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Introduction

1.1 THE ELECTRICAL/ELECTRONICS INDUSTRY

The growing sensitivity to the technologies on Wall Street is clear evidence that the electrical/electronics industry is one that will have a sweeping impact on future development in a wide range of areas that affect our life style, general health, and capabilities. Even the arts, initially so determined not to utilize technological methods, are embracing some of the new, innovative techniques that permit exploration into areas they never thought possible. The new Windows approach to computer simulation has made computer systems much friendlier to the average person, resulting in an expanding market which further stimulates growth in the field. The computer in the home will eventually be as common as the telephone or television. In fact, all three are now being integrated into a single unit.

Every facet of our lives seems touched by developments that appear to surface at an ever-increasing rate. For the layperson, the most obvious improvement of recent years has been the reduced size of electrical/ electronics systems. Televisions are now small enough to be hand-held and have a battery capability that allows them to be more portable. Computers with significant memory capacity are now smaller than this textbook. The size of radios is limited simply by our ability to read the numbers on the face of the dial. Hearing aids are no longer visible, and pacemakers are significantly smaller and more reliable. All the reduction in size is due primarily to a marvelous development of the last few decades—the **integrated circuit (IC).** First developed in the late 1950s, the IC has now reached a point where cutting 0.18-micrometer lines is commonplace. The integrated circuit shown in Fig. 1.1 is the Intel® Pentium® 4 processor, which has 42 million transistors in an area measuring only 0.34 square inches. Intel Corporation recently presented a technical paper describing 0.02-micrometer (20-nanometer) transistors, developed in its silicon research laboratory. These small, ultra-fast transistors will permit placing nearly one billion transistors on a sliver of silicon no larger than a fingernail. Microprocessors built from these transistors will operate at about 20 GHz. It leaves us only to wonder about the limits of such development.

It is natural to wonder what the limits to growth may be when we consider the changes over the last few decades. Rather than following a steady growth curve that would be somewhat predictable, the industry is subject to surges that revolve around significant developments in the field. Present indications are that the level of miniaturization will continue, but at a more moderate pace. Interest has turned toward increasing the quality and yield levels (percentage of good integrated circuits in the production process).

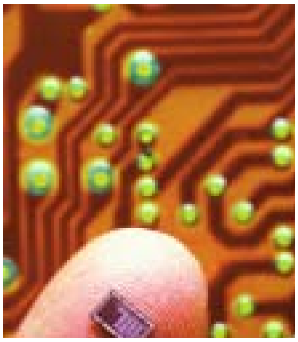

FIG. 1.1
Computer chip on finger. (Courtesy of Intel Corp.)

History reveals that there have been peaks and valleys in industry growth but that revenues continue to rise at a steady rate and funds set aside for research and development continue to command an increasing share of the budget. The field changes at a rate that requires constant retraining of employees from the entry to the director level. Many companies have instituted their own training programs and have encouraged local universities to develop programs to ensure that the latest concepts and procedures are brought to the attention of their employees. A period of relaxation could be disastrous to a company dealing in competitive products.

No matter what the pressures on an individual in this field may be to keep up with the latest technology, there is one saving grace that becomes immediately obvious: Once a concept or procedure is clearly and correctly understood, it will bear fruit throughout the career of the individual at any level of the industry. For example, once a fundamental equation such as Ohm's law (Chapter 4) is understood, it will not be *replaced* by another equation as more advanced theory is considered. It is a relationship of fundamental quantities that can have application in the most advanced setting. In addition, once a procedure or method of analysis is understood, it usually can be applied to a wide (if not infinite) variety of problems, making it unnecessary to learn a different technique for each slight variation in the system. The content of this text is such that every morsel of information will have application in more advanced courses. It will not be replaced by a different set of equations and procedures unless required by the specific area of application. Even then, the new procedures will usually be an expanded application of concepts already presented in the text.

It is paramount therefore that the material presented in this introductory course be clearly and precisely understood. It is the foundation for the material to follow and will be applied throughout your working days in this growing and exciting field.

1.2 A BRIEF HISTORY

In the sciences, once a hypothesis is proven and accepted, it becomes one of the building blocks of that area of study, permitting additional investigation and development. Naturally, the more pieces of a puzzle available, the more obvious the avenue toward a possible solution. In fact, history demonstrates that a single development may provide the key that will result in a mushroom effect that brings the science to a new plateau of understanding and impact.

If the opportunity presents itself, read one of the many publications reviewing the history of this field. Space requirements are such that only a brief review can be provided here. There are many more contributors than could be listed, and their efforts have often provided important keys to the solution of some very important concepts.

As noted earlier, there were periods characterized by what appeared to be an explosion of interest and development in particular areas. As you will see from the discussion of the late 1700s and the early 1800s, inventions, discoveries, and theories came fast and furiously. Each new concept has broadened the possible areas of application until it becomes almost impossible to trace developments without picking a particular area of interest and following it through. In the review, as you read about the development of the radio, television, and computer, keep in mind that similar progressive steps were occurring in the areas of the telegraph, the telephone, power generation, the phonograph, appliances, and so on.

There is a tendency when reading about the great scientists, inventors, and innovators to believe that their contribution was a totally individual effort. In many instances, this was not the case. In fact, many of the great contributors were friends or associates who provided support and encouragement in their efforts to investigate various theories. At the very least, they were aware of one another's efforts to the degree possible in the days when a letter was often the best form of communication. In particular, note the closeness of the dates during periods of rapid development. One contributor seemed to spur on the efforts of the others or possibly provided the key needed to continue with the area of interest.

In the early stages, the contributors were not electrical, electronic, or computer engineers as we know them today. In most cases, they were physicists, chemists, mathematicians, or even philosophers. In addition, they were not from one or two communities of the Old World. The home country of many of the major contributors introduced in the paragraphs to follow is provided to show that almost every established community had some impact on the development of the fundamental laws of electrical circuits.

As you proceed through the remaining chapters of the text, you will find that a number of the units of measurement bear the name of major contributors in those areas—*volt* after Count Alessandro Volta, *ampere* after André Ampère, *ohm* after Georg Ohm, and so forth—fitting recognition for their important contributions to the birth of a major field of study.

Time charts indicating a limited number of major developments are provided in Fig. 1.2, primarily to identify specific periods of rapid development and to reveal how far we have come in the last few decades. In essence, the current state of the art is a result of efforts that

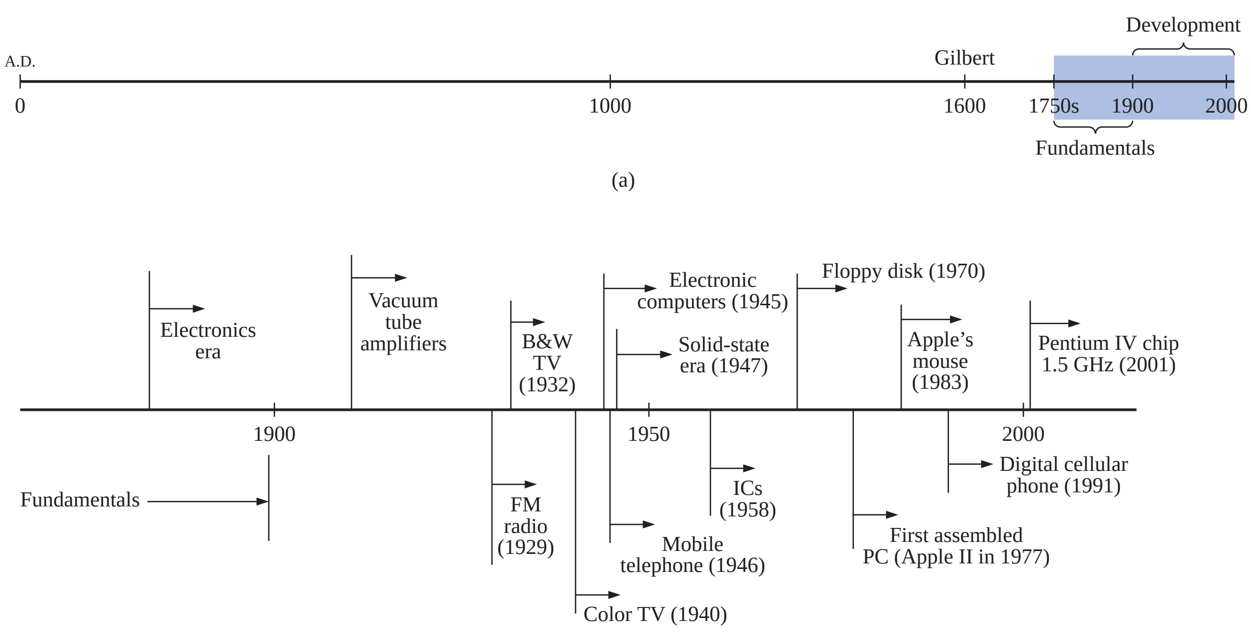

FIG. 1.2
Time charts: (a) long-range; (b) expanded.

began in earnest some 250 years ago, with progress in the last 100 years almost exponential.

As you read through the following brief review, try to sense the growing interest in the field and the enthusiasm and excitement that must have accompanied each new revelation. Although you may find some of the terms used in the review new and essentially meaningless, the remaining chapters will explain them thoroughly.

The Beginning

The phenomenon of **static electricity** has been toyed with since antiquity. The Greeks called the fossil resin substance so often used to demonstrate the effects of static electricity *elektron*, but no extensive study was made of the subject until William Gilbert researched the event in 1600. In the years to follow, there was a continuing investigation of electrostatic charge by many individuals such as Otto von Guericke, who developed the first machine to generate large amounts of charge, and Stephen Gray, who was able to transmit electrical charge over long distances on silk threads. Charles DuFay demonstrated that charges either attract or repel each other, leading him to believe that there were two types of charge—a theory we subscribe to today with our defined positive and negative charges.

There are many who believe that the true beginnings of the electrical era lie with the efforts of Pieter van Musschenbroek and Benjamin Franklin. In 1745, van Musschenbroek introduced the **Leyden jar** for the storage of electrical charge (the first capacitor) and demonstrated electrical shock (and therefore the power of this new form of energy). Franklin used the Leyden jar some seven years later to establish that lightning is simply an electrical discharge, and he expanded on a number of other important theories including the definition of the two types of charge as *positive* and *negative.* From this point on, new discoveries and theories seemed to occur at an increasing rate as the number of individuals performing research in the area grew.

