capacitive circuits, inductance, transformers, inductive reactance, inductive circuits, *RC* and *L/R* time constants, real power, apparent power, power factor, complex numbers, resonance, filters, and three-phase AC power systems. Chapters 13–27 are considered the AC chapters since the voltages and currents used in analyzing the circuits in these chapters are primarily AC.

Chapters 28 through 34 cover the basics of electronic devices, which include semiconductor physics, diode characteristics, diode testing, half-wave and full-wave rectifier circuits, the capacitor input filter, light-emitting diodes (LEDs), zener diodes, bipolar junction transistors, transistor biasing techniques, the common-emitter, common-collector, and common-base amplifiers, JFET and MOSFET characteristics, JFET amplifiers, MOSFET amplifiers, class A, class B and class C amplifiers, diacs, SCRs, triacs, UJTs, op-amp characteristics, inverting amplifiers, noninverting amplifiers, and nonlinear op-amp circuits. ***These seven additional chapters covering electronic devices may qualify this text for those who want to use it for DC fundamentals, AC fundamentals, as well as electronic devices.***

Appendixes **A** through **G** serve as a resource for students seeking additional information on topics that may or may not be covered in the main part of the text. Appendix A provides a comprehensive list of electrical quantities and their symbols. It also includes a listing of the most popular multiple and submultiple units encountered in electronics as well as a listing of all the Greek letter symbols and their uses. Appendix B provides students with a comprehensive overview of solder and the soldering process. Appendix C provides a list of preferred values for resistors. The list of preferred values shows the multiple and submultiple values available for a specified tolerance. Appendix D provides a complete listing of electronic components and their respective schematic symbols. Appendix E provides students with an introduction on how to use an oscilloscope. Both analog and digital scopes are covered. Appendix F provides an extensive overview on the use of **Multisim,** which is an interactive circuit simulation software package that allows students to create and test electronic circuits. Appendix F introduces students to the main features of Multisim that directly relate to their study of DC circuits, AC circuits, and electronic devices. Appendix G provides thorough coverage of the damaging effects of electrostatic discharge (ESD). It also discusses the proper techniques and procedures to follow to prevent ESD from damaging sensitive electronic components and assemblies.

What's New in the Thirteenth Edition of *Grob's Basic Electronics?*

The thirteenth edition continues to provide complete and comprehensive coverage of the basics of electricity and electronics. Several sections throughout the book have been updated to reflect the latest changes in the field of electronics, and new photos and illustrations have been added and/or replaced throughout the book, giving it a fresh, new look. Significant changes are outlined below.

A new section, "*Electric Shock—Dangers, Precautions and First Aid*," has been added. Detailed coverage of the dangers associated with electricity and electronic circuits is provided in this section. A guideline of safe practices for students to follow in a laboratory setting has also been included. This section also outlines the first aid and medical treatment procedures a person should follow if assisting someone who has experienced an electric shock.

Real-World Applications* appearing throughout the book have been increased**. These ***Real-World Applications validate the importance of the topics discussed within a given chapter.

- ***Chapter 1, Electricity:*** A new section, "***Application in Understanding Alternative and Renewable Energy***," has been added. This section defines alternative and renewable energy and discusses the basics of two common types, wind and solar energy. It also discusses the benefits and limitations of solar and wind energy.
- ***Chapter 2, Resistors:*** A new section, "***Application in Understanding Varistors and Surge Protectors***," has been added. In this section, the characteristics and ratings of ***metal-oxide varistors (MOVs)*** are thoroughly examined. Furthermore, this section explains how MOVs are used in ***surge protectors*** to prevent voltage spikes (power surges) from damaging sensitive electronic equipment plugged into the 120 V AC power line.
- ***Chapter 8, Analog and Digital Multimeters:*** A new section, "***Application in Understanding Clamp-On Ammeters***," has also been added. In this section, the ***controls*, *keys***, and ***features*** of a typical clamp-on ammeter are discussed. Also discussed is the technique for using an ***AC line-splitter*** to measure the AC current in a power cord without splitting the conductors and/or breaking open the circuit.
- ***Chapter 15, Alternating Voltage and Current:*** New information on ***ground-fault circuit interrupters (GFCIs)*** has been added to the section "***Application in Understanding the 120-V Duplex Receptacle*.**" The basic operation, methods of testing, and safety benefits of GFCIs are thoroughly covered.

A new chapter, "*Three Phase AC Power Systems*," has been added. This chapter provides in-depth coverage of both wye (Y)- and delta (Δ)-connected three-phase AC generators. In this chapter, the relationship between the phase voltages and line voltages as well as the phase currents and line currents are thoroughly explained for a typical three-phase AC circuit. Also included are the four possible source/load configurations in three-phase AC power systems. The voltage, current, and power calculations for these configurations are thoroughly covered in this chapter. And finally, the advantages of using three-phase AC power versus single-phase AC power are explained in detail.

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New appendix covering electrostatic discharge, abbreviated ESD. ***"Appendix G—Electrostatic Discharge (ESD)"*** provides detailed coverage of the causes of ESD as well as its damaging effects. Most importantly, this appendix provides detailed information on how to prevent the build-up of ESD and in turn how to prevent ESD from damaging sensitive electronic components and assemblies.

Other Significant Changes:

- ***Chapter 1, Electricity:*** A small section has been added regarding the magnetic field surrounding a current-carrying conductor.
- ***Chapter 11, Conductors and Insulators:*** A new section has been added on fuse ratings.
- ***Chapter 33, Thyristors:*** Several additions and/or clarifications were made regarding DIACs, SCRs, and TRIACs.

Many of the features from the previous editions have been retained for this edition. For example, the ***"Lab Application Assignments"*** at the end of each chapter and the ***MultiSim*** activities embedded within each chapter still remain. These features have and will continue to be a benefit to those students and instructors using the book.

Ancillary Package

The following supplements are available to support *Grob's Basic Electronics*, thirteenth edition.

Problems Manual for Use with Grob's Basic Electronics

This book, written by Mitchel E. Schultz, provides students and instructors with hundreds of additional practice problems for self-study, homework assignments, tests, and review. The book is organized to correlate with the first 27 chapters of the textbook, including the Introduction to Powers of 10 chapter. Each chapter contains a number of solved illustrative problems demonstrating step-by-step how representative problems on a particular topic are solved. Following the solved problems are sets of problems for the students to solve. The changes in the thirteenth edition include a new section on switches and switch applications in chapter 11, Conductors and Insulators. Also new to this edition is a brand-new chapter (chapter 27) on three-phase AC power systems. Included at the end of each chapter is a brief true/false self-test. The *Problems Manual* is a must-have for students requiring additional practice in solving both DC and AC circuits. It is important to note that this book can be used as a supplement with any textbook covering DC and AC circuit theory.

Experiments Manual for Grob's Basic Electronics

This lab manual provides students and instructors with easy-to-follow laboratory experiments. The experiments range from an introduction to laboratory equipment to experiments dealing with operational amplifiers. New to this edition is an experiment involving the Y-Y configuration in three-phase AC power systems. All experiments have been student tested to ensure their effectiveness. The lab book is organized to correlate with the topics covered in the text, by chapter.

All experiments have a Multisim activity that is to be done prior to the actual physical lab activity. Multisim files are part of the Instructor's Resources on Connect. This prepares students to work with circuit simulation software, and also to do "pre-lab" preparation before doing a physical lab exercise. Multisim coverage also reflects the widespread use of circuit simulation software in today's electronics industries.

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Mitchel E. Schultz

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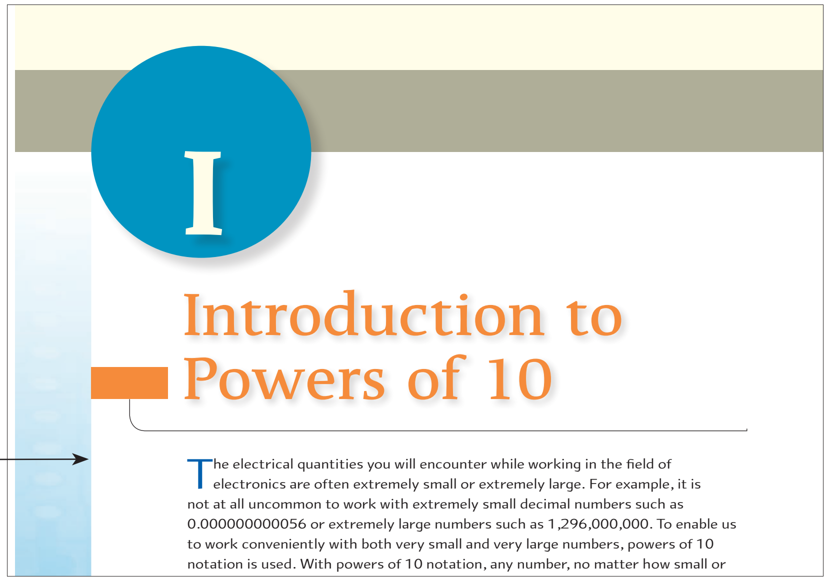
Before you read . . .

Chapter Introductions briefly outline the main chapter topics and concepts.


I

Introduction to Powers of 10

The electrical quantities you will encounter while working in the field of electronics are often extremely small or extremely large. For example, it is not at all uncommon to work with extremely small decimal numbers such as 0.000000000056 or extremely large numbers such as 1,296,000,000. To enable us to work conveniently with both very small and very large numbers, powers of 10 notation is used. With powers of 10 notation, any number, no matter how small or

Chapter Outlines guide you through the material in the chapter ahead. The outlines breakdown the individual topics covered, and each outline is tied to a main heading to emphasize important topics throughout the chapter.

Chapter Outline

1–1 Negative and Positive Polarities
1–2 Electrons and Protons in the Atom
1–3 Structure of the Atom
1–4 The Coulomb Unit of Electric Charge
1–5 The Volt Unit of Potential Difference
1–6 Charge in Motion Is Current
1–7 Resistance Is Opposition to Current
1–8 The Closed Circuit
1–9 The Direction of Current
1–10 Direct Current (DC) and Alternating Current (AC)
1–11 Sources of Electricity
1–12 The Digital Multimeter

Chapter Objectives

After studying this chapter, you should be able to

- *List* the two basic particles of electric charge.
- *Describe* the basic structure of the atom.
- *Define* the terms *conductor, insulator,* and *semiconductor* and give examples of each term.
- *Define* the coulomb unit of electric charge.
- *Define* potential difference and list its unit of measure.
- *Define* current and list its unit of measure.
- *Describe* the difference between voltage and current.
- *Define* resistance and conductance and list the unit of each.
- *List* three important characteristics of an electric circuit.
- *Define* the difference between electron flow and conventional current.
- *Describe* the difference between direct and alternating current.

