

# QUANTITIES AND UNITS

# 1

## CHAPTER OUTLINE

- 1-1 Units of Measurement
- 1-2 Scientific Notation
- 1-3 Engineering Notation and Metric Prefixes
- 1-4 Metric Unit Conversions
- 1-5 Measured Numbers

## CHAPTER OBJECTIVES

- ▶ Discuss the SI standard
- ▶ Use scientific notation (powers of ten) to represent quantities
- ▶ Use engineering notation and metric prefixes to represent large and small quantities
- ▶ Convert from one unit with a metric prefix to another
- ▶ Express measured data with the proper number of significant digits

## KEY TERMS

- ▶ SI
- ▶ Scientific notation
- ▶ Power of ten
- ▶ Exponent
- ▶ Engineering notation
- ▶ Metric prefix
- ▶ Error
- ▶ Accuracy
- ▶ Precision
- ▶ Significant digits
- ▶ Round off

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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.



## SAFETY NOTE

- ▶ When you work with electricity, you must always consider safety first. Safety notes throughout the book remind you of the importance of safety and provide tips for a safe workplace. Basic safety precautions are introduced in Chapter 2.

## 1-1 UNITS OF MEASUREMENT

In the 19th century, the principal weight and measurement units dealt with commerce. As technology advanced, scientists and engineers saw the need for international standard measurement units. In 1875, at a conference called by the French, representatives from 18 nations signed a treaty that established international standards. Today, all engineering and scientific work use an improved international system of units, Le Système International d'Unités, abbreviated **SI**\*.

After completing this section, you should be able to

- ◆ **Discuss the SI standard**
  - ◆ Specify the base (fundamental) SI units
  - ◆ Specify the supplementary units
  - ◆ Explain what derived units are

### Base and Derived Units

The SI system is based on seven base units (sometimes called *fundamental units*) and two supplementary units. All measurements can be expressed as some combination of base and supplementary units. Table 1-1 lists the base units, and Table 1-2 lists the supplementary units.

The base electrical unit, the ampere, is the unit for electrical current. Current is abbreviated with the letter *I* (for intensity) and uses the symbol A (for ampere). The ampere is unique in that it uses the base unit of time (*t*) in its definition (second). All other electrical and magnetic units (such as voltage, power, and magnetic flux) use various combinations of base units in their definitions and are called *derived units*.

For example, the derived unit of voltage, which is the volt (V), is defined in terms of base units as  $\text{m}^2 \cdot \text{kg} \cdot \text{s}^{-3} \cdot \text{A}^{-1}$ . As you can see, this combination of base units is very cumbersome and impractical. Therefore, the volt is used as the derived unit.

► **TABLE 1-1**

SI base units.

QUANTITY	UNIT	SYMBOL
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Luminous intensity	Candela	cd
Amount of substance	Mole	mol

► **TABLE 1-2**

SI supplementary units.

QUANTITY	UNIT	SYMBOL
Plane angle	Radian	r
Solid angle	Steradian	sr

\*All bold terms are in the end-of-book glossary. The bold terms in color are key terms and are also defined at the end of the chapter.

Letter symbols are used to represent both quantities and their units. One symbol is used to represent the name of the quantity, and another symbol is used to represent the unit of measurement of that quantity. For example, italic  $P$  stands for *power*, and nonitalic  $W$  stands for *watt*, which is the unit of power. Another example is voltage, where the same letter stands for both the quantity and its unit. Italic  $V$  represents voltage and nonitalic  $V$  represents *volt*, which is the unit of voltage. As a rule, italic letters stand for the quantity and nonitalic (roman) letters represent the unit of that quantity.

Table 1–3 lists the most important electrical quantities, along with their derived SI units and symbols. Table 1–4 lists magnetic quantities, along with their derived SI units and symbols.

QUANTITY	SYMBOL	SI UNIT	SYMBOL
Capacitance	$C$	Farad	F
Charge	$Q$	Coulomb	C
Conductance	$G$	Siemens	S
Energy (work)	$W$	Joule	J
Frequency	$f$	Hertz	Hz
Impedance	$Z$	Ohm	$\Omega$
Inductance	$L$	Henry	H
Power	$P$	Watt	W
Reactance	$X$	Ohm	$\Omega$
Resistance	$R$	Ohm	$\Omega$
Voltage	$V$	Volt	V

TABLE 1–3

Electrical quantities and derived units with SI symbols.