In 1784, Charles Coulomb demonstrated in Paris that the force between charges is inversely related to the square of the distance between the charges. In 1791, Luigi Galvani, professor of anatomy at the University of Bologna, Italy, performed experiments on the effects of electricity on animal nerves and muscles. The first **voltaic cell,** with its ability to produce electricity through the chemical action of a metal dissolving in an acid, was developed by another Italian, Alessandro Volta, in 1799.

The fever pitch continued into the early 1800s with Hans Christian Oersted, a Swedish professor of physics, announcing in 1820 a relationship between magnetism and electricity that serves as the foundation for the theory of **electromagnetism** as we know it today. In the same year, a French physicist, André Ampère, demonstrated that there are magnetic effects around every current-carrying conductor and that current-carrying conductors can attract and repel each other just like magnets. In the period 1826 to 1827, a German physicist, Georg Ohm, introduced an important relationship between potential, current, and resistance which we now refer to as *Ohm's law.* In 1831, an English physicist, Michael Faraday, demonstrated his theory of *electromagnetic induction,* whereby a changing current in one coil can induce a changing current in another coil, even though the two coils are not directly connected. Professor Faraday also did extensive work on a storage device he called the condenser, which we refer to today as a *capacitor.* He introduced the idea of adding a dielectric between the plates of a capacitor to increase the storage capacity (Chapter 10). James Clerk Maxwell, a Scottish professor of natural philosophy, performed extensive mathematical analyses to develop what are currently called *Maxwell's equations,* which support the efforts of Faraday linking electric and magnetic effects. Maxwell also developed the *electromagnetic theory of light* in 1862, which, among other things, revealed that electromagnetic waves travel through air at the velocity of light (186,000 miles per second or 3×10^8 meters per second). In 1888, a German physicist, Heinrich Rudolph Hertz, through experimentation with lower-frequency electromagnetic waves (microwaves), substantiated Maxwell's predictions and equations. In the mid 1800s, Professor Gustav Robert Kirchhoff introduced a series of laws of voltages and currents that find application at every level and area of this field (Chapters 5 and 6). In 1895, another German physicist, Wilhelm Röntgen, discovered electromagnetic waves of high frequency, commonly called *X rays* today.

By the end of the 1800s, a significant number of the fundamental equations, laws, and relationships had been established, and various fields of study, including electronics, power generation, and calculating equipment, started to develop in earnest.

The Age of Electronics

Radio The true beginning of the electronics era is open to debate and is sometimes attributed to efforts by early scientists in applying potentials across evacuated glass envelopes. However, many trace the beginning to Thomas Edison, who added a metallic electrode to the vacuum of the tube and discovered that a current was established between the metal electrode and the filament when a positive voltage was applied to the metal electrode. The phenomenon, demonstrated in 1883, was referred to as the **Edison effect.** In the period to follow, the transmission of radio waves and the development of the radio received widespread attention. In 1887, Heinrich Hertz, in his efforts to verify Maxwell's equations, transmitted radio waves for the first time in his laboratory. In 1896, an Italian scientist, Guglielmo Marconi (often called the father of the radio), demonstrated that telegraph signals could be sent through the air over long distances (2.5 kilometers) using a grounded antenna. In the same year, Aleksandr Popov sent what might have been the first radio message some 300 yards. The message was the name *"Heinrich Hertz"* in respect for Hertz's earlier contributions. In 1901, Marconi established radio communication across the Atlantic.

In 1904, John Ambrose Fleming expanded on the efforts of Edison to develop the first diode, commonly called **Fleming's valve**—actually the first of the *electronic devices.* The device had a profound impact on the design of detectors in the receiving section of radios. In 1906, Lee De Forest added a third element to the vacuum structure and created the first amplifier, the triode. Shortly thereafter, in 1912, Edwin Armstrong built the first regenerative circuit to improve receiver capabilities and then used the same contribution to develop the first nonmechanical oscillator. By 1915 radio signals were being transmitted across the United States, and in 1918 Armstrong applied for a patent for the superheterodyne circuit employed in virtually every television and radio to permit amplification at one frequency rather than at the full range of incoming signals. The major components of the modern-day radio were now in place, and sales in radios grew from a few million dollars in the early 1920s to over $1 billion by the 1930s. The 1930s were truly the golden years of radio, with a wide range of productions for the listening audience.

Television The 1930s were also the true beginnings of the television era, although development on the picture tube began in earlier years with Paul Nipkow and his *electrical telescope* in 1884 and John Baird and his long list of successes, including the transmission of television pictures over telephone lines in 1927 and over radio waves in 1928, and simultaneous transmission of pictures and sound in 1930. In 1932, NBC installed the first commercial television antenna on top of the Empire State Building in New York City, and RCA began regular broadcasting in 1939. The war slowed development and sales, but in the mid 1940s the number of sets grew from a few thousand to a few million. Color television became popular in the early 1960s.

Computers The earliest computer system can be traced back to Blaise Pascal in 1642 with his mechanical machine for adding and subtracting numbers. In 1673 Gottfried Wilhelm von Leibniz used the *Leibniz wheel* to add multiplication and division to the range of operations, and in 1823 Charles Babbage developed the **difference engine** to add the mathematical operations of sine, cosine, logs, and several others. In the years to follow, improvements were made, but the system remained primarily mechanical until the 1930s when electromechanical systems using components such as relays were introduced. It was not until the 1940s that totally electronic systems became the new wave. It is interesting to note that, even though IBM was formed in 1924, it did not enter the computer industry until 1937. An entirely electronic system known as **ENIAC** was dedicated at the University of Pennsylvania in 1946. It contained 18,000 tubes and weighed 30 tons but was several times faster than most electromechanical systems. Although other vacuum tube systems were built, it was not until the birth of the solid-state era that computer systems experienced a major change in size, speed, and capability.

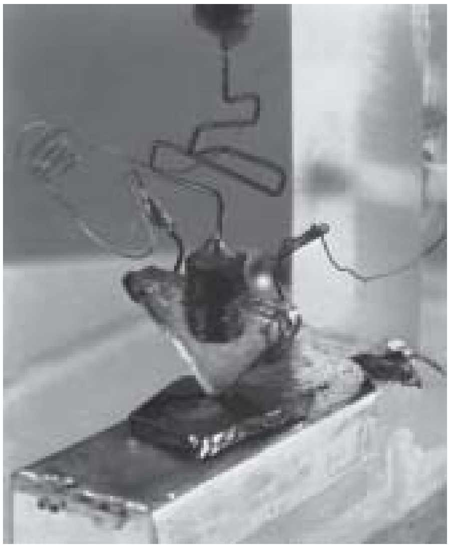

FIG. 1.3
The first transistor. (Courtesy of AT&T, Bell Laboratories.)

The Solid-State Era

In 1947, physicists William Shockley, John Bardeen, and Walter H. Brattain of Bell Telephone Laboratories demonstrated the point-contact **transistor** (Fig. 1.3), an amplifier constructed entirely of solid-state materials with no requirement for a vacuum, glass envelope, or heater voltage for the filament. Although reluctant at first due to the vast amount of material available on the design, analysis, and synthesis of tube networks, the industry eventually accepted this new technology as the wave of the future. In 1958 the first **integrated circuit (IC)** was developed at Texas Instruments, and in 1961 the first commercial integrated circuit was manufactured by the Fairchild Corporation.

It is impossible to review properly the entire history of the electrical/electronics field in a few pages. The effort here, both through the discussion and the time graphs of Fig. 1.2, was to reveal the amazing progress of this field in the last 50 years. The growth appears to be truly exponential since the early 1900s, raising the interesting question, Where do we go from here? The time chart suggests that the next few decades will probably contain many important innovative contributions that may cause an even faster growth curve than we are now experiencing.

1.3 UNITS OF MEASUREMENT

In any technical field it is naturally important to understand the basic concepts and the impact they will have on certain parameters. However, the application of these rules and laws will be successful only if the mathematical operations involved are applied correctly. In particular, it is vital that the importance of applying the proper unit of measurement to a quantity is understood and appreciated. Students often generate a numerical solution but decide not to apply a unit of measurement to the result because they are somewhat unsure of which unit should be applied. Consider, for example, the following very fundamental physics equation:

$$v = \frac{d}{t} \qquad \begin{aligned} v &= \text{velocity} \\ d &= \text{distance} \\ t &= \text{time} \end{aligned} \tag{1.1}$$

Assume, for the moment, that the following data are obtained for a moving object:

$$d = 4000 \text{ ft}$$
$$t = 1 \text{ min}$$

and v is desired in miles per hour. Often, without a second thought or consideration, the numerical values are simply substituted into the equation, with the result here that

$$v = \frac{d}{t} = \frac{4000 \text{ ft}}{1 \text{ min}} = \xcancel{4000 \text{ mi/h}}$$

As indicated above, the solution is totally incorrect. If the result is desired in *miles per hour*, the unit of measurement for distance must be *miles*, and that for time, *hours*. In a moment, when the problem is analyzed properly, the extent of the error will demonstrate the importance of ensuring that

the numerical value substituted into an equation must have the unit of measurement specified by the equation.

The next question is normally, How do I convert the distance and time to the proper unit of measurement? A method will be presented in a later section of this chapter, but for now it is given that

$$1 \text{ mi} = 5280 \text{ ft}$$
$$4000 \text{ ft} = 0.7576 \text{ mi}$$
$$1 \text{ min} = \tfrac{1}{60} \text{ h} = 0.0167 \text{ h}$$

Substituting into Eq. (1.1), we have

$$v = \frac{d}{t} = \frac{0.7576 \text{ mi}}{0.0167 \text{ h}} = 45.37 \text{ mi/h}$$

which is significantly different from the result obtained before.

To complicate the matter further, suppose the distance is given in kilometers, as is now the case on many road signs. First, we must realize that the prefix *kilo* stands for a multiplier of 1000 (to be introduced in Section 1.5), and then we must find the conversion factor between kilometers and miles. If this conversion factor is not readily available, we must be able to make the conversion between units using the conversion factors between meters and feet or inches, as described in Section 1.6.

