PEARSON NEW INTERNATIONAL EDITION

Electronics Fundamentals
Circuits, Devices and Applications

Thomas L. Floyd David L. Buchla

Eighth Edition

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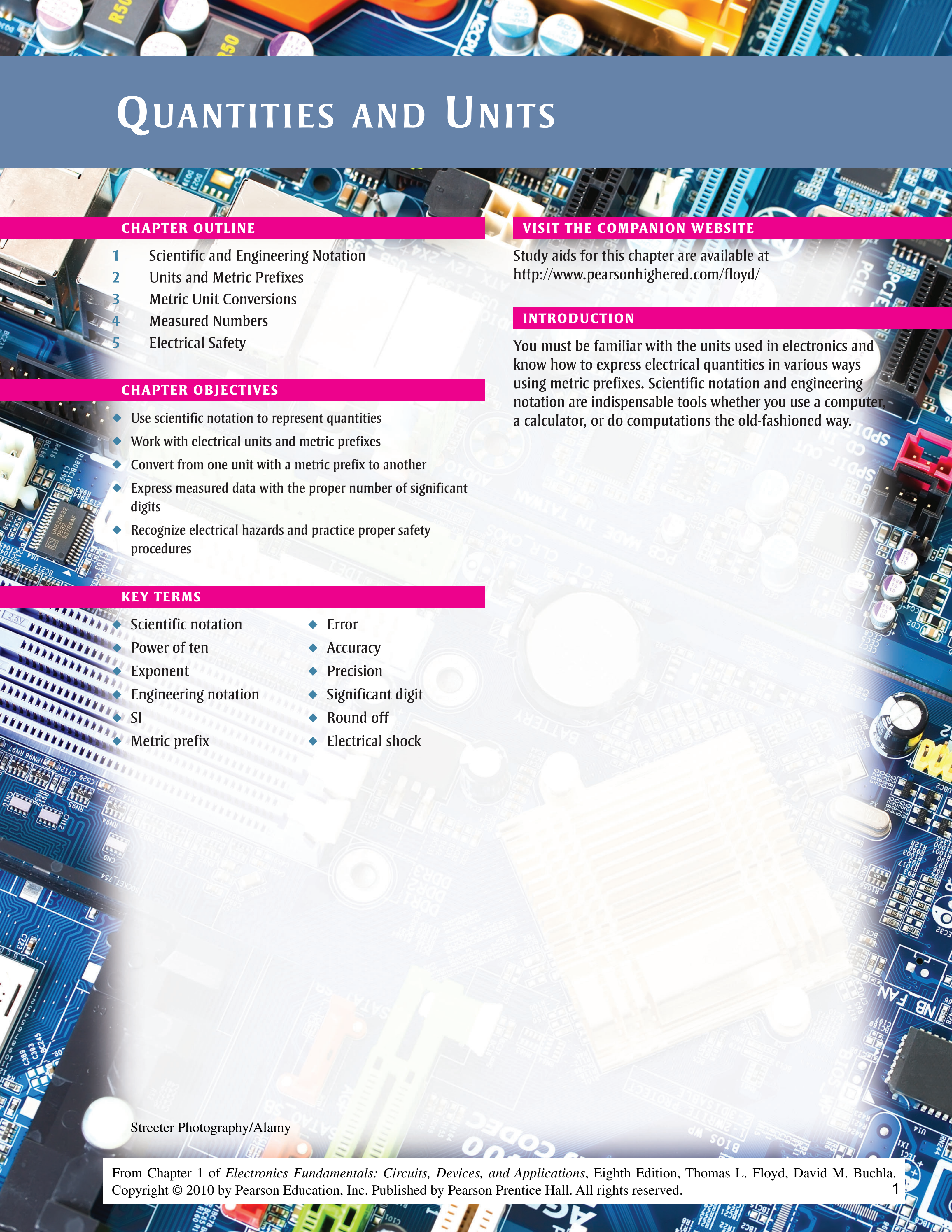

QUANTITIES AND UNITS

CHAPTER OUTLINE

CHAPTER OBJECTIVES

- Use scientific notation to represent quantities
- Work with electrical units and metric prefixes
- Convert from one unit with a metric prefix to another
- Express measured data with the proper number of significant digits
- Recognize electrical hazards and practice proper safety procedures

KEY TERMS

- Scientific notation
- Power of ten
- Exponent
- Engineering notation
- SI
- Metric prefix
- Error
- Accuracy
- Precision
- Significant digit
- Round off
- Electrical shock

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Study aids for this chapter are available at
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INTRODUCTION

You must be familiar with the units used in electronics and know how to express electrical quantities in various ways using metric prefixes. Scientific notation and engineering notation are indispensable tools whether you use a computer, a calculator, or do computations the old-fashioned way.

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1 SCIENTIFIC AND ENGINEERING NOTATION

In the electrical and electronics fields, you will encounter both very small and very large quantities. For example, electrical current can range from hundreds of amperes in power applications to a few thousandths or millionths of an ampere in many electronic circuits. This range of values is typical of many other electrical quantities also. Engineering notation is a specialized form of scientific notation. It is used widely in technical fields to express large and small quantities. In electronics, engineering notation is used to express values of voltage, current, power, resistance, and other quantities.

After completing this section, you should be able to

- **Use scientific notation to represent quantities**
    - Express any number using a power of ten
    - Perform calculations with powers of ten

Scientific notation* provides a convenient method for expressing large and small numbers and for performing calculations involving such numbers. In scientific notation, a quantity is expressed as a product of a number between 1 and 10 (one digit to the left of the decimal point) and a power of ten. For example, the quantity 150,000 is expressed in scientific notation as 1.5×10^5, and the quantity 0.00022 is expressed as 2.2×10^{-4}.

Powers of Ten

Table 1 lists some powers of ten, both positive and negative, and the corresponding decimal numbers. The **power of ten** is expressed as an *exponent* of the *base* 10 in each case.

Base ↘ ↙ Exponent

$$10^x$$

An **exponent** is a number to which a base number is raised. The exponent indicates the number of places that the decimal point is moved to the right or left to produce the decimal number. For a positive power of ten, move the decimal point to the right to get the equivalent decimal number. As an example, for an exponent of 4,

$$10^4 = 1 \times 10^4 = 1.0000. = 10{,}000.$$

TABLE 1

Some positive and negative powers of ten.

$10^6 = 1{,}000{,}000$	$10^{-6} = 0.000001$
$10^5 = 100{,}000$	$10^{-5} = 0.00001$
$10^4 = 10{,}000$	$10^{-4} = 0.0001$
$10^3 = 1{,}000$	$10^{-3} = 0.001$
$10^2 = 100$	$10^{-2} = 0.01$
$10^1 = 10$	$10^{-1} = 0.1$
$10^0 = 1$	

This icon indicates selected websites for further information on topics in this section. See the Companion Website provided with this text.

***The bold terms in color are key terms and are defined at the end of the chapter.**

For a negative power of ten, move the decimal point to the left to get the equivalent decimal number. As an example, for an exponent of −4,

$$10^{-4} = 1 \times 10^{-4} = .0001. = 0.0001$$

The negative exponent does not indicate that a number is negative; it simply moves the decimal point to the left.

EXAMPLE 1

Express each number in scientific notation:

(a) 240 **(b)** 5100 **(c)** 85,000 **(d)** 3,350,000

Solution In each case, move the decimal point an appropriate number of places to the left to determine the positive power of ten.