QUANTITY	SYMBOL	SI UNIT	SYMBOL
Magnetic field intensity	$H$	Ampere-turns/meter	At/m
Magnetic flux	$\phi$	Weber	Wb
Magnetic flux density	$B$	Tesla	T
Magnetomotive force	$F_m$	Ampere-turn	At
Permeability	$\mu$	Webers/ampere-turn • meter	Wb/At • m
Reluctance	$\mathcal{R}$	Ampere-turns/weber	At/Wb

TABLE 1–4

Magnetic quantities and derived units with SI symbols.

In addition to the common electrical units shown in Table 1–3, the SI system has many other units that are defined in terms of certain base 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*). The mole (abbreviated *mol*) was added in 1971. Three base units form the basis of the mks (for meter-kilogram-second) units that are used for derived quantities in engineering and basic physics 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 base 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.

### SECTION 1-1 CHECKUP

Answers are at the end of the chapter.

1. How does a base unit differ from a derived unit?
2. What is the base electrical unit?
3. What does *SI* stand for?
4. Without referring to Table 1-3, list as many electrical quantities as possible, including their symbols, units, and unit symbols.
5. Without referring to Table 1-4, list as many magnetic quantities as possible, including their symbols, units, and unit symbols.

## 1-2 SCIENTIFIC NOTATION

In electrical and electronics fields, both very small and very large quantities are commonly used. For example, it is common to have electrical current values of only a few thousandths or even a few millionths of an ampere and to have resistance values ranging up to several thousand or several million ohms.

After completing this section, you should be able to

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

**Scientific notation** provides a convenient method to represent large and small numbers and to perform calculations involving such numbers. In scientific notation, a quantity is expressed as a product of a number between 1 and 10 and a power of ten. For example, the quantity 150,000 is expressed in scientific notation as  $1.5 \times 10^5$ , and the quantity 0.00022 is expressed as  $2.2 \times 10^{-4}$ .

### Powers of Ten

Table 1-5 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 ( $10^x$ ). An **exponent** is a number to which a base number is raised. It indicates the number of places that the decimal point is moved to the right or left to produce the

▼ TABLE 1-5

Some positive and negative powers of ten.

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

decimal number. For a positive power of ten, move the decimal point to the right to get the equivalent decimal number. For example, for an exponent of 4,

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

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

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

**EXAMPLE 1-1**

Express each number in scientific notation.

- (a) 200                      (b) 5,000                      (c) 85,000                      (d) 3,000,000

**Solution** In each case, move the decimal point an appropriate number of places to the left to determine the positive power of ten. Notice that the result is always a number between 1 and 10 times a power of ten.

- (a)  $200 = 2 \times 10^2$                       (b)  $5,000 = 5 \times 10^3$   
 (c)  $85,000 = 8.5 \times 10^4$                       (d)  $3,000,000 = 3 \times 10^6$

**Related Problem\*** Express 4,750 in scientific notation.

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\*Answers are at the end of the chapter.

**EXAMPLE 1-2**

Express each number in scientific notation.

- (a) 0.2                      (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)  $0.2 = 2 \times 10^{-1}$                       (b)  $0.005 = 5 \times 10^{-3}$   
 (c)  $0.00063 = 6.3 \times 10^{-4}$                       (d)  $0.000015 = 1.5 \times 10^{-5}$

**Related Problem** Express 0.00738 in scientific notation.

**EXAMPLE 1-3**

Express each of the following as a regular decimal number:

- (a)  $1 \times 10^5$                       (b)  $2 \times 10^3$                       (c)  $3.2 \times 10^{-2}$                       (d)  $2.5 \times 10^{-6}$

**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)  $1 \times 10^5 = 100,000$                       (b)  $2 \times 10^3 = 2,000$   
 (c)  $3.2 \times 10^{-2} = 0.032$                       (d)  $2.5 \times 10^{-6} = 0.0000025$

**Related Problem** Express  $9.12 \times 10^3$  as a regular 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 is the power of ten of the sum.