Chapter Objectives organize and highlight the key concepts covered within the chapter text.

Important Terms

alternating current (AC)	conductor	electron valence	ohm
ampere	conventional current	element	potential difference
atom	coulomb	free electron	proton
atomic number	current	insulator	resistance
circuit	dielectric	ion	semiconductor
compound	direct current (DC)	molecule	siemens
conductance	electron	neutron	static electricity
	electron flow	nucleus	volt

Important Terms help students identify key words at the beginning of each chapter. They are defined in the text, at the end of the chapter, and in the glossary.

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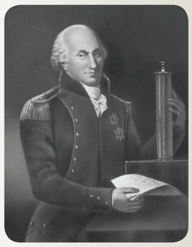
While you read . . .

Pioneers in Electronics offer background information on the scientists and engineers whose theories and discoveries were instrumental in the development of electronics.



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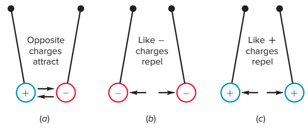
PIONEERS IN ELECTRONICS

French natural philosopher *Charles-Augustin Coulomb (1736–1806)* developed a method for measuring the force of attraction and repulsion between two electrically charged spheres. Coulomb established the law of inverse squares and defined the basic unit of charge quantity, the coulomb.

Figure 1–5 Physical force between electric charges. (*a*) Opposite charges attract. (*b*) Two negative charges repel each other. (*c*) Two positive charges repel.



repel in Fig. 1–5*b*, and two positive charges of the same value repel each other in Fig. 1–5*c*.

Polarity of a Charge

An electric charge must have either negative or positive polarity, labeled $-Q$ or $+Q$, with an excess of either electrons or protons. A neutral condition is considered zero charge. On this basis, consider the following examples, remembering that the electron is the basic particle of charge and the proton has exactly the same amount, although of opposite polarity.

Good to Know boxes provide additional information in the margins of the text.

GOOD TO KNOW

As an aid for determining the added charge ($\pm Q$) to a neutral dielectric, use the following equation:

$$\pm Q = \frac{\text{Number of electrons added or removed}}{6.25 \times 10^{18}\ \text{electrons/C}}$$

Example 1-1

A neutral dielectric has 12.5×10^{18} electrons added to it. What is its charge in coulombs?

ANSWER This number of electrons is double the charge of 1 C. Therefore, $-Q = 2$ C.

Section Self-Reviews allow students to check their understanding of the material just presented. They are located at the end of each section within a chapter, with answers at the end of the chapter.

GOOD TO KNOW

Electricity is a form of energy, where energy refers to the ability to do work. More specifically, electrical energy refers to the energy associated with electric charges.

1–1 Self-Review

Answers at the end of the chapter.

a. **Is the charge of an electron positive or negative?**
b **Is the charge of a proton positive or negative?**
c. **Is it true or false that the neutral condition means equal positive and negative charges?**

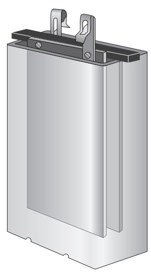
1–2 Electrons and Protons in the Atom

Although there are any number of possible methods by which electrons and protons might be grouped, they assemble in specific atomic combinations for a stable arrangement. (An **atom** is the smallest particle of the basic elements which forms

Examples throughout the text expand on key concepts and offer students a deeper understanding of complex material.

Multisim Icons, identify circuits for which there is a Multisim activity. Multisim files can be found on the Instructor Resources section for Connect.

MultiSim Figure 1–8 Chemical cell as a voltage source. (*a*) Voltage output is the potential difference between the two terminals. (*b*) Schematic symbol of any DC voltage source with constant polarity. Longer line indicates positive side.



(*a*)

then, is a voltage source, or a source of electromotive force (emf). The schematic symbol for a battery or DC voltage source is shown in Fig. 1–8*b*.

Sometimes the symbol E is used for emf, but the standard symbol V represents any potential difference. This applies either to the voltage generated by a source or to the voltage drop across a passive component such as a resistor.

It may be helpful to think of voltage as an electrical pressure or force. The higher the voltage, the more electrical pressure or force. The electrical pressure of voltage is in the form of the attraction and repulsion of an electric charge, such as an electron.

The general equation for any voltage can be stated as

$$V = \frac{W}{Q} \qquad \textbf{(1–1)}$$

where V is the voltage in volts, W is the work or energy in joules, and Q is the charge in coulombs.

Let's take a look at an example.

Example 1-5

What is the output voltage of a battery that expends 3.6 J of energy in moving 0.5 C of charge?

ANSWER Use equation 1–1.

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

After you've read . . .

Real-world **applications** bring to life the concepts covered in a specific chapter.

Application of Ohm's Law and Power Formulas

HOME APPLIANCES

Every electrical appliance in our home has a ***nameplate*** attached to it. The nameplate provides important information about the appliance such as its make and model, its electrical specifications and the Underwriters Laboratories (UL) listing mark. The nameplate is usually located on the bottom or rear-side of the appliance. The electrical specifications listed are usually its power and voltage ratings. The voltage rating is the voltage at which the appliance is designed to operate. The power rating is the power dissipation of the appliance when the rated voltage is applied. With the rated voltage and power ratings listed on the nameplate, we can calculate the current drawn from the appliance when it's being used. To calculate the current (*I*) simply divide the power rating (*P*) in watts by the voltage rating (*V*) in volts. As an example, suppose you want to know how much current your toaster draws when it's toasting your bread. To find the answer you will probably need to turn your toaster rating of 120 V and a power rating of 850 W, the current drawn by the toaster is calculated as follows;

$$I = \frac{P}{V} = \frac{850\ W}{120\ V} = 7.083\ A$$

Some appliances in our homes have a voltage rating of 240 V rather than 120 V. These are typically the appliances with very high power ratings. Some examples include: electric stoves, electric clothes dryers, electric water heaters, and air conditioning units. These appliances may have power ratings as high as 7.2 kW or more. The reason the higher power appliances have a higher voltage rating is simple. At twice the voltage you only need half the current to obtain the desired power. With half as much current, the size of the conductors connecting the appliance to the power line can be kept much smaller. This is important because a smaller diameter wire costs less and is physically much easier to handle.

Each chapter concludes with a **Summary,** a comprehensive recap of the major points and takeaways.

Summary

- Electricity is present in all matter in the form of electrons and protons.
- The electron is the basic particle of negative charge, and the proton is the basic particle of positive charge.
- A conductor is a material in which electrons can move easily from one atom to the next.
- An insulator is a material in which electrons tend to stay in their own orbit. Another name for insulator is dielectric.
- The atomic number of an element gives the number of protons in the nucleus of the atom, balanced by an
- One coulomb (C) of charge is a quantity of electricity corresponding to 6.25×10^{18} electrons or protons. The symbol for charge is *Q*.
- Potential difference or voltage is an electrical pressure or force that exists between two points. The unit of potential difference is the volt (V). $1\ V = \frac{1\ J}{1\ C}$ In general, $V = \frac{W}{Q}$.
- Current is the rate of movement of electric charge. The symbol for current is *I*, and the basic unit of measure is the ampere (A). $1\ A = \frac{1\ C}{1\ s}$ In general, $I = \frac{Q}{T}$
- An electric circuit is a closed path for current flow. A voltage must be connected across a circuit to produce current flow. In the external circuit outside the voltage source, electrons flow from the negative terminal toward the positive terminal.
- A motion of positive charges, in the opposite direction of electron flow, is considered conventional current.
- Voltage can exist without current, but current cannot exist without voltage.
- Direct current has just one direction because a DC voltage source has

Related Formulas are a quick, easy way to locate the important formulas from the chapter.

Related Formulas

$1\ C = 6.25 \times 10^{18}$ electrons

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

$I = Q/T$

$Q = I \times T$

$R = 1/G$

$G = 1/R$

Multiple-Choice Self-Tests at the end of every chapter allow for quick learning assessment.

Self-Test

Answers at the back of the book.

1. The most basic particle of negative charge is the
a. coulomb.
b. electron.
c. proton.
d. neutron.

2. The coulomb is a unit of
a. electric charge.
b. potential difference.
c. current.
d. voltage.

4. The electron valence of a neutral copper atom is
a. +1.
b. 0.
c. ±4.
d. −1.

5. The unit of potential difference is the
a. volt.
b. ampere.
c. siemens.
d. coulomb.

7. In a metal conductor, such as a copper wire,
a. positive ions are the moving charges that provide current.
b. free electrons are the moving charges that provide current.
c. there are no free electrons.
d. none of the above.

8. A 100-Ω resistor has a conductance, *G*, of
a. 0.01 S.
b. 0.1 S.
c. 0.001 S.

Essay Questions

1. Name two good conductors, two good insulators, and two semiconductors.
2. In a metal conductor, what is a free electron?
3. What is the smallest unit of a compound with the same chemical characteristics?
4. Define the term ion.
5. How does the resistance of a conductor compare to that of an insulator?
6. Explain why potential difference is necessary to produce current in a circuit.
7. List three important characteristics of an electric circuit.
8. Describe the difference between an open circuit and a short circuit.
9. Is the power line voltage available in our homes a DC or an AC voltage?
10. What is the mathematical relationship between resistance and conductance?
11. Briefly describe the electric field of a static charge.

The **Essay Questions** at the end of each chapter are great ways to spark classroom discussion, and they make great homework assignments.

End-of-Chapter Problems, organized by chapter section, provide another opportunity for students to check their understanding, and for instructors to hone in on key concepts.

Critical Thinking Problems for each chapter provide students with more challenging problems, allowing them to polish critical skills needed on the job.

Problems

SECTION 1–4 THE COULOMB UNIT OF ELECTRIC CHARGE

1–1 If 31.25×10^{18} electrons are removed from a neutral dielectric, how much charge is stored in coulombs?

1–2 If 18.75×10^{18} electrons are added to a neutral dielectric, how much charge is stored in coulombs?

1–3 A dielectric with a positive charge of +5 C has 18.75×10^{18} electrons added to it. What is the net charge of the dielectric in coulombs?

1–4 If 93.75×10^{18} electrons are removed from a neutral dielectric, how much charge is stored in coulombs?

1–5 If 37.5×10^{18} electrons are added to a neutral dielectric, how much charge is stored in coulombs?