(a) $240 = \mathbf{2.4 \times 10^2}$ **(b)** $5100 = \mathbf{5.1 \times 10^3}$

(c) $85{,}000 = \mathbf{8.5 \times 10^4}$ **(d)** $3{,}350{,}000 = \mathbf{3.35 \times 10^6}$

*Related Problem** Express 750,000,000 in scientific notation.

*Answers are at the end of the chapter.

EXAMPLE 2

Express each number in scientific notation:

(a) 0.24 **(b)** 0.005 **(c)** 0.00063 **(d)** 0.000015

Solution In each case, move the decimal point an appropriate number of places to the right to determine the negative power of ten.

(a) $0.24 = \mathbf{2.4 \times 10^{-1}}$ **(b)** $0.005 = \mathbf{5 \times 10^{-3}}$

(c) $0.00063 = \mathbf{6.3 \times 10^{-4}}$ **(d)** $0.000015 = \mathbf{1.5 \times 10^{-5}}$

Related Problem Express 0.00000093 in scientific notation.

EXAMPLE 3

Express each of the following numbers as a normal decimal number:

(a) 1×10^5 **(b)** 2.9×10^3 **(c)** 3.2×10^{-2} **(d)** 2.5×10^{-6}

Solution Move the decimal point to the right or left a number of places indicated by the positive or the negative power of ten respectively.

(a) $1 \times 10^5 = \mathbf{100{,}000}$ **(b)** $2.9 \times 10^3 = \mathbf{2900}$

(c) $3.2 \times 10^{-2} = \mathbf{0.032}$ **(d)** $2.5 \times 10^{-6} = \mathbf{0.0000025}$

Related Problem Express 8.2×10^8 as a normal decimal number.

Calculations With Powers of Ten

The advantage of scientific notation is in addition, subtraction, multiplication, and division of very small or very large numbers.

Addition The steps for adding numbers in powers of ten are as follows:

1. Express the numbers to be added in the same power of ten.
2. Add the numbers without their powers of ten to get the sum.
3. Bring down the common power of ten, which becomes the power of ten of the sum.

EXAMPLE 4 Add 2×10^6 and 5×10^7 and express the result in scientific notation.

Solution

1. Express both numbers in the same power of ten: $(2 \times 10^6) + (50 \times 10^6)$.
2. Add $2 + 50 = 52$.
3. Bring down the common power of ten (10^6); the sum is $52 \times 10^6 = \mathbf{5.2 \times 10^7}$.

Related Problem Add 4.1×10^3 and 7.9×10^2.

Subtraction The steps for subtracting numbers in powers of ten are as follows:

1. Express the numbers to be subtracted in the same power of ten.
2. Subtract the numbers without their powers of ten to get the difference.
3. Bring down the common power of ten, which becomes the power of ten of the difference.

EXAMPLE 5 Subtract 2.5×10^{-12} from 7.5×10^{-11} and express the result in scientific notation.

Solution

1. Express each number in the same power of ten: $(7.5 \times 10^{-11}) - (0.25 \times 10^{-11})$.
2. Subtract $7.5 - 0.25 = 7.25$.
3. Bring down the common power of ten (10^{-11}); the difference is $\mathbf{7.25 \times 10^{-11}}$.

Related Problem Subtract 3.5×10^{-6} from 2.2×10^{-5}.

Multiplication The steps for multiplying numbers in powers of ten are as follows:

1. Multiply the numbers directly without their powers of ten.
2. Add the powers of ten algebraically (the exponents do not have to be the same).

EXAMPLE 6 Multiply 5×10^{12} by 3×10^{-6} and express the result in scientific notation.

Solution Multiply the numbers, and algebraically add the powers.

$$(5 \times 10^{12})(3 \times 10^{-6}) = 15 \times 10^{12+(-6)} = 15 \times 10^6 = \mathbf{1.5 \times 10^7}$$

Related Problem Multiply 1.2×10^3 by 4×10^2.

Division The steps for dividing numbers in powers of ten are as follows:

1. Divide the numbers directly without their powers of ten.
2. Subtract the power of ten in the denominator from the power of ten in the numerator (the exponents do not have to be the same).

EXAMPLE 7 Divide 5.0×10^8 by 2.5×10^3 and express the result in scientific notation.

Solution Write the division problem with a numerator and denominator.

$$\frac{5.0 \times 10^8}{2.5 \times 10^3}$$

Divide the numbers and subtract the powers of ten (3 from 8).

$$\frac{5.0 \times 10^8}{2.5 \times 10^3} = 2 \times 10^{8-3} = \mathbf{2 \times 10^5}$$

Related Problem Divide 8×10^{-6} by 2×10^{-10}.

Scientific Notation on a Calculator Entering a number in scientific notation is accomplished on most calculators using the EE key as follows: Enter the number with one digit to the left of the decimal point, press EE, and enter the power of ten. This method requires that the power of ten be determined before entering the number. Some calculators can be placed in a mode that will automatically convert any decimal number entered into scientific notation.

EXAMPLE 8 Enter 23,560 in scientific notation using the EE key.

Solution Move the decimal point four places to the left so that it comes after the digit 2. This results in the number expressed in scientific notation as

$$2.3560 \times 10^4$$

Enter this number on your calculator as follows:

Related Problem Enter the number 573,946 using the EE key.

Engineering Notation

Engineering notation is similar to scientific notation. However, in **engineering notation** a number can have from one to three digits to the left of the decimal point and the power-of-ten exponent must be a multiple of three. For example, the number 33,000 expressed in engineering notation is 33×10^3. In scientific notation, it is expressed as 3.3×10^4. As another example, the number 0.045 is expressed in engineering notation as 45×10^{-3}. In scientific notation, it is expressed as 4.5×10^{-2}. Engineering notation is useful in electrical and electronic calculations that use metric prefixes (discussed in Section 2).

EXAMPLE 9 Express the following numbers in engineering notation:

(a) 82,000 **(b)** 243,000 **(c)** 1,956,000

Solution In engineering notation,

(a) 82,000 is expressed as $\mathbf{82 \times 10^3}$.

(b) 243,000 is expressed as $\mathbf{243 \times 10^3}$.

(c) 1,956,000 is expressed as $\mathbf{1.956 \times 10^6}$.

Related Problem Express 36,000,000,000 in engineering notation.

EXAMPLE 10 Convert each of the following numbers to engineering notation:

(a) 0.0022 **(b)** 0.000000047 **(c)** 0.00033

Solution In engineering notation,

(a) 0.0022 is expressed as $\mathbf{2.2 \times 10^{-3}}$.

(b) 0.000000047 is expressed as $\mathbf{47 \times 10^{-9}}$.

(c) 0.00033 is expressed as $\mathbf{330 \times 10^{-6}}$.

Related Problem Express 0.0000000000056 in engineering notation.

Engineering Notation on a Calculator Use the EE key to enter the number with one, two, or three digits to the left of the decimal point, press EE, and enter the power of ten that is a multiple of three. This method requires that the appropriate power of ten be determined before entering the number.

EXAMPLE 11 Enter 51,200,000 in engineering notation using the EE key.

Solution Move the decimal point six places to the left so that it comes after the digit 1. This results in the number expressed in engineering notation as

$$51.2 \times 10^6$$

Enter this number on your calculator as follows:

Related Problem Enter the number 273,900 in engineering notation using the EE key.

SECTION 1 CHECKUP
Answers are at the end of the chapter.