### EXAMPLE 1–4

Add  $2 \times 10^6$  and  $5 \times 10^7$  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  $3.1 \times 10^3$  and  $5.5 \times 10^4$ .

**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 is the power of ten of the difference.

### EXAMPLE 1–5

Subtract  $2.5 \times 10^{-12}$  from  $7.5 \times 10^{-11}$  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  $3.5 \times 10^{-6}$  from  $2.2 \times 10^{-5}$ .

**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 1–6

Multiply  $5 \times 10^{12}$  and  $3 \times 10^{-6}$  and express the result in scientific notation.

**Solution** Multiply the numbers, and algebraically add the powers.

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

**Related Problem** Multiply  $3.2 \times 10^6$  and  $1.5 \times 10^{-3}$ .

**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 (the exponent) in the denominator from the power of ten in the numerator (the powers do not have to be the same).

#### EXAMPLE 1-7

Divide  $5.0 \times 10^8$  by  $2.5 \times 10^3$  and express the result in scientific notation.

**Solution** Write the division problem with a numerator and denominator as

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

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

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

**Related Problem** Divide  $8 \times 10^{-6}$  by  $2 \times 10^{-10}$ .

#### SECTION 1-2 CHECKUP

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) 4,350      (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)  $(2.5 \times 10^{-6}) - (1.3 \times 10^{-7})$

## 1-3 ENGINEERING NOTATION AND METRIC PREFIXES

Engineering notation, a specialized form of scientific notation, is used widely in technical fields to represent large and small quantities. In electronics, engineering notation is used to represent values of voltage, current, power, resistance, capacitance, inductance, and time, to name a few. Metric prefixes are used in conjunction with engineering notation as a “short hand” for the certain powers of ten that are multiples of three.

After completing this section, you should be able to

- ♦ Use engineering notation and metric prefixes to represent large and small quantities
  - ♦ List the metric prefixes
  - ♦ Change a power of ten in engineering notation to a metric prefix
  - ♦ Use metric prefixes to express electrical quantities
  - ♦ Convert one metric prefix to another

## 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  $33 \times 10^3$ . In scientific notation, it is expressed as  $3.3 \times 10^4$ . As another example, the number 0.045 expressed in engineering notation is  $45 \times 10^{-3}$ . In scientific notation, it is expressed as  $4.5 \times 10^{-2}$ .

### EXAMPLE 1–8

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  $82 \times 10^3$ .  
 (b) 243,000 is expressed as  $243 \times 10^3$ .  
 (c) 1,956,000 is expressed as  $1.956 \times 10^6$ .

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

### EXAMPLE 1–9

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  $2.2 \times 10^{-3}$ .  
 (b) 0.000000047 is expressed as  $47 \times 10^{-9}$ .  
 (c) 0.00033 is expressed as  $330 \times 10^{-6}$ .

*Related Problem* Express 0.000000000056 in engineering notation.

## Metric Prefixes

A metric prefix is an affix that precedes a measured quantity and represents a multiple or power of 10 multiple of the quantity. In engineering notation **metric prefixes** represent each of the most commonly used powers of ten in electronics and electrical work. The most commonly used metric prefixes are listed in Table 1–6 with their symbols and corresponding powers of ten.

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  $25 \times 10^{-3}$  A. This quantity expressed using a metric prefix is 25 mA, which is read 25 milliamps. Note that 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 M $\Omega$ , which is read 10 megohms. The metric prefix *mega* has replaced  $10^6$ .

METRIC PREFIX	SYMBOL	POWER OF TEN	VALUE
pico	p	$10^{-12}$	One-trillionth
nano	n	$10^{-9}$	One-billionth
micro	$\mu$	$10^{-6}$	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

TABLE 1-6

Common metric prefixes used in electronics and electrical work with their symbols and corresponding powers of ten and values.

