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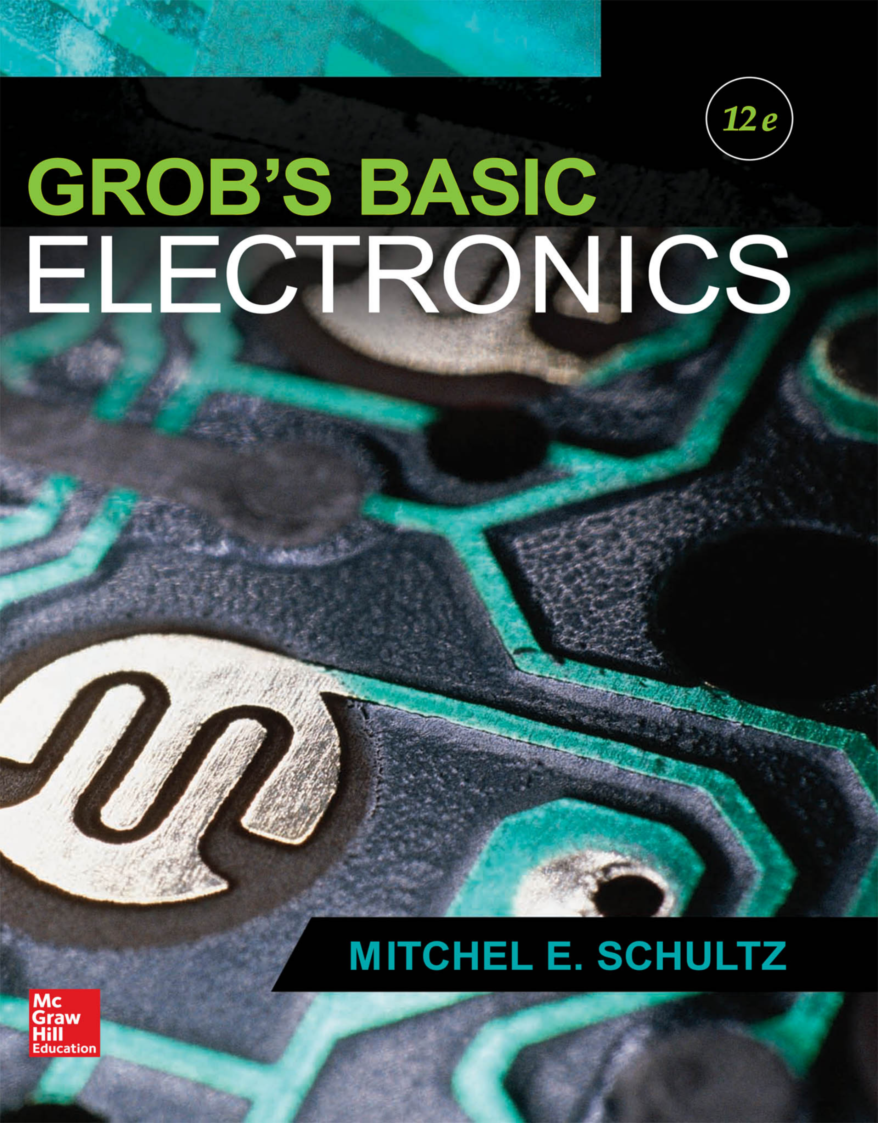
GROB'S BASIC ELECTRONICS



MITCHEL E. SCHULTZ

Mc Graw Hill Education

Grob's Basic Electronics

Grob's Basic Electronics

12th Edition

Mitchel E. Schultz

Western Technical College

Mc Graw Hill Education

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Dedication

This textbook is dedicated to all of my students, both past and present.

Brief Contents

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Preface

The twelfth 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 26 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, and filters. Chapters 13–26 are considered the AC chapters since the voltages and currents used in analyzing the circuits in these chapters are primarily AC.

Chapters 27 through 33 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 **F** 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 lists all of the 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.