1. Scientific notation uses powers of ten. (True or False)
2. Express 100 as a power of ten.
3. Express the following numbers in scientific notation:
   (a) 4350 **(b)** 12,010 **(c)** 29,000,000
4. Express the following numbers in scientific notation:
   (a) 0.760 **(b)** 0.00025 **(c)** 0.000000597
5. Do the following operations:
   (a) $(1 \times 10^5) + (2 \times 10^5)$ **(b)** $(3 \times 10^6)(2 \times 10^4)$
   (c) $(8 \times 10^3) \div (4 \times 10^2)$ **(d)** $(2.5 \times 10^{-6}) - (1.3 \times 10^{-7})$
6. Enter the numbers expressed in scientific notation in Problem 3 into your calculator.
7. Express the following numbers in engineering notation:
   (a) 0.0056 **(b)** 0.0000000283
   (c) 950,000 **(d)** 375,000,000,000
8. Enter the numbers in Problem 7 into your calculator using engineering notation.

2 UNITS AND METRIC PREFIXES

In electronics, you must deal with measurable quantities. For example, you must be able to express how many volts are measured at a certain test point in a circuit, how much current there is through a conductor, or how much power a certain amplifier delivers. In this section, you are introduced to the units and symbols for most of the electrical quantities that are used throughout the text. Metric prefixes are used in conjunction with engineering notation as a "shorthand" for the certain powers of ten that commonly are used.

After completing this section, you should be able to

- **Work with electrical units and metric prefixes**
  - Name the units for twelve electrical quantities
  - Specify the symbols for the electrical units
  - List the metric prefixes
  - Change a power of ten in engineering notation to a metric prefix
  - Use metric prefixes to express electrical quantities

Electrical Units

Letter symbols are used in electronics to represent both quantities and their units. One symbol is used to represent the name of the quantity, and another is used to represent the unit of measurement of that quantity. Table 2 lists the most important electrical quantities, along with their SI units and symbols. For example, italic P stands for *power* and nonitalic (roman) W stands for *watt,* which is the unit of power. In general, italic letters represent quantities and nonitalic letters represent units. Notice that energy is abbreviated with an italic W that represents *work;* and both *energy* and *work* have the same unit (the joule). The term **SI** is the French abbreviation for *International System* (*Système International* in French).

▶ TABLE 2

Electrical quantities and their corresponding units with SI symbols.

QUANTITY	SYMBOL	SI UNIT	SYMBOL
capacitance	C	farad	F
charge	Q	coulomb	C
conductance	G	siemens	S
current	I	ampere	A
energy or work	W	joule	J
frequency	f	hertz	Hz
impedance	Z	ohm	Ω
inductance	L	henry	H
power	P	watt	W
reactance	X	ohm	Ω
resistance	R	ohm	Ω
voltage	V	volt	V

In addition to the common electrical units shown in Table 2, the SI system has many other units that are defined in terms of certain fundamental units. In 1954, by international agreement, *meter, kilogram, second, ampere, degree kelvin,* and *candela* were adopted as the basic SI units (*degree kelvin* was later changed to just *kelvin*). These units form the basis of the mks (for meter-kilogram-second) units that are used for derived quantities and have become the preferred units for nearly all scientific and engineering work. An older metric system, called the cgs system, was based on the centimeter, gram, and second as fundamental units. There are still a number of units in common use based on the cgs system; for example, the gauss is a magnetic flux unit in the cgs system and is still in common usage. In keeping with preferred practice, this text uses mks units, except when otherwise noted.

Metric Prefixes

In engineering notation **metric prefixes** represent each of the most commonly used powers of ten. These metric prefixes are listed in Table 3 with their symbols and corresponding powers of ten.

▶ TABLE 3

Metric prefixes with their symbols and corresponding powers of ten and values.

METRIC PREFIX	SYMBOL	POWER OF TEN	VALUE
femto	f	10^{-15}	one-quadrillionth
pico	p	10^{-12}	one-trillionth
nano	n	10^{-9}	one-billionth
micro	μ	10^{-6}	one-millionth
milli	m	10^{-3}	one-thousandth
kilo	k	10^{3}	one thousand
mega	M	10^{6}	one million
giga	G	10^{9}	one billion
tera	T	10^{12}	one trillion

Metric prefixes are used only with numbers that have a unit of measure, such as volts, amperes, and ohms, and precede the unit symbol. For example, 0.025 amperes can be expressed in engineering notation as 25×10^{-3} A. This quantity expressed using a metric prefix is 25 mA, which is read 25 milliamps. The metric prefix *milli* has replaced 10^{-3}. As another example, 10,000,000 ohms can be expressed as $10 \times 10^{6}\ \Omega$. This quantity expressed using a metric prefix is 10 MΩ, which is read 10 megohms. The metric prefix *mega* has replaced 10^{6}.

EXAMPLE 12

Express each quantity using a metric prefix:

(a) 50,000 V **(b)** 25,000,000 Ω **(c)** 0.000036 A

Solution **(a)** $50{,}000\ \text{V} = 50 \times 10^3\ \text{V} = \mathbf{50\ kV}$ **(b)** $25{,}000{,}000\ \Omega = 25 \times 10^6\ \Omega = \mathbf{25\ M\Omega}$

(c) $0.000036\ \text{A} = 36 \times 10^{-6}\ \text{A} = \mathbf{36\ \mu A}$

Related Problem Express each quantity using metric prefixes:

(a) 56,000,000 Ω **(b)** 0.000470 A

SECTION 2 CHECKUP

1. List the metric prefix for each of the following powers of ten: 10^6, 10^3, 10^{-3}, 10^{-6}, 10^{-9}, and 10^{-12}.
2. Use a metric prefix to express 0.000001 A.
3. Use a metric prefix to express 250,000 W.

3 METRIC UNIT CONVERSIONS

It is sometimes necessary or convenient to convert a quantity from one unit with a metric prefix to another, such as from milliamperes (mA) to microamperes (μA). Moving the decimal point in the number an appropriate number of places to the left or to the right, depending on the particular conversion, results in a metric unit conversion.

After completing this section, you should be able to

- **Convert from one unit with a metric prefix to another**
  - Convert between milli, micro, nano, and pico
  - Convert between kilo and mega

The following basic rules apply to metric unit conversions:

1. When converting from a larger unit to a smaller unit, move the decimal point to the right.
2. When converting from a smaller unit to a larger unit, move the decimal point to the left.
3. Determine the number of places to move the decimal point by finding the difference in the powers of ten of the units being converted.

For example, when converting from milliamperes (mA) to microamperes (μA), move the decimal point three places to the right because there is a three-place difference between the two units (mA is 10^{-3} A and μA is 10^{-6} A). The following examples illustrate a few conversions.

EXAMPLE 13

Convert 0.15 milliampere (0.15 mA) to microamperes (μA).

Solution Move the decimal point three places to the right.

$$0.15\ \text{mA} = 0.15 \times 10^{-3}\ \text{A} = 150 \times 10^{-6}\ \text{A} = \mathbf{150\ \mu A}$$

Related Problem Convert 1 mA to microamperes.

EXAMPLE 14 Convert 4500 microvolts (4500 μV) to millivolts (mV).

Solution Move the decimal point three places to the left.

$$4500\ \mu\text{V} = 4500 \times 10^{-6}\ \text{V} = 4.5 \times 10^{-3}\ \text{V} = \mathbf{4.5\ mV}$$

Related Problem Convert 1000 μV to millivolts.

EXAMPLE 15 Convert 5000 nanoamperes (5000 nA) to microamperes (μA).