SECTION 1–5 THE VOLT UNIT OF POTENTIAL DIFFERENCE

1–6 What is the output voltage of a battery if 10 J of energy is expended in moving 1.25 C of charge?

1–7 What is the output voltage of a battery if 6 J of energy is expended in moving 1 C of charge?

1–8 What is the output voltage of a battery if 12 J of energy is expended in moving 1 C of charge?

1–9 How much is the potential difference between two points if 0.5 J of energy is required to move 0.4 C of charge between the two points?

1–10 How much energy is expended, in joules, if a voltage of 12 V moves 1.25 C of charge between two points?

SECTION 1–6 CHARGE IN MOTION IS CURRENT

1–11 A charge of 2 C moves past a given point every 0.5 s. How much is the current?

1–12 A charge of 1 C moves past a given point every 0.1 s. How much is the current?

1–13 A charge of 0.05 C moves past a given point every 0.1 s. How much is the current?

1–14 A charge of 6 C moves past a given point every 0.3 s. How much is the current?

1–15 A charge of 0.1 C moves past a given point every 0.01 s. How much is the current?

1–16 If a current of 1.5 A charges a dielectric for 5 s, how much charge is stored in the dielectric?

1–17 If a current of 500 mA charges a dielectric for 2 s, how much charge is stored in the dielectric?

1–18 If a current of 200 μA charges a dielectric for 20 s, how much charge is stored in the dielectric?

SECTION 1–7 RESISTANCE IS OPPOSITION TO CURRENT

1–19 Calculate the resistance value in ohms for the following conductance values: (a) 0.001 S (b) 0.01 S (c) 0.1 S (d) 1 S.

1–20 Calculate the resistance value in ohms for the following conductance values: (a) 0.002 S (b) 0.004 S (c) 0.00833 S (d) 0.25 S.

1–21 Calculate the conductance value in siemens for each of the following resistance values: (a) 200 Ω (b) 100 Ω (c) 50 Ω (d) 25 Ω.

1–22 Calculate the conductance value in siemens for each of the following resistance values: (a) 1 Ω (b) 10 kΩ (c) 40 Ω (d) 0.5 Ω.

Critical Thinking

1–23 Suppose that 1000 electrons are removed from a neutral dielectric. How much charge, in coulombs, is stored in the dielectric?

1–24 How long will it take an insulator that has a charge of +5 C to charge to +30 C if the charging current is 2 A?

1–25 Assume that 6.25×10^{15} electrons flow past a given point in a conductor every 10 s. Calculate the current I in amperes.

1–26 The conductance of a wire at 100°C is one-tenth its value at 25°C. If the wire resistance equals 10 Ω at 25°C calculate the resistance of the wire at 100°C.

Laboratory Application Assignment

In your first lab application assignment you will use a DMM to measure the voltage, current, and resistance in Fig. 1–22. Refer to Section 1–12, "The Digital Multimeter," if necessary.

Equipment: Obtain the following items from your instructor.

- Variable dc power supply
- 1-kΩ, ½-W resistor
- DMM
- Connecting leads

Measuring Voltage

Set the DMM to measure DC voltage. Be sure the meter leads are inserted into the correct jacks (red lead in the VΩ jack and the black lead in the COM jack). Also, be sure the voltmeter range exceeds the voltage being measured. Connect the DMM test leads to the variable DC power supply as shown in Fig. 1–22*a*. Adjust the variable DC power supply voltage to any value between 5 and 15 V. Record your measured voltage. V = __________ Note: Keep the power supply voltage set to this value when measuring the current in Fig. 1–22*c*.

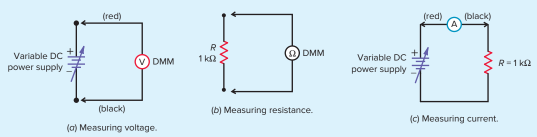
Measuring Resistance

Disconnect the meter leads from the power supply terminals. Set the DMM to measure resistance. Keep the meter leads in the same jacks you used for measuring voltage. Connect the DMM test leads to the leads of the 1 kΩ resistor, as shown in Fig. 1–22*b*. Record your measured resistance. R = __________ (The measured resistance will most likely be displayed as a decimal fraction in kΩ.)

Measuring Current

Set the DMM to measure DC current. Also, move the red test lead to the appropriate jack for measuring small DC currents (usually labeled mA). Turn off the variable DC power supply. Connect the red test lead of the DMM to the positive (+) terminal of the variable DC power supply as shown in Fig. 1–22*c*. Also, connect the black test lead of the DMM to one lead of the 1 kΩ resistor as shown. Finally, connect the other lead of the resistor to the negative (−) terminal of the variable DC power supply. Turn on the variable DC power supply. Record your measured current. I = __________

Figure 1–22 Measuring electrical quantities. (*a*) Measuring voltage. (*b*) Measuring resistance. (*c*) Measuring current.



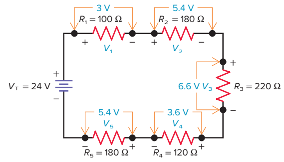
Laboratory Application Assignments, reinforce one or more of the chapter's main topics by asking students to build and test circuits in a laboratory environment.

Troubleshooting Challenges appear in selected chapters to give students a feel for troubleshooting real circuits, again providing real-world applications of chapter content.

Troubleshooting Challenge

Table 4–1 shows voltage measurements taken in Fig. 4–50. The first row shows the normal values that exist when the circuit is operating properly. Rows 2 to 15 are voltage measurements taken when one component in the circuit has failed. For each row, identify which component is defective and determine the type of defect that has occurred in the component.

Figure 4–50 Circuit diagram for Troubleshooting Challenge. Normal values for V_1, V_2, V_3, V_4, and V_5 are shown on schematic.



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About the Author

Mitchel E. Schultz is an instructor at Western Technical College in La Crosse, Wisconsin, where he has taught electronics for the past 31 years. Prior to teaching at Western, he taught electronics for 8 years at Riverland Community College in Austin, Minnesota. He has also provided training for a variety of different electronic industries over the past 39 years.

Before he began teaching, Mitchel worked for several years as an electronic technician. His primary work experience was in the field of electronic communication, which included designing, testing, and troubleshooting rf communications systems. Mitchel graduated in 1978 from Minnesota State, Southeast Technical College, where he earned an Associate's Degree in Electronics Technology. He also attended Winona State University, Mankato State University, and the University of Minnesota. He is an ISCET Certified Electronics Technician and also holds his Extra Class Amateur Radio License.

Mitchel has authored and/or co-authored several other electronic textbooks which include Problems Manual for use with Grob's Basic Electronics, Electric Circuits: A Text and Software Problems Manual, Electronic Devices: A Text and Software Problems Manual, Basic Mathematics for Electricity and Electronics, *and* Shaum's Outline of Theory and Problems of Electronic Communication.

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Electric Shock—Dangers, Precautions, and First Aid

Electricity is a form of energy that provides an endless number of useful functions in our daily lives. However, no matter how useful electricity may be, it can also be very dangerous. Perhaps the greatest danger is from an electric shock. If a person comes into contact with a "live" conductor or circuit, it only takes a small amount of current through the human body to paralyze the victim, making it impossible for him or her to let go. A current in excessive of about $\frac{1}{100}$ of an Ampere (A), which is the basic unit of current, is about all it takes. If the current approaches $\frac{1}{10}$ of an Ampere, or more, the shock can be fatal. The danger of electric shock increases with higher voltages because a higher voltage can produce more current through the skin and internal organs. Lower voltages, such as those associated with AA or AAA batteries, for example, can be handled with little or no danger because the resistance of human skin is normally high enough to keep the current well below the threshold of sensation. However, when a person's skin is moist or cut, the resistance to the flow of current decreases drastically. When this happens, even moderate voltages can produce an electric shock. Therefore, safe practices must always be followed when working in and around electric circuits to avoid accidental electric shock, fires, and explosions.

Guideline of Safe Practices

The following is a list of ***safe practices*** that will help protect you and your fellow classmates while performing experiments in the laboratory. These same rules apply to those individuals working in industry. It is a good idea to review these safe practices from time to time so that you are reminded of their importance.

1. Never work on electrical equipment and/or machinery if you are under the influence of either drugs or alcohol.
2. Never work on electrical equipment and/or machinery if the lighting is poor or insufficient.
3. Never work on electrical equipment and/or machinery if your shoes and/or clothing are wet.
4. Wear rubber-soled shoes or stand on an insulated mat when working on electrical equipment.
5. If possible, never work alone.
6. Avoid wearing any metal objects such as bracelets, rings, necklaces, etc., when working in and around electric circuits.
7. Never assume that the power applied to a circuit is off! Either unplug the equipment you are working on or use a known-good meter to check for power.
8. Measure voltages with one hand in your pocket or behind your back when possible.
9. Do not remove safety grounds on three-prong power plugs and never use AC adapters to defeat the ground connection on any electrical equipment.
10. Power cords should always be checked before use. If the insulation is cracked or cut, they should not be used until they are properly repaired.

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Figure S-1 Safety glasses are required when soldering and/or de-soldering.

Monty Rakusen/Cultura/Getty Images

Figure S-2 Lockout-tagout (LOTO) procedure used in industry.

alacatr/iStock/Getty Images

11. Wear eye protection (safety glasses or goggles) when appropriate, especially when soldering, de-soldering, or clipping wires and/or wire leads. See Fig. S-1.
12. Avoid having liquids such as water, coffee, or soda at your workstation or around electrical equipment or machinery in general. Liquids are excellent conductors of electricity and therefore increase the risk of electric shock.
13. When possible, use a **lockout-tagout** (LOTO) procedure when working on electrical equipment and/or machinery. See Fig. S-2. Lockout-tagout or lock and tag is a safety procedure that is used in laboratory, industrial, and research settings. LOTO ensures that dangerous machines are properly shut off and are not able to be started up again prior to the completion of maintenance or repair work.
14. Some components, like capacitors, can store a lethal electric charge and should be fully discharged before repairing and/or replacing components or modules in an electronic system.
15. Never override any safety devices, such as an **interlock** switch, when working on electrical equipment and/or machinery. An **interlock** switch (usually a micro switch) is a switch that shuts off power to components (motors and lamps, for example) if a machine is opened. The purpose of an interlock switch is to prevent injury if someone inadvertently attempts to open a machine while it is still powered up and running. An interlock switch is sometimes called a "safety switch."
16. Keep your work station or work area organized and clean. A cluttered, disorganized work area is hazardous.
17. Be sure to secure loose-fitting clothing and ties when working near rotating machinery.
18. Make sure you know the proper procedures and potential safety hazards before working on any equipment, either electrical or mechanical.
19. Keep all tools and test equipment in good working condition. Be sure to regularly inspect the insulation on the handles of tools as well as the insulation on both test leads and insulated probes.
20. In a laboratory or industrial setting, be sure you know the location of the circuit breaker panel or main power-off switch so you can turn off power quickly, if necessary.
21. Know the location and operation of all fire alarms and fire extinguishers.
22. Know the location of all emergency exits.
23. Do not indulge in horseplay or practical jokes in the laboratory.
24. Know the location of the first-aid kit. If an accident should occur, notify your instructor and/or supervisor immediately.
25. Take a careful and deliberate approach to each task while working in the lab.