Before substituting numerical values into an equation, try to mentally establish a reasonable range of solutions for comparison purposes. For instance, if a car travels 4000 ft in 1 min, does it seem reasonable that the speed would be 4000 mi/h? Obviously not! This self-checking procedure is particularly important in this day of the hand-held calculator, when ridiculous results may be accepted simply because they appear on the digital display of the instrument.

Finally,

if a unit of measurement is applicable to a result or piece of data, then it must be applied to the numerical value.

To state that $v = 45.37$ without including the unit of measurement *mi/h* is meaningless.

Equation (1.1) is not a difficult one. A simple algebraic manipulation will result in the solution for any one of the three variables. However, in light of the number of questions arising from this equation, the reader may wonder if the difficulty associated with an equation will increase at the same rate as the number of terms in the equation. In the broad sense, this will not be the case. There is, of course, more room for a mathematical error with a more complex equation, but once the proper system of units is chosen and each term properly found in that system, there should be very little added difficulty associated with an equation requiring an increased number of mathematical calculations.

In review, before substituting numerical values into an equation, be absolutely sure of the following:

1. ***Each quantity has the proper unit of measurement as defined by the equation.***
2. ***The proper magnitude of each quantity as determined by the defining equation is substituted.***
3. ***Each quantity is in the same system of units (or as defined by the equation).***
4. ***The magnitude of the result is of a reasonable nature when compared to the level of the substituted quantities.***
5. ***The proper unit of measurement is applied to the result.***

1.4 SYSTEMS OF UNITS

In the past, the *systems of units* most commonly used were the English and metric, as outlined in Table 1.1. Note that while the English system is based on a single standard, the metric is subdivided into two interrelated standards: the **MKS** and the **CGS.** Fundamental quantities of these systems are compared in Table 1.1 along with their abbreviations. The MKS and CGS systems draw their names from the units of measurement used with each system; the MKS system uses *M*eters, *K*ilograms, and *S*econds, while the CGS system uses *C*entimeters, *G*rams, and *S*econds.

Understandably, the use of more than one system of units in a world that finds itself continually shrinking in size, due to advanced technical developments in communications and transportation, would introduce

TABLE 1.1

Comparison of the English and metric systems of units.

English	Metric		
	MKS	**CGS**	**SI**
Length: Yard (yd) (0.914 m)	Meter (m) (39.37 in.) (100 cm)	Centimeter (cm) (2.54 cm = 1 in.)	**Meter (m)**
Mass: **Slug** (14.6 kg)	Kilogram (kg) (1000 g)	Gram (g)	**Kilogram (kg)**
Force: **Pound** (lb) (4.45 N)	Newton (N) (100,000 dynes)	Dyne	**Newton (N)**
Temperature: Fahrenheit (°F) $\left(= \frac{9}{5}°\text{C} + 32\right)$	Celsius or Centigrade (°C) $\left(= \frac{5}{9}(°\text{F} - 32)\right)$	Centigrade (°C)	**Kelvin (K)** K = 273.15 + °C
Energy: Foot-pound (ft-lb) (1.356 joules)	Newton-meter (N•m) or joule (J) (0.7376 ft-lb)	Dyne-centimeter or erg (1 joule = 10^7 ergs)	**Joule (J)**
Time: Second (s)	Second (s)	Second (s)	**Second (s)**

unnecessary complications to the basic understanding of any technical data. The need for a standard set of units to be adopted by all nations has become increasingly obvious. The International Bureau of Weights and Measures located at Sèvres, France, has been the host for the General Conference of Weights and Measures, attended by representatives from all nations of the world. In 1960, the General Conference adopted a system called Le Système International d'Unités (International System of Units), which has the international abbreviation **SI.** Since then, it has been adopted by the Institute of Electrical and Electronic Engineers, Inc. (IEEE) in 1965 and by the United States of America Standards Institute in 1967 as a standard for all scientific and engineering literature.

For comparison, the SI units of measurement and their abbreviations appear in Table 1.1. These abbreviations are those usually applied to each unit of measurement, and they were carefully chosen to be the most effective. Therefore, it is important that they be used whenever applicable to ensure universal understanding. Note the similarities of the SI system to the MKS system. This text will employ, whenever possible and practical, all of the major units and abbreviations of the SI system in an effort to support the need for a universal system. Those readers requiring additional information on the SI system should contact the information office of the American Society for Engineering Education (ASEE).*

*American Society for Engineering Education (ASEE), 1818 N Street N.W., Suite 600, Washington, D.C. 20036-2479; (202) 331-3500; http://www.asee.org/.

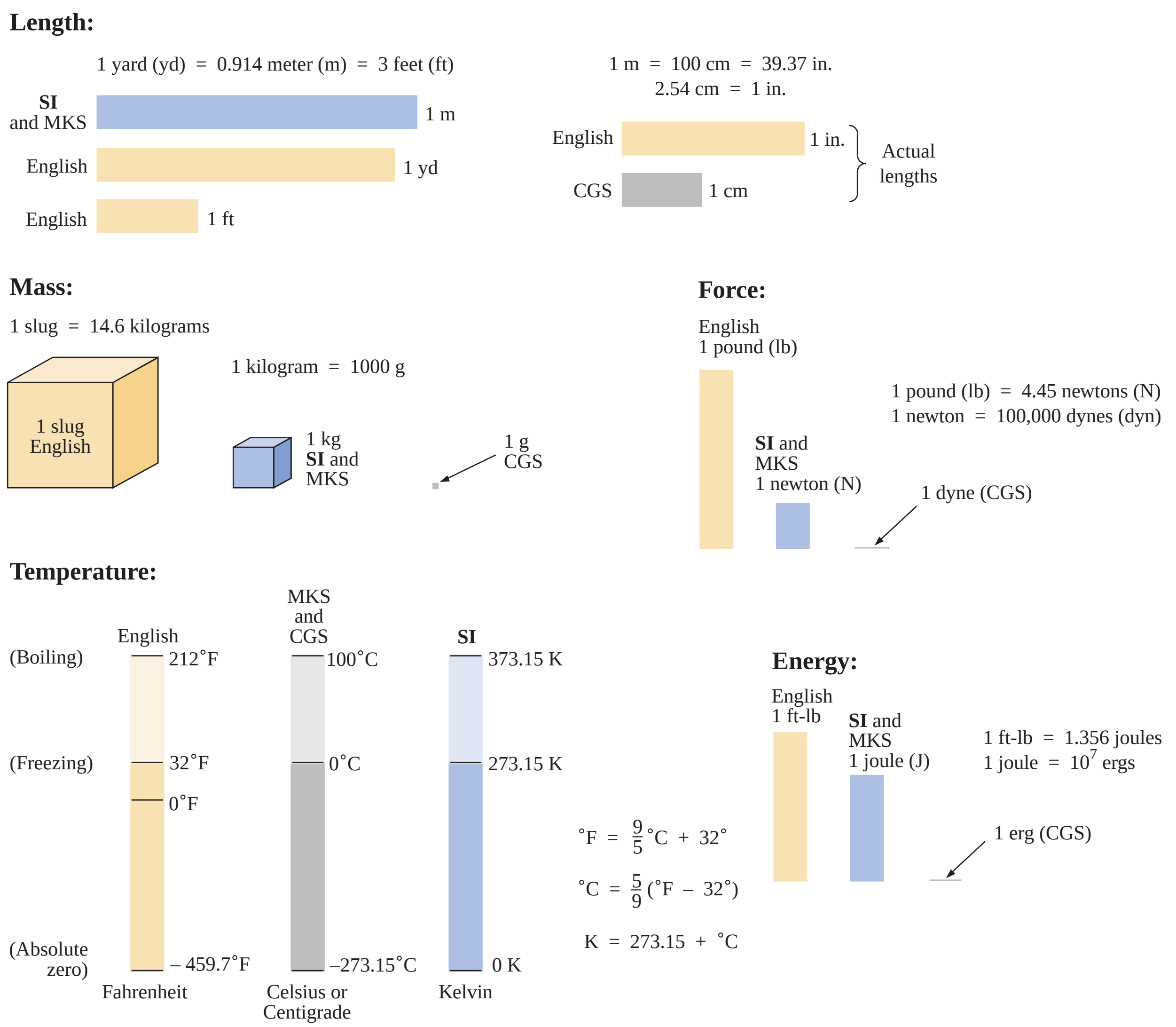

FIG. 1.4
Comparison of units of the various systems of units.

Figure 1.4 should help the reader develop some feeling for the relative magnitudes of the units of measurement of each system of units. Note in the figure the relatively small magnitude of the units of measurement for the CGS system.

A standard exists for each unit of measurement of each system. The standards of some units are quite interesting.

The **meter** was originally defined in 1790 to be 1/10,000,000 the distance between the equator and either pole at sea level, a length preserved on a platinum-iridium bar at the International Bureau of Weights and Measures at Sèvres, France.

The meter is now defined with reference to the speed of light in a vacuum, which is 299,792,458 m/s.

The kilogram is defined as a mass equal to 1000 times the mass of one cubic centimeter of pure water at 4°C.

This standard is preserved in the form of a platinum-iridium cylinder in Sèvres.

The **second** was originally defined as 1/86,400 of the mean solar day. However, since Earth's rotation is slowing down by almost 1 second every 10 years,

the second was redefined in 1967 as 9,192,631,770 periods of the electromagnetic radiation emitted by a particular transition of cesium atom.

1.5 SIGNIFICANT FIGURES, ACCURACY, AND ROUNDING OFF

This section will emphasize the importance of being aware of the source of a piece of data, how a number appears, and how it should be treated. Too often we write numbers in various forms with little concern for the format used, the number of digits that should be included, and the unit of measurement to be applied.

For instance, measurements of 22.1″ and 22.10″ imply different levels of accuracy. The first suggests that the measurement was made by an instrument accurate only to the tenths place; the latter was obtained with instrumentation capable of reading to the hundredths place. The use of zeros in a number, therefore, must be treated with care and the implications must be understood.