**EXAMPLE 1-10**

Express each quantity using a metric prefix:

- (a) 50,000 V      (b) 5,000,000  $\Omega$       (c) 0.000036 A

*Solution*

(a)  $50,000 \text{ V} = 50 \times 10^3 \text{ V} = \mathbf{50 \text{ kV}}$

(b)  $5,000,000 \Omega = 5 \times 10^6 \Omega = \mathbf{5 \text{ M}\Omega}$

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

*Related Problem*

Express using metric prefixes:

- (a) 56,000  $\Omega$       (b) 0.000470 A

## Calculator Tip

All scientific and graphing calculators provide features for entering and displaying numbers in various formats. Scientific and engineering notation are special cases of exponential (power of ten) notation. Most calculators have a key labeled EE (or EXP) that is used to enter the exponent of numbers. To enter a number in exponential notation, enter the base number first, including the sign, and then press the EE key, followed by the exponent, including the sign.

Scientific and graphing calculators have displays for showing the power of ten. Some calculators display the exponent as a small raised number on the right side of the display.

**47.0<sup>03</sup>**

Other calculators display the number with a small E followed by the exponent.

**47.0E03**

Notice that the base 10 is not generally shown, but it is implied or represented by the E. When you write out the number, you need to include the base 10. The displayed number shown above is written out as  $47.0 \times 10^3$  in engineering notation.

Some calculators are placed in the scientific or engineering notation mode using a secondary or tertiary function, such as SCI or ENG. Then numbers are entered in regular decimal form. The calculator automatically converts them to the proper format. Other calculators provide for mode selection using a menu.

Always check the owner's manual for your particular calculator to determine how to use the exponential notation features.

SECTION 1-3  
CHECKUP

- Express the following numbers in engineering notation:  
(a) 0.0056    (b) 0.0000000283    (c) 950,000    (d) 375,000,000,000
- List the metric prefix for each of the following powers of ten:  
 $10^6$ ,  $10^3$ ,  $10^{-3}$ ,  $10^{-6}$ ,  $10^{-9}$ , and  $10^{-12}$
- Use an appropriate metric prefix to express 0.000001 A.
- Use an appropriate metric prefix to express 250,000 W.

## 1-4 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 ( $\mu\text{A}$ ). 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 rules apply to metric unit conversions:

- When converting from a larger unit to a smaller unit, move the decimal point to the right.
- When converting from a smaller unit to a larger unit, move the decimal point to the left.
- 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 ( $\mu\text{A}$ ), 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  $\mu\text{A}$  is  $10^{-6}$  A). Notice that when the unit is made smaller, the number is made larger by a corresponding amount and vice versa. The following examples illustrate a few conversions.

## EXAMPLE 1-11

Convert 0.15 milliamperes (0.15 mA) to microamperes ( $\mu\text{A}$ ).

*Solution* Move the decimal point three places to the right.

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

*Related Problem* Convert 1 mA to microamperes.

## EXAMPLE 1-12

Convert 4,500 microvolts (4,500  $\mu\text{V}$ ) to millivolts (mV).

*Solution* Move the decimal point three places to the left.

$$4,500 \mu\text{V} = 4,500 \times 10^{-6} \text{ V} = 4.5 \times 10^{-3} \text{ V} = \mathbf{4.5 \text{ mV}}$$

*Related Problem* Convert 1,000  $\mu\text{V}$  to millivolts.

**EXAMPLE 1–13**Convert 5,000 nanoamperes (5,000 nA) to microamperes ( $\mu\text{A}$ ).*Solution* Move the decimal point three places to the left.

$$5,000 \text{ nA} = 5,000 \times 10^{-9} \text{ A} = 5 \times 10^{-6} \text{ A} = \mathbf{5 \mu\text{A}}$$

*Related Problem* Convert 893 nA to microamperes.**EXAMPLE 1–14**Convert 47,000 picofarads (47,000 pF) to microfarads ( $\mu\text{F}$ ).*Solution* Move the decimal point six places to the left.

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

*Related Problem* Convert 10,000 pF to microfarads.**EXAMPLE 1–15**Convert 0.00022 microfarad (0.00022  $\mu\text{F}$ ) to picofarads (pF).*Solution* Move the decimal point six places to the right.