Solution Move the decimal point three places to the left.

$$5000\ \text{nA} = 5000 \times 10^{-9}\ \text{A} = 5 \times 10^{-6}\ \text{A} = \mathbf{5\ \mu A}$$

Related Problem Convert 893 nA to microamperes.

EXAMPLE 16 Convert 47,000 picofarads (47,000 pF) to microfarads (μF).

Solution Move the decimal point six places to the left.

$$47{,}000\ \text{pF} = 47{,}000 \times 10^{-12}\ \text{F} = 0.047 \times 10^{-6}\ \text{F} = \mathbf{0.047\ \mu F}$$

Related Problem Convert 10,000 pF to microfarads.

EXAMPLE 17 Convert 0.00022 microfarad (0.00022 μF) to picofarads (pF).

Solution Move the decimal point six places to the right.

$$0.00022\ \mu\text{F} = 0.00022 \times 10^{-6}\ \text{F} = 220 \times 10^{-12}\ \text{F} = \mathbf{220\ pF}$$

Related Problem Convert 0.0022 μF to picofarads.

EXAMPLE 18 Convert 1800 kilohms (1800 kΩ) to megohms (MΩ).

Solution Move the decimal point three places to the left.

$$1800\ \text{k}\Omega = 1800 \times 10^{3}\ \Omega = 1.8 \times 10^{6}\ \Omega = \mathbf{1.8\ M\Omega}$$

Related Problem Convert 2.2 kΩ to megohms.

When adding (or subtracting) quantities with different metric prefixes, first convert one of the quantities to the same prefix as the other quantity.

EXAMPLE 19 Add 15 mA and 8000 μA and express the result in milliamperes.

Solution Convert 8000 μA to 8 mA and add.

$$15\ \text{mA} + 8000\ \mu\text{A} = 15\ \text{mA} + 8\ \text{mA} = \mathbf{23\ mA}$$

Related Problem Add 2873 mA and 10,000 μA.

SECTION 3 CHECKUP

1. Convert 0.01 MV to kilovolts (kV).
2. Convert 250,000 pA to milliamperes (mA).
3. Add 0.05 MW and 75 kW and express the result in kW.
4. Add 50 mV and 25,000 μV and express the result in mV.

4 MEASURED NUMBERS

Whenever a quantity is measured, there is uncertainty in the result due to limitations of the instruments used. When a measured quantity contains approximate numbers, the digits known to be correct are called significant digits. When reporting measured quantities, the number of digits that should be retained are the significant digits and no more than one uncertain digit.

After completing this section, you should be able to

- **Express measured data with the proper number of significant digits**
  - Define *accuracy, error,* and *precision*
  - Round numbers properly

Error, Accuracy, and Precision

Data taken in experiments are not perfect because the accuracy of the data depends on the accuracy of the test equipment and the conditions under which the measurement was made. In order to properly report measured data, the error associated with the measurement should be taken into account. Experimental error should not be thought of as a mistake. All measurements that do not involve counting are approximations of the true value. The difference between the true or best-accepted value of some quantity and the measured value is the **error**. A measurement is said to be accurate if the error is small. **Accuracy** is an indication of the range of error in a measurement. For example, if you measure thickness of a 10.00 mm gauge block with a micrometer and find that it is 10.8 mm, the reading is not accurate because a gauge block is considered to be a working standard. If you measure 10.02 mm, the reading is accurate because it is in reasonable agreement with the standard.

Another term associated with the quality of a measurement is *precision.* **Precision** is a measure of the repeatability (or consistency) of a measurement of some quantity. It is possible to have a precise measurement in which a series of readings are not scattered, but each measurement is inaccurate because of an instrument error. For example, a meter may be out of calibration and produce inaccurate but consistent (precise) results. However, it is not possible to have an accurate instrument unless it is also precise.

Significant Digits

The digits in a measured number that are known to be correct are called **significant digits**. Most measuring instruments show the proper number of significant digits, but some instruments can show digits that are not significant, leaving it to the user to determine what should be reported. This may occur because of an effect called *loading*. A meter can change the actual reading in a circuit by its very presence. It is important to recognize when a reading may be inaccurate; you should not report digits that are known to be inaccurate.

Another problem with significant digits occurs when you perform mathematical operations with numbers. The number of significant digits should never exceed the number in the original measurement. For example, if 1.0 V is divided by 3.0 Ω, a calculator will show 0.33333333. Since the original numbers each contain 2 significant digits, the answer should be reported as 0.33 A, the same number of significant digits.

The rules for determining if a reported digit is significant are

1. Nonzero digits are always considered to be significant.
2. Zeros to the left of the first nonzero digit are never significant.
3. Zeros between nonzero digits are always significant.
4. Zeros to the right of the decimal point for a decimal number are significant.
5. Zeros to the left of the decimal point with a whole number may or may not be significant depending on the measurement. For example, the number 12,100 Ω can have 3, 4, or 5 significant digits. To clarify the significant digits, scientific notation (or a metric prefix) should be used. For example, 12.10 kΩ has 4 significant digits.

When a measured value is reported, one uncertain digit may be retained but other uncertain digits should be discarded. To find the number of significant digits in a number, ignore the decimal point, and count the number of digits from left to right starting with the first nonzero digit and ending with the last digit to the right. All of the digits counted are significant except zeros to the right end of the number, which may or may not be significant. In the absence of other information, the significance of the right-hand zeros is uncertain. Generally, zeros that are placeholders, and not part of a measurement, are considered to be not significant. To avoid confusion, numbers should be shown using scientific or engineering notation if it is necessary to show the significant zeros.

EXAMPLE 20 Express the measured number 4300 with 2, 3, and 4 significant digits.

Solution Zeros to the right of the decimal point in a decimal number are significant. Therefore, to show two significant digits, write

$$\mathbf{4.3 \times 10^3}$$

To show three significant digits, write

$$\mathbf{4.30 \times 10^3}$$

To show four significant digits, write

$$\mathbf{4.300 \times 10^3}$$

Related Problem How would you show the number 10,000 showing three significant digits?

EXAMPLE 21 Underline the significant digits in each of the following measurements:

(a) 40.0 **(b)** 0.3040 **(c)** 1.20×10^5 **(d)** 120,000 **(e)** 0.00502

Solution

(a) 40.0 has three significant digits; see rule 4.

(b) 0.3040 has four significant digits; see rules 2 and 3.

(c) 1.20×10^5 has three significant digits; see rule 4.

(d) 120,000 has at least two significant digits. Although the number has the same value as in (c), zeros in this example are uncertain; see rule 5. This is *not* a recommended method for reporting a measured quantity; use scientific notation or a metric prefix in this case. See Example 20.

(e) 0.00502 has three significant digits; see rules 2 and 3.

Related Problem What is the difference between a measured quantity of 10 and 10.0?

Rounding Off Numbers

Since they always contain approximate numbers, measurements should be shown only with those digits that are significant plus no more than one uncertain digit. The number of digits shown is indicative of the precision of the measurement. For this reason, you should **round off** a number by dropping one or more digits to the right of the last significant digit. Use only the most significant dropped digit to decide how to round off. The rules for rounding off are

1. If the most significant digit dropped is greater than 5, increase the last retained digit by 1.
2. If the digit dropped is less than 5, do not change the last retained digit.
3. If the digit dropped is 5, increase the last retained digit *if* it makes it an even number, otherwise do not. This is called the "round-to-even" rule.