First Aid

The danger from an electric shock depends on

- The type of current (AC or DC)
- The amount of voltage present
- How the current traveled through the person's body
- The person's overall health
- How quickly the person receives treatment

An electric shock may cause minor to severe burns or leave no visible mark at all. Either way, an electric current can cause internal damage, including cardiac arrest or other injuries. Even a small amount of electricity through the body can be fatal under certain circumstances.

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A person who has suffered an injury from contact with electricity should ALWAYS see a doctor!

If you are trying to help a person who is suffering from an electric shock, follow these guidelines:

- Do not touch them if they are still in contact with the source of electricity.
- Stay at least 20 feet away from any high-voltage wires until the power has been turned off.
- Don't move the person unless they are in immediate danger.

Call 911 if the injured person experiences the following:

- Injuries from a high-voltage wire or lightning
- Severe burns
- Confusion
- Loss of consciousness
- Breathing difficulty
- Cardiac arrest
- Muscle pain and contractions
- Heart rhythm problems
- Seizures

Take these actions immediately while waiting for medical help:

- If possible, turn off the electricity. If not, use a dry, nonconducting object (cardboard, plastic, or wood) to move the source away from you and the injured person.
- If there are no signs of circulation (breathing, coughing, or movement) begin CPR.
- Keep the injured person from becoming chilled.
- Cover any burned areas with a sterile gauze bandage, if possible. Otherwise use a clean cloth. Don't use a towel or blanket, as the loose fibers can stick to the burns.

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Grob's Basic Electronics

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I

Introduction to Powers of 10

The electrical quantities you will encounter while working in the field of electronics are often extremely small or extremely large. For example, it is not at all uncommon to work with extremely small decimal numbers such as 0.000000000056 or extremely large numbers such as 1,296,000,000. To enable us to work conveniently with both very small and very large numbers, powers of 10 notation is used. With powers of 10 notation, any number, no matter how small or large, can be expressed as a decimal number multiplied by a power of 10. A power of 10 is an exponent written above and to the right of 10, which is called the base. The power of 10 indicates how many times the base is to be multiplied by itself. For example, 10^3 means $10 \times 10 \times 10$ and 10^6 means $10 \times 10 \times 10 \times 10 \times 10 \times 10$. In electronics, the base 10 is common because multiples of 10 are used in the metric system of units.

Scientific and engineering notation are two common forms of powers of 10 notation. In electronics, engineering notation is generally more common than scientific notation because it ties in directly with the metric prefixes so often used. When a number is written in standard form without using any form of powers of 10 notation, it is said to be written in decimal notation (sometimes referred to as floating decimal notation). When selecting a calculator for solving problems in electronics, be sure to choose one that can display the answers in decimal, scientific, and engineering notation. ■

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Chapter Outline

Chapter Objectives

After studying this chapter, you should be able to

- *Express* any number in scientific or engineering notation.
- *List* the metric prefixes and their corresponding powers of 10.
- *Change* a power of 10 in engineering notation to its corresponding metric prefix.
- *Convert* between metric prefixes.
- *Add* and *subtract* numbers expressed in powers of 10 notation.
- *Multiply* and *divide* numbers expressed in powers of 10 notation.
- *Determine* the reciprocal of a power of 10.
- *Find* the square of a number expressed in powers of 10 notation.
- *Find* the square root of a number expressed in powers of 10 notation.
- *Enter* numbers written in scientific and engineering notation into your calculator.

Important Terms

decimal notation
engineering notation
metric prefixes
powers of 10
scientific notation

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I–1 Scientific Notation

Table I–1	Powers of 10
	$1{,}000{,}000{,}000 = 10^9$
	$100{,}000{,}000 = 10^8$
	$10{,}000{,}000 = 10^7$
	$1{,}000{,}000 = 10^6$
	$100{,}000 = 10^5$
	$10{,}000 = 10^4$
	$1{,}000 = 10^3$
	$100 = 10^2$
	$10 = 10^1$
	$1 = 10^0$
	$0.1 = 10^{-1}$
	$0.01 = 10^{-2}$
	$0.001 = 10^{-3}$
	$0.0001 = 10^{-4}$
	$0.00001 = 10^{-5}$
	$0.000001 = 10^{-6}$
	$0.0000001 = 10^{-7}$
	$0.00000001 = 10^{-8}$
	$0.000000001 = 10^{-9}$
	$0.0000000001 = 10^{-10}$
	$0.00000000001 = 10^{-11}$
	$0.000000000001 = 10^{-12}$

Before jumping directly into **scientific notation**, let's take a closer look at **powers of 10**. A power of 10 is an exponent of the base 10 and can be either positive or negative.

Base ⟶ 10^X ⟵ Exponent

Positive powers of 10 are used to indicate numbers greater than 1, whereas negative powers of 10 are used to indicate numbers less than 1. Table I–1 shows the powers of 10 ranging from 10^{-12} to 10^9 and their equivalent decimal values. In electronics, you will seldom work with powers of 10 outside this range. From Table I–1, notice that $10^0 = 1$ and that $10^1 = 10$. In the case of $10^0 = 1$, it is important to realize that any number raised to the zero power equals 1. In the case of $10^1 = 10$, it is important to note that any number written without a power is assumed to have a power of 1.

Expressing a Number in Scientific Notation

The procedure for using any form of powers of 10 notation is to write the original number as two separate factors. Scientific notation is a form of powers of 10 notation in which a number is expressed as a number between 1 and 10 times a power of 10. The power of 10 is used to place the decimal point correctly. The power of 10 indicates the number of places by which the decimal point has been moved to the left or right in the original number. If the decimal point is moved to the left in the original number, then the power of 10 will increase or become more positive. Conversely, if the decimal point is moved to the right in the original number then the power of 10 will decrease or become more negative. Let's take a look at an example.

Example I-1

Express the following numbers in scientific notation: (a) 3900 (b) 0.0000056.

ANSWER (a) To express 3900 in scientific notation, write the number as a number between 1 and 10, which is 3.9 in this case, times a power of 10. To do this, the decimal point must be shifted three places to the left. The number of places by which the decimal point is shifted to the left indicates the positive power of 10. Therefore, $3900 = 3.9 \times 10^3$ in scientific notation.

(b) To express 0.0000056 in scientific notation, write the number as a number between 1 and 10, which is 5.6 in this case, times a power of 10. To do this, the decimal point must be shifted six places to the right. The number of places by which the decimal point is shifted to the right indicates the negative power of 10. Therefore, $0.0000056 = 5.6 \times 10^{-6}$ in scientific notation.

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When expressing a number in scientific notation, remember the following rules:

Rule 1: Express the number as a number between 1 and 10 times a power of 10.

Rule 2: If the decimal point is moved to the left in the original number, make the power of 10 positive. If the decimal point is moved to the right in the original number, make the power of 10 negative.

Rule 3: The power of 10 always equals the number of places by which the decimal point has been shifted to the left or right in the original number.

Let's try another example.

Example I-2

Express the following numbers in scientific notation: (a) 235,000 (b) 364,000,000 (c) 0.000756 (d) 0.00000000000016.

ANSWER (a) To express the number 235,000 in scientific notation, move the decimal point five places to the left, which gives us a number of 2.35. Next, multiply this number by 10^5. Notice that the power of 10 is a positive 5 because the decimal point was shifted five places to the left in the original number. Therefore, $235{,}000 = 2.35 \times 10^5$ in scientific notation.

(b) To express 364,000,000 in scientific notation, move the decimal point eight places to the left, which gives us a number of 3.64. Next, multiply this number by 10^8. Notice that the power of 10 is a positive 8 because the decimal point was shifted eight places to the left in the original number. Therefore, $364{,}000{,}000 = 3.64 \times 10^8$ in scientific notation.

(c) To express 0.000756 in scientific notation, move the decimal point four places to the right, which gives us a number of 7.56. Next, multiply this number by 10^{-4}. Notice that the power of 10 is a negative 4 because the decimal point was shifted four places to the right in the original number. Therefore, $0.000756 = 7.56 \times 10^{-4}$.

(d) To express 0.00000000000016 in scientific notation, move the decimal point 13 places to the right, which gives us a number of 1.6. Next, multiply this number by 10^{-13}. Notice that the power of 10 is a negative 13 because the decimal point was shifted thirteen places to the right in the original number. Therefore, $0.00000000000016 = 1.6 \times 10^{-13}$ in scientific notation.

Decimal Notation

Numbers written in standard form without using any form of powers of 10 notation are said to be written in **decimal notation**, sometimes called floating decimal notation. In some cases, it may be necessary to change a number written in scientific notation into decimal notation. When converting from scientific to decimal notation, observe the following rules:

Rule 4: If the exponent or power of 10 is positive, move the decimal point to the right, the same number of places as the exponent.

Rule 5: If the exponent or power of 10 is negative, move the decimal point to the left, the same number of places as the exponent.

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Example I–3

Convert the following numbers written in scientific notation into decimal notation: (a) 4.75×10^2 (b) 6.8×10^{-5}.

ANSWER (a) To convert 4.75×10^2 into decimal notation, the decimal point must be shifted two places to the right. The decimal point is shifted to the right because the power of 10, which is 2 in this case, is positive. Therefore, $4.75 \times 10^2 = 475$ in decimal notation.

(b) To convert 6.8×10^{-5} into decimal notation, the decimal point must be shifted five places to the left. The decimal point is shifted to the left because the power of 10, which is −5 in this case, is negative. Therefore, $6.8 \times 10^{-5} = 0.000068$ in decimal notation.

I–1 *Self-Review*

Answers at the end of the chapter.

a. Are positive or negative powers of 10 used to indicate numbers less than 1?
b. Are positive or negative powers of 10 used to indicate numbers greater than 1?
c. $10^0 = 1$. (True/False)
d. Express the following numbers in scientific notation: (a) 13,500 (b) 0.00825 (c) 95,600,000 (d) 0.104.
e. Convert the following numbers written in scientific notation into decimal notation: (a) 4.6×10^{-7} (b) 3.33×10^3 (c) 5.4×10^8 (d) 2.54×10^{-2}.