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

*Related Problem* Convert 0.0022  $\mu\text{F}$  to picofarads.**EXAMPLE 1–16**Convert 1,800 kilohms (1,800 k $\Omega$ ) to megohms (M $\Omega$ ).*Solution* Move the decimal point three places to the left.

$$1,800 \text{ k}\Omega = 1,800 \times 10^3 \Omega = 1.8 \times 10^6 \Omega = \mathbf{1.8 \text{ M}\Omega}$$

*Related Problem* Convert 2.2 k $\Omega$  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 1–17**Add 15 mA and 8,000  $\mu\text{A}$  and express the sum in milliamperes.*Solution* Convert 8,000  $\mu\text{A}$  to 8 mA and add.

$$\begin{aligned} 15 \text{ mA} + 8,000 \mu\text{A} &= 15 \times 10^{-3} \text{ A} + 8,000 \times 10^{-6} \text{ A} \\ &= 15 \times 10^{-3} \text{ A} + 8 \times 10^{-3} \text{ A} = 15 \text{ mA} + 8 \text{ mA} = \mathbf{23 \text{ mA}} \end{aligned}$$

*Related Problem* Add 2,873 mA to 10,000  $\mu\text{A}$ ; express the sum in milliamperes.**SECTION 1–4  
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  $\mu\text{V}$  and express the result in mV.
5. Which is larger: 2000 pF or 0.02  $\mu\text{F}$ ?

## 1–5 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. It is a measure of how well a given measurement agrees with a standard. 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  $\Omega$ , a calculator will show 0.33333333. Since the original numbers each contain two 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  $\Omega$  can have three, four, or five significant digits. To clarify the significant digits, scientific notation (or a metric prefix) should be used. For example, 12.10 k $\Omega$  has four 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 not significant. To avoid confusion, numbers should be shown using scientific or engineering notation if it is necessary to show the significant zeros.

**EXAMPLE 1–18**

Express the measured number 4,300 with two, three, and four significant digits.

*Solution*

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

$$4.3 \times 10^3$$

To show three significant digits, write

$$4.30 \times 10^3$$

To show four significant digits, write

$$4.300 \times 10^3$$

*Related Problem*

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

**EXAMPLE 1–19**

Underline the significant digits in each of the following measurements:

- (a) 40.0    (b) 0.3040    (c)  $1.20 \times 10^5$     (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  $\times 10^5$  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 1–18.

(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 or a 5 is followed by any nonzero digits, increase the last retained digit by 1.
2. If the most significant digit dropped is less than 5, do not change the last retained digit.
3. If the most significant digit dropped is 5 and there are no following nonzero digits, increase the last retained digit by 1 *if* it makes the number even. If it makes the number odd, do not change the retained digit. This is called the “round-to-even” rule.

**EXAMPLE 1–20**

Round off the following numbers to three significant digits:

(a) 10.071    (b) 29.961    (c) 6.3948    (d) 123.52    (e) 122.5    (f) 328.52

*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) 122.5 rounds to **122**.                                (f) 328.52 rounds to **329**.

*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 one part in 1,000. 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 1–5  
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 1,000  $\Omega$  resistor listed as 1.0 k $\Omega$ . 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?

**SUMMARY**

- SI is an abbreviation for Le Système International d’Unités and is a standardized system of units.
- A base unit is an SI unit from which other SI units are derived. There are seven base units and two supplementary units.
- Scientific notation is a method for representing 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 modified form of scientific notation in which quantities are represented 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 represent powers of ten in numbers. In electronics work, prefixes represent powers of ten expressed in engineering notation.
- 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.

## KEY TERMS

These key terms are also defined in the end-of-book glossary.

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

**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** An affix that precedes a measured quantity and represents a multiple or power of 10 multiple of the quantity.

**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 internationalized system of units used for all engineering and scientific work; abbreviation for French *Le Système International d'Unités*.

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

## TRUE/FALSE QUIZ

Answers are at the end of the chapter.