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

- The twelfth edition of *Grob's Basic Electronics* continues to provide students and instructors with a ***Laboratory Application Assignment*** at the end of every chapter in the book! In the twelfth edition, many of the lab application assignments have been modified and/or expanded based on the recommendations of several reviewers. Each laboratory application assignment is a hands-on lab exercise in which students build and test circuits in a laboratory environment. Each lab application assignment reinforces one or more of the main topics covered within the chapter. ***The labs are short and concise yet thorough and complete.*** With the inclusion of the lab application assignments, additional lab supplements may not be necessary. Never before has an electronics book of this magnitude provided a laboratory activity as part of the main text.
- ***Multisim*** continues to be a key component in the twelfth edition of *Grob's Basic Electronics.* All of the Multisim files for use with this textbook have been updated to version 12.1, the latest version of Multisim software available at the time of publication. ***Appendix F, Introduction to Multisim,*** has also been completely updated to reflect the latest changes in version 12.1 of the software.
- The ***Good to Know*** feature, appearing in the margins of the text, has once again been expanded in several chapters of the book.
- In Chapter 3, ***Ohm's Law,*** coverage of the inverse relation between *I* and *R* has been expanded. Also, a streamlined approach for calculating energy costs has been included.
- Chapter 7, ***Voltage Dividers and Current Dividers,*** has been expanded to include variable voltage dividers. Also, increased emphasis has been placed on the voltage divider rule (VDR) and the current divider rule (CDR).
- Also new to the twelfth edition is a much heavier emphasis of ***real-world applications.*** At the end of several chapters throughout the book, new sections including real-world applications have been added. These real-world applications bring to life the concepts covered in a specific chapter. In Chapter 3, ***Ohm's Law,*** calculating the current drawn by several different home appliances is discussed. In Chapters 4 and 5, ***Series Circuits*** and ***Parallel Circuits,*** respectively, the wiring and characteristics of holiday lights are thoroughly discussed. In Chapter 11, ***Conductors and Insulators,*** the electrical wire used in residential house wiring is explained in detail. Extension cords and speaker wire are also discussed. In Chapter 12, ***Batteries,*** lead-acid battery ratings are covered along with information on charging, testing, storage, and disposal. In Chapter 14, ***Electromagnetism,*** solenoids and solenoid valves are discussed. In Chapter 15, ***Alternating Voltage and Current,*** the 120-V duplex receptacle is thoroughly covered. In Chapter 16, ***Capacitance,*** an emerging new type of capacitor, known as a supercapacitor, is thoroughly explained. Several of its applications are also discussed. In Chapter 19, ***Inductance,*** isolation transformers and their advantages are carefully examined. And finally, in Chapter 23, ***Alternating Current Circuits,*** the different types of power in AC circuits are explained as well as power factor and the need for power factor correction.

Ancillary Package

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

Problems Manual for use with Grob's Basic Electronics

This book, written by Mitchel E. Schultz, provides students and instructors with hundreds of practice problems for self-study, homework assignments, tests, and review. The book is organized to correlate chapter by chapter with the textbook. 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 *Problems Manual* is a must-have for students requiring additional practice in solving circuits.

Experiments Manual for Grob's Basic Electronics

This lab book, written by Wes Ponick, 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. All experiments have been student tested to ensure their effectiveness. The lab book is organized to correlate with 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.

Digital Resources

Connect Engineering

The online resources for this edition include McGraw-Hill Connect®, a web-based assignment and assessment platform that can help students perform better in their coursework and master important concepts. With Connect®, instructors can deliver assignments, quizzes, and tests easily online. Students can practice important skills at their own pace and on their own schedule. Ask your McGraw-Hill Representative for more details, and check it out at www.mcgrawhillconnect.com.

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Before you read . . .

Chapter Introductions briefly outline the main chapter topics and concepts.

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.

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 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 voltage and list the unit of each.
- *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)	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

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

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.

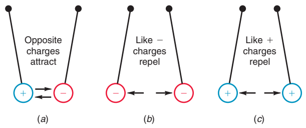
While you read . . .

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

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.

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

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.

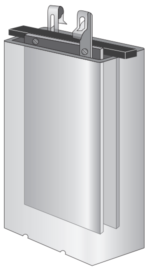
a. **Is the charge of an electron positive or negative?**
b **Is the charge of a proton positive or negative?**
c. **Is it true or false that the neutral condition means equal positive and negative charges?**

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 the

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. 1–18. Refer to Sec. 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. 1–18*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. 1-18*c*.

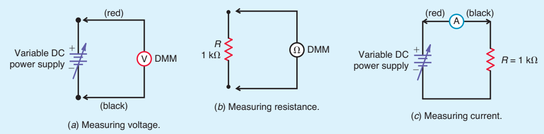
Measuring Resistance

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. 1–18*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. 1–18*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 1–18 Measuring electrical quantities. (*a*) Measuring voltage. (*b*) Measuring resistance. (*c*) Measuring current.

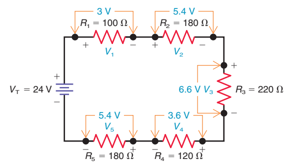


Laboratory Application Assignments, reinforce one or more of the chapter's main topics by asking students to build and test circuits in a laboratory environment.

Troubleshooting 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.



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

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Grob's Basic Electronics

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.

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

I–1 Scientific Notation

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

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	$= 10^{-12}$

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.

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.

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 2 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 5 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.

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

Notice 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*

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.