I–2 Engineering Notation and Metric Prefixes

Engineering notation is another form of powers of 10 notation. Engineering notation is similar to scientific notation except that in engineering notation, the powers of 10 are always multiples of 3 such as 10^{-12}, 10^{-9}, 10^{-6}, 10^{-3}, 10^3, 10^6, 10^9, 10^{12}, etc. More specifically, a number expressed in engineering notation is always expressed as a number between 1 and 1000 times a power of 10 which is a multiple of 3.

Example I–4

Express the following numbers in engineering notation: (a) 27,000 (b) 0.00047.

ANSWER (a) To express the number 27,000 in engineering notation, it must be written as a number between 1 and 1000 times a power of 10 which is a multiple of 3. It is often helpful to begin by expressing the number in scientific notation: $27{,}000 = 2.7 \times 10^4$. Next, examine the power of 10 to see if it should be increased to 10^6 or decreased to 10^3. If the power of 10 is increased to 10^6, then the decimal point in the number 2.7 would have to be shifted two places to the left.

Because 0.027 is not a number between 1 and 1000, the answer of 0.027×10^6 is not representative of engineering notation. If the power of 10 were decreased to 10^3, however, then the decimal point in the number 2.7 would have to be shifted one place to the right and the answer would be 27×10^3, which is representative of engineering notation. In summary, $27{,}000 = 2.7 \times 10^4 = 27 \times 10^3$ in engineering notation.

(b) To express the number 0.00047 in engineering notation, it must be written as a number between 1 and 1000 times a power of 10 which is a multiple of 3. Begin by expressing the number in scientific notation: $0.00047 = 4.7 \times 10^{-4}$. Next, examine the power of 10 to see if it should be increased to 10^{-3} or decreased to 10^{-6}. If the power of 10 were increased to 10^{-3}, then the decimal point in the number 4.7 would have to be shifted one place to the left. Because 0.47 is not a number between 1 and 1000, the answer 0.47×10^{-3} is not representative of engineering notation. If the power of 10 were decreased to 10^{-6}, however, then the decimal point in the number 4.7 would have to be shifted two places to the right and the answer would be 470×10^{-6} which is representative of engineering notation. In summary, $0.00047 = 4.7 \times 10^{-4} = 470 \times 10^{-6}$ in engineering notation.

When expressing a number in engineering notation, remember the following rules:

Rule 6: Express the original number in scientific notation first. If the power of 10 is a multiple of 3, the number appears the same in both scientific and engineering notation.

Rule 7: If the original number expressed in scientific notation does not use a power of 10 which is a multiple of 3, the power of 10 must either be increased or decreased until it is a multiple of 3. The decimal point in the numerical part of the expression must be adjusted accordingly to compensate for the change in the power of 10.

Rule 8: Each time the power of 10 is increased by 1, the decimal point in the numerical part of the expression must be moved one place to the left. Each time the power of 10 is decreased by 1, the decimal point in the numerical part of the expression must be moved one place to the right.

You know that a quantity is expressed in engineering notation when the original number is written as a number between 1 and 1000 times a power of 10 which is a multiple of 3.

Metric Prefixes

The **metric prefixes** represent those powers of 10 that are multiples of 3. In the field of electronics, engineering notation is much more common than scientific notation because most values of voltage, current, resistance, power, and so on are specified in terms of the metric prefixes. Once a number is expressed in engineering notation, its power of 10 can be replaced directly with its corresponding metric prefix. Table I–2 lists the most common metric prefixes and their corresponding powers of 10. Notice

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GOOD TO KNOW

The uppercase letter K is not used as the abbreviation for the metric prefix kilo because its use is reserved for the kelvin unit of absolute temperature.

Table I–2 Metric Prefixes

Power of 10	Prefix	Abbreviation
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

that uppercase letters are used for the abbreviations of the prefixes involving positive powers of 10, whereas lowercase letters are used for negative powers of 10. There is one exception to the rule however; the lowercase letter "k" is used for kilo corresponding to 10^3. Because the metric prefixes are used so often in electronics, it is common practice to express the value of a given quantity in engineering notation first so that the power of 10, which is a multiple of 3, can be replaced directly with its corresponding metric prefix. For example, a resistor whose value is 33,000 Ω can be expressed in engineering notation as 33×10^3 Ω. In Table I–2, we see that the metric prefix kilo (k) corresponds to 10^3. Therefore, 33,000 Ω or 33×10^3 Ω can be expressed as 33 kΩ. (Note that the unit of resistance is the ohm abbreviated Ω.) As another example, a current of 0.0000075 A can be expressed in engineering notation as 7.5×10^{-6} A. In Table I–2, we see that the metric prefix micro (μ) corresponds to 10^{-6}. Therefore, 0.0000075 A or 7.5×10^{-6} A can be expressed as 7.5 μA. (The unit of current is the ampere, abbreviated A.)

In general, when using metric prefixes to express the value of a given quantity, write the original number in engineering notation first and then substitute the appropriate metric prefix corresponding to the power of 10 involved. As this technique shows, metric prefixes are direct substitutes for the powers of 10 used in engineering notation.

Table I–3 lists many of the electrical quantities that you will encounter in your study of electronics. For each electrical quantity listed in Table I–3, take special note

Table I–3 Electrical Quantities with Their Units and Symbols

Quantity	Unit	Symbol
Current	Ampere (A)	I
Voltage	Volt (V)	V
Resistance	Ohm (Ω)	R
Frequency	Hertz (Hz)	f
Capacitance	Farad (F)	C
Inductance	Henry (H)	L
Power	Watt (W)	P

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of the unit and symbol shown. In the examples and problems that follow, we will use several numerical values with various symbols and units from this table. Let's take a look at a few examples.

Example I–5

Express the resistance of 1,000,000 Ω using the appropriate metric prefix from Table I–2.

ANSWER First, express 1,000,000 Ω in engineering notation: 1,000,000 Ω = 1.0×10^6 Ω. Next, replace 10^6 with its corresponding metric prefix. Because the metric prefix mega (M) corresponds to 10^6, the value of 1,000,000 Ω can be expressed as 1 MΩ. In summary, 1,000,000 Ω = 1.0×10^6 Ω = 1 MΩ.

Example I–6

Express the voltage value of 0.015 V using the appropriate metric prefix from Table I–2.

ANSWER First, express 0.015 V in engineering notation: 0.015 V = 15×10^{-3} V. Next, replace 10^{-3} with its corresponding metric prefix. Because the metric prefix milli (m) corresponds to 10^{-3}, the value 0.015 V can be expressed as 15 mV. In summary, 0.015 V = 15×10^{-3} V = 15 mV.

Example I–7

Express the power value of 250 W using the appropriate metric prefix from Table I–2.

ANSWER In this case, it is not necessary or desirable to use any of the metric prefixes listed in Table I–2. The reason is that 250 W cannot be expressed as a number between 1 and 1000 times a power of 10 which is a multiple of 3. In other words, 250 W cannot be expressed in engineering notation. The closest we can come is 0.25×10^3 W, which is not representative of engineering notation. Although 10^3 can be replaced with the metric prefix kilo (k), it is usually preferable to express the power as 250 W and not as 0.25 kW.

In summary, whenever the value of a quantity lies between 1 and 1000, only the basic unit of measure should be used for the answer. As another example, 75 V should be expressed as 75 V and not as 0.075 kV or 75,000 mV, and so forth.

I–2 Self-Review

Answers at the end of the chapter.

a. Express the following numbers in engineering notation: (a) 36,000,000 (b) 0.085 (c) 39,300 (d) 0.000093.

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b. **List the metric prefixes for each of the powers of 10 listed: (a) 10^{-9} (b) 10^{6} (c) 10^{-12} (d) 10^{3} (e) 10^{4}.**
c. **Express the following values using the appropriate metric prefixes: (a) 0.000010 A (b) 2,200,000 Ω (c) 0.000000045 V (d) 5600 Ω (e) 18 W.**

I–3 Converting between Metric Prefixes

As you have seen in the previous section, metric prefixes can be substituted for powers of 10 that are multiples of 3. This is true even when the value of the original quantity is not expressed in proper engineering notation. For example, a capacitance value of 0.047×10^{-6} F could be expressed as 0.047 μF. Also, a frequency of 1510×10^{3} Hz could be expressed as 1510 kHz. Furthermore, the values of like quantities in a given circuit may be specified using different metric prefixes such as 22 kΩ and 1.5 MΩ or 0.001 μF and 3300 pF, as examples. In some cases, therefore, it may be necessary or desirable to convert from one metric prefix to another when combining values. Converting from one metric prefix to another is actually a change in the power of 10. When the power of 10 is changed, however, care must be taken to make sure that the numerical part of the expression is also changed so that the value of the original number remains the same. When converting from one metric prefix to another, observe the following rule:

Rule 9: When converting from a larger metric prefix to a smaller one, increase the numerical part of the expression by the same factor by which the metric prefix has been decreased. Conversely, when converting from a smaller metric prefix to a larger one, decrease the numerical part of the expression by the same factor by which the metric prefix has been increased.

Example I–8

Make the following conversions: (a) convert 25 mA to μA (b) convert 2700 kΩ to MΩ.

ANSWER (a) To convert 25 mA to μA, recall that the metric prefix milli (m) corresponds to 10^{-3} and that metric prefix micro (μ) corresponds to 10^{-6}. Since 10^{-6} is less than 10^{-3} by a factor of 1000 (10^{3}), the numerical part of the expression must be increased by a factor of 1000 (10^{3}). Therefore, 25 mA = 25×10^{-3} A = $25{,}000 \times 10^{-6}$ A = 25,000 μA.

(b) To convert 2700 kΩ to MΩ, recall that the metric prefix kilo (k) corresponds to 10^{3} and that the metric prefix mega (M) corresponds to 10^{6}. Since 10^{6} is larger than 10^{3} by a factor of 1000 (10^{3}), the numerical part of the expression must be decreased by a factor of 1000 (10^{3}). Therefore, 2700 kΩ = 2700×10^{3} Ω = 2.7×10^{6} Ω = 2.7 MΩ.