1. Derived units in the SI system use base units in their definition.
2. The base electrical unit in the SI system is the volt.
3. The supplementary SI units are for angular measurements.
4. The number 3,300 is written as  $3.3 \times 10^3$  in both scientific and engineering notation.
5. A negative number that is expressed in scientific notation will always have a negative exponent.
6. When you multiply two numbers written in scientific notation, the exponents need to be the same.
7. When you divide two numbers written in scientific notation, the exponent of the denominator is subtracted from the exponent of the numerator.
8. The metric prefix *micro* has an equivalent power of ten equal to  $10^6$ .
9. To express  $56 \times 10^6$  with a metric prefix, the result is 56 M.
10.  $0.047 \mu\text{F}$  is equal to 47 nF.
11.  $0.010 \mu\text{F}$  is equal to 10,000 pF.
12. 10,000 kW is equal to 1 MW.
13. The number of significant digits in the number 0.0102 is three.
14. To express 10,000 with three significant figures, you could write  $10.000 \times 10^3$ .
15. When you apply the *round-to-even* rule to round off 26.25 to three digits, the result is 26.3.
16. If a series of measurements are precise, they must also be accurate.
17. The base SI electrical unit is the ampere.

**SELF-TEST****Answers are at the end of the chapter.**

- Which of the following is not an electrical quantity?  
(a) current      (b) voltage      (c) time      (d) power
- The unit of current is  
(a) volt      (b) watt      (c) ampere      (d) joule
- The number of base units in the SI system is  
(a) 3      (b) 5      (c) 6      (d) 7
- An mks measurement unit is one that  
(a) can be expressed as a combination of the meter, kilogram and second  
(b) uses a supplemental unit in its definition  
(c) is always a base unit  
(d) includes all base units in its definition
- In the SI system, the prefix k means to multiply the unit by  
(a) 100      (b) 1,000      (c) 10,000      (d) 1,000,000
- 15,000 W is the same as  
(a) 15 mW      (b) 15 kW      (c) 15 MW      (d) 15  $\mu$ W
- The quantity  $4.7 \times 10^3$  is the same as  
(a) 470      (b) 4,700      (c) 47,000      (d) 0.0047
- The quantity  $56 \times 10^{-3}$  is the same as  
(a) 0.056      (b) 0.560      (c) 560      (d) 56,000
- The number 3,300,000 can be expressed in engineering notation as  
(a)  $33 \times 10^5$       (b)  $3.3 \times 10^{-6}$       (c)  $3.3 \times 10^6$       (d)  $330 \times 10^4$
- Ten milliamperes can be expressed as  
(a) 10 MA      (b) 10  $\mu$ A      (c) 10 kA      (d) 10 mA
- Five thousand volts can be expressed as  
(a) 5,000 V      (b) 5 MV      (c) 5 kV      (d) either answer (a) or (c)
- Twenty million ohms can be expressed as  
(a) 20 m $\Omega$       (b) 20 MW      (c) 20 M $\Omega$       (d) 20  $\mu\Omega$
- The number of significant digits in 0.1050 is  
(a) two      (b) three      (c) four      (d) five
- When reporting a measured value, it is okay to include  
(a) the entire result as shown on a calculator  
(b) one uncertain digit  
(c) two digits to the right of the decimal place  
(d) three digits to the right of the decimal place

**PROBLEMS****Answers to odd-numbered problems are at the end of the book.****SECTION 1-2 Scientific Notation**

- Express each of the following numbers in scientific notation:  
(a) 3,000      (b) 75,000      (c) 2,000,000
- Express each fractional number in scientific notation:  
(a) 1/500      (b) 1/2,000      (c) 1/5,000,000
- Express each of the following numbers in scientific notation:  
(a) 8,400      (b) 99,000      (c)  $0.2 \times 10^6$