EXAMPLE 22 Round each of the following numbers to three significant digits:

(a) 10.071 **(b)** 29.961 **(c)** 6.3948 **(d)** 123.52 **(e)** 122.52

Solution

(a) 10.071 rounds to **10.1**. **(b)** 29.961 rounds to **30.0**.

(c) 6.3948 rounds to **6.39**. **(d)** 123.52 rounds to **124**.

(e) 122.52 rounds to **122**.

Related Problem Round 3.2850 to three significant digits using the round-to-even rule.

In most electrical and electronics work, components have tolerances greater than 1% (5% and 10% are common). Most measuring instruments have accuracy specifications better than this, but it is unusual for measurements to be made with higher accuracy than 1 part in 1000. For this reason, three significant digits are appropriate for numbers that represent measured quantities in all but the most exacting work. If you are working with a problem with several intermediate results, keep all digits in your calculator, but round the answers to three when reporting a result.

SECTION 4 CHECKUP

1. What is the rule for showing zeros to the right of the decimal point?
2. What is the round-to-even rule?
3. On schematics, you will frequently see a 1000 Ω resistor listed as 1.0 kΩ. What does this imply about the value of the resistor?
4. If a power supply is required to be set to 10.00 V, what does this imply about the accuracy needed for the measuring instrument?
5. How can scientific or engineering notation be used to show the correct number of significant digits in a measurement?

5 ELECTRICAL SAFETY

Safety is a major concern when working with electricity. The possibility of an electric shock or a burn is always present, so caution should always be used. You provide a current path when voltage is applied across two points on your body, and current produces electrical shock. Electrical components often operate at high temperatures, so you can sustain skin burns when you come in contact with them. Also, the presence of electricity creates a potential fire hazard.

After completing this section, you should be able to

- **Recognize electrical hazards and practice proper safety procedures**
  - Describe the cause of electrical shock
  - List the groups of current paths through the body
  - Discuss the effects of current on the human body
  - List the safety precautions that you should observe when you work with electricity

Electrical Shock

Current through your body, not the voltage, is the cause of **electrical shock**. Of course, it takes voltage across a resistance to produce current. When a point on your body comes in contact with a voltage and another point comes in contact with a different voltage or with ground, such as a metal chassis, there will be current through your body from one point to the other. The path of the current depends on the points across which the voltage occurs. The severity of the resulting electrical shock depends on the amount of voltage and the path that the current takes through your body.

The current path through the body determines which tissues and organs will be affected. The current paths can be placed into three groups which are referred to as *touch potential, step potential,* and *touch/step potential.* These are illustrated in Figure 1.

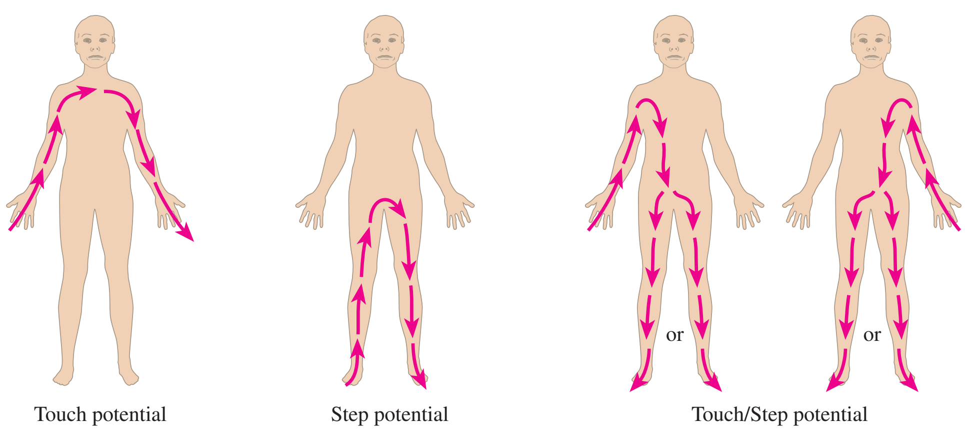


FIGURE 1

Shock hazard in terms of three basic current path groups.

Effects of Current on the Human Body The amount of current is dependent on voltage and resistance. The human body has resistance that depends on many factors, which include body mass, skin moisture, and points of contact of the body with a voltage potential. Table 4 shows the effects for various values of current in milliamperes.

CURRENT (mA)	PHYSICAL EFFECT
0.4	Slight sensation
1.1	Perception threshold
1.8	Shock, no pain, no loss of muscular control
9	Painful shock, no loss of muscular control
16	Painful shock, let-go threshold
23	Severe painful shock, muscular contractions, breathing difficulty
75	Ventricular fibrillation, threshold
235	Ventricular fibrillation, usually fatal for duration of 5 seconds or more
4,000	Heart paralysis (no ventricular fibrillation)
5,000	Tissue burn

TABLE 4

Physical effects of electrical current. Values vary depending on body mass.

Body Resistance Resistance of the human body is typically between 10 kΩ and 50 kΩ and depends on the two points between which it is measured. The moisture of the skin also affects the resistance between two points. The resistance determines the amount of voltage required to produce each of the effects listed in Table 4. For example, if you have a resistance of 10 kΩ between two given points on your body, 90 V across those two points will produce enough current (9 mA) to cause painful shock.

Utility Voltages

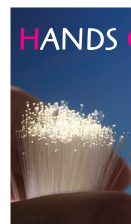
We tend to take utility voltages for granted, but they can be and have been lethal. It is best to be careful around any source of voltage (even low voltages can present a serious burn hazard). As a general rule, you should avoid working on any energized circuit, and check that the power is off with a known good meter. Most work in educational labs uses low voltages, but you should still avoid touching any energized circuit. If you are working on a circuit that is connected to utility voltages, the service should be disconnected, a notice should be placed on the equipment or place where the service is disconnected, and a padlock should be used to prevent someone from accidentally turning on the power. This procedure is called *lockout/tagout* and is widely used in industry. There are specific OSHA and industry standards for lockout/tagout.

Most laboratory equipment is connected to the utility line ("ac") and in North America, this is 120 V rms. A faulty piece of equipment can cause the "hot" lead to inadvertently become exposed. You should inspect cords for exposed wires and check equipment for missing covers or other potential safety problems. The single-phase utility lines in homes and electrical laboratories use three insulated wires that are referred to as the "hot" (black or red wire), neutral (white wire), and safety ground (green wire). The hot and neutral wires will have current, but the green safety line should never have current in normal operation. The safety wire is connected to the metal exterior of encased equipment and is also connected to conduit and the metal boxes for housing receptacles. Figure 2 shows the location of these conductors on a standard receptacle. Notice on the receptacle that the neutral lead is larger than the hot lead.

The safety ground should be connected to the neutral at the service panel. The metal chassis of an instrument or appliance is also connected to ground. In the event that the hot wire is accidentally in contact with ground, the resulting high current should trip the circuit breaker or open a fuse to remove the hazard. However, a broken or missing ground lead may not have high current until it is contacted by a person. This danger is one obvious reason for ensuring that line cords have not been altered by removing the ground pin.