I–3 Self-Review

Answers at the end of the chapter.

a. **Converting from one metric prefix to another is actually a change in the power of 10. (True/False)**
b. **Make the following conversions: (a) convert 2.2 MΩ to kΩ (b) convert 47,000 pF to nF (c) convert 2500 μA to mA (d) convert 6.25 mW to μW.**

I–4 Addition and Subtraction Involving Powers of 10 Notation

When adding or subtracting numbers expressed in powers of 10 notation, observe the following rule:

Rule 10: Before numbers expressed in powers of 10 notation can be added or subtracted, both terms must be expressed using the same power of 10. When both terms have the same power of 10, just add or subtract the numerical parts of each term and multiply the sum or difference by the power of 10 common to both terms. Express the final answer in the desired form of powers of 10 notation.

Let's take a look at a couple of examples.

Example I–9

Add 170×10^3 and 23×10^4. Express the final answer in scientific notation.

ANSWER First, express both terms using either 10^3 or 10^4 as the common power of 10. Either one can be used. In this example, we will use 10^3 as the common power of 10 for both terms. Rewriting 23×10^4 using 10^3 as the power of 10 gives us 230×10^3. Notice that because the power of 10 was decreased by a factor of 10, the numerical part of the expression was increased by a factor of 10. Next, add the numerical parts of each term and multiply the sum by 10^3 which is the power of 10 common to both terms. This gives us $(170 + 230) \times 10^3$ or 400×10^3. Expressing the final answer in scientific notation gives us 4.0×10^5. In summary, $(170 \times 10^3) + (23 \times 10^4) = (170 \times 10^3) + (230 \times 10^3) = (170 + 230) \times 10^3 = 400 \times 10^3 = 4.0 \times 10^5$.

Example I–10

Subtract 250×10^3 from 1.5×10^6. Express the final answer in scientific notation.

ANSWER First, express both terms using either 10^3 or 10^6 as the common power of 10. Again, either one can be used. In this example, we will use 10^6 as the common power of 10 for both terms. Rewriting 250×10^3 using 10^6 as the power of 10 gives us 0.25×10^6. Notice that because the power of 10 was increased by a factor 1000 (10^3), the numerical part of the expression was decreased by a factor of 1000 (10^3). Next, subtract 0.25 from 1.5 and multiply the difference by 10^6, which is the power of 10 common to both terms. This gives us $(1.5 - 0.25) \times 10^6$ or 1.25×10^6. Notice that the final answer is already in scientific notation. In summary, $(1.5 \times 10^6) - (250 \times 10^3) = (1.5 \times 10^6) - (0.25 \times 10^6) = (1.5 - 0.25) \times 10^6 = 1.25 \times 10^6$.

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I–4 Self-Review

Answers at the end of the chapter.

a. **Add the following terms expressed in powers of 10 notation. Express the answers in scientific notation. (a) $(470 \times 10^4) + (55 \times 10^6)$ (b) $(3.5 \times 10^{-2}) + (1500 \times 10^{-5})$.**

b. **Subtract the following terms expressed in powers of 10 notation. Express the answers in scientific notation. (a) $(65 \times 10^4) - (200 \times 10^3)$ (b) $(850 \times 10^{-3}) - (3500 \times 10^{-4})$.**

I–5 Multiplication and Division Involving Powers of 10 Notation

When multiplying or dividing numbers expressed in powers of 10 notation, observe the following rules:

Rule 11: When multiplying numbers expressed in powers of 10 notation, multiply the numerical parts and powers of 10 separately. When multiplying powers of 10, simply add the exponents to obtain the new power of 10. Express the final answer in the desired form of powers of 10 notation.

Rule 12: When dividing numbers expressed in powers of 10 notation, divide the numerical parts and powers of 10 separately. When dividing powers of 10, subtract the power of 10 in the denominator from the power of 10 in the numerator. Express the final answer in the desired form of powers of 10 notation.

Let's take a look at a few examples.

Example I–11

Multiply (3×10^6) by (150×10^2). Express the final answer in scientific notation.

ANSWER First, multiply 3×150 to obtain 450. Next, multiply 10^6 by 10^2 to obtain $10^6 \times 10^2 = 10^{6+2} = 10^8$. To review, $(3 \times 10^6) \times (150 \times 10^2) = (3 \times 150) \times (10^6 \times 10^2) = 450 \times 10^{6+2} = 450 \times 10^8$. The final answer expressed in scientific notation is 4.5×10^{10}.

Example I–12

Divide (5.0×10^7) by (2.0×10^4). Express the final answer in scientific notation.

ANSWER First, divide 5 by 2 to obtain 2.5. Next, divide 10^7 by 10^4 to obtain $10^{7-4} = 10^3$. To review, $\frac{5.0 \times 10^7}{2.0 \times 10^4} = \frac{5}{2} \times \frac{10^7}{10^4} = 2.5 \times 10^3$. Notice that the final answer is already in scientific notation.

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I–5 *Self-Review*

Answers at the end of the chapter.

a. **Multiply the following numbers expressed in powers of 10 notation. Express your answers in scientific notation. (a) $(3.3 \times 10^{-2}) \times (4.0 \times 10^{-3})$ (b) $(2.7 \times 10^{2}) \times (3 \times 10^{-5})$.**

b. **Divide the following numbers expressed in powers of 10 notation. Express your answers in scientific notation. (a) $(7.5 \times 10^{8}) \div (3.0 \times 10^{4})$ (b) $(15 \times 10^{-6}) \div (5 \times 10^{-3})$.**

I–6 Reciprocals with Powers of 10

Taking the reciprocal of a power of 10 is really just a special case of division using powers of 10 because 1 in the numerator can be written as 10^0 since $10^0 = 1$. With zero as the power of 10 in the numerator, taking the reciprocal results in a sign change for the power of 10 in the denominator. Let's take a look at an example to clarify this point.

Example I-13

Find the reciprocals for the following powers of 10: (a) 10^5 (b) 10^{-3}.

ANSWER (a) $\frac{1}{10^5} = \frac{10^0}{10^5} = 10^{0-5} = 10^{-5}$; therefore, $\frac{1}{10^5} = 10^{-5}$.

(b) $\frac{1}{10^{-3}} = \frac{10^0}{10^{-3}} = 10^{0-(-3)} = 10^3$; therefore, $\frac{1}{10^{-3}} = 10^3$.

Notice that in both (a) and (b), the power of 10 in the denominator is subtracted from zero, which is the power of 10 in the numerator.

Here's a simple rule for reciprocals of powers of 10.

Rule 13: When taking the reciprocal of a power of 10, simply change the sign of the exponent or power of 10.

Negative Powers of 10

Recall that a power of 10 indicates how many times the base, 10, is to be multiplied by itself. For example, $10^4 = 10 \times 10 \times 10 \times 10$. But you might ask how this definition fits with negative powers of 10. The answer is that negative powers of 10 are just reciprocals of positive powers of 10. For example, $10^{-4} = \frac{1}{10^4} = \frac{1}{10 \times 10 \times 10 \times 10}$.

I–6 *Self-Review*

Answers at the end of the chapter.

a. **Take the reciprocals of each of the powers of 10 listed. (a) 10^{-4} (b) 10^{9} (c) 10^{-18} (d) 10^{0}.**

I–7 Squaring Numbers Expressed in Powers of 10 Notation

When squaring a number expressed in powers of 10 notation, observe the following rule:

Rule 14: To square a number expressed in powers of 10 notation, square the numerical part of the expression and double the power of 10. Express the answer in the desired form of powers of 10 notation.

Example I–14

Square 3.0×10^4. Express the answer in scientific notation.

ANSWER First, square 3.0 to obtain 9.0. Next, square 10^4 to obtain $(10^4)^2 = 10^8$. Therefore, $(3.0 \times 10^4)^2 = 9.0 \times 10^8$.

I–7 *Self-Review*

Answers at the end of the chapter.

a. Obtain the following answers and express them in scientific notation. (a) $(4.0 \times 10^{-2})^2$ (b) $(6.0 \times 10^5)^2$ (c) $(2.0 \times 10^{-3})^2$.

I–8 Square Roots of Numbers Expressed in Powers of 10 Notation

When taking the square root of a number expressed in powers of 10 notation, observe the following rule:

Rule 15: To find the square root of a number expressed in powers of 10 notation, take the square root of the numerical part of the expression and divide the power of 10 by 2. Express the answer in the desired form of powers of 10 notation.

Example I–15

Find the square root of 4×10^6. Express the answer in scientific notation.

ANSWER $\sqrt{4 \times 10^6} = \sqrt{4} \times \sqrt{10^6} = 2 \times 10^3$

Notice that the answer is already in scientific notation.

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Example I–16

Find the square root of 90×10^5. Express the answer in scientific notation.

ANSWER The problem can be simplified if we increase the power of 10 from 10^5 to 10^6 and decrease the numerical part of the expression from 90 to 9. This gives us $\sqrt{90 \times 10^5} = \sqrt{9 \times 10^6} = \sqrt{9} \times \sqrt{10^6} = 3.0 \times 10^3$. Again, the answer is already in scientific notation.

Figure I–1 Scientific calculator (Sharp EL–531 X).

Sarah Schultz Photography

GOOD TO KNOW

When entering the number 25×10^{-6}, *do not* press the multiplication (×) key and then enter the number 10 prior to pressing the [EXP] key. If you do, the number you are intending to enter (25×10^{-6}) will be larger than it should be by a factor of 10. Since pressing the [EXP] key is equivalent to entering $\times 10^{00}$, you do not have to duplicate these steps! If you enter ×10 prior to pressing the [EXP] key, this is what you have actually entered: $25 \times 10 \times 10^{-6}$ which is equivalent to 250.000×10^{-6}.

I–8 Self-Review

Answers at the end of the chapter.

a. Obtain the following answers and express them in scientific notation. (a) $\sqrt{36 \times 10^4}$ (b) $\sqrt{160 \times 10^{-5}}$ (c) $\sqrt{25 \times 10^{-8}}$.

I–9 The Scientific Calculator

Throughout your study of electronics, you will make several calculations involving numerical values that are expressed in decimal, scientific, or engineering notation. In most cases, you will want to use a scientific calculator to aid you in your calculations. Be sure to select a calculator that can perform all of the mathematical functions and operations that you will encounter in your study of electronics. Also, make sure the calculator you select can store and retrieve mathematical results from one or more memory locations. If the school or industry responsible for your training does not recommend or mandate a specific calculator, be sure to ask your instructor or supervisor for his or her recommendation on which calculator to buy. And finally, once you have purchased your calculator, carefully read the instructions that are included with it. At first, you may not understand many of your calculators functions and features, but as you progress in your studies, you will become more familiar with them. Figure I–1 shows an example of a typical scientific calculator.