In general, there are two types of numbers, *exact* and *approximate.* Exact numbers are precise to the exact number of digits presented, just as we know that there are 12 apples in a dozen and not 12.1. Throughout the text the numbers that appear in the descriptions, diagrams, and examples are considered *exact,* so that a battery of 100 V can be written as 100.0 V, 100.00 V, and so on, since it is 100 V at any level of precision. The additional zeros were not included for purposes of clarity. However, in the laboratory environment, where measurements are continually being taken and the level of accuracy can vary from one instrument to another, it is important to understand how to work with the results. Any reading obtained in the laboratory should be considered *approximate.* The analog scales with their pointers may be difficult to read, and even though the digital meter provides only specific digits on its display, it is limited to the number of digits it can provide, leaving us to wonder about the less significant digits not appearing on the display.

The precision of a reading can be determined by the number of *significant figures (digits)* present. Significant digits are those integers (0 to 9) that can be assumed to be accurate for the measurement being made. The result is that all nonzero numbers are considered significant, with zeros being significant in only some cases. For instance, the zeros in 1005 are considered significant because they define the size of the number and are surrounded by nonzero digits. However, for a number such as 0.064, the two zeros are not considered significant because they are used only to define the location of the decimal point and not the accuracy of the reading. For the number 0.4020, the zero to the left of the decimal point is not significant, but the other two are because they define the magnitude of the number and the fourth-place accuracy of the reading.

When adding approximate numbers, it is important to be sure that the accuracy of the readings is consistent throughout. To add a quantity accurate only to the tenths place to a number accurate to the thousandths place will result in a total having accuracy only to the tenths place. One cannot expect the reading with the higher level of accuracy to improve the reading with only tenths-place accuracy.

In the addition or subtraction of approximate numbers, the entry with the lowest level of accuracy determines the format of the solution.

For the multiplication and division of approximate numbers, the result has the same number of significant figures as the number with the least number of significant figures.

For approximate numbers (and exact, for that matter) there is often a need to *round off* the result; that is, you must decide on the appropriate level of accuracy and alter the result accordingly. The accepted procedure is simply to note the digit following the last to appear in the rounded-off form, and add a 1 to the last digit if it is greater than or equal to 5, and leave it alone if it is less than 5. For example, $3.186 \cong 3.19 \cong 3.2$, depending on the level of precision desired. The symbol $\cong$ appearing means *approximately equal to.*

EXAMPLE 1.1 Perform the indicated operations with the following approximate numbers and round off to the appropriate level of accuracy.

a. $532.6 + 4.02 + 0.036 = 536.656 \cong \mathbf{536.7}$ (as determined by 532.6)
b. $0.04 + 0.003 + 0.0064 = 0.0494 \cong \mathbf{0.05}$ (as determined by 0.04)
c. $4.632 \times 2.4 = 11.1168 \cong \mathbf{11}$ (as determined by the two significant digits of 2.4)
d. $3.051 \times 802 = 2446.902 \cong \mathbf{2450}$ (as determined by the three significant digits of 802)
e. $1402/6.4 = 219.0625 \cong \mathbf{220}$ (as determined by the two significant digits of 6.4)
f. $0.0046/0.05 = 0.0920 \cong \mathbf{0.09}$ (as determined by the one significant digit of 0.05)

1.6 POWERS OF TEN

It should be apparent from the relative magnitude of the various units of measurement that very large and very small numbers will frequently be encountered in the sciences. To ease the difficulty of mathematical operations with numbers of such varying size, *powers of ten* are usually employed. This notation takes full advantage of the mathematical properties of powers of ten. The notation used to represent numbers that are integer powers of ten is as follows:

$$
\begin{array}{rr}
1 = 10^0 & 1/10 = 0.1 = 10^{-1} \\
10 = 10^1 & 1/100 = 0.01 = 10^{-2} \\
100 = 10^2 & 1/1000 = 0.001 = 10^{-3} \\
1000 = 10^3 & 1/10{,}000 = 0.0001 = 10^{-4}
\end{array}
$$

In particular, note that $10^0 = 1$, and, in fact, any quantity to the zero power is 1 ($x^0 = 1$, $1000^0 = 1$, and so on). Also, note that the numbers in the list that are greater than 1 are associated with positive powers of ten, and numbers in the list that are less than 1 are associated with negative powers of ten.

A quick method of determining the proper power of ten is to place a caret mark to the right of the numeral 1 wherever it may occur; then count from this point to the number of places to the right or left before arriving at the decimal point. Moving to the right indicates a positive power of ten, whereas moving to the left indicates a negative power. For example,

$$10{,}000.0 = 1\underbrace{0,000}_{1\ 2\ 3\ 4}. = 10^{+4}$$

$$0.00001 = 0.\underbrace{0000}_{5\ 4\ 3\ 2\ 1}1 = 10^{-5}$$

Some important mathematical equations and relationships pertaining to powers of ten are listed below, along with a few examples. In each case, *n* and *m* can be any positive or negative real number.

$$\frac{1}{10^n} = 10^{-n} \qquad \frac{1}{10^{-n}} = 10^n \tag{1.2}$$

Equation (1.2) clearly reveals that shifting a power of ten from the denominator to the numerator, or the reverse, requires simply changing the sign of the power.

EXAMPLE 1.2

a. $\frac{1}{1000} = \frac{1}{10^{+3}} = 10^{-3}$

b. $\frac{1}{0.00001} = \frac{1}{10^{-5}} = 10^{+5}$

The product of powers of ten:

$$(10^n)(10^m) = 10^{(n+m)} \tag{1.3}$$

EXAMPLE 1.3

a. $(1000)(10{,}000) = (10^3)(10^4) = 10^{(3+4)} = 10^7$

b. $(0.00001)(100) = (10^{-5})(10^2) = 10^{(-5+2)} = 10^{-3}$

The division of powers of ten:

$$\frac{10^n}{10^m} = 10^{(n-m)} \tag{1.4}$$

EXAMPLE 1.4

a. $\frac{100{,}000}{100} = \frac{10^5}{10^2} = 10^{(5-2)} = 10^3$

b. $\frac{1000}{0.0001} = \frac{10^3}{10^{-4}} = 10^{(3-(-4))} = 10^{(3+4)} = 10^7$

Note the use of parentheses in part (b) to ensure that the proper sign is established between operators.

The power of powers of ten:

$$(10^n)^m = 10^{(nm)} \tag{1.5}$$

EXAMPLE 1.5

a. $(100)^4 = (10^2)^4 = 10^{(2)(4)} = 10^8$
b. $(1000)^{-2} = (10^3)^{-2} = 10^{(3)(-2)} = 10^{-6}$
c. $(0.01)^{-3} = (10^{-2})^{-3} = 10^{(-2)(-3)} = 10^6$

Basic Arithmetic Operations

Let us now examine the use of powers of ten to perform some basic arithmetic operations using numbers that are not just powers of ten. The number 5000 can be written as $5 \times 1000 = 5 \times 10^3$, and the number 0.0004 can be written as $4 \times 0.0001 = 4 \times 10^{-4}$. Of course, 10^5 can also be written as 1×10^5 if it clarifies the operation to be performed.

Addition and Subtraction To perform addition or subtraction using powers of ten, the power of ten *must be the same for each term;* that is,

$$A \times 10^n \pm B \times 10^n = (A \pm B) \times 10^n \tag{1.6}$$

Equation (1.6) covers all possibilities, but students often prefer to remember a verbal description of how to perform the operation.

Equation (1.6) states

when adding or subtracting numbers in a powers-of-ten format, be sure that the power of ten is the same for each number. Then separate the multipliers, perform the required operation, and apply the same power of ten to the result.

EXAMPLE 1.6

a. $6300 + 75{,}000 = (6.3)(1000) + (75)(1000)$
$= 6.3 \times 10^3 + 75 \times 10^3$
$= (6.3 + 75) \times 10^3$
$= \mathbf{81.3 \times 10^3}$

b. $0.00096 - 0.000086 = (96)(0.00001) - (8.6)(0.00001)$
$= 96 \times 10^{-5} - 8.6 \times 10^{-5}$
$= (96 - 8.6) \times 10^{-5}$
$= \mathbf{87.4 \times 10^{-5}}$

Multiplication In general,

$$(A \times 10^n)(B \times 10^m) = (A)(B) \times 10^{n+m} \tag{1.7}$$

revealing that the *operations with the powers of ten can be separated from the operation with the multipliers.*

Equation (1.7) states

when multiplying numbers in the powers-of-ten format, first find the product of the multipliers and then determine the power of ten for the result by adding the power-of-ten exponents.

EXAMPLE 1.7

a. $$(0.0002)(0.000007) = [(2)(0.0001)][(7)(0.000001)] = (2 \times 10^{-4})(7 \times 10^{-6}) = (2)(7) \times (10^{-4})(10^{-6}) = \mathbf{14 \times 10^{-10}}$$

b. $$(340{,}000)(0.00061) = (3.4 \times 10^{5})(61 \times 10^{-5}) = (3.4)(61) \times (10^{5})(10^{-5}) = 207.4 \times 10^{0} = \mathbf{207.4}$$

Division In general,

$$\frac{A \times 10^n}{B \times 10^m} = \frac{A}{B} \times 10^{n-m} \qquad \textbf{(1.8)}$$

revealing again that the *operations with the powers of ten can be separated from the same operation with the multipliers.*

Equation (1.8) states

when dividing numbers in the powers-of-ten format, first find the result of dividing the multipliers. Then determine the associated power for the result by subtracting the power of ten of the denominator from the power of ten of the numerator.

EXAMPLE 1.8

a. $$\frac{0.00047}{0.002} = \frac{47 \times 10^{-5}}{2 \times 10^{-3}} = \left(\frac{47}{2}\right) \times \left(\frac{10^{-5}}{10^{-3}}\right) = \mathbf{23.5 \times 10^{-2}}$$

b. $$\frac{690{,}000}{0.00000013} = \frac{69 \times 10^{4}}{13 \times 10^{-8}} = \left(\frac{69}{13}\right) \times \left(\frac{10^{4}}{10^{-8}}\right) = \mathbf{5.31 \times 10^{12}}$$

Powers In general,

$$(A \times 10^n)^m = A^m \times 10^{nm} \qquad \textbf{(1.9)}$$

which again permits the separation of the *operation with the powers of ten from the multipliers.*

Equation (1.9) states

when finding the power of a number in the power-of-ten format, first separate the multiplier from the power of ten and determine each separately. Determine the power-of-ten component by multiplying the power of ten by the power to be determined.