Many circuits are further protected with a special device called a ground-fault circuit interrupter (GFCI, which is sometimes called just GFI). If a fault occurs in a GFCI circuit, a sensor detects that the current in the hot line and the neutral line are not equal as they

HANDS ON TIP

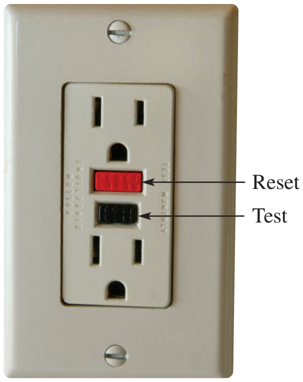


Receptacle testers are designed for use with specific receptacle types including specialized outlets. They can pinpoint problems such as open lines, faulty wiring, or reversed polarity; they show results with a lighted LED or neon bulb. Some testers are designed to test ground fault circuit interrupters (GFCI) for proper operation.

olivier/Shutterstock

FIGURE 2

Standard receptacle and connections.



▲ FIGURE 3

GFCI receptacle.

should be and trips the circuit breaker. The GFCI breaker is very fast acting and can trip faster than the breaker on the main panel. GFCI breakers are required in areas where a shock hazard exists such as wherever there is water or moisture. Pools, bathrooms, kitchens, basements, and garages should all have GFCI outlets. Figure 3 shows a ground-fault receptacle with reset and test buttons. When the test button is pressed, the circuit should immediately open. The reset button restores power.

Safety Precautions

There are many practical things that you should do when you work with electrical and electronic equipment. Some important precautions are listed here.

- Avoid contact with any voltage source. Turn power off before you work on circuits when you need to touch circuit parts.
- Do not work alone. A telephone should be available for emergencies.
- Do not work when tired or taking medications that make you drowsy.
- Remove rings, watches, and other metallic jewelry when you work on circuits.
- Do not work on equipment until you know proper procedures and are aware of potential hazards.
- Make sure power cords are in good condition and grounding pins are not missing or bent.
- Keep your tools properly maintained. Make sure the insulation on metal tool handles is in good condition.
- Handle tools properly and maintain a neat work area.
- Wear safety glasses when appropriate, particularly when soldering and clipping wires.
- Always shut off power and discharge capacitors before you touch any part of a circuit with your hands.
- Know the location of the emergency power-off switch and emergency exits.
- Never try to override or tamper with safety devices such as an interlock switch or ground pin on a three-prong plug.
- Always wear shoes and keep them dry. Do not stand on metal or wet floors when working on electrical circuits.
- Never handle instruments when your hands are wet.
- Never assume that a circuit is off. Double-check it with a reliable meter before handling.
- Set the limiter on electronic power supplies to prevent currents larger than necessary to supply the circuit under test.
- Some devices such as capacitors can store a lethal charge for long periods after power is removed. They must be properly discharged before you work with them.
- When making circuit connections, always make the connection to the point with the highest voltage as your last step.
- Avoid contact with the terminals of power supplies.
- Always use wires with insulation and connectors or clips with insulating shrouds.
- Keep cables and wires as short as possible. Connect polarized components properly.
- Report any unsafe condition.
- Be aware of and follow all workplace and laboratory rules. Do not have drinks or food near equipment.
- If another person cannot let go of an energized conductor, switch the power off immediately. If that is not possible, use any available nonconductive material to try to separate the body from the contact.
- Use a lockout/tagout procedure to avoid someone turning power on while you are working on a circuit.

SAFETY NOTE

A GFCI outlet does not prevent shock or injury in all cases. If you are touching the hot and neutral wires without being grounded, no ground fault is detected and the GFCI breaker will not trip. In another case, the GFCI may prevent electrocution but not the initial electric shock before it interrupts the circuit. The initial shock could cause a secondary injury, such as from a fall.

SECTION 5 CHECKUP

1. What causes physical pain and/or damage to the body when electrical contact is made?
2. It's OK to wear a ring when working on an electrical circuit. (T or F)
3. Standing on a wet floor presents no safety hazard when working with electricity. (T or F)
4. A circuit can be rewired without removing the power if you are careful. (T or F)
5. Electrical shock can be extremely painful or even fatal. (T or F)
6. What does *GFCI* stand for?

SUMMARY

- Scientific notation is a method for expressing very large and very small numbers as a number between one and ten (one digit to left of decimal point) times a power of ten.
- Engineering notation is a form of scientific notation in which quantities are expressed with one, two, or three digits to the left of the decimal point times a power of ten that is a multiple of three.
- Metric prefixes are symbols used to represent powers of ten that are multiples of three.
- The uncertainty of a measured quantity depends on the accuracy and precision of the measurement.
- The number of significant digits in the result of a mathematical operation should never exceed the significant digits in the original numbers.
- Standard connections to electrical plugs include a hot wire, a neutral, and a safety ground.
- GFCI breakers sense the current in the hot wire and in the neutral wire and trip the breaker if they are different, indicating a ground fault.

KEY TERMS

Accuracy An indication of the range of error in a measurement.

Electrical shock The physical sensation resulting from current through the body.

Engineering notation A system for representing any number as a one-, two-, or three-digit number times a power of ten with an exponent that is a multiple of 3.

Error The difference between the true or best-accepted value of some quantity and the measured value.

Exponent The number to which a base number is raised.

Metric prefix A symbol that is used to replace the power of ten in numbers expressed in engineering notation.

Power of ten A numerical representation consisting of a base of 10 and an exponent; the number 10 raised to a power.

Precision A measure of the repeatability (or consistency) of a series of measurements.

Round off The process of dropping one or more digits to the right of the last significant digit in a number.

Scientific notation A system for representing any number as a number between 1 and 10 times an appropriate power of ten.

SI Standardized international system of units used for all engineering and scientific work; abbreviation for French *Le Systeme International d'Unites.*

Significant digit A digit known to be correct in a number.

TRUE/FALSE QUIZ

Answers are at the end of the chapter.

1. The number 3300 is written as 3.3×10^3 in both scientific and engineering notation.
2. A negative number that is expressed in scientific notation will always have a negative exponent.
3. When you multiply two numbers written in scientific notation, the exponents need to be the same.

4. When you divide two numbers written in scientific notation, the exponent of the denominator is subtracted from the exponent of the numerator.
5. The metric prefix *micro* has an equivalent power of ten equal to 10^6.
6. To express 56×10^6 with a metric prefix, the result is 56 M.
7. 0.047 μF is equal to 47 nF.
8. The number of significant digits in the number 0.0102 is three.
9. When you apply the *round-to-even* rule to round off 26.25 to three digits, the result is 26.3.
10. The white neutral lead for ac power should have the same current as the hot lead.

SELF-TEST

Answers are at the end of the chapter.

1. The quantity 4.7×10^3 is the same as
   (a) 470 **(b)** 4700 **(c)** 47,000 **(d)** 0.0047
2. The quantity 56×10^{-3} is the same as
   (a) 0.056 **(b)** 0.560 **(c)** 560 **(d)** 56,000
3. The number 3,300,000 can be expressed in engineering notation as
   (a) 3300×10^3 **(b)** 3.3×10^{-6} **(c)** 3.3×10^6 **(d)** either (a) or (c)
4. Ten milliamperes can be expressed as
   (a) 10 MA **(b)** 10 μA **(c)** 10 kA **(d)** 10 mA
5. Five thousand volts can be expressed as
   (a) 5000 V **(b)** 5 MV **(c)** 5 kV **(d)** either (a) or (c)
6. Twenty million ohms can be expressed as
   (a) 20 mΩ **(b)** 20 MW **(c)** 20 MΩ **(d)** 20 $\mu\Omega$
7. 15,000 W is the same as
   (a) 15 mW **(b)** 15 kW **(c)** 15 MW **(d)** 15 μW
8. Which of the following is not an electrical quantity?
   (a) current **(b)** voltage **(c)** time **(d)** power
9. The unit of current is
   (a) volt **(b)** watt **(c)** ampere **(d)** joule
10. The unit of voltage is
    (a) ohm **(b)** watt **(c)** volt **(d)** farad
11. The unit of resistance is
    (a) ampere **(b)** henry **(c)** hertz **(d)** ohm
12. Hertz is the unit of
    (a) power **(b)** inductance **(c)** frequency **(d)** time
13. The number of significant digits in the number 0.1050 is
    (a) two **(b)** three **(c)** four **(d)** five

PROBLEMS

Answers to odd-numbered problems are at the end of the chapter.