Entering and Displaying Values

Scientific calculators typically have four notation systems for displaying calculation results: *floating decimal notation, fixed decimal notation (FIX), scientific notation (SCI),* and *engineering notation (ENG).* The calculator display typically shows the current notation system being used. When the FIX, SCI, or ENG symbol is displayed, the number of digits to the right of the decimal point can usually be set to any value from 0 to 9. With floating decimal notation, however, there is no set number of digits displayed for any given answer. For the examples that follow, assume that the calculator has been set to display three digits to the right of the decimal point.

Most scientific calculators have a key labeled [EXP], [EE], or [×10^] for entering the exponents associated with scientific and engineering notation. When entering a number expressed in any form of powers of 10 notation, always enter the numerical part of the expression first, followed by the exponent or power of 10. Use the *change sign* [+/–] key for entering negative exponents or for changing the sign of an existing exponent. To illustrate an example, the keystrokes involved in entering the number 25×10^{-6} would be as follows:

[2] [5] [EXP] [+/–] [6]

(Some calculators require that you press the [+/–] key after the exponent is entered.)

It must be understood that pressing the [EXP] key is the same as entering $\times 10^{00}$. After the [EXP] key is pressed, the exponent in 10^{00} can be changed to any desired

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value, which is 10^{-06} in this case. Most calculators will display the value just entered as either

$$25.000 \times 10^{-06} \quad \text{or} \quad 25E\text{-}06$$

For *25E-06,* the base 10 is implied by the uppercase letter *E*.

Most students, like yourself, are very comfortable with decimal notation because you have been exposed to it your entire life. In contrast, this chapter may be your first exposure to engineering notation. As a result, you may be tempted to enter and display all the values in decimal notation rather than engineering notation. For example, you may find yourself entering 47 kΩ as

[4] [7] [0] [0] [0] (decimal notation)

instead of

[4] [7] [EXP] [3] (engineering notation)

Entering and displaying values in decimal notation is a bad habit to get into for two reasons:

1. Very small and very large values cannot be entered in decimal notation because most calculators have only an 8- or 10-digit display.
2. Mentally converting between decimal and engineering notation is cumbersome and time-consuming, not to mention the fact that this practice is prone to error.

The main argument against using decimal notation is that most calculations encountered in electronics involve the use of the metric prefixes and hence engineering notation. By entering and displaying all values in engineering notation, you will be forced to learn the metric prefixes and their corresponding powers of 10.

When entering and displaying values in engineering notation remember that:

10^{-12} = pico (p) $\qquad$ 10^{3} = kilo (k)

10^{-9} = nano (n) $\qquad$ 10^{6} = mega (M)

10^{-6} = micro (μ) $\qquad$ 10^{9} = giga (G)

10^{-3} = milli (m) $\qquad$ 10^{12} = tera (T)

Example I-17

Show the keystrokes for multiplying 40×10^{-3} by 5×10^{6}.

ANSWER The keystrokes would be as follows:

[4] [0] [EXP] [+/−] [3] [×] [5] [EXP] [6] [=]

In engineering notation, the answer would be displayed as either

$$200.000 \times 10^{03} \quad \text{or} \quad 200E03$$

As mentioned earlier, take the time to read the instruction manual for your calculator and keep it with you for future reference. I guarantee you, it will come in handy!

I–9 Self-Review

Answers at the end of the chapter.

a. **When using a scientific calculator for the calculations encountered in electronics, decimal notation is the preferred notation system when entering and displaying values. (True/False)**

b. **Which key on a scientific calculator is used to enter the exponents associated with scientific and engineering notation?**

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Summary

- A power of 10 is an exponent that is written above and to the right of 10, which is called the base.
- A power of 10 indicates how many times the base, 10, is to be multiplied by itself.
- Positive powers of 10 indicate numbers greater than 1 and negative powers of 10 indicate numbers less than 1. Also, $10^0 = 1$ and $10^1 = 10$.
- Powers of 10 notation is a convenient method for expressing very small or very large numbers as a decimal number multiplied by a power of 10.
- Scientific and engineering notation are two forms of powers of 10 notation.
- A number expressed in scientific notation is always expressed as a number between 1 and 10 times a power of 10.
- A number expressed in engineering notation is always expressed as a number between 1 and 1000 times a power of 10 which is a multiple of 3.
- Decimal notation refers to those numbers that are written in standard form without any form of powers of 10 notation.
- Metric prefixes are letter symbols used to replace the powers of 10 that are multiples of 3. Refer to Table I–2 for a complete listing of the metric prefixes and their corresponding powers of 10.
- Converting from one metric prefix to another is a change in the power of 10 used to express a given quantity.
- Before numbers expressed in powers of 10 notation can be added or subtracted, both terms must have the same power of 10. When both terms have the same power of 10, just add or subtract the numerical parts of the expression and multiply the sum or difference by the power of 10 common to both terms.
- When multiplying numbers expressed in powers of 10 notation, multiply the numerical parts and powers of 10 separately. When multiplying powers of 10, simply add the exponents.
- When dividing numbers expressed in powers of 10 notation, divide the numerical parts and powers of 10 separately. When dividing powers of 10, simply subtract the power of 10 in the denominator from the power of 10 in the numerator.
- Taking the reciprocal of a power of 10 is the same as changing the sign of the exponent.
- To square a number expressed in powers of 10 notation, square the numerical part of the expression and double the power of 10.
- To take the square root of a number expressed in powers of 10 notation, take the square root of the numerical part of the expression and divide the power of 10 by 2.
- On a scientific calculator, the [EXP], [EE], or [×10^] key is used for entering the exponents associated with scientific and engineering notation.

Important Terms

Decimal notation — numbers that are written in standard form without using powers of 10 notation.

Engineering notation — a form of powers of 10 notation in which a number is expressed as a number between 1 and 1000 times a power of 10 that is a multiple of 3.

Metric prefixes — letter symbols used to replace the powers of 10 that are multiples of 3.

Powers of 10 — a numerical representation consisting of a base of 10 and an exponent; the base 10 raised to a power.

Scientific notation — a form of powers of 10 notation in which a number is expressed as a number between 1 and 10 times a power of 10.

Self-Test

Answers at the back of the book.

1. 10^4 means the same thing as

a. 10,000.
b. 10×4.
c. $10 \times 10 \times 10 \times 10$.
d. both a and c.

2. Negative powers of 10

a. indicate numbers less than 1.
b. are not used with engineering notation.
c. indicate numbers greater than 1.
d. are used only with scientific notation.

3. A number expressed in scientific notation is always expressed as a number between

a. 1 and 1000 times a power of 10 which is a multiple of 3.
b. 1 and 10 times a power of 10.
c. 1 and 100 times a power of 10.
d. 0 and 1 times a power of 10.

4. A number expressed in engineering notation is always expressed as a number between

a. 1 and 10 times a power of 10 that is a multiple of 3.
b. 1 and 10 times a power of 10.
c. 1 and 1000 times a power of 10 that is a multiple of 3.
d. 0 and 1 times a power of 10 that is a multiple of 3.

5. 10^0 equals

a. 0.

b. 10.

c. 1.

d. none of the above.

6. Metric prefixes are used only with those powers of 10 that are

a. multiples of 3.

b. negative.

c. associated with scientific notation.

d. both a and b.

7. 40×10^{-3} A is the same as

a. 40 mA.

b. 40 μA.

c. 40 kA.

d. 40 MA.

8. 3.9 MΩ is the same as

a. $3.9 \times 10^3\ \Omega$.

b. $3.9 \times 10^6\ \Omega$.

c. 3,900 kΩ.

d. both b and c.

9. A number written in standard form without any form of powers of 10 notation is said to be written in

a. scientific notation.

b. decimal notation.

c. engineering notation.

d. metric prefix notation.

10. The metric prefix pico (p) corresponds to

a. 10^{12}.

b. 10^{-9}.

c. 10^{-12}.

d. 10^{-6}.

11. Positive powers of 10

a. indicate numbers less than 1.

b. are not used with engineering notation.

c. indicate numbers greater than 1.

d. are used only with scientific notation.

12. 10^1 equals

a. 0.

b. 10.

c. 1.

d. none of the above.

13. In engineering notation, the number 0.000452 is expressed as

a. 452×10^{-6}.

b. 4.52×10^{-4}.

c. 4.52×10^{-6}.

d. 0.452×10^{-3}.

14. $(40 \times 10^2) + (5.0 \times 10^3)$ equals

a. 90×10^3.

b. 9.0×10^2.

c. 20×10^5.

d. 9.0×10^3.

15. When dividing powers of 10

a. subtract the power of 10 in the numerator from the power of 10 in the denominator.

b. change the sign of the power of 10 in the numerator.

c. subtract the power of 10 in the denominator from the power of 10 in the numerator.

d. add the exponents.

16. When multiplying powers of 10

a. subtract the exponents.

b. add the exponents.

c. multiply the exponents.

d. none of the above.

17. 10,000 μV is the same as

a. 0.01 mV.

b. 10 kV.

c. 10 mV.

d. 0.0001 V.

18. $\sqrt{81 \times 10^6}$ equals

a. 9×10^3.

b. 9×10^6.

c. 9×10^2.

d. 81×10^3.

19. $(4.0 \times 10^3)^2$ equals

a. 16×10^5.

b. 1.6×10^7.

c. 4.0×10^5.

d. 16×10^1.

20. The number 220×10^3 is the same as

a. 2.2×10^5.

b. 220,000.

c. 2200.

d. both a and b.

Essay Questions

1. For 10^7, which is the base and which is the exponent?

2. Define: (a) scientific notation (b) engineering notation (c) decimal notation.

3. In electronics, why is engineering notation more common than scientific notation?

4. List the metric prefixes for each of the following powers of 10: (a) 10^{-3} (b) 10^3 (c) 10^{-6} (d) 10^6 (e) 10^{-9} (f) 10^9 (g) 10^{-12} (h) 10^{12}.

5. List the units and symbols for each of the following quantities: (a) frequency (b) voltage (c) power (d) resistance (e) capacitance (f) inductance (g) current.

Problems

SECTION I–1 SCIENTIFIC NOTATION

Express each of the following numbers in scientific notation:

I–1 3,500,000

I–2 678

I–3 160,000,000

I–4 0.00055

I–5 0.150

I–6 0.00000000000942

I–7 2270

I–8 42,100

I–9 0.033

I–10 0.000006

I–11 77,700,000

I–12 100

I–13 87

I–14 0.0018

I–15 0.000000095

I–16 18,200

I–17 640,000

I–18 0.011

I–19 0.00000000175

I–20 3,200,000,000,000

Convert each of the following numbers expressed in scientific notation into decimal notation.