4. Express each of the following numbers in scientific notation:  
 (a) 0.0002                      (b) 0.6                      (c)  $7.8 \times 10^{-2}$
5. Express each of the following numbers in scientific notation:  
 (a)  $32 \times 10^3$                       (b)  $6,800 \times 10^{-6}$                       (c)  $870 \times 10^8$
6. Express each of the following as a regular decimal number:  
 (a)  $2 \times 10^5$                       (b)  $5.4 \times 10^{-9}$                       (c)  $1.0 \times 10^1$
7. Express each of the following as a regular decimal number:  
 (a)  $2.5 \times 10^{-6}$                       (b)  $5.0 \times 10^2$                       (c)  $3.9 \times 10^{-1}$
8. Express each number in regular decimal form:  
 (a)  $4.5 \times 10^{-6}$                       (b)  $8 \times 10^{-9}$                       (c)  $4.0 \times 10^{-12}$
9. 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)  $(5.6 \times 10^{-8}) + (4.6 \times 10^{-9})$
10. 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)  $(1.5 \times 10^{-12}) - (8 \times 10^{-13})$
11. Perform the following multiplications:  
 (a)  $(5 \times 10^3)(4 \times 10^5)$                       (b)  $(1.2 \times 10^{12})(3 \times 10^2)$   
 (c)  $(2.2 \times 10^{-9})(7 \times 10^{-6})$
12. 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)  $(4.2 \times 10^8) \div (2 \times 10^{-5})$
13. Perform the indicated operations:  
 (a)  $(8 \times 10^4 + 4 \times 10^3) \div 2 \times 10^2$                       (b)  $(3 \times 10^7)(5 \times 10^5) - 9 \times 10^{12}$   
 (c)  $(2.2 \times 10^2 \div 1.1 \times 10^2)(5.5 \times 10^4)$

### SECTION 1-3 Engineering Notation and Metric Prefixes

14. Starting with  $10^{-12}$ , list the powers of ten in increasing order used in engineering notation.
15. Express each of the following numbers in engineering notation:  
 (a) 89,000                      (b) 450,000                      (c) 12,040,000,000,000
16. Express each number in engineering notation:  
 (a)  $2.35 \times 10^5$                       (b)  $7.32 \times 10^7$                       (c)  $1.333 \times 10^9$
17. Express each number in engineering notation:  
 (a) 0.000345                      (b) 0.025                      (c) 0.00000000129
18. Express each number in engineering notation:  
 (a)  $9.81 \times 10^{-3}$                       (b)  $4.82 \times 10^{-4}$                       (c)  $4.38 \times 10^{-7}$
19. 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)  $(1.25 \times 10^6) + (250 \times 10^3)$
20. 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)  $100(55 \times 10^{-3})$
21. 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)  $560 \times 10^3 \div (660 \times 10^3)$

22. Express each number in Problem 15 in ohms using a metric prefix.
23. Express each number in Problem 17 in amperes using a metric prefix.
24. Express each of the following as a quantity having a metric prefix:  
 (a)  $31 \times 10^{-3} \text{ A}$       (b)  $5.5 \times 10^3 \text{ V}$       (c)  $20 \times 10^{-12} \text{ F}$
25. Express the following using metric prefixes:  
 (a)  $3 \times 10^{-6} \text{ F}$       (b)  $3.3 \times 10^6 \Omega$       (c)  $350 \times 10^{-9} \text{ A}$
26. Express the following using metric prefixes:  
 (a)  $2.5 \times 10^{-12} \text{ A}$       (b)  $8 \times 10^9 \text{ Hz}$       (c)  $4.7 \times 10^3 \Omega$
27. Express each quantity by converting the metric prefix to a power-of-10:  
 (a) 7.5 pA      (b) 3.3 GHz      (c) 280 nW
28. Express each quantity in engineering notation:  
 (a) 5  $\mu\text{A}$       (b) 43 mV      (c) 275 k $\Omega$       (d) 10 MW

#### SECTION 1-4 Metric Unit Conversions

29. Perform the indicated conversions:  
 (a) 5 mA to microamperes      (b) 3,200  $\mu\text{W}$  to milliwatts  
 (c) 5,000 kV to megavolts      (d) 10 MW to kilowatts
30. 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
31. Add the following quantities:  
 (a)  $50 \text{ mA} + 680 \mu\text{A}$       (b)  $120 \text{ k}\Omega + 2.2 \text{ M}\Omega$       (c)  $0.02 \mu\text{F} + 3,300 \text{ pF}$
32. Do the following operations:  
 (a)  $10 \text{ k}\Omega \div (2.2 \text{ k}\Omega + 10 \text{ k}\Omega)$       (b)  $250 \text{ mV} \div 50 \mu\text{V}$   
 (c)  $1 \text{ MW} \div 2 \text{ kW}$