BASIC PROBLEMS

SECTION 1 Scientific and Engineering Notation

1. Express each of the following numbers in scientific notation:
   (a) 3000 **(b)** 75,000 **(c)** 2,000,000
2. Express each fractional number in scientific notation:
   (a) 1/500 **(b)** 1/2000 **(c)** 1/5,000,000
3. Express each of the following numbers in scientific notation:
   (a) 8400 **(b)** 99,000 **(c)** 0.2×10^6

4. Express each of the following numbers in scientific notation:
   (a) 0.0002 **(b)** 0.6 **(c)** 7.8×10^{-2}
5. Express each of the following as a regular decimal number:
   (a) 2.5×10^{-6} **(b)** 5.0×10^{2} **(c)** 3.9×10^{-1}
6. Express each number in regular decimal form:
   (a) 4.5×10^{-6} **(b)** 8×10^{-9} **(c)** 4.0×10^{-12}
7. Add the following numbers:
   (a) $(9.2 \times 10^{6}) + (3.4 \times 10^{7})$ **(b)** $(5 \times 10^{3}) + (8.5 \times 10^{-1})$
   (c) $(5.6 \times 10^{-8}) + (4.6 \times 10^{-9})$
8. Perform the following subtractions:
   (a) $(3.2 \times 10^{12}) - (1.1 \times 10^{12})$ **(b)** $(2.6 \times 10^{8}) - (1.3 \times 10^{7})$
   (c) $(1.5 \times 10^{-12}) - (8 \times 10^{-13})$
9. Perform the following multiplications:
   (a) $(5 \times 10^{3})(4 \times 10^{5})$ **(b)** $(1.2 \times 10^{12})(3 \times 10^{2})$ **(c)** $(2.2 \times 10^{-9})(7 \times 10^{-6})$
10. Divide the following:
    (a) $(1.0 \times 10^{3}) \div (2.5 \times 10^{2})$ **(b)** $(2.5 \times 10^{-6}) \div (5.0 \times 10^{-8})$
    (c) $(4.2 \times 10^{8}) \div (2 \times 10^{-5})$
11. Express each number in engineering notation:
    (a) 89,000 **(b)** 450,000 **(c)** 12,040,000,000,000
12. Express each number in engineering notation:
    (a) 2.35×10^{5} **(b)** 7.32×10^{7} **(c)** 1.333×10^{9}
13. Express each number in engineering notation:
    (a) 0.000345 **(b)** 0.025 **(c)** 0.00000000129
14. Express each number in engineering notation:
    (a) 9.81×10^{-3} **(b)** 4.82×10^{-4} **(c)** 4.38×10^{-7}
15. Add the following numbers and express each result in engineering notation:
    (a) $2.5 \times 10^{-3} + 4.6 \times 10^{-3}$ **(b)** $68 \times 10^{6} + 33 \times 10^{6}$
    (c) $1.25 \times 10^{6} + 250 \times 10^{3}$
16. Multiply the following numbers and express each result in engineering notation:
    (a) $(32 \times 10^{-3})(56 \times 10^{3})$ **(b)** $(1.2 \times 10^{-6})(1.2 \times 10^{-6})$ **(c)** $100(55 \times 10^{-3})$
17. Divide the following numbers and express each result in engineering notation:
    (a) $50 \div (2.2 \times 10^{3})$ **(b)** $(5 \times 10^{3}) \div (25 \times 10^{-6})$
    (c) $(560 \times 10^{3}) \div (660 \times 10^{3})$

SECTION 2 Units and Metric Prefixes

18. Express each number in Problem 11 in ohms using a metric prefix.
19. Express each number in Problem 13 in amperes using a metric prefix.
20. Express each of the following as a quantity having a metric prefix:
    (a) 31×10^{-3} A **(b)** 5.5×10^{3} V **(c)** 20×10^{-12} F
21. Express the following using metric prefixes:
    (a) 3×10^{-6} F **(b)** $3.3 \times 10^{6}\ \Omega$ **(c)** 350×10^{-9} A
22. Express each quantity with a power of ten:
    (a) 5 μA **(b)** 43 mV **(c)** 275 kΩ **(d)** 10 MW

SECTION 3 Metric Unit Conversions

23. Perform the indicated conversions:
    (a) 5 mA to microamperes **(b)** 3200 μW to milliwatts
    (c) 5000 kV to megavolts **(d)** 10 MW to kilowatts

24. Determine the following:
- **(a)** The number of microamperes in 1 milliampere
- **(b)** The number of millivolts in 0.05 kilovolt
- **(c)** The number of megohms in 0.02 kilohm
- **(d)** The number of kilowatts in 155 milliwatts

25. Add the following quantities:
(a) 50 mA + 680 μA **(b)** 120 kΩ + 2.2 MΩ **(c)** 0.02 μF + 3300 pF

26. Do the following operations:
(a) 10 kΩ ÷ (2.2 kΩ + 10 kΩ) **(b)** 250 mV ÷ 50 μV **(c)** 1 MW ÷ 2 kW

SECTION 4 Measured Numbers

27. How many significant digits are in each of the following numbers:
(a) 1.00×10^3 **(b)** 0.0057 **(c)** 1502.0
(d) 0.000036 **(e)** 0.105 **(f)** 2.6×10^2

28. Round each of the following numbers to three significant digits. Use the "round-to-even" rule.
(a) 50,505 **(b)** 220.45 **(c)** 4646 **(d)** 10.99 **(e)** 1.005

ANSWERS

SECTION CHECKUPS

SECTION 1 Scientific and Engineering Notation

1. True
2. 10^2
3. **(a)** 4.35×10^3 **(b)** 1.201×10^4 **(c)** 2.9×10^7
4. **(a)** 7.6×10^{-1} **(b)** 2.5×10^{-4} **(c)** 5.97×10^{-7}
5. **(a)** 3×10^5 **(b)** 6×10^{10} **(c)** 2×10^1 **(d)** 2.37×10^{-6}
6. Enter the digits, press EE, and enter the power of ten.
7. **(a)** 5.6×10^{-3} **(b)** 28.3×10^{-9} **(c)** 950×10^3 **(d)** 375×10^9
8. Enter the digits, press EE, and enter the power of ten.

SECTION 2 Units and Metric Prefixes

1. Mega (M), kilo (k), milli (m), micro (μ), nano (n), and pico (p)
2. 1 *m*A (one microampere)
3. 250 kW (250 kilowatts)

SECTION 3 Metric Unit Conversions

1. 0.01 MV = 10 kV
2. 250,000 pA = 0.00025 mA
3. 125 kW
4. 75 mV

SECTION 4 Measured Numbers

1. Zeros should be retained only if they are significant because if they are shown, they are considered significant.
2. If the digit dropped is 5, increase the last retained digit *if* it makes it even, otherwise do not.
3. A zero to the right of the decimal point implies that the resistor is accurate to the nearest 100 Ω (0.1 kΩ).