EXAMPLE 1.9

a. $(0.00003)^3 = (3 \times 10^{-5})^3 = (3)^3 \times (10^{-5})^3$
$= \mathbf{27 \times 10^{-15}}$

b. $(90{,}800{,}000)^2 = (9.08 \times 10^7)^2 = (9.08)^2 \times (10^7)^2$
$= \mathbf{82.4464 \times 10^{14}}$

In particular, remember that the following operations are not the same. One is the product of two numbers in the powers-of-ten format, while the other is a number in the powers-of-ten format taken to a power. As noted below, the results of each are quite different:

$$(10^3)(10^3) \neq (10^3)^3$$
$$(10^3)(10^3) = 10^6 = 1{,}000{,}000$$
$$(10^3)^3 = (10^3)(10^3)(10^3) = 10^9 = 1{,}000{,}000{,}000$$

Fixed-Point, Floating-Point, Scientific, and Engineering Notation

There are, in general, four ways in which numbers appear when using a computer or calculator. If powers of ten are not employed, they are written in the **fixed-point** or **floating-point notation.** The fixed-point format requires that the decimal point appear in the same place each time. In the floating-point format, the decimal point will appear in a location defined by the number to be displayed. Most computers and calculators permit a choice of fixed- or floating-point notation. In the fixed format, the user can choose the level of precision for the output as tenths place, hundredths place, thousandths place, and so on. Every output will then fix the decimal point to one location, such as the following examples using thousandths place accuracy:

$$\frac{1}{3} = \mathbf{0.333} \qquad \frac{1}{16} = \mathbf{0.063} \qquad \frac{2300}{2} = \mathbf{1150.000}$$

If left in the floating-point format, the results will appear as follows for the above operations:

$$\frac{1}{3} = \mathbf{0.333333333333} \qquad \frac{1}{16} = \mathbf{0.0625} \qquad \frac{2300}{2} = \mathbf{1150}$$

Powers of ten will creep into the fixed- or floating-point notation if the number is too small or too large to be displayed properly.

Scientific (also called *standard*) **notation** and **engineering notation** make use of powers of ten with restrictions on the mantissa (multiplier) or scale factor (power of the power of ten). Scientific notation requires that the decimal point appear directly after the first digit greater than or equal to 1 but less than 10. A power of ten will then appear with the number (usually following the power notation E), even if it has to be to the zero power. A few examples:

$$\frac{1}{3} = \mathbf{3.33333333333E{-}1} \qquad \frac{1}{16} = \mathbf{6.25E{-}2} \qquad \frac{2300}{2} = \mathbf{1.15E3}$$

Within the scientific notation, the fixed- or floating-point format can be chosen. In the above examples, floating was employed. If fixed is chosen and set at the thousandths-point accuracy, the following will result for the above operations:

$$\frac{1}{3} = \mathbf{3.333E-1} \qquad \frac{1}{16} = \mathbf{6.250E-2} \qquad \frac{2300}{2} = \mathbf{1.150E3}$$

The last format to be introduced is **engineering notation,** which specifies that all powers of ten must be multiples of 3, and the mantissa must be greater than or equal to 1 but less than 1000. This restriction on the powers of ten is due to the fact that specific powers of ten have been assigned prefixes that will be introduced in the next few paragraphs. Using engineering notation in the floating-point mode will result in the following for the above operations:

$$\frac{1}{3} = \mathbf{333.333333333E-3} \qquad \frac{1}{16} = \mathbf{62.5E-3} \qquad \frac{2300}{2} = \mathbf{1.15E3}$$

Using engineering notation with three-place accuracy will result in the following:

$$\frac{1}{3} = \mathbf{333.333E-3} \qquad \frac{1}{16} = \mathbf{62.500E-3} \qquad \frac{2300}{2} = \mathbf{1.150E3}$$

Prefixes

Specific powers of ten in engineering notation have been assigned prefixes and symbols, as appearing in Table 1.2. They permit easy recognition of the power of ten and an improved channel of communication between technologists.

TABLE 1.2

Multiplication Factors	SI Prefix	SI Symbol
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p

EXAMPLE 1.10

a. 1,000,000 ohms = 1×10^{6} ohms
= 1 megohm (MΩ)

b. 100,000 meters = 100×10^{3} meters
= 100 kilometers (km)

c. 0.0001 second = 0.1×10^{-3} second
= 0.1 millisecond (ms)

d. 0.000001 farad = 1×10^{-6} farad
= 1 microfarad (μF)

Here are a few examples with numbers that are not strictly powers of ten.

EXAMPLE 1.11

a. 41,200 m is equivalent to 41.2×10^3 m = 41.2 kilometers = **41.2 km.**
b. 0.00956 J is equivalent to 9.56×10^{-3} J = 9.56 millijoules = **9.56 mJ.**
c. 0.000768 s is equivalent to 768×10^{-6} s = 768 microseconds = **768 μs.**
d. $$\frac{8400\text{ m}}{0.06} = \frac{8.4 \times 10^3\text{ m}}{6 \times 10^{-2}} = \left(\frac{8.4}{6}\right) \times \left(\frac{10^3}{10^{-2}}\right)\text{m}$$
$$= 1.4 \times 10^5\text{ m} = 140 \times 10^3\text{ m} = 140\text{ kilometers} = \mathbf{140\ km}$$
e. $$(0.0003)^4\text{ s} = (3 \times 10^{-4})^4\text{ s} = 81 \times 10^{-16}\text{ s}$$
$$= 0.0081 \times 10^{-12}\text{ s} = 0.008\text{ picosecond} = \mathbf{0.0081\ ps}$$

1.7 CONVERSION BETWEEN LEVELS OF POWERS OF TEN

It is often necessary to convert from one power of ten to another. For instance, if a meter measures kilohertz (kHz), it may be necessary to find the corresponding level in megahertz (MHz), or if time is measured in milliseconds (ms), it may be necessary to find the corresponding time in microseconds (μs) for a graphical plot. The process is not a difficult one if we simply keep in mind that an increase or a decrease in the power of ten must be associated with the opposite effect on the multiplying factor. The procedure is best described by a few examples.

EXAMPLE 1.12

a. Convert 20 kHz to megahertz.
b. Convert 0.01 ms to microseconds.
c. Convert 0.002 km to millimeters.

Solutions:

a. In the power-of-ten format:

$$20\text{ kHz} = 20 \times 10^3\text{ Hz}$$

The conversion requires that we find the multiplying factor to appear in the space below:

Increase by 3

$$20 \times 10^3\text{ Hz} \Rightarrow \_\_\_ \times 10^6\text{ Hz}$$

Decrease by 3

Since the power of ten will be *increased* by a factor of *three*, the multiplying factor must be *decreased* by moving the decimal point *three* places to the left, as shown below:

$$\underbrace{020.}_{3} = 0.02$$

and $$20 \times 10^3\text{ Hz} = 0.02 \times 10^6\text{ Hz} = \mathbf{0.02\ MHz}$$

b. In the power-of-ten format:

$$0.01\text{ ms} = 0.01 \times 10^{-3}\text{ s}$$

Reduce by 3

and $$0.01 \times 10^{-3}\text{ s} = \_\_\_ \times 10^{-6}\text{ s}$$

Increase by 3

Since the power of ten will be *reduced* by a factor of three, the multiplying factor must be *increased* by moving the decimal point three places to the right, as follows:

$$0.\underbrace{010}_{3} = 10$$

and $$0.01 \times 10^{-3}\text{ s} = 10 \times 10^{-6}\text{ s} = \mathbf{10\ \mu s}$$

There is a tendency when comparing -3 to -6 to think that the power of ten has increased, but keep in mind when making your judgment about increasing or decreasing the magnitude of the multiplier that 10^{-6} is a great deal smaller than 10^{-3}.

c.

Reduce by 6

$$0.002 \times 10^{3}\text{ m} \Rightarrow \_\_\_ \times 10^{-3}\text{ m}$$

Increase by 6

In this example we have to be very careful because the difference between $+3$ and -3 is a factor of 6, requiring that the multiplying factor be modified as follows:

$$0.\underbrace{002000}_{6} = 2000$$

and $$0.002 \times 10^{3}\text{ m} = 2000 \times 10^{-3}\text{ m} = \mathbf{2000\ mm}$$

1.8 CONVERSION WITHIN AND BETWEEN SYSTEMS OF UNITS

The conversion within and between systems of units is a process that cannot be avoided in the study of any technical field. It is an operation, however, that is performed incorrectly so often that this section was included to provide one approach that, if applied properly, will lead to the correct result.

There is more than one method of performing the conversion process. In fact, some people prefer to determine mentally whether the conversion factor is multiplied or divided. This approach is acceptable for some elementary conversions, but it is risky with more complex operations.

The procedure to be described here is best introduced by examining a relatively simple problem such as converting inches to meters. Specifically, let us convert 48 in. (4 ft) to meters.

If we multiply the 48 in. by a factor of 1, the magnitude of the quantity remains the same:

$$48\text{ in.} = 48\text{ in.}(1) \tag{1.10}$$

Let us now look at the conversion factor, which is the following for this example:

$$1\text{ m} = 39.37\text{ in.}$$

Dividing both sides of the conversion factor by 39.37 in. will result in the following format:

$$\frac{1\text{ m}}{39.37\text{ in.}} = (1)$$

Note that the end result is that the ratio 1 m/39.37 in. equals 1, as it should since they are equal quantities. If we now substitute this factor (1) into Eq. (1.10), we obtain

$$48\text{ in.}(1) = 48\,\cancel{\text{in.}}\left(\frac{1\text{ m}}{39.37\,\cancel{\text{in.}}}\right)$$

which results in the cancellation of inches as a unit of measure and leaves meters as the unit of measure. In addition, since the 39.37 is in the denominator, it must be divided into the 48 to complete the operation:

$$\frac{48}{39.37}\text{ m} = \mathbf{1.219\text{ m}}$$

Let us now review the method, which has the following steps:

1. ***Set up the conversion factor to form a numerical value of (1) with the unit of measurement to be removed from the original quantity in the denominator.***
2. ***Perform the required mathematics to obtain the proper magnitude for the remaining unit of measurement.***

EXAMPLE 1.13

a. Convert 6.8 min to seconds.
b. Convert 0.24 m to centimeters.