#### SECTION 1-5 Measured Numbers

33. How many significant digits are in each of the following numbers:  
 (a)  $1.00 \times 10^3$       (b) 0.0057      (c) 1502.0  
 (d) 0.000036      (e) 0.105      (f)  $2.6 \times 10^2$
34. Round each of the following numbers to three significant digits. Use the “round-to-even” rule.  
 (a) 50,505      (b) 220.45      (c) 4,646  
 (d) 10.99      (e) 1.005

## ANSWERS

### SECTION CHECKUPS

#### SECTION 1-1 Units of Measurement

- Base units define derived units.
- Ampere
- SI is the abbreviation for *Système International*.
- Refer to Table 1-3 after you have compiled your list of electrical quantities.
- Refer to Table 1-4 after you have compiled your list of magnetic quantities.

#### SECTION 1-2 Scientific Notation

- True
- $10^2$

3. (a)  $4.35 \times 10^3$  (b)  $1.201 \times 10^4$  (c)  $2.9 \times 10^7$   
 4. (a)  $7.6 \times 10^{-1}$  (b)  $2.5 \times 10^{-4}$  (c)  $5.97 \times 10^{-7}$   
 5. (a)  $3 \times 10^5$  (b)  $6 \times 10^{10}$  (c)  $2 \times 10^1$  (d)  $2.37 \times 10^{-6}$

### SECTION 1-3 Engineering Notation and Metric Prefixes

1. (a)  $5.6 \times 10^{-3}$  (b)  $28.3 \times 10^{-9}$  (c)  $950 \times 10^3$  (d)  $375 \times 10^9$   
 2. Mega (M), kilo (k), milli (m), micro ( $\mu$ ), nano (n), and pico (p)  
 3.  $1 \mu\text{A}$  (one microampere)  
 4. 250 kW (250 kilowatts)

### SECTION 1-4 Metric Unit Conversions

1.  $0.01 \text{ MV} = 10 \text{ kV}$   
 2.  $250,000 \text{ pA} = 0.00025 \text{ mA}$   
 3.  $0.05 \text{ MW} + 75 \text{ kW} = 50 \text{ kW} + 75 \text{ kW} = 125 \text{ kW}$   
 4.  $50 \text{ mV} + 25,000 \mu\text{V} = 50 \text{ mV} + 25 \text{ mV} = 75 \text{ mV}$   
 5.  $0.02 \mu\text{F}$

### SECTION 1-5 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  $100 \Omega$  (0.1 k $\Omega$ ).  
 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.

### RELATED PROBLEMS FOR EXAMPLES

- 1-1  $4.75 \times 10^3$   
 1-2  $7.38 \times 10^{-3}$   
 1-3 9120  
 1-4  $5.81 \times 10^4$   
 1-5  $1.85 \times 10^{-5}$   
 1-6  $4.8 \times 10^3$   
 1-7  $4 \times 10^4$   
 1-8  $36 \times 10^9$   
 1-9  $5.6 \times 10^{-12}$   
 1-10 (a)  $56 \text{ k}\Omega$  (b)  $470 \mu\text{A}$   
 1-11  $1,000 \mu\text{A}$   
 1-12 1 mV  
 1-13  $0.893 \mu\text{A}$   
 1-14  $0.01 \mu\text{F}$   
 1-15 2,200 pF  
 1-16  $0.0022 \text{ M}\Omega$   
 1-17 2,883 mA  
 1-18  $10.0 \times 10^3$   
 1-19 The number 10 has two significant digits; the number 10.0 has three.  
 1-20 3.28

**TRUE/FALSE QUIZ**

- |      |       |       |       |
|------|-------|-------|-------|
| 1. T | 6. F  | 11. T | 16. F |
| 2. F | 7. T  | 12. F | 17. T |
| 3. T | 8. T  | 13. T |       |
| 4. T | 9. T  | 14. F |       |
| 5. F | 10. T | 15. F |       |

**SELF-TEST**

- |        |        |         |         |
|--------|--------|---------|---------|
| 1. (c) | 5. (b) | 9. (c)  | 13. (c) |
| 2. (c) | 6. (b) | 10. (d) | 14. (b) |
| 3. (d) | 7. (b) | 11. (d) |         |
| 4. (a) | 8. (a) | 12. (c) |         |