4. The instrument must be accurate to four significant digits.
5. Scientific and engineering notation can show any number of digits to the right of a decimal. Numbers to the right of the decimal are always considered significant.

SECTION 5 Electrical Safety

1. Current
2. F
3. F
4. F
5. T
6. Ground-fault circuit interrupter

RELATED PROBLEMS FOR EXAMPLES

1 7.5×10^{8}
2 9.3×10^{-7}
3 820,000,000
4 4.89×10^{3}
5 1.85×10^{-5}
6 4.8×10^{5}
7 4×10^{4}
8 Enter 5.73946; press EE, enter 5.
9 36×10^{9}
10 5.6×10^{-12}
11 Enter 273.9, press EE, enter 3.
12 **(a)** 56 MΩ **(b)** 470 μA
13 1000 μA
14 1 mV
15 0.893 μA
16 0.01 μF
17 2200 pF
18 0.0022 MΩ
19 2883 mA
20 10.0×10^{3}
21 The number 10 has two significant digits; the number 10.0 has three.
22 3.28

TRUE/FALSE QUIZ

1. T **2.** F **3.** F **4.** T **5.** F **6.** T **7.** T **8.** T **9.** F **10.** T

SELF-TEST

1. (b) **2.** (a) **3.** (c) **4.** (d) **5.** (d) **6.** (c) **7.** (b)
8. (c) **9.** (c) **10.** (c) **11.** (d) **12.** (c) **13.** (c)

PROBLEMS – ODD-NUMBERED ANSWERS

1. **(a)** 3×10^{3} **(b)** 7.5×10^{4} **(c)** 2×10^{6}
3. **(a)** 8.4×10^{3} **(b)** 9.9×10^{4} **(c)** 2×10^{5}
5. **(a)** 0.0000025 **(b)** 500 **(c)** 0.39
7. **(a)** 4.32×10^{7} **(b)** 5.00085×10^{3} **(c)** 6.06×10^{-8}

9.	**(a)** 2.0×10^9	**(b)** 3.6×10^{14}	**(c)** 1.54×10^{-14}			
11.	**(a)** 89×10^3	**(b)** 450×10^3	**(c)** 12.04×10^{12}			
13.	**(a)** 345×10^{-6}	**(b)** 25×10^{-3}	**(c)** 1.29×10^{-9}			
15.	**(a)** 7.1×10^{-3}	**(b)** 101×10^6	**(c)** 1.50×10^6			
17.	**(a)** 22.7×10^{-3}	**(b)** 200×10^6	**(c)** 848×10^{-3}			
19.	**(a)** 345 μA	**(b)** 25 mA	**(c)** 1.29 nA			
21.	**(a)** 3 μF	**(b)** 3.3 MΩ	**(c)** 350 nA			
23.	**(a)** 5000 μA	**(b)** 3.2 mW	**(c)** 5 MV	**(d)** 10,000 kW		
25.	**(a)** 50.68 mA	**(b)** 2.32 MΩ	**(c)** 0.0233 μF			
27.	**(a)** 3	**(b)** 4	**(c)** 5	**(d)** 6	**(e)** 3	**(f)** 2

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Voltage, Current, and Resistance

Voltage, Current, and Resistance

CHAPTER OUTLINE

CHAPTER OBJECTIVES

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

KEY TERMS

- Atom
- Electron
- Free electron
- Conductor
- Semiconductor
- Insulator
- Charge
- Coulomb's law
- Coulomb (C)
- Voltage
- Volt (V)
- Voltage source
- Fuel cell
- Current
- Ampere (A)
- Current source
- Resistance
- Ohm (Ω)
- Conductance
- Siemens (S)
- Resistor
- Potentiometer
- Rheostat
- Circuit
- Load
- Schematic
- Closed circuit
- Open circuit
- Switch
- Fuse
- Circuit breaker
- AWG
- Ground
- Voltmeter
- Ammeter
- Ohmmeter
- DMM

APPLICATION ASSIGNMENT PREVIEW

Assume you wanted to have an interactive quiz board as part of a science fair display. The quiz board will use a rotary switch to select one of four options that represent battery types. Each position of the switch lights a light. The person viewing the display selects the matching answer by pressing a pushbutton next to one of the four possible answers. If the correct pushbutton is pressed, a "correct" light is illuminated; otherwise, nothing happens. The overall brightness of the lights is controlled by a single rheostat.

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

VISIT THE COMPANION WEBSITE

Study aids for this chapter are available at http://www.pearsonhighered.com/floyd/

INTRODUCTION

Three basic electrical quantities presented in this chapter are voltage, current, and resistance. No matter what type of electrical or electronic equipment you may work with, these quantities will always be of primary importance. This is true for dc and ac circuits, but our focus will be dc circuits. Because of its importance in electrical applications, an ac circuit may be used occasionally to illustrate a particular concept; however, in these special cases the analysis and calculations are the same as for an equivalent lent dc circuit.

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

Streeter Photography/Alamy

1 Atoms

All matter is made of atoms; and all atoms consist of electrons, protons, and neutrons. The configuration of certain electrons in an atom is the key factor in determining how well a conductive or semiconductive material conducts electric current.

After completing this section, you should be able to

- **Describe the basic structure of an atom**
  - Define *nucleus, proton, neutron,* and *electron*
  - Define *atomic number*
  - Define *shell*
  - Explain what a valence electron is
  - Describe ionization
  - Explain what a free electron is
  - Define *conductor, semiconductor,* and *insulator*

An **atom** is the smallest particle of an **element** that retains the characteristics of that element. Each of the known 110 elements has atoms that are different from the atoms of all other elements. This gives each element a unique atomic structure. According to the classic Bohr model, an atom is visualized as having a planetary type of structure that consists of a central nucleus surrounded by orbiting electrons, as illustrated in Figure 1. The **nucleus** consists of positively charged particles called **protons** and uncharged particles called **neutrons**. The basic particles of negative charge are called **electrons**. Electrons orbit the nucleus.

Each type of atom has a certain number of protons that distinguishes it from the atoms of all other elements. For example, the simplest atom is that of hydrogen, which has one proton and one electron, as pictured in Figure 2(a). As another example, the helium atom, shown in Figure 2(b), has two protons and two neutrons in the nucleus and two electrons orbiting the nucleus.

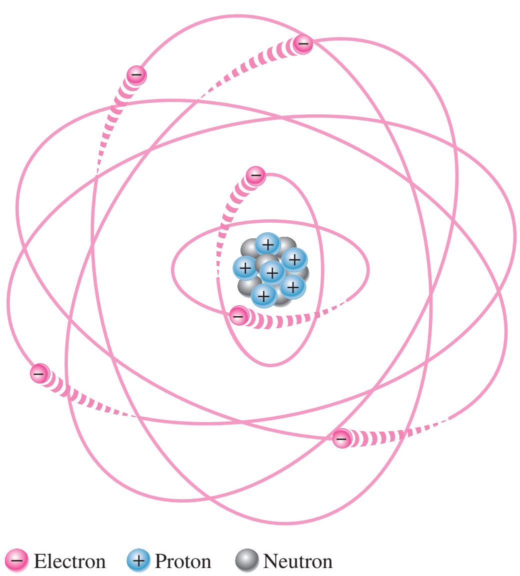

FIGURE 1

The Bohr model of an atom showing electrons in circular orbits around the nucleus. The "tails" on the electrons indicate they are moving.

This icon indicates selected websites for further information on topics in this section. See the Companion Website provided with this text.