Solutions:

a. The conversion factor is

$$1\text{ min} = 60\text{ s}$$

Since the minute is to be removed as the unit of measurement, it must appear in the denominator of the (1) factor, as follows:

Step 1: $$\left(\frac{60\text{ s}}{1\text{ min}}\right) = (1)$$

Step 2: $$6.8\text{ min}(1) = 6.8\,\cancel{\text{min}}\left(\frac{60\text{ s}}{1\,\cancel{\text{min}}}\right) = (6.8)(60)\text{ s} = \mathbf{408\text{ s}}$$

b. The conversion factor is

$$1\text{ m} = 100\text{ cm}$$

Since the meter is to be removed as the unit of measurement, it must appear in the denominator of the (1) factor as follows:

Step 1: $$\left(\frac{100\text{ cm}}{1\text{ m}}\right) = 1$$

Step 2: $$0.24\text{ m}(1) = 0.24\,\cancel{\text{m}}\left(\frac{100\text{ cm}}{1\,\cancel{\text{m}}}\right) = (0.24)(100)\text{ cm} = \mathbf{24\text{ cm}}$$

The products (1)(1) and (1)(1)(1) are still 1. Using this fact, we can perform a series of conversions in the same operation.

EXAMPLE 1.14

a. Determine the number of minutes in half a day.
b. Convert 2.2 yards to meters.

Solutions:

a. Working our way through from days to hours to minutes, always ensuring that the unit of measurement to be removed is in the denominator, will result in the following sequence:

$$0.5\,\cancel{\text{day}}\left(\frac{24\,\cancel{\text{h}}}{1\,\cancel{\text{day}}}\right)\left(\frac{60\text{ min}}{1\,\cancel{\text{h}}}\right) = (0.5)(24)(60)\text{ min}$$
$$= \mathbf{720\ min}$$

b. Working our way through from yards to feet to inches to meters will result in the following:

$$2.2\,\cancel{\text{yards}}\left(\frac{3\,\cancel{\text{ft}}}{1\,\cancel{\text{yard}}}\right)\left(\frac{12\,\cancel{\text{in.}}}{1\,\cancel{\text{ft}}}\right)\left(\frac{1\text{ m}}{39.37\,\cancel{\text{in.}}}\right) = \frac{(2.2)(3)(12)}{39.37}\text{ m}$$
$$= \mathbf{2.012\ m}$$

The following examples are variations of the above in practical situations.

EXAMPLE 1.15

a. In Europe and Canada, and many other locations throughout the world, the speed limit is posted in kilometers per hour. How fast in miles per hour is 100 km/h?
b. Determine the speed in miles per hour of a competitor who can run a 4-min mile.

Solutions:

a. $\left(\frac{100\text{ km}}{\text{h}}\right)(1)(1)(1)(1)$

$$= \left(\frac{100\,\cancel{\text{km}}}{\text{h}}\right)\left(\frac{1000\,\cancel{\text{m}}}{1\,\cancel{\text{km}}}\right)\left(\frac{39.37\,\cancel{\text{in.}}}{1\,\cancel{\text{m}}}\right)\left(\frac{1\,\cancel{\text{ft}}}{12\,\cancel{\text{in.}}}\right)\left(\frac{1\text{ mi}}{5280\,\cancel{\text{ft}}}\right)$$
$$= \frac{(100)(1000)(39.37)}{(12)(5280)}\ \frac{\text{mi}}{\text{h}}$$
$$= \mathbf{62.14\ mi/h}$$

Many travelers use 0.6 as a conversion factor to simplify the math involved; that is,

$$(100\text{ km/h})(0.6) \cong 60\text{ mi/h}$$

and

$$(60\text{ km/h})(0.6) \cong 36\text{ mi/h}$$

b. Inverting the factor 4 min/1 mi to 1 mi/4 min, we can proceed as follows:

$$\left(\frac{1\text{ mi}}{4\,\cancel{\text{min}}}\right)\left(\frac{60\,\cancel{\text{min}}}{\text{h}}\right) = \frac{60}{4}\text{ mi/h} = \mathbf{15\ mi/h}$$

1.9 SYMBOLS

Throughout the text, various symbols will be employed that the reader may not have had occasion to use. Some are defined in Table 1.3, and others will be defined in the text as the need arises.

TABLE 1.3

Symbol	Meaning
$\neq$	Not equal to $6.12 \neq 6.13$
$>$	Greater than $4.78 > 4.20$
$\gg$	Much greater than $840 \gg 16$
$<$	Less than $430 < 540$
$\ll$	Much less than $0.002 \ll 46$
$\geq$	Greater than or equal to $x \geq y$ is satisfied for $y = 3$ and $x > 3$ or $x = 3$
$\leq$	Less than or equal to $x \leq y$ is satisfied for $y = 3$ and $x < 3$ or $x = 3$
$\cong$	Approximately equal to $3.14159 \cong 3.14$
Σ	Sum of $\Sigma\,(4 + 6 + 8) = 18$
$\|\ \|$	Absolute magnitude of $\|a\| = 4$, where $a = -4$ or $+4$
$\therefore$	Therefore $x = \sqrt{4} \quad \therefore x = \pm 2$
$\equiv$	By definition Establishes a relationship between two or more quantities

1.10 CONVERSION TABLES

Conversion tables such as those appearing in Appendix B can be very useful when time does not permit the application of methods described in this chapter. However, even though such tables appear easy to use, frequent errors occur because the operations appearing at the head of the table are not performed properly. In any case, when using such tables, try to establish mentally some order of magnitude for the quantity to be determined compared to the magnitude of the quantity in its original set of units. This simple operation should prevent several impossible results that may occur if the conversion operation is improperly applied.

For example, consider the following from such a conversion table:

To convert from	To	Multiply by
Miles	Meters	1.609×10^3

A conversion of 2.5 mi to meters would require that we multiply 2.5 by the conversion factor; that is,

$$2.5 \text{ mi}(1.609 \times 10^3) = 4.0225 \times 10^3 \text{ m}$$

A conversion from 4000 m to miles would require a division process:

$$\frac{4000 \text{ m}}{1.609 \times 10^3} = 2486.02 \times 10^{-3} = 2.48602 \text{ mi}$$

In each of the above, there should have been little difficulty realizing that 2.5 mi would convert to a few thousand meters and 4000 m would be only a few miles. As indicated above, this kind of anticipatory thinking will eliminate the possibility of ridiculous conversion results.

1.11 CALCULATORS

In some texts, the calculator is not discussed in detail. Instead, students are left with the general exercise of choosing an appropriate calculator and learning to use it properly on their own. However, some discussion about the use of the calculator must be included to eliminate some of the impossible results obtained (and often strongly defended by the user—because the calculator says so) through a correct understanding of the process by which a calculator performs the various tasks. Time and space do not permit a detailed explanation of all the possible operations, but it is assumed that the following discussion will enlighten the user to the fact that it is important to understand the manner in which a calculator proceeds with a calculation and not to expect the unit to accept data in any form and always generate the correct answer.

When choosing a calculator (scientific for our use), be absolutely sure that it has the ability to operate on complex numbers (polar and rectangular) which will be described in detail in Chapter 13. For now simply look up the terms in the index of the operator's manual, and be sure that the terms appear and that the basic operations with them are discussed. Next, be aware that some calculators perform the operations with a minimum number of steps while others can require a downright lengthy or complex series of steps. Speak to your instructor if unsure about your purchase. For this text, the TI-86 of Fig. 1.5 was chosen because of its treatment of complex numbers.

FIG. 1.5
Texas Instruments TI-86 calculator. (Courtesy of Texas Instruments, Inc.)

Initial Settings

Format and accuracy are the first two settings that must be made on any scientific calculator. For most calculators the choices of formats are *Normal*, *Scientific*, and *Engineering*. For the TI-86 calculator, pressing the 2nd function (yellow) key followed by the [MODE] key will provide a list of options for the initial settings of the calculator. For calculators without a [MODE] choice, consult the operator's manual for the manner in which the format and accuracy level are set.

Examples of each are shown below:

Normal: 1/3 = 0.33
Scientific: 1/3 = 3.33E−1
Engineering: 1/3 = 333.33E−3

Note that the Normal format simply places the decimal point in the most logical location. The Scientific ensures that the number preceding the decimal point is a single digit followed by the required power of ten. The Engineering format will always ensure that the power of ten is a multiple of 3 (whether it be positive, negative, or zero).

In the above examples the accuracy was hundredths place. To set this accuracy for the TI-86 calculator, return to the [MODE] selection and choose 2 to represent two-place accuracy or hundredths place.

Initially you will probably be most comfortable with the Normal mode with hundredths-place accuracy. However, as you begin to analyze networks, you may find the Engineering mode more appropriate since you will be working with component levels and results that have powers of ten that have been assigned abbreviations and names. Then again, the Scientific mode may the best choice for a particular analysis. In any event, take the time now to become familiar with the differences between the various modes, and learn how to set them on your calculator.

Order of Operations

Although being able to set the format and accuracy is important, these features are not the source of the impossible results that often arise because of improper use of the calculator. Improper results occur primarily because users fail to realize that no matter how simple or complex an equation, the calculator will perform the required operations in a specific order.

For instance, the operation

$$\frac{8}{3+1}$$

is often entered as

$$\boxed{8}\boxed{\div}\boxed{3}\boxed{+}\boxed{1} = \frac{8}{3} + 1 = 2.67 + 1 = 3.67$$

which is totally incorrect (2 is the answer).

The user must be aware that the calculator ***will not*** perform the addition first and then the division. In fact, addition and subtraction are the last operations to be performed in any equation. It is therefore very important that the reader carefully study and thoroughly understand the next few paragraphs in order to use the calculator properly.