I–21 1.65×10^{-4}

I–22 5.6×10^{5}

I–23 8.63×10^{2}

I–24 3.15×10^{-3}

I–25 1.7×10^{-9}

I–26 4.65×10^{6}

I–27 1.66×10^{3}

I–28 2.5×10^{-2}

I–29 3.3×10^{-12}

I–30 9.21×10^{4}

SECTION I-2 ENGINEERING NOTATION AND METRIC PREFIXES

Express each of the following numbers in engineering notation:

I–31 5500

I–32 0.0055

I–33 6,200,000

I–34 150,000

I–35 99,000

I–36 0.01

I–37 0.00075

I–38 0.55

I–39 10,000,000

I–40 0.0000000032

I–41 0.000068

I–42 92,000,000,000

I–43 270,000

I–44 0.000000000018

I–45 0.000000450

I–46 0.00010

I–47 2,570,000,000,000

I–48 20,000

I–49 0.000070

I–50 2500

Express the following values using the metric prefixes from Table I–2. (Note: The metric prefix associated with each answer must coincide with engineering notation.)

I–51 1000 W

I–52 10,000 Ω

I–53 0.035 V

I–54 0.000050 A

I–55 0.000001 F

I–56 1,570,000 Hz

I–57 2,200,000 Ω

I–58 162,000 V

I–59 1,250,000,000 Hz

I–60 0.00000000033 F

I–61 0.00025 A

I–62 0.000000000061 F

I–63 0.5 W

I–64 2200 Ω

I–65 180,000 Ω

I–66 240 V

I–67 4.7 Ω

I–68 0.001 H

I–69 0.00005 W

I–70 0.0000000001 A

SECTION I-3 CONVERTING BETWEEN METRIC PREFIXES

Make the following conversions:

I–71 55,000 μA = __________ mA

I–72 10 nF = __________ pF

I–73 6800 pF = __________ μF

I–74 1.49 MHz = __________ kHz

I–75 22,000 nF = __________ μF

I–76 1500 μH = __________ mH

I–77 1.5 MΩ = __________ kΩ

I–78 2.2 GHz = __________ MHz

I–79 0.039 MΩ = __________ kΩ

I–80 5600 kΩ = __________ MΩ

I–81 7500 μA = __________ mA

I–82 1 mA = __________ μA

I–83 100 kW = __________ W

I–84 50 MW = __________ kW

I–85 4700 pF = __________ nF

I–86 560 nF = __________ μF

I–87 1296 MHz = __________ GHz

I–88 50 mH = __________ μH

I–89 7.5 μF = __________ pF

I–90 220,000 MΩ = __________ GΩ

SECTION I-4 ADDITION AND SUBTRACTION INVOLVING POWERS OF 10 NOTATION

Add the following numbers and express your answers in scientific notation:

I–91 $(25 \times 10^{3}) + (5.0 \times 10^{4})$

I–92 $(4500 \times 10^{3}) + (5.0 \times 10^{6})$

I–93 $(90 \times 10^{-12}) + (0.5 \times 10^{-9})$

I–94 $(15 \times 10^{-3}) + (100 \times 10^{-4})$

I–95 $(150 \times 10^{-6}) + (2.0 \times 10^{-3})$

I–96 $(150 \times 10^{0}) + (0.05 \times 10^{3})$

Subtract the following numbers and express your answers in scientific notation:

I–97 $(100 \times 10^{6}) - (0.5 \times 10^{8})$

I–98 $(20 \times 10^{-3}) - (5000 \times 10^{-6})$

I–99 $(180 \times 10^{-4}) - (3.5 \times 10^{-3})$

I–100 $(7.5 \times 10^{2}) - (0.25 \times 10^{3})$

I–101 $(5.0 \times 10^{4}) - (240 \times 10^{2})$

I–102 $(475 \times 10^{-5}) - (1500 \times 10^{-7})$

SECTION I-5 MULTIPLICATION AND DIVISION INVOLVING POWERS OF 10 NOTATION

Multiply the following numbers and express your answers in scientific notation:

I–103 $(6.0 \times 10^{3}) \times (3.0 \times 10^{2})$

I–104 $(4.0 \times 10^{-9}) \times (2.5 \times 10^{6})$

I–105 $(50 \times 10^{4}) \times (6.0 \times 10^{3})$

I–106 $(2.2 \times 10^{-2}) \times (6.5 \times 10^{0})$

I–107 $(5.0 \times 10^{-5}) \times (2.0 \times 10^{-1})$

I–108 $(100 \times 10^{-3}) \times (50 \times 10^{-6})$

Divide the following numbers and express your answers in scientific notation:

I–109 $(100 \times 10^{5}) \div (4.0 \times 10^{2})$

I–110 $(90 \times 10^{-9}) \div (3.0 \times 10^{-5})$

I–111 $(5.0 \times 10^{6}) \div (40 \times 10^{3})$

I–112 $(750 \times 10^{-7}) \div (3.0 \times 10^{-4})$

I–113 $(55 \times 10^{9}) \div (11 \times 10^{2})$

I–114 $(220 \times 10^{3}) \div (2.0 \times 10^{7})$

SECTION I-6 RECIPROCALS WITH POWERS OF 10

Find the reciprocal for each power of 10 listed.

I–115 10^{4}

I–116 10^{-4}

I–117 10^{1}

I–118 10^{-8}

I–119 10^{-7}

I–120 10^{-13}

I–121 10^{15}

I–122 10^{18}

SECTION I-7 SQUARING NUMBERS EXPRESSED IN POWERS OF 10 NOTATION

Express the following answers in scientific notation:

I–123 $(5.0 \times 10^{3})^{2}$

I–124 $(2.5 \times 10^{-7})^{2}$

I–125 $(90 \times 10^4)^2$

I–126 $(7.0 \times 10^5)^2$

I–127 $(12 \times 10^{-9})^2$

I–128 $(800 \times 10^{-12})^2$

SECTION I-8 SQUARE ROOTS OF NUMBERS EXPRESSED IN POWERS OF 10 NOTATION

Express the following answers in scientific notation:

I–129 $\sqrt{40 \times 10^{-5}}$

I–130 $\sqrt{50 \times 10^4}$

I–131 $\sqrt{36 \times 10^{-12}}$

I–132 $\sqrt{49 \times 10^{-3}}$

I–133 $\sqrt{150 \times 10^{-5}}$

I–134 $\sqrt{35 \times 10^{-6}}$

SECTION I-9 THE SCIENTIFIC CALCULATOR

Show the keystrokes on a scientific calculator for entering the following math problems. Display all answers in engineering notation.

I–135 $(15 \times 10^{-3}) \times (1.2 \times 10^3)$

I–136 $60 \div (1.5 \times 10^3)$

I–137 $12 \div (10 \times 10^3)$

I–138 $(5 \times 10^{-3}) \times (120 \times 10^3)$

I–139 $(6.5 \times 10^4) + (25 \times 10^3)$

I–140 $(2.5 \times 10^{-4}) - (50 \times 10^{-6})$

Answers to Self-Reviews

I–1
- **a.** negative powers of 10
- **b.** positive powers of 10
- **c.** true
- **d.** (a) 1.35×10^4
  (b) 8.25×10^{-3}
  (c) 9.56×10^7
  (d) 1.04×10^{-1}
- **e.** (a) 0.00000046 (b) 3330
  (c) 540,000,000 (d) 0.0254

I–2
- **a.** (a) 36×10^6 (b) 85×10^{-3}
  (c) 39.3×10^3 (d) 93×10^{-6}
- **b.** (a) nano (n) (b) mega (M)
  (c) pico (p) (d) kilo (k)
  (e) none
- **c.** (a) 10 μA (b) 2.2 MΩ
  (c) 45 nV (d) 5.6 kΩ
  (e) 18 W

I–3
- **a.** true
- **b.** (a) 2.2 MΩ = 2200 kΩ
  (b) 47,000 pF = 47 nF
  (c) 2500 μA = 2.5 mA
  (d) 6.25 mW = 6250 μW

I–4
- **a.** (a) 5.97×10^7 (b) 5.0×10^{-2}
- **b.** (a) 4.5×10^5 (b) 5.0×10^{-1}

I–5
- **a.** (a) 1.32×10^{-4} (b) 8.1×10^{-3}
- **b.** (a) 2.5×10^4 (b) 3.0×10^{-3}

I–6
- **a.** (a) 10^4 (b) 10^{-9}
  (c) 10^{18} (d) 10^0

I–7
- **a.** (a) 1.6×10^{-3} (b) 3.6×10^{11}
  (c) 4.0×10^{-6}

I–8
- **a.** (a) 6.0×10^2 (b) 4.0×10^{-2}
  (c) 5.0×10^{-4}

I–9
- **a.** false
- **b.** the [EXP], [EE], or [×10^] key

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chapter 1

Electricity

We see applications of electricity all around us, especially in the electronic products we own and operate every day. For example, we depend on electricity for lighting, heating, and air conditioning and for the operation of our vehicles, cell phones, appliances, computers, and home entertainment systems, to name a few. The applications of electricity are extensive and almost limitless to the imagination.

Although there are many applications of electricity, electricity itself can be explained in terms of electric charge, voltage, and current. In this chapter, you will be introduced to the basic concepts of electricity, which include a discussion of the following topics: basic atomic structure, the coulomb unit of electric charge, the volt unit of potential difference, the ampere unit of current, and the ohm unit of resistance. You will also be introduced to conductors, semiconductors, insulators, and the basic characteristics of an electric circuit.

Chapter Outline

Chapter Objectives

After studying this chapter, you should be able to

- *List* the two basic particles of electric charge.
- *Describe* the basic structure of the atom.
- *Define* the terms *conductor, insulator,* and *semiconductor* and give examples of each term.
- *Define* the coulomb unit of electric charge.
- *Define* potential difference and list its unit of measure.
- *Define* current and list its unit of measure.
- *Describe* the difference between voltage and current.
- *Define* resistance and conductance and list the unit of each.
- *List* three important characteristics of an electric circuit.
- *Define* the difference between electron flow and conventional current.
- *Describe* the difference between direct and alternating current.

Important Terms

alternating current (AC)
ampere
atom
atomic number
circuit
compound
conductance
conductor
conventional current
coulomb
current
dielectric
direct current (DC)
electron
electron flow
electron valence
element
free electron
insulator
ion
molecule
neutron
nucleus
ohm
potential difference
proton
resistance
semiconductor
siemens
static electricity
volt