1. The first operations to be performed by a calculator can be set using ***parentheses ( ).*** It does not matter which operations are within the parentheses. The parentheses simply dictate that this part of the equation is to be determined first. There is no limit to the number of parentheses in each equation—all operations within parentheses will be performed first. For instance, for the example above, if parentheses are added as shown below, the addition will be performed first and the correct answer obtained:

$$\frac{8}{(3+1)} = \boxed{8}\,\boxed{\div}\,\boxed{(}\,\boxed{3}\,\boxed{+}\,\boxed{1}\,\boxed{)} = \frac{8}{4} = \mathbf{2}$$

2. Next, ***powers and roots*** are performed, such as x^2, $\sqrt{x}$, and so on.
3. ***Negation*** (applying a negative sign to a quantity) and ***single-key operations*** such as sin, $\tan^{-1}$, and so on, are performed.
4. ***Multiplication and division*** are then performed.
5. ***Addition and subtraction*** are performed last.

It may take a few moments and some repetition to remember the order, but at least you are now aware that there is an order to the operations and are aware that ignoring them can result in meaningless results.

EXAMPLE 1.16

a. Determine

$$\sqrt{\frac{9}{3}}$$

b. Find

$$\frac{3+9}{4}$$

c. Determine

$$\frac{1}{4} + \frac{1}{6} + \frac{2}{3}$$

Solutions:

a. The following calculator operations will result in an incorrect answer of 1 because the square-root operation will be performed before the division.

$$\boxed{\sqrt{\ }}\,\boxed{9}\,\boxed{\div}\,\boxed{3} = \frac{\sqrt{9}}{3} = \frac{3}{3} = 1$$

However, recognizing that we must first divide 9 by 3, we can use parentheses as follows to define this operation as the first to be performed, and the correct answer will be obtained:

$$\boxed{\sqrt{\ }}\,\boxed{(}\,\boxed{9}\,\boxed{\div}\,\boxed{3}\,\boxed{)} = \sqrt{\left(\frac{9}{3}\right)} = \sqrt{3} = \mathbf{1.67}$$

b. If the problem is entered as it appears, the incorrect answer of 5.25 will result.

$$\boxed{3}\,\boxed{+}\,\boxed{9}\,\boxed{\div}\,\boxed{4} = 3 + \frac{9}{4} = 5.25$$

Using brackets to ensure that the addition takes place before the division will result in the correct answer as shown below:

$$\boxed{(}\,\boxed{3}\,\boxed{+}\,\boxed{9}\,\boxed{)}\,\boxed{\div}\,\boxed{4} = \frac{(3+9)}{4} = \frac{12}{4} = \mathbf{3}$$

c. Since the division will occur first, the correct result will be obtained by simply performing the operations as indicated. That is,

$$\boxed{1}\boxed{\div}\boxed{4}\boxed{+}\boxed{1}\boxed{\div}\boxed{6}\boxed{+}\boxed{2}\boxed{\div}\boxed{3} = \frac{1}{4} + \frac{1}{6} + \frac{2}{3} = \mathbf{1.08}$$

1.12 COMPUTER ANALYSIS

The use of computers in the educational process has grown exponentially in the past decade. Very few texts at this introductory level fail to include some discussion of current popular computer techniques. In fact, the very accreditation of a technology program may be a function of the depth to which computer methods are incorporated in the program.

There is no question that a basic knowledge of computer methods is something that the graduating student should carry away from a two-year or four-year program. Industry is now expecting students to have a basic knowledge of computer jargon and some hands-on experience.

For some students, the thought of having to become proficient in the use of a computer may result in an insecure, uncomfortable feeling. Be assured, however, that through the proper learning experience and exposure, the computer can become a very "friendly," useful, and supportive tool in the development and application of your technical skills in a professional environment.

For the new student of computers, two general directions can be taken to develop the necessary computer skills: the study of computer languages or the use of software packages.

Languages

There are several languages that provide a direct line of communication with the computer and the operations it can perform. A **language** is a set of symbols, letters, words, or statements that the user can enter into the computer. The computer system will "understand" these entries and will perform them in the order established by a series of commands called a **program.** The program tells the computer what to do on a sequential, line-by-line basis in the same order a student would perform the calculations in longhand. The computer can respond only to the commands entered by the user. This requires that the programmer understand fully the sequence of operations and calculations required to obtain a particular solution. In other words, the computer can only respond to the user's input—it does not have some mysterious way of providing solutions unless told how to obtain those solutions. A lengthy analysis can result in a program having hundreds or thousands of lines. Once written, the program has to be checked carefully to be sure the results have meaning and are valid for an expected range of input variables. Writing a program can, therefore, be a long, tedious process, but keep in mind that once the program has been tested and proven true, it can be stored in memory for future use. The user can be assured that any future results obtained have a high degree of accuracy but require a minimum expenditure of energy and time. Some of the popular languages applied in the electrical/electronics field today include C++, QBASIC, Pascal, and FORTRAN. Each has its own set of commands and statements to communicate with the computer, but each can be used to perform the same type of analysis.

This text includes **C++** in its development because of its growing popularity in the educational community. The C language was first developed at Bell Laboratories to establish an efficient communication link between the user and the machine language of the central processing unit (CPU) of a computer. The language has grown in popularity throughout industry and education because it has the characteristics of a high-level language (easily understood by the user) with an efficient link to the computer's operating system. The C++ language was introduced as an extension of the C language to assist in the writing of complex programs using an enhanced, modular, top-down approach.

In any event, it is not assumed that the coverage of C++ in this text is sufficient to permit the writing of additional programs. The inclusion is meant as an introduction only: to reveal the appearance and characteristics of the language, and to follow the development of some simple programs. A proper exposure to C++ would require a course in itself, or at least a comprehensive supplemental program to fill in the many gaps of this text's presentation.

Software Packages

The second approach to computer analysis—**software packages**—avoids the need to know a particular language; in fact, the user may not be aware of which language was used to write the programs within the package. All that is required is a knowledge of how to input the network parameters, define the operations to be performed, and extract the results; the package will do the rest. The individual steps toward a solution are beyond the needs of the user—all the user needs is an idea of how to get the network parameters into the computer and how to extract the results. Herein lie two of the concerns of the author with packaged programs—obtaining a solution without the faintest idea of either how the solution was obtained or whether the results are valid or way off base. It is imperative that the student realize that the computer should be used as a tool to assist the user—it must not be allowed to control the scope and potential of the user! Therefore, as we progress through the chapters of the text, be sure that concepts are clearly understood before turning to the computer for support and efficiency.

Each software package has a **menu,** which defines the range of application of the package. Once the software is entered into the computer, the system will perform all the functions appearing in the menu, as it was preprogrammed to do. Be aware, however, that if a particular type of analysis is requested that is not on the menu, the software package cannot provide the desired results. The package is limited solely to those maneuvers developed by the team of programmers who developed the software package. In such situations the user must turn to another software package or write a program using one of the languages listed above.

In broad terms, if a software package is available to perform a particular analysis, then it should be used rather than developing routines. Most popular software packages are the result of many hours of effort by teams of programmers with years of experience. However, if the results are not in the desired format, or if the software package does not provide all the desired results, then the user's innovative talents should be put to use to develop a software package. As noted above, any program the user writes that passes the tests of range and accuracy can be considered a software package of his or her authorship for future use.

Three software packages will be used throughout this text: Cadence's OrCAD PSpice 9.2, Electronics Workbench's Multisim, and MathSoft's Mathcad 2000, all of which appear in Fig. 1.6. Although PSpice and Electronics Workbench are both designed to analyze electric circuits, there are sufficient differences between the two to warrant covering each approach separately. The growing use of some form of mathematical support in the educational and industrial environment justifies the introduction and use of Mathcad throughout the text. There is no requirement that the student obtain all three to proceed with the content of this text. The primary reason for their inclusion was simply to introduce each and demonstrate how they can support the learning process. In most cases, sufficient detail has been provided to actually use the software package to perform the examples provided, although it would certainly be helpful to have someone to turn to if questions arise. In addition, the literature supporting all three packages has improved dramatically in recent years and should be available through your bookstore or a major publisher.

Appendix A lists all the system requirements, including how to get in touch with each company.

(a)

(b)

(c)

FIG. 1.6

Software packages: (a) Cadence's OrCAD (PSpice) release 9.2; (b) Electronics Workbench's Multisim; (c) MathSoft's Mathcad 2000.

PROBLEMS

Note: More difficult problems are denoted by an asterisk (*) throughout the text.

SECTION 1.2 A Brief History

1. Visit your local library (at school or home) and describe the extent to which it provides literature and computer support for the technologies—in particular, electricity, electronics, electromagnetics, and computers.

2. Choose an area of particular interest in this field and write a very brief report on the history of the subject.

3. Choose an individual of particular importance in this field and write a very brief review of his or her life and important contributions.

SECTION 1.3 Units of Measurement

4. Determine the distance in feet traveled by a car moving at 50 mi/h for 1 min.

5. How many hours would it take a person to walk 12 mi if the average pace is 15 min/mile?

SECTION 1.4 Systems of Units

6. Are there any relative advantages associated with the metric system compared to the English system with respect to length, mass, force, and temperature? If so, explain.

7. Which of the four systems of units appearing in Table 1.1 has the smallest units for length, mass, and force? When would this system be used most effectively?

*8. Which system of Table 1.1 is closest in definition to the SI system? How are the two systems different? Why do you think the units of measurement for the SI system were chosen as listed in Table 1.1? Give the best reasons you can without referencing additional literature.

9. What is room temperature (68°F) in the MKS, CGS, and SI systems?

10. How many foot-pounds of energy are associated with 1000 J?

11. How many centimeters are there in $\frac{1}{2}$ yd?

SECTION 1.6 Powers of Ten

12. Express the following numbers as powers of ten:
   a. 10,000 **b.** 0.0001
   c. 1000 **d.** 1,000,000
   e. 0.0000001 **f.** 0.00001

13. Using only those powers of ten listed in Table 1.2, express the following numbers in what seems to you the most logical form for future calculations:
   a. 15,000 **b.** 0.03000
   c. 7,400,000 **d.** 0.0000068
   e. 0.00040200 **f.** 0.0000000002

14. Perform the following operations and express your answer as a power of ten:
   a. $4200 + 6{,}800{,}000$
   b. $9 \times 10^4 + 3.6 \times 10^3$
   c. $0.5 \times 10^{-3} - 6 \times 10^{-5}$
   d. $1.2 \times 10^3 + 50{,}000 \times 10^{-3} - 0.006 \times 10^5$

15. Perform the following operations and express your answer as a power of ten:
   a. $(100)(100)$ **b.** $(0.01)(1000)$
   c. $(10^3)(10^6)$ **d.** $(1000)(0.00001)$
   e. $(10^{-6})(10{,}000{,}000)$ **f.** $(10{,}000)(10^{-8})(10^{35})$

16. Perform the following operations and express your answer as a power of ten:
   a. $(50{,}000)(0.0003)$
   b. 2200×0.08
   c. $(0.000082)(0.00007)$
   d. $(30 \times 10^{-4})(0.0002)(7 \times 10^8)$

17. Perform the following operations and express your answer as a power of ten:
   a. $\dfrac{100}{1000}$ **b.** $\dfrac{0.01}{100}$
   c. $\dfrac{10{,}000}{0.00001}$ **d.** $\dfrac{0.0000001}{100}$
   e. $\dfrac{10^{38}}{0.000100}$ **f.** $\dfrac{(100)^{1/2}}{0.01}$

18. Perform the following operations and express your answer as a power of ten:
   a. $\dfrac{2000}{0.00008}$ **b.** $\dfrac{0.00408}{60{,}000}$
   c. $\dfrac{0.000215}{0.00005}$ **d.** $\dfrac{78 \times 10^9}{4 \times 10^{-6}}$

19. Perform the following operations and express your answer as a power of ten:
   a. $(100)^3$ **b.** $(0.0001)^{1/2}$
   c. $(10{,}000)^8$ **d.** $(0.00000010)^9$

20. Perform the following operations and express your answer as a power of ten:
   a. $(2.2 \times 10^3)^3$
   b. $(0.0006 \times 10^2)^4$
   c. $(0.004)(6 \times 10^2)^2$
   d. $((2 \times 10^{-3})(0.8 \times 10^4)(0.003 \times 10^5))^3$

21. Perform the following operations and express your answer in scientific notation:
   a. $(-0.001)^2$ **b.** $\dfrac{(100)(10^{-4})}{10}$
   c. $\dfrac{(0.001)^2(100)}{10{,}000}$ **d.** $\dfrac{(10^2)(10{,}000)}{0.001}$
   e. $\dfrac{(0.0001)^3(100)}{1{,}000{,}000}$ ***f.** $\dfrac{[(100)(0.01)]^{-3}}{[(100)^2][0.001]}$

*22. Perform the following operations and express your answer in engineering notation:
   a. $\dfrac{(300)^2(100)}{10^4}$ **b.** $[(40{,}000)^2][(20)^{-3}]$
   c. $\dfrac{(60{,}000)^2}{(0.02)^2}$ **d.** $\dfrac{(0.000027)^{1/3}}{210{,}000}$
   e. $\dfrac{[(4000)^2][300]}{0.02}$
   f. $[(0.000016)^{1/2}][(100{,}000)^5][0.02]$
   g. $\dfrac{[(0.003)^3][(0.00007)^2][(800)^2]}{[(100)(0.0009)]^{1/2}}$ (a challenge)

SECTION 1.7 Conversion between Levels of Powers of Ten

23. Fill in the blanks of the following conversions:
   a. $6 \times 10^3 = \_\_\_\_ \times 10^6$
   b. $4 \times 10^{-4} = \_\_\_\_ \times 10^{-6}$
   c. $50 \times 10^5 = \_\_\_\_ \times 10^3 = \_\_\_\_ \times 10^6 = \_\_\_\_ \times 10^9$
   d. $30 \times 10^{-8} = \_\_\_\_ \times 10^{-3} = \_\_\_\_ \times 10^{-6} = \_\_\_\_ \times 10^{-9}$

24. Perform the following conversions:
   a. 2000 μs to milliseconds
   b. 0.04 ms to microseconds
   c. 0.06 μF to nanofarads
   d. 8400 ps to microseconds
   e. 0.006 km to millimeters
   f. 260×10^3 mm to kilometers

SECTION 1.8 Conversion within and between Systems of Units

For Problems 25 to 27, convert the following:

25. **a.** 1.5 min to seconds
b. 0.04 h to seconds
c. 0.05 s to microseconds
d. 0.16 m to millimeters
e. 0.00000012 s to nanoseconds
f. 3,620,000 s to days
g. 1020 mm to meters

26. **a.** 0.1 μF (microfarad) to picofarads
b. 0.467 km to meters
c. 63.9 mm to centimeters
d. 69 cm to kilometers
e. 3.2 h to milliseconds
f. 0.016 mm to micrometers
g. 60 sq cm (cm^2) to square meters (m^2)

***27.** **a.** 100 in. to meters
b. 4 ft to meters
c. 6 lb to newtons
d. 60,000 dyn to pounds
e. 150,000 cm to feet
f. 0.002 mi to meters (5280 ft = 1 mi)
g. 7800 m to yards

28. What is a mile in feet, yards, meters, and kilometers?

29. Calculate the speed of light in miles per hour using the defined speed of Section 1.4.

30. Find the velocity in miles per hour of a mass that travels 50 ft in 20 s.

31. How long in seconds will it take a car traveling at 100 mi/h to travel the length of a football field (100 yd)?

32. Convert 6 mi/h to meters per second.

33. If an athlete can row at a rate of 50 m/min, how many days would it take to cross the Atlantic ($\cong$3000 mi)?

34. How long would it take a runner to complete a 10-km race if a pace of 6.5 min/mi were maintained?

35. Quarters are about 1 in. in diameter. How many would be required to stretch from one end of a football field to the other (100 yd)?

36. Compare the total time in hours to cross the United States ($\cong$3000 mi) at an average speed of 55 mi/h versus an average speed of 65 mi/h. What is your reaction to the total time required versus the safety factor?

***37.** Find the distance in meters that a mass traveling at 600 cm/s will cover in 0.016 h.

***38.** Each spring there is a race up 86 floors of the 102-story Empire State Building in New York City. If you were able to climb 2 steps/second, how long would it take you to reach the 86th floor if each floor is 14 ft. high and each step is about 9 in.?

***39.** The record for the race in Problem 38 is 10 minutes, 47 seconds. What was the racer's speed in min/mi for the race?

***40.** If the race of Problem 38 were a horizontal distance, how long would it take a runner who can run 5-minute miles to cover the distance? Compare this with the record speed of Problem 39. Gravity is certainly a factor to be reckoned with!

SECTION 1.10 Conversion Tables

41. Using Appendix B, determine the number of
a. Btu in 5 J of energy.
b. cubic meters in 24 oz of a liquid.
c. seconds in 1.4 days.
d. pints in 1 m^3 of a liquid.

SECTION 1.11 Calculators

Perform the following operations using a calculator:

42. $6(4 + 8)$

43. $\sqrt{3^2 + 4^2}$

44. $\tan^{-1}\frac{4}{3}$

45. $\sqrt{\frac{400}{6^2 + 10}}$

SECTION 1.12 Computer Analysis

46. Investigate the availability of computer courses and computer time in your curriculum. Which languages are commonly used, and which software packages are popular?

47. Develop a list of five popular computer languages with a few characteristics of each. Why do you think some languages are better for the analysis of electric circuits than others?

GLOSSARY

C++ A computer language having an efficient communication link between the user and the machine language of the central processing unit (CPU) of a computer.

CGS system The system of units employing the *C*entimeter, *G*ram, and *S*econd as its fundamental units of measure.

Difference engine One of the first mechanical calculators.

Edison effect Establishing a flow of charge between two elements in an evacuated tube.

Electromagnetism The relationship between magnetic and electrical effects.

Engineering notation A method of notation that specifies that all powers of ten used to define a number be multiples of 3 with a mantissa greater than or equal to 1 but less than 1000.

ENIAC The first totally electronic computer.

Fixed-point notation Notation using a decimal point in a particular location to define the magnitude of a number.

Fleming's valve The first of the electronic devices, the diode.

Floating-point notation Notation that allows the magnitude of a number to define where the decimal point should be placed.

Integrated circuit (IC) A subminiature structure containing a vast number of electronic devices designed to perform a particular set of functions.

Joule (J) A unit of measurement for energy in the SI or MKS system. Equal to 0.7378 foot-pound in the English system and 10^7 ergs in the CGS system.

Kelvin (K) A unit of measurement for temperature in the SI system. Equal to 273.15 + °C in the MKS and CGS systems.

Kilogram (kg) A unit of measure for mass in the SI and MKS systems. Equal to 1000 grams in the CGS system.

Language A communication link between user and computer to define the operations to be performed and the results to be displayed or printed.

Leyden jar One of the first charge-storage devices.

Menu A computer-generated list of choices for the user to determine the next operation to be performed.

Meter (m) A unit of measure for length in the SI and MKS systems. Equal to 1.094 yards in the English system and 100 centimeters in the CGS system.

MKS system The system of units employing the *M*eter, *K*ilogram, and *S*econd as its fundamental units of measure.

Newton (N) A unit of measurement for force in the SI and MKS systems. Equal to 100,000 dynes in the CGS system.

Pound (lb) A unit of measurement for force in the English system. Equal to 4.45 newtons in the SI or MKS system.

Program A sequential list of commands, instructions, etc., to perform a specified task using a computer.

PSpice A software package designed to analyze various dc, ac, and transient electrical and electronic systems.

Scientific notation A method for describing very large and very small numbers through the use of powers of ten, which requires that the multiplier be a number between 1 and 10.

Second (s) A unit of measurement for time in the SI, MKS, English, and CGS systems.

SI system The system of units adopted by the IEEE in 1965 and the USASI in 1967 as the International System of Units (*S*ystème *I*nternational d'Unités).

Slug A unit of measure for mass in the English system. Equal to 14.6 kilograms in the SI or MKS system.

Software package A computer program designed to perform specific analysis and design operations or generate results in a particular format.

Static electricity Stationary charge in a state of equilibrium.

Transistor The first semiconductor amplifier.

Voltaic cell A storage device that converts chemical to electrical energy.